Laboratoire Traitement et Communication de l'Information

Auto-évaluation HCERES vague E

2013 – 2018

Contents

Chapter 1

General information

In this chapter we give a general presentation of the laboratory, its organization, its scientific production and its project for the five coming years.

1.1 Presentation of the LTCI

LTCI (Laboratoire Traitement et Communication de l'Information) is a laboratory of Télécom ParisTech. It extends, since January 2017, the work carried out within the UMR LTCI (Unité Mixte de Recherche), a joint research laboratory with the CNRS (Centre National de la Recherche Scientifique). Established in 1982 (see Table 1.1), LTCI is characterized by its broad coverage of the field of information and communication science and technology. Its research activities range from the hardware layer (electronics, opto-electronics, system on chip, antennae, microwaves ...) to the software layer (systems, algorithms, protocols ...), and to applied mathematics (graph theory, optimization, probabilities, statistics ...). They encompass studies on different kinds of data (audio, video, images, semi-structured data and web content) as well as works on network performance and services, or quantum cryptography issues.

The laboratory is located in the premises of Télécom ParisTech, *46 rue Barrault* (main building) and *23 Avenue d'Italie* in Paris, with one team (LabSoC) located at the Eurecom[1] campus in Sophia Antipolis.

The LTCI is headed by Talel Abdessalem, Professor at Télécom ParisTech, since January 2017. The director of the laboratory is also the director of research of Télécom ParisTech since March 2018.

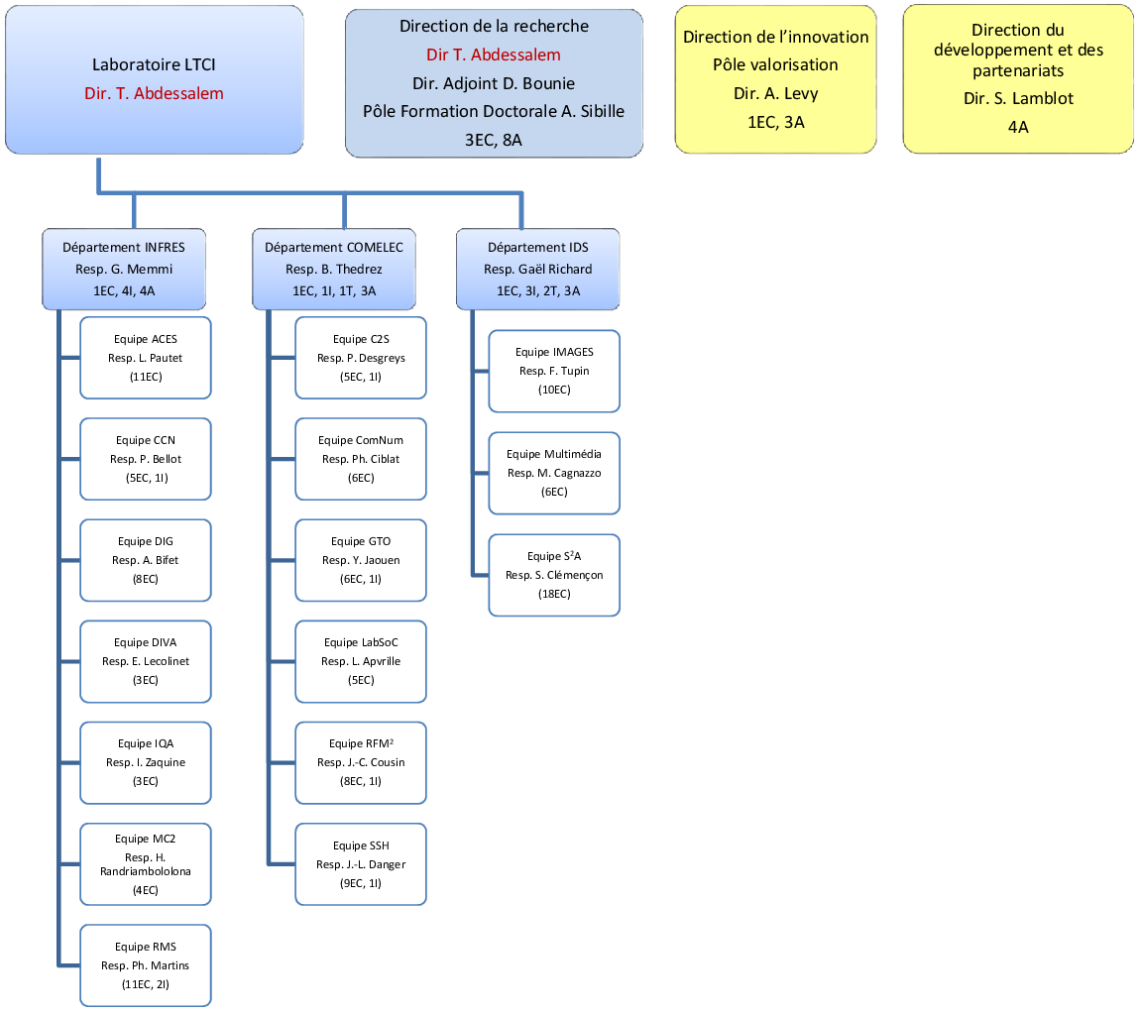
Date	Founding institutions	Status	Scope	Director
1982	ENST, CNRS	ERA	Communications & Signal Processing	C. Gueguen
1994	ENST, CNRS	URA 820, UMR 5152	Communications & Signal Processing	J.-P. Tubach
2003	Télécom Paris, CNRS	UMR 5141	ICT[a] & Social sciences	H. Maître
2013	Télécom ParisTech, CNRS	UMR 5141	ICT	O. Cappé
2016	Télécom ParisTech, CNRS	FRE	ICT	O. Cappé
2017	Télécom ParisTech	TPT lab	ICT	T. Abdessalem

Table 1.1: Main steps in the history of LTCI

[a] Information and Communication Technology

In this report, the structure of the LTCI is presented in its current form, which has been

[1] http://www.eurecom.fr



EC=faculty members, I=engineers, T=technicians and A=administrative staff

FIGURE 1.1: Organizational chart of the LTCI.

adopted since October 2017. The next subsections briefly present some further relevant elements on the context of the LTCI.

1.1.1 Organization of the lab

The organizational chart of the LTCI is shown in Figure 1.1 together with the administrative and technical support staff of the lab (yellow boxes correspond to administrative and management staff of Télécom ParisTech dedicated to the development of partnerships and innovation). The LTCI is composed of sixteen research teams belonging to three research and teaching departments. Each team is headed by a Professor chosen by the members of the team. Each department is managed by the department head who is the line manager of all the academic and administrative staff in his department.

Communications and Electronics department (Bruno Thedrez). The Communications and Electronics department (COMELEC) headed by Bruno Thedrez focuses on the communica-

tion and networking tasks with researches that range from the physical layer of information and communication technology (electromagnetism, optical components) to performance evaluation of large-scale communication systems, including works on mixed (analog and digital) signals or safety against physical attacks or digital systems. The department hosts six teams of the LTCI:

- Circuits and Communication Systems (C2S), headed by Patricia Desgreys
- Digital Communications (ComNum), headed by Philippe Ciblat
- Optical Communications (GTO), headed by Yves Jaouen
- Systems on Chip (LabSoC), headed by Ludovic Aprville
- Radio-Frequencies, Micro and Millimeter Waves (RFM^2), headed by Jean-Christophe Cousin
- Secure and Safe Hardware (SSH), headed by Jean-Luc Danger

The department remained with a structure of six teams along the 2013-2018 period. While seven faculties left the department (temporary leave or retirement), six new faculties were hired. Two new technical staff were engaged for the TTool platform (LabSoC team) and the SSH circuit design team. Overall, the department reinforced its cyber-security domain with the SSH team evolving from seven to ten people, while the optical communication team and the digital and mixed signal team decreased by one position each. These changes are consistent with the socio-economical evolution along the period. With the end of the UMR LTCI, the digital communication team suffered from two CNRS leaves, partially compensated by one new Telecom ParisTech position, and the optical communication team lost one CNRS researcher.

While maintaining a strong position in experimental research (1.3 M€ in equipment purchased in five years), a shift was also engaged towards an increase in abstraction, with new faculties involved in Artificial Intelligence and with strong algorithmic background in the Digital Communications team and in the Optical Communications team.

Networks and Computer Science department (Gérard Memmi). The Networks and Computer Science department (INFRES) is headed by Gérard Memmi and focuses, as the name suggests, on various aspects of computer science (embedded and real time systems, data management and mining, Human-Computer interaction, cryptography ...) with a strong emphasis on networks (performance evaluation, network control and monitoring, design of innovative network services). The department hosts seven LTCI teams:

- Autonomic and Critical Embedded Systems (ACES), headed by Laurent Pautet
- Cybersecurity for Communication and Networking (CCN), headed by Patrick Bellot
- Data, Intelligence and Graphs (DIG), headed by Albert Bifet
- Design, Interaction, Visualization and Applications (DIVA), headed by Eric Lecolinet
- Discrete Mathematics, Coding and Cryptography (MC2), headed by Hugues Randriambololona
- Quantum Information and Applications (IQA), headed by Isabelle Zaquine
- Network, Mobility and Services (RMS), headed by Philippe Martins

After the departure of the CNRS researchers (six in total), the Computer Science and Networks department reshaped its organization into smaller and more focused teams; hence the creation of DIVA in cooperation with researchers from the UMR i^3, hence the split of the security group into a team focusing on cybersecurity and another team dedicated on the one hand to quantum information and on the other hand to its applications.

The department is constantly developing a strategy of alliances, first with the other departments of LTCI, but also within the IMT cluster (IMT-Atlantique, Telecom SudParis, or Mines-ParisTech) and many actors of Université Paris-Saclay (in order to prepare the move to Saclay).

SEIDO, our common lab with EDF has been opened to the COMELEC departement and Telecom SudParis (as well as to LAAS in Toulouse). In 2017, EDF, Telecom ParisTech and Telecom SudParis signed a general scientific cooperation agreement. We also signed a similar agreement between CEA and Telecom ParisTech. In March 2018, we kicked off BART, a research initiative on the blockchain together with Inria, Telecom SudParis and IRT SystemX. Today, Ecole polytechnique and Mines ParisTech asked to join BART.

Since 2016, we also have initiated together with CEA and CentralSupelec a new lab on 5G telecommunication which will gather many academic partners from Saclay: LRI, Inria, UVSQ, Ecole polytechnique, as well as three major industrial partners of the domain: Orange, Thales and Nokia.

Last but not least, during the period, we launched a number of chairs and common labs with several French companies and one US company (Cisco). We also actively participate to the Franco-German Academia between IMT and TUM working on industry 4.0.

Image, Data and Signal department (Gaël Richard). The Image, Data and Signal (IDS) department (formerly Signal and Image Processing (TSI) department) headed by Gaël Richard covers all aspects of signal and image processing (computer graphics and 3D images, video coding, audio applications, medical imaging, statistical signal processing ...) with a specialization in further topics such as emotional aspects in human-agent interactions or statistical learning. The department has faced a significant reorganization following the leave of nine CNRS researchers at the end of 2016. It is now organized in three teams, a development group and transversal research topics. The three teams are:

- Machine learning, Statistics and Signal (S2A) which gathers the former Statistics and Applications (STA) and Audio, Acoustics and Waves (AAO) teams and two researchers involved in machine learning from the former Multimedia team. The team is headed by Stephan Clémençon.
- Multimedia (MM) which now focuses on its core activities on coding, transmission and orchestration of multimedia signals and related interactive services. The team is headed by Marco Cagnazzo.
- Image, Modeling, Analysis, Geometry, Synthesis (IMAGES) which evolved with the departure of its CNRS members (more than 1/3 of the team) on the one hand, and the launch of new scientific directions (in particular in artificial intelligence and machine learning) on the other hand. The team is headed by Florence Tupin.

The new development group, which gathers three persons, operates in a project mode and supports software development projects in turn for the three teams.

In parallel, eight transversal research topics were defined to facilitate collaboration and scientific animation on more focused important research directions, and to better cope with the variable team sizes. Each topic has its own seminar and mailing lists. The topics are: Machine learning, Audio data analysis and signal processing, Computer graphics, Probabilities and statistics, Mathematics for images, Remote Sensing Data and Images, Social Computing, Biomedical image and digital health.

1.1.2 Permanent staff, postdocs and PhD students

Overall, the permanent staff of the LTCI consists of 118 professors from Télécom ParisTech (62 of them being associate professors and 56 full professors), 13 engineers and 3 technicians and 10 people in the administrative staffs working primarily in the service of research. The detailed evolution of the staff of permanent researchers and professors is given in Table 1.2. It can be observed that the main event of the period is the departure of all the CNRS researchers (18 in total), because of the end of the UMR CNRS.

In the teams reports we used the following acronyms: JRS for Junior Research Scientist (Chargé de recherches), SRS for Senior Research Scientist (Directeur de recherches), AP for Associate Professor (Maître de conférences), FP for Full Professor (Professeur) and RE for Research Engineer (Ingénieur de recherche).

In mid 2018, the non-permanent staff includes 21 postdocs and 188 PhD students, including 53 CIFRE (Convention industrielle de formation par la recherche) who are employees of industrial partners of the lab, and 3 PhDs in "co-tutelle" who are jointly supervised by members of the lab and foreign academic partners. The lab also benefits from the presence of 10 invited professors and associated researchers and 10 emeritus professors who are actively contributing to our research.

The lab has an important potential for supervising doctoral students as 73 of its members have an "Habilitation à diriger des recherches (HdR)". On average, 3 new HdR grades have been obtained by members of the lab every year in the period between 2013 and 2018 (16 in total). Table 1.5 shows that the number of defended PhD theses is relatively stable over the period, around 65 per year with an average duration slightly above 40 months. As of mid 2018, the large majority of PhD students are either CIFRE/industry PhDs (28% of them) or employed directly by Télécom ParisTech (under a so-called "Contrat doctoral"), for 49% of them.

Over the period, the PhD students have in part been registered at EDITE doctoral school (ED 130 – École doctorale Informatique, Télécommunications, Électronique), of which Telecom ParisTech is a founding member, and in part in doctoral schools from Paris-Saclay University. This stems from the transition between the two universities in 2015. In Paris-Saclay, our PhD students are mostly affiliated to the STIC doctoral school (ED 580 – Ecole Doctorale Sciences et Technologies de l'Information et de la Communication), which is managed by Alain Denise, Professor at Université Paris-Sud. LTCI has PhD students in the four domains "Pôles thématiques" of the doctoral school and is involved in the management of "Pôle 2" (Networks, Information and Communications) through its director Alain Sibille, Professor at Télécom ParisTech. However, a small proportion of LTCI PhD students are registered in other doctoral schools, such as EOBE (Electrical, optical and bio engineering) and EDMH (mathematics), in which François Roueff, Professor at Télécom ParisTech, has a managing responsibility.

Several members of the lab are actively involved in teaching at the M2 (2^{nd} year) level in several masters of Paris-Saclay, and in some Parisian masters. An important part of our PhD students are recruited from these masters.

1.2 Ecosystem

The ecosystem of LTCI is now mainly organized around Télécom ParisTech, Paris-Saclay (Université Paris-Saclay and, since October 2018, the new project around Ecole Polytechnique denoted temporarily NewUni) and the PIA objects (Labex, Equipex ...) structuring the research activity in Paris-Saclay.

1.2.1 Télécom ParisTech

Télécom ParisTech is a leading French higher education institution in the domain of ICT (Information and Communication Technology). Its ambition summarized by its motto "innovating in a digital world" is to train students either during their initial engineering studies or through life-long learning to develop a high-level of both technical and entrepreneurial skills. Télécom ParisTech hosts about 800 engineering students, 70 Master students and 300 PhD students.

Télécom ParisTech belongs to the IMT Institut Mines-Télécom group (formerly known as Institut Télécom or GET) of French higher education institutions. The Institut Mines-Télécom is the leading group of engineering schools in France, with a network of thirteen schools[2] located

[2]IMT Atlantique, IMT Lille Douai, IMT Mines Albi, IMT Mines Alès, Mines Saint-Étienne, Institut Mines-Télécom Business School, Télécom ParisTech, Télécom SudParis, Eurecom, INSIC, Mines ParisTech, Mines Nancy, ENSIIE

throughout the national territory. Among those schools, Eurecom, located in Nice Sophia Antipolis, has strong connections with Télécom ParisTech as it hosts students from Télécom ParisTech as well as a limited number of its faculty members (six faculty members in total, in the domains of SoC and sociology, five of them are members of the LTCI). The Institut Mines-Télécom plays an important role in the scientific strategy of the LTCI, notably through its yearly funding program Futur et Ruptures which provides funding of PhD theses that serves all the schools affiliated to the Institut, with a significant fraction of them being awarded to LTCI (the call funds a dozen of PhDs and about a quarter of them are attributed to the LTCI lab).

Télécom ParisTech is one of the components of the Télécom & Société numérique Carnot Institute (TSN), the premier Carnot institute in a network of 29 dedicated to information and communication science and technology. The TSN center brings together more than 20 joint laboratories – including LTCI – totaling over 2,000 researchers and doctoral students, in order to offer cutting-edge research and integrated solutions for issues linked to information and communication technology. More specifically, it supports research on the technical, financial and social implications of the digital transition, enabling it to reach the following markets: communication networks and devices, health and autonomy, the environment, information and communication security. The Carnot label was created in 2006 to support partnership-based research, in other words to promote research projects undertaken by both public research players and those from the socio-economic world. This label for excellence takes the form of financial support from the French National Research Agency (ANR), calculated on the basis of the income generated by partnership-based research contracts. The Carnot TSN funding plays an important role in the development of our research activity, since it funds part of administrative staff (2-3 persons) dedicated to the development of partnerships and innovation, some PhD theses, postdocs and invited professors.

Télécom ParisTech is also a member of the ParisTech alliance of Parisian Grandes Ecoles. The role of ParisTech has evolved since its creation: initially conceived as a PRES (Pôle de recherche et d'enseignement supérieur) in 2007, it is now mostly active in the fields of industrial and international partnerships. In 2013, ParisTech opened a school on the Shanghai Jiao Tong campus (China) as well as the Institut Villebon-Georges Charpak (in Palaiseau), both projects in which Télécom ParisTech plays a major role.

The LTCI continues the work carried out by the UMR LTCI between 2003 and 2016. The CNRS contributed until December 2016, end date of the UMR CNRS, to the scientific management of LTCI and allocates several full-time researchers (24 as of mid 2013, 21 in 2016) to the lab. Within the CNRS, the UMR LTCI was managed by the Institute for Information Sciences and Technologies (INS2I).

1.2.2 Paris-Saclay

Télécom ParisTech and the Institut Mines-Télécom are strongly involved in Paris-Saclay project, which aims to become a world-class campus by gathering several higher education institutions physically located in the south-west of Paris. The campus is not limited to research and education centers as several major French companies (including, among others, Thales, EDF, and Danone) already settled part of their research activities on the campus. The project was funded through the Investissements d'Avenir program in 2012 and a new public organization called Université Paris-Saclay (UpSay) was created (as a Communauté Scientifique d'Universités et d'Etablissements) in December 2014. After three years on intense discussions and work on the definition of the target organization of UpSay, the government decided to split the project into two parts (UpSay around Université Paris Sud and a new project around Ecole Polytechnique, denoted temporarily NewUni). Both projects are expected to become world-class universities, ranked in the top tier of the international universities, with a certain degree of complementarity and collaboration between them.

Télécom ParisTech is one of the founding members of NewUni. This project gathers five Grandes Ecoles (Ecole Polytechnique, ENSTA ParisTech, ENSAE ParisTech, Télécom ParisTech and Télécom SudParis) and aims to create a world-class Institute of Science and Technology, following the model of EPFL in Switzerland or MIT in the US. Télécom ParisTech will move to its

new building in Saclay, close to the other members of NewUni, for the academic year 2019-2020. Télécom ParisTech is completely involved in the definition of the main components of NewUni, its organization and its governance.

1.2.3 Labex, Equipex and other PIA objects

Télécom ParisTech, as part of the Institut Télécom, joined the RTRA (Réseau Thématique de Recherche Avancée) Digiteo in 2009. At the time of its creation Digiteo was the only Excellence cluster in information science and technology in France, situated in the Paris-Saclay Campus.

Télécom ParisTech was partner of the Equipex Digiscope, which is a network of high-performance platforms for interactive visualization of large datasets and complex computation. Distributed throughout its nine scientific partners (CNRS, INRIA, CEA, Université Paris-Sud, Intitut Mines-Télécom, Université de Versailles Saint-Quentin, CentraleSupélec, ENS Paris-Saclay, Maison de la simulation), Digiscope's ten rooms feature extremely large displays and advanced interaction devices, and are interconnected via a telepresence network that supports remote collaboration. Anticipated applications include scientific research, computer-aided design, decision support systems, and education. The project was led by the research network RTRA Digiteo, which was hosted by the "Fondation de Coopération Scientifique Campus Paris-Saclay", then replaced by Université Paris-Saclay.

LTCI is an active member of the LMH (Labex Mathématique Hadamard) and the DigiCosme (Mondes Numériques, Programmes et Architectures Distribués) laboratories of Excellence (labex).

The DigiCosme labex, headed by Florence D'Alché-Buc, Professor at Télécom ParisTech, brings together 300 researchers and as many PhD students, spread over the sites of its 11 member institutions: CEA, CNRS, Ecole polytechnique, Supélec, Inria, Paris-Sud University, Ecole Centrale Paris, ENS Cachan, ENSTA ParisTech, Institut Mines-Télécom, University of Versailles St-Quentin. The goal of this Labex is to respond to the scientific and technological challenges of the digital revolution. To this end, three scientific axes are developed by the labex. The first one is on the reliability of the digital world by its resistance to design errors, random or intentional failures. The second one is on the ability of the digital world to transmit or collect information of all types in a scalable way through distributed architectures. The third one is on the intelligence of the digital world through the development of new mechanisms to access, interact with and make sense of the unprecedented amounts Fifteen professors from the LTCI are involved in the LMH as of mid-2018.of data that are made available now.

The LMH, headed by Vincent Giovangigli, Senior Researcher at CNRS and member of the CMAP laboratory at École Polytechnique, covers the full spectrum of research in mathematics, from pure and fundamental studies to applied mathematics. The labex coordinates its actions with the department of mathematics of UPSay, and the doctoral school EDMH (Ecole Doctorale Mathematique Hadamard) which manages about 300 PhD students. The LMH funds PhD grants, postdocs, master's scholarships and different other actions for the the Paris-Saclay community of mathematicians (invitation of foreign researchers, sponsoring of scientific events, etc.). Télécom ParisTech is one of the partners of the LMH and, as of mid-2018, fifteen professors from the LTCI are involved in the LMH.

1.3 Production and research activities

Key figures and facts

The details of noticeable facts and events are given for each team in the next chapters. Let us just mention here some prestigious prizes (4 ERC, 1 google faculty research award, 1 Blondel medal, and numerous prizes for best PhD theses and best papers), the organization of international conferences, the involvement and important responsibilities in program committees and scientific boards (area chairs of NIPS, IJCAI..., chair of IEEE NEWCAS, etc.), as well as the invitations to give plenary talks and tutorials. Similarly editorial activities are worth to be mentioned and several members of the LTCI are associate editors of top-level journals.

The evolution of the number of professors and researchers in the LTCI is shown in Table 1.2. Since the professors have to share their time between teaching and research (around 50% each), and since some members of the lab are working on part time basis, we measure in Table 1.3 the LTCI staff in Equivalent Full-Time Researchers (ETPR – Equivalent temps plein recherche) during the period 2013-2018, in each department. We observe clearly a significant drop in 2017, especially in IDS and INFRES, corresponding to the end of the UMR CNRS. Figure 1.5 details the repartition of the Equivalent Full-Time Researchers in sixteen teams of the LTCI.

	2013	2014	2015	2016	2017	2018
Professors & Associate Professors	110	114	116	117	121	113
COMELEC	37	38	39	39	40	38
INFRES	46	47	47	46	46	44
IDS	27	29	30	32	35	31

	2013	2014	2015	2016	2017	2018
Researchers (CNRS)	24	25	24	21	0	0
COMELEC	4	5	5	3	0	0
INFRES	7	8	8	8	0	0
IDS	13	12	11	10	0	0

Table 1.2: LTCI staff (Professors and Researchers) in the period 2013–2018.

	2013	2014	2015	2016	2017	2018
Equivalent Full-Time Researchers	74.8	76.9	77.2	72.6	56.3	54.3
COMELEC	21.3	21.9	21.8	19.9	17.7	17.3
INFRES	27.9	29.8	30.5	28.7	22.4	22.0
IDS	25.6	25.2	24.9	24.0	16.2	15.0

Table 1.3: LTCI staff measured in Equivalent Full-Time Researchers.

	2013	2014	2015	2016	2017	2018	Total
Peer reviwed journals	173	204	181	177	163	62	960
COMELEC	53	79	63	65	50	24	334
INFRES	51	52	56	49	59	17	284
IDS	69	73	62	63	54	21	342

	2013	2014	2015	2016	2017	2018	Total
Peer reviewed conferences	454	490	443	365	385	138	2 276
COMELEC	149	178	149	121	120	47	764
INFRES	139	154	162	135	141	49	780
IDS	166	158	132	109	124	42	731

	2013	2014	2015	2016	2017	2018	Total
Books and book chapters	33	18	27	20	24	5	127
COMELEC	4	3	7	2	4	0	20
INFRES	14	6	8	9	15	1	53
IDS	15	9	12	9	5	4	54

Table 1.4: Scientific production (until mid-2018).

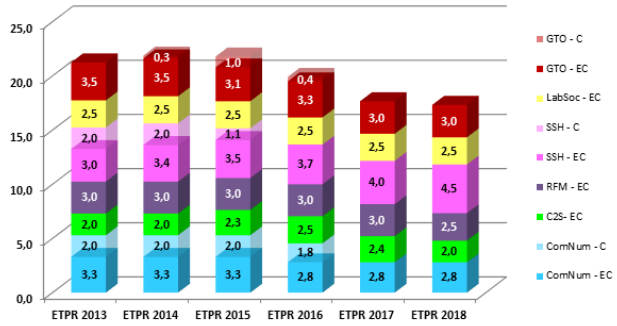


FIGURE 1.2: COMELEC teams.

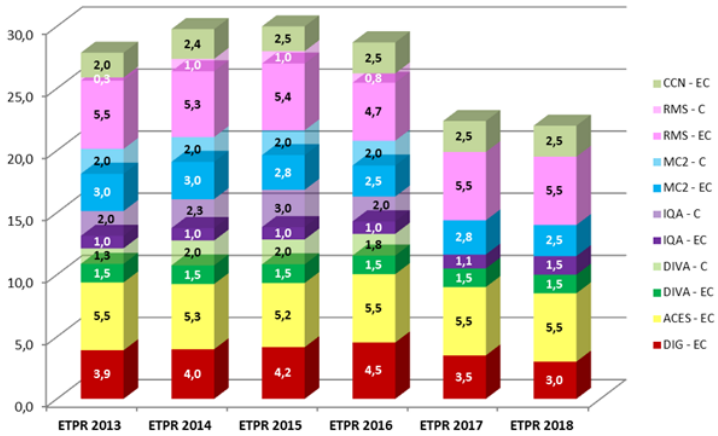


FIGURE 1.3: INFRES teams.

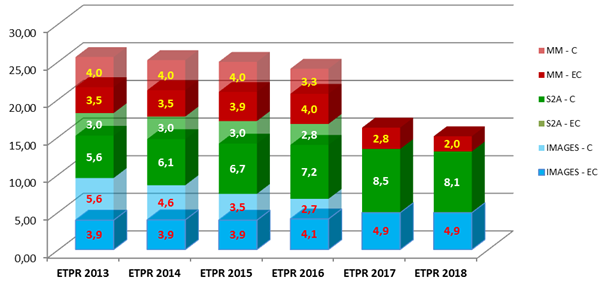


FIGURE 1.4: IDS teams.

FIGURE 1.5: Teams staff measured in Equivalent Full-Time Researchers.

Scientific report

The scientific production of LTCI in the period 2013–2018 can be measured from Table 1.4 and Figure 1.6. Note that the last year of the period is often atypical due to a number of publications not properly registered, being for instance submitted an not yet accepted or accepted and not yet published. This effect is here combined with the end of the UMR CNRS in 2016 and the loss

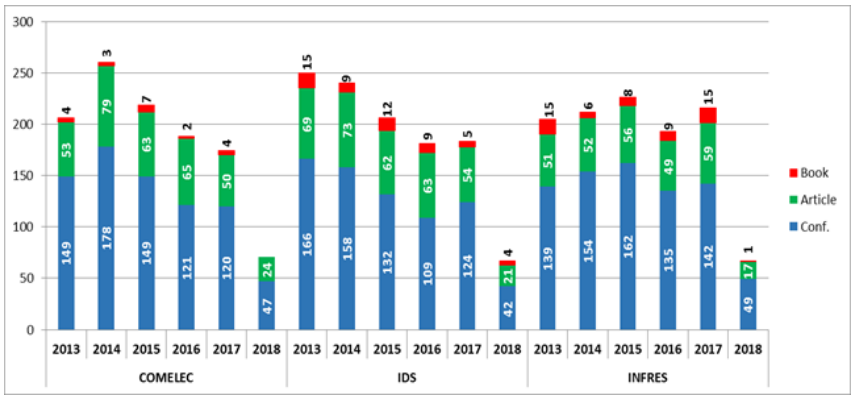


FIGURE 1.6: Scientific production evolution during the period 2013-2018.

	2013	2014	2015	2016	2017	2018
Defended PhD	68	68	62	73	57	29
COMELEC	19	21	16	21	10	6
INFRES	19	25	19	25	26	7
IDS	30	22	27	27	21	16
Average duration (months)	41	40	41	41	41	

TABLE 1.5: Defended PhD.

	2013	2014	2015	2016	2017	2018
LTCI	13(6)	18(12)	26(18)	19(14)	7(6)	6(6)
COMELEC	3(2)	8 (8)	15(14)	12(12)	1(1)	4(4)
INFRES	7(2)	3(3)	3(2)	3(1)	2(1)	2(2)
IDS	3(2)	7(1)	8(2)	4(1)	4(4)	0(0)

TABLE 1.6: Patents.

	2013	2014	2015	2016	2017
LTCI	10 425	9 551	8 904	9 661	9 423
COMELEC	2 643	2 675	2 259	2 591	2 887
INFRES	3 806	3 298	3 412	3 606	3 265
IDS	3 137	2 928	2 566	3 035	3 271
CNRS	839	650	667	430	

TABLE 1.7: Financial resources from grants and contracts in K€ by management entity.

of around 22% of our forces measured in Equivalent Full-Time research (see Table 1.3). Despite this unfavorable situation, we can observe that the decrease of the scientific production was less important than expected (11% less publications in journals, 12% less in conferences). This can be explained by the fact that part of the former CNRS members of the LTCI continued working and publishing with their former teams. Globally, the ratio between the number of publications and the number of Equivalent Full-Time Researchers is almost stable over the period: slightly above 6 conference papers per year and per full-time researcher (6.1 in 2013 and 6.8 in 2017), and above 2 journal papers per year and per full-time researcher (2.3 in 2013 and 2.8 in 2017).

Note that in these figures, every publication is counted only once. However, some cited publications can be co-authored by members of different teams and may appear in the publication list of each of these teams (with a unique number). This is due to some team reconfigurations, and also to common publications from members of different teams.

Involvement in teaching at the M2 (second year of master) level

The members of the LTCI are highly involved in masters organization and teaching:

- direction of the master in Computer Science (mention informatique) at Paris-Saclay,
- direction or co-direction of several master tracks: ACN, Data & Knowledge and Data Sciences at Paris-Saclay, Image at Sorbonne Université, Biomedical Engineering at Paris Descartes....
- responsibilities of numerous courses in the master in Computer Science at Sorbonne Université, the masters in Mathematics, Computer Science, Electronics, and Physics at Paris-Saclay...

They are also involved in the Doctoral Schools, have participated in creating some of them, and are co-directors, or members of organization or managing structures of

- EDITE Paris,
- ED STIC Paris-Saclay,
- EDMH Paris-Saclay...

1.4 Internal animation and lab life

Direction of the lab The director of the LTCI is assisted by three research deputies, from each department. They meet regularly, at least once a month, also with the department heads. These meetings aim at preparing the lab council meetings and at strengthening the relations between the direction of the labs, the departments and the team.

The director was chosen by the director of Télécom ParisTech, after the formal approval of the lab council (based on a vote).

The director has an assistant and one administrative staff (on part-time base) in charge of the communication (Website, News, the organization of events for the laboratory, etc.). He also has the help of the administrative staff of the departments, for the management of the registrations of the PhD students, and the access to the information which concerns the contractual activity of the teams (contracts, revenues, etc.).

Lab council The lab council is composed of the director and the three deputy directors, 9 members (7 faculties, 1 administrative/technical representative, 1 PhD candidate), along with substitute members. Among the 9 members, 7 are elected and 2 faculties are chosen by the direction team to guarantee a good balance between the scientific domains and the teams.

The department heads and the director of the doctoral studies are invited at the council meetings.

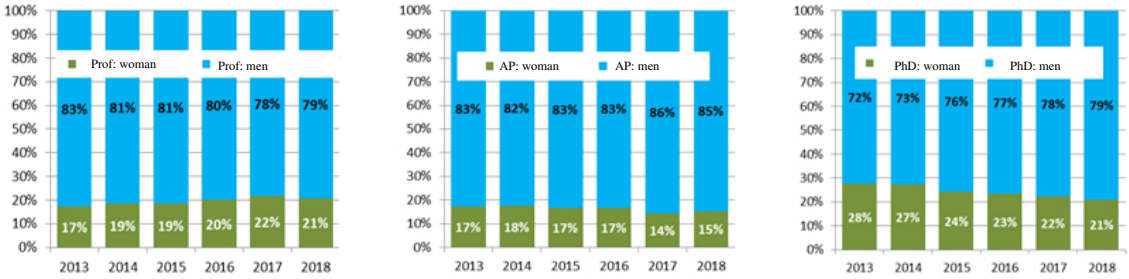
The lab meetings take place regularly, once a month. The council discusses the budget, the lab life, the scientific animation and the main directions the lab should promote, the open faculty positions, the invitations of foreign researchers, the interactions within the ecosystem... Concerning the budget, a part is directly handled by the teams. The remaining common part and the actions to be taken are discussed by the lab council. On all these points, the council makes decisions.

Scientific animation Although the scientific animation on each main research axis is mostly done by the teams, a transversal animation takes also place at the lab level. This includes a general scientific seminar (Journée Recherche du LTCI[3]), once a year, and the promotion of transverse seminars, across teams (for instance, the Data Science seminar[4] or the newly launched seminar on Critical Embedded Systems[5]). Also, all invited researchers give talks open to all the teams.

Equality of chances Although no parity exists in the scientific domains of the LTCI, we pay attention to the equality of chances, both in recruitment and in communication. This includes an attention paid to the language itself, to ensure equal communication in a process of deconstructing discrimination, whether conscious and subconscious.

In the LTCI, the proportion of woman is around 21% among the professors (slightly increasing during the last years) and around 15% among associate professors (slightly decreasing). For PhD candidates, the proportion is around 21%, also decreasing, which calls for a specific attention. An effort for the promotions from associate professors to professors is visible, and is still ongoing. Three teams of the LTCI are headed by women.

It should be noted that a lot of national committees require to tend towards parity, which means a huge additional charge for the women of the lab.



(A) Full Professors (B) Associate Professors (C) PhD students

FIGURE 1.7: Gender distribution of the faculty and the PhD students.

1.5 SWOT analysis

As shown in Figure 1.8, the main strengths of the lab are:

- A broad coverage of the field of information and communication science and technology. This helps, for instance, in managing large projects that require different expertises, at the theoretical level and for the applications aspects.
- A significant scientific production at very good level (see Section 1.3). The overall number of publications of the lab is relatively high, with more than 500 main publications per year (journals, conference proceedings and books). This gives a publication rate (for 118 researchers) around 4.23 per researcher and per year). During the period 2013-2018 4 members of the lab won 4 ERC grants (3 starting grants and one consolidator grant).

[3]https://ltci.telecom-paristech.fr/journee-recherche-du-ltci/
[4]https://ltci.telecom-paristech.fr/data-science-seminar/
[5]https://ltci.telecom-paristech.fr/critical-embedded-systems/

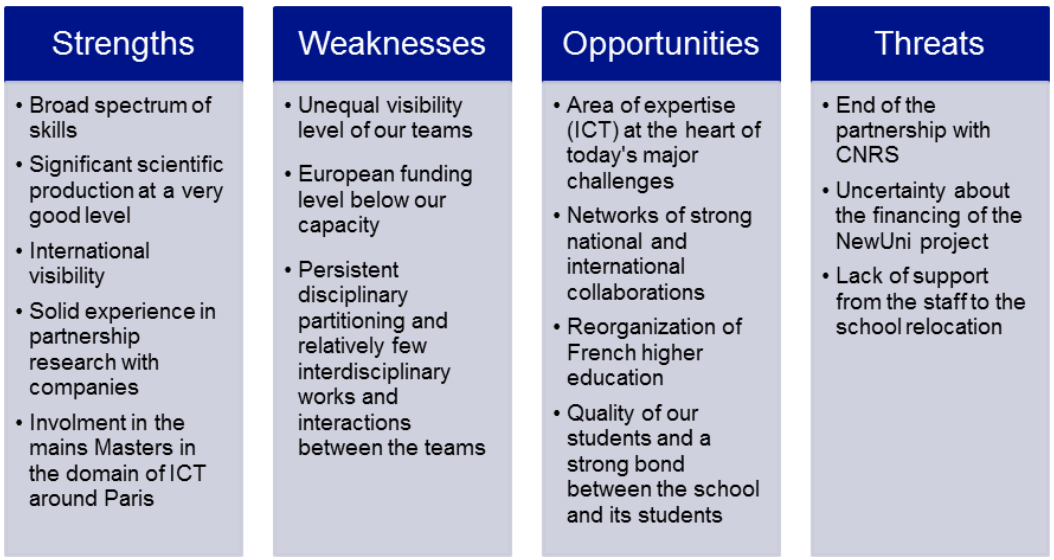


FIGURE 1.8: Summary of the SWOT Analysis.

- An international visibility, materialized by a large number of publications co-authored with researchers from foreign laboratories.
- A solid experience in partnership research, especially with companies. Many collaborations and a strong partnership activity: a turnover approaching 85KE per EC and per year (10ME in total). More than half of it comes from partnerships with companies (Chairs, joint labs and other joint projects).
- Involvement in the Masters constituting the main pools of PhD candidates around Paris (Paris-Saclay Masters and some other Parisian Masters). This guarantees a direct access to good PhD candidates.
- Involvement in the scientific animation and management at national and international levels.

The possible weaknesses on which we have to work are:

- A unequal visibility level of the teams. This is probably the case in all major laboratories. We have some extremely dynamic teams whose activity is very visible internationally and others a little less visible, but who are nevertheless doing research of good quality. Several retirements, but also the loss of CNRS researchers, have affected the activity of our smallest teams. We have tried to compensate for these losses by restructuring certain teams and opening new positions, but this work is not yet complete and must continue in the coming years. We have also worked for several years on the quality of our recruitments.
- A European funding level below our capacity. This is the case of most of the French labs. We believe that this weakness can be resolved by a more proactive strategy and a real support for our researchers while finding the right calls, the right partners and in preparing their answers to the calls. This opinion is shared with IMT and our partners in NewUni. One of NewUni's first proposals was the establishment of a Grants Office to help in following the European calls and preparing the answers to these calls (ERC, H2020 and the next research and innovation framework program Horizon Europe).
- A persistent disciplinary partitioning and relatively few interdisciplinary works and interactions between the teams. The number of interdisciplinary publications, involving researchers from different disciplines, is not particularly low in the LTCI, if we take into account the publications

co-authored with researchers from other laboratories. However, if we limit ourselves to LTCI we can hope for more results common to different teams. In an attempt to improve the interactions between our teams, we opened some positions on shared profiles supported by at least two teams. We succeeded in doing that, for instance, between SSH and ACES, DIVA and IMAGES, but the benefits of this initiative remained limited. We are now trying to involve in our major projects (especially in the Chairs), several teams with complementary expertise around concrete challenges (AI, cybersecurity, autonomous cars, etc.).

The opportunities are:

- An area of expertise (ICT) at the heart of today's major challenges. This is very motivating for our researchers (including our doctoral students and postdocs) in addition to the fact that it allows obtaining significant funding for our work. A lot of challenging problems and concrete applications are raising continuously in this domain.
- Networks of strong national and international collaborations, which is very useful for our recruitments (at all levels) and our reputation.
- The reorganization of French higher education. This is a unique opportunity for Télécom Paristech and LTCI, in particular, to try to bring its experience and expertise, together with those of its partners, to create a top-tier university internationally known. We are doing our best to reach this challenging goal with our partners in NewUni.
- Quality of our students and a strong bond between the school and its students. This is an asset for Télécom ParisTech and the LTCI. We have a pool of very good students of which a small part is pursuing doctoral studies after their graduation from Télécom ParisTech. We try to raise the awareness of these students to scientific research and to offer funding for those who wish to pursue doctoral studies in our laboratories (for instance, through the Future & Rupture Programme of the IMT). This effort will certainly continue in the coming years.

The possible threats for the coming period are:

- End of the partnership with CNRS. The end of the UMR CNRS had as a consequence for the laboratory the loss of some very dynamic researchers. We tried to limit this impact by restructuring the most impacted teams and by the opening of new positions. We have also made some changes in the governance of the laboratory: 1. participation of the director of the LTCI in the main committees and governance bodies of Télécom ParisTech (executive committee, recruitment commissions, promotions committee, etc.); 2. coupling of the Direction of Research of Télécom ParisTech with the Direction of the LTCI in order to make it easier, for the Director of the LTCI, the access to the administrative and management staff dedicated to the research activity of Télécom ParisTech; 3. creation of a monthly coordination meeting between the director of LTCI, his deputy directors, and the three heads of the departments composing the LTCI; 4. establishment of a clear procedure, managed by LTCI, for prioritizing research profiles in the open positions (profils de postes), based on the needs expressed by the teams, in which the board of the lab plays a major role (selecting, reviewing and ranking the proposals); 5. involvement of LTCI in the redistribution of the financial resources generated by the contracts through grants given by the lab to its 16 teams (3% of turnover of the departments is thus redistributed by LTCI).

  However, we believe that the National Research Organizations (in particular the CNRS and INRIA) will have to play an important role in the structuring of the research activity in Paris-Saclay and NewUni. This will necessarily impact the future of our laboratory. LTCI, like all other NewUni laboratories, should therefore be associated with a national research organization within NewUni. Direct discussions, and through NewUni, will, therefore, be done with the CNRS and INRIA in the coming period to agree on a common vision of the organization of research and its governance within NewUni. LTCI intends to participate in these discussions and in the elaboration of the choices that will be made.

- Uncertainty about the financing of the NewUni project. These kinds of projects of major importance for the country require a lot of support in the first years, so long as the model on which the project is conceived can function fully and show its efficiency. All the research activity of NewUni, including the LTCI, will be impacted by whether we will get this support or not and its importance.
- Lack of support from the staff to the school relocation. The move to Saclay does not please the staff members who expect difficulties related to the lengthening of the distance between their workplace and their place of residence. Thus, there is a risk of losing some of our good researchers because of this move and, probably, difficulties in maintaining at the current level all the excellent collaborations we have with our partners in Paris.

1.6 Scientific project

This section presents the project of the LTCI. To better understand the perspectives for the LTCI, we first discuss the current situation in Section 1.6.1, then we present the project of the laboratory in Section 1.6.2.

1.6.1 Analysis of the current situation

LTCI is a laboratory of Télécom ParisTech (Institut Mines-Télécom) and one of NewUni's main laboratories in the field of Information and Communications Technology (ICT), in terms of size and terms of scientific production. Its mission is to contribute, by the excellence of its research, to the advancement of the knowledge in the field of information sciences and the development of the potential of French innovation in the digital domain. Fully integrated into the NewUni project, where it is considered as one of the pillars of the Faculty of Data Sciences and Information Technologies, LTCI aims to contribute to some of its major objectives, namely the development of scientific research at the highest level, the strengthening of the PhD Program, the emergence of interdisciplinary research, and the development of the innovation potential and transfer to the industry.

LTCI is composed of 3 research and teaching departments, gathering 16 teams and covering different scientific disciplines in the ICT field. As each department operates autonomously, handling such a diversity while targeting the emergence of a collective vision is not an easy task. To strengthen the link between the lab and its teams and enable the LTCI to better play its role, we carried out the five actions mentioned in the SWOT analysis (threats in Section 1.5), following the end of the partnership with CNRS. We also opened a discussion on the recomposition of the teams, regardless of frontiers of the departments, and called for the recomposition of the teams around a clear scientific project carried by a team leader freely chosen by the members of the team. This took us more than six months in 2017. It results in few changes in the composition of the teams, but we succeeded in clarifying the scientific project of each team and in clarifying the role of the teams and their responsibilities.

The work done for the definition of the scientific projects of the teams led to a set of documents, summarizing the main expertise of each team, their main scientific objectives, and the associated SWOT analysis. It gives us a global vision of the expertises of the lab and the complementarity between its teams. The project described below gives our current vision of the strategy of the lab for the coming years, based on the scientific projects of the teams and the SWOT analysis given in the previous section. This strategy could evolve during the next period, especially with the creation of NewUni and the definition of a global strategy for this new university.

1.6.2 Perspectives and project

In the past years, the LTCI has contributed to the emergence of new ideas and techniques to tackle the challenges raised by the digital transformation and the key societal transitions. Among theses challenges we can mention three that are in the core interests of the LTCI: security and

reliability, scalability (of the digital systems and the communication networks), agility and intelligence (of the proposed techniques and tools). The emergence of these challenges, coupled with the unprecedented increase in data volumes, computational capabilities, and access to communication networks is gradually emphasizing the limitations of existing solutions. This is a source of new challenges for our laboratory, which hosts a large spectrum of expertise in the domain of information and communication sciences and technologies.

An important and thorough work was done in 2013 to define a common project for the laboratory and for Télécom ParisTech in general. It mobilized for several months the research direction of Télécom ParisTech, the director of LTCI and all the research teams and departments. Since then, some issues have evolved, leading to new challenges and priorities, but most of this work is still relevant for the laboratory.

The LTCI project for the next period is therefore based on this previous work, that we extended and adapted in order to take into account the new priorities and updates in the strategy of the laboratory. It is built around the following five axes:

Digital Trust: security, risk and reliability

Security and reliability are studied at Télécom ParisTech at all hierarchical levels of the systems, from the physical layer to the applications via the mathematical tools, the software layers, the networks and the societal aspects.

The major challenge of this axes is the development of tools and methods guaranteeing a high level of reliability and trust and ensuring the best compromise according to two directions: (1) Studying reliability and security in a joint way (horizontal challenge), i.e. modeling and managing synergies and conflicts between these two issues; (2) Integration of the protection/reaction mechanisms at all the hierarchical layers (vertical challenge), from the physical layer to the applications via the mathematical models, the software layers, the networks, and the societal impact.

Data Science and Artificial Intelligence

In this axis we focus on the theoretical foundations of the management and analysis of data in all its forms (massive, complex, heterogeneous, uncertain, etc.) and their concrete applications in domains of major interest like health and wellbeing and cybersecurity. This axis relies on the expertise of our teams in statistics, mathematics and computer science and on the close collaboration we maintain with the Department of Social Sciences and Economics of Télécom ParisTech. It mobilizes different teams and creates a multidisciplinary exchange framework open to the socio-economic world around issues such as image processing, predictive analysis, recommendation systems, anomaly detection, web mining, social networks analysis, scalability or knowledge management.

The two main challenges of this axis are: (1) Scalability of the solutions, control of their complexity and the explainability of the algorithms; (2) Leverage the multidisciplinary dimension combining methods, technologies and uses.

Very large networks and systems

The research interests in this axis lie in the design and study of future emerging networking technologies, whether it is for mobile networks, wireless networks, optical networks, the Future Internet, etc. The LTCI has skills covering all of the research areas in this domain, it designs the systems and infrastructures of tomorrow, that should be global, integrated, agile, and sustainable.

The two main challenges of this axis are: (1) The scalability of the systems, i.e. a continuous but tenable increase in the capacities of transmission (optical, radio ...), communication, storage, and processing, in the number and diversity of objects to connect, contents and users; (2) New architectural paradigms, global, integrated and distributed, agile and programmable, intelligent and self-organized leading to the emergence of unpredictable behavior.

Design, Interaction and Perception

Here the main objectives are:

- Design digital and semantic models of physical, social, emotional reality from multimodal data perceived in complex environments ("in the wild");
- Build new forms and languages for interaction between humans and systems;
- Exploit these models for the design of objects, worlds and experiences.

The two main challenges of this axis are: (1) Processing information that allows the machine to take full advantage of the multiple sources and computing capabilities; and (2) Design effective, expressive and evolving interactions and devices for environments with a multiplicity of data, artifacts and humans.

Mathematical Modeling

This axis is transverse to the first previous ones, in the sense that it contributes to each of these axes, and is one of the strengths of the laboratory which, as it was underlined previously, is interested at the same time in the theoretical and practical aspects of research in ICT. It can be divided into three parts:

- Content, Knowledge and Interactions Modeling;
- Networks and Systems Modeling;
- Information (and its ecosystems) Modeling.

For all these issues, advanced mathematical models are developed to effectively represent a complex reality and at best exploit it.

The two main challenges of the axis are: (1) The compromise between fidelity to the real world and the efficiency of the models (usability, computability, adequacy to needs); and (2) The ability to address problems with a high level of complexity, involving heterogeneous, possibly massive or incomplete data, involving poorly controlled uncertainties or needs for unbounded calculation resources.

For all the axes described above, our objective is twofolds: develop a research activity at the highest level and contribute to the innovation effort and transfer to the industry. Thus, the implementation of our project requires a special effort in the coming years on three main points:

- The attractiveness of our teams and the quality of our recruitments at all levels (researchers, doctoral students, post-docs), in order to strengthen our expertise and to have the best assets to meet the challenges mentioned above. This effort will have to be done in coordination with our partners in NewUni and the IMT.
- Strengthen the synergy between our teams around the axes defined above in order to take advantage of their complementarities and also to create a momentum that is profitable for large teams as well as for smaller or less visible teams. This effort should also be extended to NewUni's Faculty of Data Sciences and Information Technologies, in order to take advantage of the complementarities between NewUni's laboratories.
- Develop a solid partnership strategy that enables the emergence of some big projects, which may involve several teams with complementary expertise, and that can provide them with the necessary financial support to develop their work over years. This must be done without neglecting other sources of funding, especially public funding at national and European level. We started structuring our efforts around this goal in coordination with IMT and our partners in NewUni.

Note that our project is consistent with the priorities of NewUni, since three of our axes are among its main priorities (Cybersecurity, AI and Data Science, Networks and IoT). The same three axes appear also in the priorities (Thématiques Phares) of the IMT, and two of these priorities are led by Télécom ParisTech: Artificial Intelligence and Data Analytics are led by the director of LTCI and Networks and IoT is led by Bruno Thedrez, head of the COMELEC department.

1.7 Appendix

In this appendix, some additional information is provided, on some official decisions, lab equipments, etc. Due to the nature of this information, some documents are in French and others are in English. If needed, translations can be provided on request.

1.7.1 Appointment and mission of the Director of the LTCI

TELECOM ParisTech

INSTITUT Mines-Télécom

Affaire suivie par : Yves Poilane

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Ref. : YP/ID/DIR

Destinataires :

Diff-Z
Mr le Directeur Général de l'IMT
Mr le Directeur de la Recherche et de l'Innovation de l'IMT

Paris, le 3 janvier 2017

Décision n° 01/2017/DIR

Objet : Nomination du directeur du Laboratoire LTCI

A compter du 1er janvier 2017, sur proposition du Conseil de Laboratoire, au vu de sa profession de foi et de sa présentation en Conseil de Laboratoire et après avoir échangé avec lui, Talel Abdessalem, Professeur au département InfRes, est nommé directeur du nouveau LTCI, laboratoire propre de Telecom ParisTech, qui succède à l'UMR CNRS du même nom.

Ce laboratoire devra continuer à conjuguer excellence académique et utilité économique, évaluées au travers des indicateurs les plus couramment utilisés dans ces domaines et, pour ce faire, conduira des travaux de recherche disciplinaires et interdisciplinaires.

Talel Abdessalem devient, à ce titre, membre de droit du Conseil de direction de l'école et participe à ses prises de décision, tout particulièrement à celles qui sont relatives à la définition ou à la mise en œuvre de la politique de recherche de l'école (financement de la recherche, définition des postes à pourvoir, recrutements et promotions de personnels d'enseignement-recherche et support à la recherche...).

Dans ses fonctions, il est chargé d'assurer dès le 1er janvier la meilleure continuité de fonctionnement de l'ex-UMR, d'en ajuster au besoin le projet, d'en préparer le bilan pour la période en cours puis le projet pour la période future (2020-2024). Il participe également activement à l'étude de faisabilité de la fusion de Telecom ParisTech et Telecom SudParis, puis au projet de réalisation de cette fusion, si elle devait être décidée.

Il dirige le LTCI selon des modalités inspirées du fonctionnement antérieur de l'UMR auxquelles s'ajoute une très large part des évolutions proposées par l'école au CNRS dans le cadre de la négociation relative au retour au statut d'UMR, notamment sur les questions de moyens financiers et d'intervention dans les principaux processus RH de l'école pour les activités de recherche. Il travaillera tout particulièrement sur la structuration de l'animation

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TELECOM ParisTech

INSTITUT Mines-Télécom

de la recherche au sein du LTCI ainsi que sur la mise en valeur du laboratoire et la communication sur ses activités.

Il agit par délégation du directeur de l'école, dans le respect de sa gouvernance et en étroite coordination avec les membres du conseil de direction, au premier rang desquels, le directeur de la recherche, le directeur de l'innovation et du développement, les chefs de département d'enseignement-recherche du périmètre, le secrétaire général, le doyen et la directrice des ressources humaines.

A ce titre, les propositions qu'il fera, aussi bien à court terme pour assurer la continuité de l'action qu'à plus long terme pour préparer le projet 2020-2024, en s'appuyant sur la gouvernance nouvellement installée du laboratoire, seront régulièrement présentées pour décision en Conseil de Direction, voire aux instances statutaires de l'école, dans le respect des textes relatifs à son fonctionnement.

Les travaux d'élaboration du projet pour la période 2020-2024 seront conduits dans le cadre de la stratégie plus large de recherche de l'école (qui s'appuie sur 2 laboratoires, LTCI et I3 et œuvre à développer les interactions entre eux) et avec l'ambition de faire du nouveau LTCI un laboratoire de référence dans le domaine du numérique, reconnu au niveau national et international, attractif pour d'autres chercheurs et enseignants-chercheurs, et en interaction croissante avec les autres laboratoires de Paris Saclay, de façon cohérente avec la structuration progressive de la recherche sur le plateau.

Le directeur du LTCI travaillera tout particulièrement avec les chefs de département qui sont et resteront en charge :

-du management individuel des enseignants-chercheurs, dans l'objectif de leur permettre de progresser dans la maitrise de leur poste et dans leur carrière

-du management collectif des personnels et des budgets au périmètre de leur département, dans l'objectif d'assurer une coordination, des régulations et des arbitrages dans les domaines de l'enseignement et de la recherche, ainsi qu'entre enseignement et recherche.

Il est chargé d'élaborer, pour la fin janvier 2017, en lien tout particulier avec le directeur de la recherche et le doyen, une première proposition de description plus précise de ses fonctions et d'activités, qui sera examinée à la fois par le conseil du LTCI et par le conseil de direction de l'école, avant décision par le directeur, qui sera entérinée sous forme d'une description de fonction.

Yves Poilane
Directeur

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Missions du Directeur du LTCI, laboratoire de recherche de Télécom ParisTech
V15/01/2017

Le Laboratoire Traitement et Communication de l'Information (LTCI) se définit comme le laboratoire de recherche propre de Télécom ParisTech qui couvre les domaines scientifiques des réseaux et télécommunications, de l'électronique, de l'informatique et du traitement du signal, des images et des données. Il recouvre à l'heure de sa création les activités de recherche des trois départements d'enseignement-recherche *communications et électronique*, *informatique et réseaux* et *traitement du signal et des images*. Il succède à l'UMR CNRS du même nom et en prolonge les activités. Ce laboratoire devra continuer à conjuguer excellence académique et utilité économique, évaluées au travers des indicateurs les plus couramment utilisés dans ces domaines et, pour ce faire, conduira des travaux de recherche disciplinaires et interdisciplinaires.

Missions pour une période transitoire s'étendant jusqu'au 30 Juin 2017

- Etablit la liste complète des membres du conseil de laboratoire (CL) associant aux membres élus en décembre 2016, des membres nommés et des représentants des départements d'enseignement-recherche
- Clarifie le rôle de cette instance, son mode de fonctionnement et le règlement intérieur du laboratoire.
- Etablit une liste consolidée des agents de Télécom ParisTech membres du laboratoire après avoir débattu des règles d'inclusion en Conseil de laboratoire.
- Met en place une procédure donnant la possibilité d'associer au laboratoire des personnes non agents de Télécom ParisTech (en particulier, les personnes bénéficiant d'une appellation de professeurs/maîtres de conférences invité/émérite/titulaire d'une chaire).
- Informe le HCERES du changement de statut du laboratoire et ajuste au besoin le projet scientifique du laboratoire LTCI qui a été déposé à l'AERES en 2013. Ceci, en collaboration avec les responsables des départements d'enseignement-recherche ou leurs représentants au sein du conseil de laboratoire. Ce document devra être validé par le conseil de laboratoire.
- Initie le processus visant à mettre en place une recomposition des équipes de recherche dans le domaine couvert par le LTCI.
- Contribue à mettre en place des mesures qui rendent l'organisation du LTCI plus compatible avec celle d'une UMR.
- Participe activement à l'étude de faisabilité du projet de fusion entre TPT et TSP

Missions pérennes

Le directeur du laboratoire agit par délégation du directeur de l'école, dans le respect de sa gouvernance et en étroite coordination avec les membres du conseil de direction, au premier rang desquels, le directeur de la recherche, le directeur de l'innovation et du développement, les responsables de département d'enseignement-recherche du périmètre, le secrétaire général, le doyen et la directrice des ressources humaines

Il dirige le LTCI selon les modalités inspirées du fonctionnement antérieur de l'UMR auxquelles s'ajoutent une très large part des évolutions proposées par l'école au CNRS, en particulier les moyens financiers et l'intervention dans les principaux processus RH pour les activités de recherche. Il travaille tout particulièrement sur la structuration de l'animation de la recherche au sein du LTCI ainsi que sur la mise en valeur du laboratoire et la communication sur ses activités.

Participer aux instances de Télécom ParisTech

- est membre de droit du conseil de direction de l'école (CODIR) et participe à ses prises de décision, tout particulièrement à celles qui sont relatives à la définition ou à la mise en œuvre de la politique de recherche de l'école (financement de la recherche, définition des postes à pourvoir, recrutements et promotions de personnels d'enseignement-recherche et support à la recherche…)
- est membre nommé du collège de la direction dans la *Commission de qualification pour promotion et changement d'appellation*
- est membre de droit des commissions de recrutement portant sur les postes du domaine scientifique du LTCI
- est membre de droit du Bureau de la Recherche, de la formation Doctorale et de l'Innovation (BURDI) de Télécom ParisTech auquel il contribue activement

  En cas d'indisponibilité, il ne peut être remplacé dans ces instances mais peut demander à un autre membre (Directeur de la recherche ou Doyen) de porter son avis.

Assurer la Direction Scientifique du LTCI

- Définit la stratégie de recherche du LTCI, sur la base des propositions établies par les équipes de recherche du LTCI et en relation directe avec la Stratégie Recherche de Télécom ParisTech, de l'Institut Mines-Télécom et de l'UPSaclay. Il propose à la direction de l'école la stratégie de recherche pour la période 2020-2024, avec l'ambition de faire du LTCI un laboratoire de référence dans le domaine du numérique, connu au niveau national et international, attractif pour d'autres chercheurs et enseignants-chercheurs, et en interaction

croissante avec d'autres laboratoires de Paris Saclay, de façon cohérente avec la structuration progressive de la recherche sur le plateau.

- Pilote la rédaction des bilans d'activité du LTCI, en particulier celui qui fera l'objet de l'évaluation HCERES de 2018
- Maintient et met à jour régulièrement, en concertation avec le conseil de laboratoire, une liste de besoins (recrutements, équipements, supports) en réponse aux priorités scientifiques du LTCI
- Reçoit et examine les candidatures des personnes extérieures à Télécom ParisTech souhaitant devenir chercheur associé au LTCI. Etablit la convention standard précisant les droits et devoirs du chercheur associé vis-à-vis de l'établissement et du LTCI
- Gère les relations entre le LTCI et les écoles doctorales auxquelles appartiennent les membres du laboratoire. En particulier, il est informé des demandes d'inscriptions des membres du LTCI aux écoles doctorales, valide les projets de thèses proposés par les membres du laboratoire et les dossiers de candidatures à ces thèses. Ceci, en coordination avec les responsables de département concernés.
- S'informe de l'ouverture d'appels à projets et des offres de financement nationales et internationales dans le périmètre des thématiques portées par le LTCI et s'assure de la diffusion de l'information auprès des chercheurs/enseignants-chercheurs concernés. Lors d'appels à projet limitant le nombre de réponses par laboratoire, il arbitre avec l'aide du conseil de laboratoire entre les propositions
- Gère les relations entre le LTCI et les organismes publics de financement de la recherche, en coordination avec la direction de la recherche de Télécom ParisTech. Intervient dans le processus de validation des projets montés par les chercheurs du laboratoire.

Piloter l'organisation et la gestion du Laboratoire

- Travaille sur la structuration de l'animation de la recherche au sein du LTCI. Ainsi que sur la mise en valeur du laboratoire et la communication sur ses activités.

- Préside le conseil de laboratoire du LTCI. Etablit le calendrier des réunions et les ordres du jour. Convoque les membres du conseil de laboratoire
- Convoque, préside et anime les assemblées générales du LTCI sur la base minimum d'une par an
- Met à jour la gouvernance du laboratoire autant que nécessaire en référant pour décision au conseil de direction de l'école, voire aux instances statutaires de l'école, dans le respect des textes relatifs à son fonctionnement.
- Tient la comptabilité budgétaire du laboratoire, avec l'aide de personnel qualifié et sous le couvert du secrétaire général de Télécom ParisTech
- Planifie et propose, pour avis, au conseil de laboratoire l'utilisation des fonds disponibles au budget du LTCI pour les actions de recherche
- Collecte régulièrement (*au moins une fois par an*) les indicateurs de la recherche et des contrats, au périmètre du LTCI

Coordonner les relations entre le LTCI et les autres services de l'École

- Contribue, sur la base des avis exprimés par le conseil de laboratoire et les équipes qui composent le LTCI, à l'élaboration par la direction de la recherche de Télécom ParisTech de la stratégie de l'en matière et recherche et d'innovation
- Assure la mise en œuvre de cette stratégie au périmètre du LTCI
- Participe à la réflexion menée par le Directeur de la recherche sur la répartition des moyens d'intervention destinés à la recherche
- Rend compte régulièrement auprès du conseil de direction de son activité et des indicateurs du LTCI. Informe le conseil de laboratoire et les membres du LTCI de sujets d'attention discutés en CODIR et / ou en BuRDI
- Coordonne, en matière de recherche, les interactions entre le LTCI et les départements d'enseignement et de recherche dans le périmètre du LTCI. Travaille tout particulièrement avec les responsables de département qui restent en charge :

    - du management individuel des enseignants-chercheurs, dans l'objectif de leur permettre de progresser dans la maitrise de leur poste et dans leur carrière
    - du management collectif des personnels et des budgets au périmètre de leur département, dans l'objectif d'assurer une coordination, des régulations et des arbitrages dans les domaines de l'enseignement et de la recherche, ainsi qu'entre enseignement et recherche.

- Coordonne, en matière de formation par la recherche, les interactions entre le LTCI et les écoles doctorales dans le périmètre du LTCI
- Contribue activement à l'élaboration par la direction de la communication d'une politique de communication des activités de recherche de Télécom ParisTech et veille tout particulièrement, en collaboration avec les équipes qui composent le LTCI, à la mise en place d'une présentation cohérente des activités de recherche de l'école au périmètre du LTCI sur le site web de l'école.

Représenter et promouvoir le LTCI

- Représente le LTCI en interne à l'Ecole, dans l'IMT, au sein de l'UPSaclay, nationalement et internationalement
- Promeut la visibilité du LTCI en participant à des instances, groupes de travail, etc. (jurys HCERES par exemple)
- Prend une part active à la défense des intérêts du LTCI au sein des départements STIC, Mathématiques et EOE de l'UPSaclay, informe l'École des initiatives / informations clés de ces départements
- Contribue à promouvoir le laboratoire et ses chercheurs en utilisant tous les moyens de communication (site web, logo, plaquettes, événements, etc.), en relation avec la direction de la communication de l'école

Participer à la gestion des ressources humaines

- Evalue les candidatures à promotion des chercheurs/enseignants-chercheurs à l'aune de la stratégie de recherche du LTCI au sein du collège de la direction lors des réunions de la *Commission de qualification pour promotion et changement d'appellation* et exprime son avis
- Participe au sein du conseil de direction à la définition des profils des postes de chercheurs/enseignants-chercheurs ouverts au recrutement
- Evalue les candidats à l'aune de la stratégie de recherche du LTCI lors des commissions de recrutement de chercheurs/enseignants-chercheurs
- Valide l'intégration dans le LTCI des personnels nouvellement recrutés ou ceux dont les activités ont évolué et qui répondent aux critères d'intégration dans le laboratoire et gère leur insertion dans une équipe.
- Transmet, à la demande des responsables de département, et en amont des entretiens annuels, une évaluation des activités de recherche des chercheurs/enseignants-chercheurs membres du LTCI
- Assure l'encadrement fonctionnel des personnels mis à la disposition du LTCI par l'école.

1.7.2 Main equipment and platforms

Moyens de calculs informatiques pour la recherche

Les départements INFRES et IDS disposent d'un ensemble de ressources informatiques mis à la disposition de l'ensemble des chercheurs de Télécom-Paristech.

Les ressources du département INFRES sont notamment constituées de serveurs *rackables* installés dans 2 salles climatisés dédiées. Ces serveurs sont administrés et supervisés par nos soins en collaboration avec la DSI de Télécom-Paristech. La DSI gère l'aspect hébergement hardware (alimentation électrique et refroidissement) mais aussi pour partie l'authentification des utilisateurs via l'annuaire centralisé LDAP de Télécom-Paristech.

Notre parc de machines est constitué de cinquante serveurs et de dix serveurs personnels. Parmi les cinquante serveurs, vingt sont constitués de machines très performantes en matière de nombre de cœurs et de mémoire. Les caractéristiques de ces serveurs sont résumées dans les 2 tableaux ci-dessous.

Nombre de cœurs CPU

Nb de cœurs	80	40	32	24	16
Nb de serveurs	1	5	9	3	2

Mémoire vives

Mémoire (Go)	512	384	256	64	48
Nb de serveurs	3	1	1	7	8

L'un de ces serveurs possède deux cartes NVIDIA K80 permettant d'avoir 4 ressources GPU à disposition pour le calcul scientifique.

Ces serveurs disposent d'un espace de stockage local dédié aux applications et d'un espace de stockage réseau dédié aux utilisateurs. Ces utilisateurs ont aussi accès depuis ces serveurs à leur espace de stockage personnel, hébergé par la DSI, ainsi qu'à des espaces sans quota hébergés sur nos serveurs NAS, dédiés au calcul scientifique nécessitant de gros volume de données.

Les caractéristiques des serveurs NAS INFRES sont décrites ci-dessous :

modèle	capacité	Protocole	Connectivité	Niveau de RAID	Haute disponibilité
EMC VNXe3150	4,1+1,9 = 6To	nfs V3	1GB	5	Non
Qnap TS-E879U-RP	0,7+1,5+3+1,3= 6,5To	nfs V4	1GB	5	Non
QNAP ES1640DCV2	15 + 19,6 = 34,6 To	Nfs V4	10GB	5 et 6	Oui

Les trois distributions Linux suivantes sont installés sur nos serveurs : Centos 6 pour les applications demandant de la stabilité dans le temps, Ubuntu 16.04 TLS (bientôt 18.04) pour les applications nécessitant un compromis en stabilité et dernière version logicielle et enfin Fedora 28 pour les applications demandant les versions les plus récentes des logiciels.

Tous les outils logiciels *open source* de ces distributions sont à disposition des utilisateurs ainsi que certains outils propriétaires, comme par exemple Matlab.

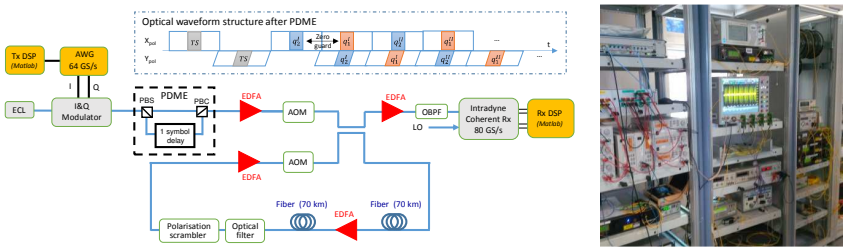
Comme évoqué précédemment, ces serveurs sont en accès libre en ssh avec les identifiants du compte utilisateur de Télécom-Paristech. Néanmoins pour répondre au besoin de la réalisation des tests de performance des algorithmes développées par les chercheurs, certaines machines peuvent être réservées pendant une période fixe de manière à garantir l'utilisation exclusive de ces ressources hardware par le code de l'algorithme à tester.

L'ensemble de ces serveurs est supervisé à l'aide du logiciel Nagios. Ce système mesure en permanence sur chaque serveur, l'état de la connectivité réseau, la charge CPU, l'occupation mémoire ainsi que l'occupation des différentes partitions des disques locaux. En fonction des mesures réalisées et des seuils configurés, des alarmes peuvent être générées. Ces alarmes nous informent au plus tôt d'une surcharge de la machine ou d'une défaillance matérielle. Cet outil de supervision est complété par une application Web propriétaire qui permet aux utilisateurs de visualiser très rapidement l'état de charge des serveurs.

Le *cluster* de calcul d'IDS contient 14 nœuds (14 serveurs). En tout, il y a 20 GPU. La mémoire, selon les serveurs, varie de 126 G à 378 G. Le nombre de cœurs par serveurs varie de 24 à 80. La distribution Linux Debian 9 est installée. La configuration logicielle est adaptable si les logiciels demandés sont des paquets Debian 9. De nombreuses librairies python sont également installées, ainsi que l'environnement CUDA. Le logiciel propriétaire matlab est également accessible. Les calculs sont lancés à l'aide de *scripts shell*, soumis par *qsub*.

Plateform: High-bit rate coherent transmission

Progress in digital signal processing and optical integration have enabled a new generation of optical transmission systems using complex modulation formats, coherent detection and digital algorithms to compensate for transmission impairments.
GTO has developed a high bitrate system platform based coherent detection combined with digital signal processing for evaluating the performance of 100Gb/s and 400Gb/s transmission The digital signal processing is done "off-line" from recorded time traces. Such platform is mainly based on specific pieces of equipment: Arbitrary Waveform Generator (AWG) combined with Dual polarization I&Q modulator at Tx, Real-time oscilloscope combined with intradyne polarization diversity at Rx, associated to various optical devices (tunable laser, I & Q modulators, balanced PIN-FET photoreceivers, 90 ° hybrid couplers, ...) .The transmission line consists in a 4x100km recirculation loop in WDM configuration (fiber sections, polarization scrambler, EDFAs, ...).



AOM : Acousto Optical Modulator; **AWG**: Arbitrary Wave Generator; **DSP** : Digital Signal Processing; **ECL**: External Cavity Laser; **OBPF** : Optical BandPass Filter; **PBC**: Polarization Beam Combiner; **PBS**: Polarization Beam Splitter; **PDME** : Polarization Division Multiplexing Emulator.

Main equipments

- At Tx: 25GHz Dual Polarization I&Q modulator (Fujitsu FTM7977HQA)
  64 Gs/s Arbitrary Waveform Generator (Keysigth M8195A)
  ~50 kHz linewidth Tunable sources (Yenista)
- At Rx : >40 GHz Dual Polarization Coherent receiver (home-made solution)
  Real-time Digital oscilloscope 80Gs/s (Keysigth)
  10 GHz Resolution optical filter (Yenista XTA-50))
- Recirculation loop : 4 spans of 100Km fiber length , EDFAs

It includes dynamic gain equalizer (Finisar WaveShaper 4000S) and Polarization scrambler (Agilent N7788B)

- Test & Measurements
  10 pm High resolution Optical Spectrum Analyser (Advantest Q8384)
  0.16 pm Ultra-High resolution Optical Spectrum Analyser (Apex AP2050A))

Main results

- 1st demonstration of Space-time coding to mitigate PDL in long-haul transmission systems (E. Awwad et al., *ECOC* 2013, *Opt. Express* 2013)
- Full ROADM solution based on Brillouin scattering in Fiber (W. Wei et al., *OFC* 2015, *ECOC* 2015)
- New modulations formats for FFTH applications (M. Chaibi et al. , *Photon. Technol. Lett* 2013, D.Erasme et al. *Lightwave Technol.* 2014)
- 1st Polarization Multiplexed NFDM transmission (W. Gemechu et al. *ECOC* 2017, T. Gui et al, *CLEO* 2018)

TTool Platform

- **TTool is a software workshop** that allows you to edit diagrams in UML and SysML, which are among the most commonly used software modelling languages in the industry.

- **TTool** focuses on the modelling of embedded systems. It allows you to model the three main phases of the development of these systems:
  - The modelling of requirements and properties that the system must respect
  - The exploration of embedded system architecture, that is to say the distribution of system functions between software and hardware
  - The design of software components

- **TTool** can be used for several types of embedded systems: base stations, mobile phones, transportation, embedded system security, etc. Its high abstraction capacities make it sufficiently versatile to deal with distributed systems. As such, it is currently being used in the context of IoT/5G for the simplified programming of future digital infrastructures.

- **TTool** sets itself apart from its competition, both academic (for example Papyrus) and industrial (for example, Artisan Studio, IBM Rhapsody):
  - **Proof of operating reliability and safety** can be achieved with a push-button approach, thus greatly facilitating the engineers' access to mathematical proof techniques.
  - **The inclusion of underlying hardware.** Most embedded software design platforms include little or no constraints of the embedded system hardware.
  - **Ease of use**: The basic functions of TTool can be learned in about an hour.

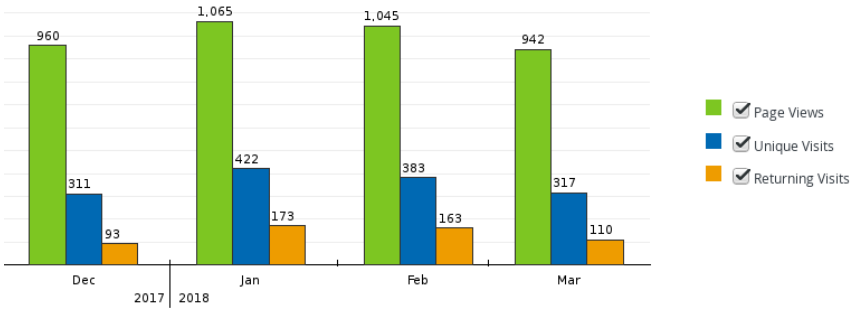
- **TTool** is used by these companies:
  - **FREESCALE** contributed to the code, notably for the "rapid simulation" by involving several engineers. On this basis, FreeScale created a model of a base station in the space of about a week of engineer time. A comparison of the results of the TTool model with the system C base station code (representing 6 months of development), showed the accuracy and relevance of the simulations performed in TTool (works published jointly). The closure of the industrial site of FREESCALE put an end to this initiative.
  - **SIEMENS** (Austria) decided to involve TTool in the H2020 AQUAS project following the internal use of TTool (https://artemis-ia.eu/project/123-AQUAS.html). The AQUAS project focuses primarily on the safety and security of complex critical systems. Several companies and institutions use the tool as part of this project (e.g. Trustport).
  - **NOKIA** is developing a private branch of TTool for automatic code verification and generation of future digital architectures. Nokia also contributes to the public branch of TTool.

- **TTool** is used as part of the teaching at Télécom ParisTech, at ISAE, and in several universities in Brazil. There have also been tutorials and training sessions at international conferences (e.g. MODELSWARD 2015).

History and use

TTool began in 2004. It has benefitted from contributions from academic organisations (INRIA, ISAE, LIP6), private companies (Texas Instruments, Freescale, Alcatel Lucent, Nokia), as well as funded projects (FP7, EVITA, FUI Netcom, H2020 AQUAS).

The figure below shows access to the TTool website (https://ttool.telecom-paristech.fr/) during a given week. The green bars represent the number of pages viewed, the blue bars represent the number of visitors, and the orange bars represent the returning visitors.



Plateforme Hadoop

Dans le cadre des recherches menées autours de la thématique Big Data, une plateforme logicielle Hadoop a été déployée sur notre infrastructure hardware.

Les caractéristiques de la plateforme Hadoop INFRES sont décrites ci-dessous :

Nbre de serveurs	Nbre de CPU	Mémoire (Go)	Stockage HDFS (To)	Version logicielle
29	554	670	53	2.9

Les composants logiciels suivants sont disponibles sur cette plateforme :

- Hadoop Distributed File System (HDFS)
- Ressource manager: YARN
- Hadoop Map-Reduce
- Apache Spark
- Zookepper
- Apache HBase
- Apache Hive

Plateforme de Cloud Computing OpenStack

De manière à répondre au besoin du calcul scientifique mais aussi au déploiement de services issus des travaux scientifiques, une plateforme de Cloud Computing OpenStack a été récemment implémentée sur un ensemble de serveurs dédiés.

Les caractéristiques des serveurs de notre plateforme OpenStack sont décrites ci-dessous :

machine	threads	mémoire(Go)	stockage(Go)
controller	6	16	2000
netstack	6	16	2000
compute 1	40	384	7300
compute 2	40	384	7300
compute 3	48	384	1800
compute 4	48	384	1800
compute 5	48	384	1800
compute 6	48	384	1800
storage 1	6	16	14600
storage 2	6	16	14600
storage 3	6	16	14600
block storage	8	16	14600

Les caractéristiques de la plateforme OpenStack sont donc les suivantes :

Nbr de coeurs	Mémoire (To)	Stockage (To)	Stockage block (To)	Stockage objet (To)
272	2,304	21,8	14,6	43,8

Cette plateforme permet de créer jusqu'à 500 Virtual Machines de type Medium (2x CPU virtuels, mémoire 4 Go, disque 40Go) avec un « over-provisioning » de 2 pour les CPUs .

A ce jour 86 machines virtuelles sont opérationnelles. Le nombre de machines virtuelles en fonction du gabarit utilisé est décrit ci-dessous :

Nom du gabarit	small	medium	large	xlarge	xmemory
Nombre de VM	25	27	4	16	10

Les machines virtuelles crées dans la plateforme OpenStack sont connectées à Internet via des réseaux virtuels et des routeurs/pare-feu virtuels. Ces derniers sont connectés à un réseau physique nommé Réseau de Recherche (R2), mis en place et administré par nos soins. Ce dernier point nous permet notamment d'avoir une grande réactivité en termes de gestion de l'accessibilité des services déployés sur les machines virtuelles OpenStack depuis l'extérieur de l'école.

Plateforme Digiscope

Digiscope est un réseau de plateformes pour la visualisation interactive de grandes quantités de données et de calculs complexes. Les dix salles de Digiscope sont installées en Ile de France, majoritairement sur le campus de Paris-Saclay, et ont vocation a être interconnectées par un réseau de téléprésence autorisant la collaboration à distance. Les applications visées sont la recherche scientifique, la conception industrielle, l'aide à la décison et la formation.

Telecom-Paristech accueille deux de ces plateformes, PiXLs sur le site Barrault et Iris sur le site Italie. PiXLs est un mur d'écrans tactile de 4.1 m x1.15 m, de résolution 16588800 pixels grace à l'assemblage de 8 écrans LCD de 46 pouces chacun. Iris est un mur d'écrans tactile de 2.4 m x 1.37 m, de résolution 8294400 pixels grace à l'assemblage de 4 écrans LCD de 55 pouces chacun. Les deux plateformes sont opérationnelles depuis juin 2014.

Plateform FIT

FIT is a set of complementary components that enable experimentation on innovative services for academic and industrial users on the area of IoT. The project gives french Internet stakeholders a way to experiment on mobile wireless communications to the network and on application layers, thereby accelerating the design of advanced networking technologies for the Future Internet.
FIT is provided by a consortium of five French institutions of higher education and research that are devoted to development of testbeds for network computer communications available to industries, scientific researchers, and education actors (Université Pierre et Marie Curie (UPMC), Inria, Université de Strasbourg, Institut Mines Télécom and CNRS). These instituions have been building wireless, sensing and mobility testbeds, the interfaces that allow the testbeds to operate in a federation, and the tools that easily access the testbeds. Coordinated by Professor Serge Fdida of UPMC Sorbonne Universités and running over a nine-year period, the project will benefit from a 5.8 million euro grant from the French government.
In 2017, FIT has merged with Grid 5000 Equipex to propose a new testbed infrastructure named SILECS. SILECS has obtained the TGIR (Très Grande infrastructure de recherche) label from French ministry of higher education and research. It is evolving towards an European platform and a proposal has been submitted to ESFRI.

Plateform Ramsès

RAMSES (Refinement of AADL Models for Synthesis of Embedded Systems) is a model transformation and code generation tool that produces C code forPOSIX, ARINC653, or OSEK compliant operating systems. RAMSES interfaces with OSATE2, reference IDE for AADL developed by the Software Engineering Institute.

RAMSES proceeds by refinements insofar as it produces a simplified versionof an AADL model as an intermediate step towards code generation. This simplified model includes a behavior specification that expresses the behavior resulting from the expansion of AADL components and connexions.

This intermediate model is used to analyse the impact of the expansion on non-functional properties of the system under design. RAMSES has been extended recently to support multiple objective optimization techniques for design space exploration. It is also evolving to address the challenge of mixed-criticality real-time scheduling on multi-core architectures.

RAMSES is a mature experimental platform for critical real-time and embedded systems design has been (and is being) used and developed in several collaborative projects with several industrial and academic partners:

- the Chaire sur l'Ingénierie des Systèmes Complexes, https://www.telecom-paristech.fr/recherche/chaires/chaire-ingenierie-des-systemes-complexes.html (Polytechnique, ENSTA, Thales, Dassault Aviation, Naval group, DGA)
- the S3P project, http://www.esterel-technologies.com/S3P.html (Alstom, Airbus, Thales, ANSYS, Sysgo, etc.)
- the IRT SystemX FSF https://www.irt-systemx.fr/en/project/fsf/ and PST https://www.irt-systemx.fr/en/project/pst/ projects (Alstom, Safran, etc.)
- the AADL ARINC653 Code Generator project (SEI, ARMDEC/DoD).

Fablab de Télécom ParisTech

Le Fablab T-P est un projet conjoint des départements INFRES, TSI et SES de Telecom-Paristech. Au travers notamment d'équipements 3D grand public, il a pour vocation de permettre l'accès des étudiants et des enseignants-chercheurs à la fabrication numérique en mettant à leur disposition les outils nécessaires au prototypage rapide de leurs projets. Il dispose pour cela de cinq imprimantes 3D de diverses technologies, d'une découpeuse laser, d'une fraiseuse numérique, de deux petits scanners 3D ainsi que des ordinateurs et logiciels de conception 3D adaptés. Un espace équipés de kits (Arduino©, Rasberry Pi©) et d'appareils de mesure est consacré aux réalisations électroniques

Le Fablab T-P s'intègre dans une structure plus large d'équipements complémentaires englobant le eLab et le Studio Design, tous localisés sur le site Telecom-Paristech Barrault. Il fait partie du réseau de Fablabs présents ou à venir sur le campus Paris Saclay et est référencé sur la plateforme « Plug In Lab » de l'Université Paris Saclay.

Audio-visual platforms and equipments

The LTCI benfits from a number of platforms and equipments dedicated to audio-visual acquisitions and processing. This includes:

- A multi-modal acquisition lab, equiped with cameras, kinects, microphones...
- An anechoic chamber.

- An audio studio recording lab, with several music instruments and performant recording material.
- A black chamber dedicated to computational photography, with a marble table and high precision digital photo cameras.
- Equipment for multimedia information processing and analysis.
- Screens described abobe in the Digiscope platform.

Le Réseau de Recherche R2

Il s'agit d'un réseau dédié aux activités de recherche. Il est totalement différencié du réseau opérationnel de l'école.

Le réseau R2 est constitué d'un ensemble de :

- 2x pare-feu Fortigate F600D en mode actif/passif
- 2x routeurs Brocade ICX7450 en mode actif/passif
- 6x commutateurs 48 ports ICX6450

Ce réseau possède 4 VLANs IPV4 de 512 adresses. Ces équipements ainsi que les services Linux OpenStack sont supervisés à l'aide d'un serveur Nagios. Ce réseau est aussi utilisé directement par l'équipe de recherche RMS (Radio Mobility Service) et par la plateforme Digiscope décrite ci-dessus.

1.7.3 Organizational chart

Le LTCI est dirigé par Talel Abdessalem, assisté d'un conseil de laboratoire composé de sept membres élus et quatre membres nommés.

COMPOSITION DU CONSEIL DE LABORATOIRE

Talel Abdessalem

Directeur

Isabelle Bloch

Adjoint au directeur

Jean-Luc Danger

Adjoint au directeur

Laurent Decreusefond

Adjoint au directeur

MEMBRES

Marco Cagnazzo

Maître de Conférences

Florence D'Alché-Buc

Professeur

Tarik Graba

Maître de Conférences

Eric Lecolinet

Maître de Conférences

Thibault Lescoat

Doctorant

Gérard Mouret

Ingénieur de recherche

Laurent Pautet

Professeur

Hugues Randriambololona

Maître de Conférences

Michèle Wigger

Professeur

SUPPLÉANTS

Isabelle Bloch

Professeur

Etienne Borde

Maître de Conférences

Marie-Laure Chauveaux

Cadre de gestion

Jean Le Feuvre

Maître de Conférences

François Roueff

Professeur

Cédric Ware

Maître de Conférences

INVITÉS PERMANENTS

Gérard Memmi

Chef du Département INFRES

Gaël Richard

Chef du Département IDS

Alain Sibille

Directeur de la Formation Doctorale de Télécom ParisTech

Bruno Thédrez

Chef du Département Comelec

Part I

Detailed activities: Networks and Computer Science

Chapter 2

ACES

Autonomous and Critical Embedded Systems

2.1 Presentation of the team

Team leader: Elie Najm (FP,- 08/17), Laurent Pautet (FP)

Faculty between 2013 and 2018: Dominique Blouin (RE, 08/16 -, 50%), Etienne Borde (AP), Florian Brandner (AP, 09/15 -), Isabelle Demeure (FP, - 09/14), Ada Diaconescu (AP), Petr Kuznetsov (FP), Jean Leneutre (AP), Gérard Memmi (FP, 25%), Elie Najm (FP), Laurent Pautet (FP), Thomas Robert (AP), Remi Sharrock (AP, - 09/17), Samuel Tardieu (AP), Sylvie Vignes (AP)

PhD Students: Rayhana Baghli (03/14 - 12/17 [PL[1] 9 months], E. Najm), Fabien Cadoret (11/09 - 10/13 [ML[2] 10 months], L. Pautet, E. Borde), Castellanos Cuauhtémoc (10/10 - 05/15, L. Pautet, E. Borde), Bassem Debbabi (09/09 - 01/14, A. Diaconescu), Karel De Vogeleer (02/12 - 9/15, G. Memmi, P. Jouvelot), Sylvain Frey (10/10 - 09/13, A. Diaconescu), Julian Garbiso (10/14 - 11/17, A. Diaconescu), Romain Gratia (10/13 - 01/17, L. Pautet, T. Robert), Ziad Ismaïl (02/13 - 04/16, J. Leneutre), Antoine Jaouen (11/13 - 09/14, L. Pautet, resigned), Xavier Jean (05/11 - 06/15, L. Pautet, T. Robert), Vincent Legout (03/11 - 04/14, L. Pautet), Bertrand Mercier (10/13 - 08/14, L. Pautet, resigned), Jonathan Michaux (10/10 - 10/14, E. Najm), Trung Nguyen (02/12 - 02/16, J. Leneutre), Gérard Nicolas (02/10 - 01/13, E. Najm), Smail Rahmoun (11/13 - 02/17, L. Pautet, E. Borde), Srivatsan Ravi (09/10 - 06/15, P.Kuznetsov [TUB/DE]) Elie Richa (05/12 - 12/15, L. Pautet, E. Borde), Yanjun Sun (01/13 - 10/17 [PL 6 months], G. Memmi, S. Vignes)
Vitaly Aksenov (09/15 - , P. Kuznetsov), Aida Diop (09/17 - , J. Leneutre), Antoine Durant (09/17, -, G. Memmi), Mohamed Hassine (09/17 - , L. Pautet, E. Borde), Farouk Hebbache (11/16 - , L. Pautet, F. Brandner), Katarzyna Kapusta (10/14 - , G. Memmi), Roberto Medina (10/15 - , L. Pautet, E. Borde), Amine Naji (10/14 - , F. Brandner), Jean Oudot (10/17 - , L. Pautet, E. Borde [NTU/SG]), Arles Rodrigues (02/16 - , A. Diaconescu [UNC/CO]), Thibault Rieutord (10/15 - , P. Kuznetsov), Kristen Vanhulst (01/17 - , E. Najm, J. Leneutre, T. Robert)

PostDocs, Research Engineers: Sebastien Gardoll (RE, - 03/15, CNRS), Zohir Bouzid (PD, 10/13-08/14) Achille Biyeck (PD, 11/13 - 12/13) Hoa Dung Ha Duong (PD, 03/12 - 02/14), Asma Hamitou (PD, 03/15 - 03/16), Christophe Kiennert (PD, 9/13 - 04/15), Grzegorz Loniewski (PD, 06/12 - 06/13), Thomas Megel (PD, 04/12 – 04/13), Sarah Nait Bahloul (PD, 12/13 - 11/14), Kameswar Roa Vaddina (PD, 09/16 -)

Sabbatical Professors: Christian Müller Schloer (FP, Hanover University, DE, 06/14 - 08/14), Jeremy Pitt (FP, Imperial College London, UK, 01/17 - 02/17), Eric Ruppert (AP, Univ.

[1] Parental Leave
[2] Medical Leave

York, CA, 03/14 - 05/14), Eli Gafni (FP, UCLA, USA, 06/15 - 07/15, 06/16 - 07/16, 06/17 - 07/17), Sergio Rajsbaum (FP, Univ. Nacional Autonoma de Mexico, ME, 05/17 - 06/17)

Platforms:

- RAMSES, a model transformation, analysis and code generation platform for AADL (collaboration with CMU/SEI) (`penelope.enst.fr/aadl/wiki/Projects#RAMSES`)
- Patmos, a processor at the heart of a time-predictable computing platform for real-time systems (collaboration with ENSTA, IRISA, Vienna Univ. of Technology, Technical Univ. of Denmark) (`patmos.compute.dtu.dk`)
- CodeCast, WebLinux and TaskGrader, platforms to teach and design MOOCs such as "ABC for C" (Award of the "Best MOOC of the year 2016") (`www.fun-mooc.fr`)

Scientific Production Overview:

Journals	Articles in Proceedings	Books and Book Chapters	Patents	Invited Talks
27	122	22	2	21

Table 2.1: Overall Scientific Production

2.2 Research activities

2.2.1 Overview

The research topics of the ACES team revolve around concurrent systems in general, for which non-functional properties such as criticality, autonomy or security have to be ensured. These may be systems running in parallel on the same unicore processor, enforcing timing properties as in real-time embedded systems. They may also consist of distributed systems running on different processors and competitively accessing shared resources in a consistent manner. Similarly, this concurrency can occur in secure systems for which the attacker and the defender act in competition. To cover the entire continuum of concurrent systems, the ACES team chose to structure its activities around two themes: loosely coupled systems and strongly coupled systems. It should be noted however that this separation remains soft. As a consequence, the activities of the different team members overlap and complement each other greatly. For example, the critical architectures in the transport domain (mostly categorized as strongly coupled systems) tend to open up to external services – less safe, but more adaptive (mostly categorized as loosely coupled systems).

2.2.2 Strongly Coupled Systems

This research topic focuses on embedded systems such as control systems in engines or plants. These systems are often considered critical and often have to adhere to strict certification requirements. Consequently, these systems are rather closed (limited interaction with users and other systems, little or no evolution) and exhibit strong coupling (actions performed by the systems are typically orchestrated and inter-dependent). This topic concerns 2 professors (G. Memmi, L. Pautet) and 3 associate professors (E. Borde, F. Brandner, T. Robert). In addition, a research engineer (D. Blouin) is shared with the LabSoC team (LTCI, Sophia-Antipolis).

The main focus of the research activities is on *critical real-time systems*, ranging from theoretical aspects of real-time task scheduling, over model-driven design, to the design of low-level hardware components improving time-predictability and determinism. A major challenge in real-time systems are modern multi-core computer platforms, which are problematic in terms of certification due to the multitude of interactions that concurrent programs may experience (e.g., due to contention on shared resources).

Real-Time Systems (Borde, Brandner, Pautet, Robert)

The team has gained considerable reputation in studying and designing real-time task scheduling algorithms, and their implementation in the operating system (OS), that address the challenges associated with multi-core platforms. For instance, a recent contribution on scheduling for mixed-criticality systems, which was developed in collaboration with Renault in the context of the IRT SystemX (thesis Gratia, project ELA), was shown to outperform previous approaches in terms of processor utilization as well as the number of task preemptions [23]. Another strong contribution on scheduling mixed-critical dependant real-time tasks was proposed in the context of the ISC chair was also shown to outperform the state of the art (thesis Medina [29]). The follow-up project CTI (thesis Oudot) is currently starting, again in the context of the IRT SystemX, and allowed to establish a new collaboration with A. Easwaran (NTU, Singapore). Another collaboration with Thales financed by the CORAC institute (project CORAIL) leveraged similar techniques in order to control the timing behavior of software controlling the information flow (filtering, encryption, ...) through a gateway between the internal AFDX network of an airplane to the *open-world network*. Other collaborations include teams from CEA (e.g., M. Jan), INRIA (e.g., A. Cohen), and LIGM (e.g., L. George). The outstanding quality of the team's contributions to real-time task scheduling have been recognized by a Best Paper Award [28] (thesis Vincent Legout).

Deterministic Platform (Brandner, Pautet, Robert)

Complementing the work on task scheduling, the team additionally explores the use of deterministic and time-predictable computing platforms. The goal of this work is to improve the analyzability of critical software in terms of its worst-case behavior, while ensuring competitive performance in the average case. Predictability can be ensured in software using hypervisors on off-the-shelf hardware, as demonstrated in a collaboration with Thales Avionics (thesis Jean). The hypervisor intercepts accesses to shared resources (e.g., memory) and thus can manage these accesses to avoid contention and improve isolation. The quality of this work has been acknowledged through a Best Paper Award [25] and resulted in a joint patent with Thales (patent [42]). Another means to improve the predictability of a platform is through specialized hardware. For instance, joint work with M. Jan (CEA List) on the analysis of a time-predictable cache design for stack data in multi-tasking systems received an Outstanding Paper Award [16, 1] (thesis Naji). Ideas from this work have been further developed to improve the average-case performance of the cache, while preserving worst-case bounds. Current work (thesis Hebbache) aims at generalizing these concepts to the memory hierarchy of the Patmos multi-core platform by using dynamic arbitration schemes that converge to predictable Time-Division Multiplexing (TDM) in the worst-case. The Patmos platform is developed jointly with partners at the national (ENSTA ParisTech, IRISA) and international (Vienna Univ. of Technology, and Technical Univ. of Denmark) level.

Critical Systems Design Process (Borde, Pautet)

The research cited above aims at providing a suitable computing platform (OS, runtime, hardware) for critical real-time systems. A third pillar of the team's research activities are techniques and tools that help to design such systems via model-based design – exploiting, among others, the aforementioned computing platforms. The team strongly contributes to the state-of-the-art in model-based design at various steps of the design process (model refinement, test, code generation, ...) and at various technical and formal levels (thesis Richa [9]), but also the definition of modelling languages. Etienne Borde is actively contributing to the AADL language standardization, which resulted in a long-lasting collaboration with the SEI laboratory (CMU, USA), a contract with the US DoD, and major industrial players in the avionics domain (Airbus, Boeing, ...). Current work is focused around the RAMSES tool, which is a model transformation, analysis and code generation platform for AADL models.

RAMSES allows to automatically derive implementation models from high-level design models (thesis Cadoret) in order to validate low-level software implementations, to analyze the availability as well as the schedulability of mixed-criticality applications (thesis Medina), or, even, to explore

the design space of implementations through model transformation (thesis Rahmoun [31]). Parts of this work have been carried out with industrial partners such as Alstom in the context of the IRT SystemX as well as the chair "Ingénierie de Systèmes Complexes" with academic partners from École Polytechnique and ENSTA ParisTech. A follow-up project ISC recently started (thesis Hassine) aiming at managing uncertainty in model-based design exploration. The RAMSES tool has also been selected as a showcase project by Institute Mines-Télécom (IMT) and its continuous development is supported by a permanent research engineer (Dominique Blouin shared with the LabSoC laboratory) since 2016. The team's contributions on model-driven engineering have been acknowledged by the scientific community, e.g., through a Best Paper Award at ICMT 2015.

Security and Safety (Leneutre, Robert)

Apart from timing and availability mentioned previously, the team addresses also other non-functional properties such as safety and security in critical systems. These works model attacker behaviors to assess the threat they represent either for certification or design improvement purposes. It consist in establishing a model of the attacker's action capabilities and their impact on system assets. Design improvement is related to balance the budget (skills, time, money, ...) that both, the attacker and the system designer, are willing to invest to compromise/defend the system. In order to help security engineers in optimising their design choices, game-theory-based approaches have been proposed (thesis/postdoc Ismaïl [5, 6]). They rely on modelling the defense of a system as a non-cooperative game. The goal is then to develop optimal defense strategies in constrained environments. Game-theory-based models have successfully been applied to the modelling of intelligent energy management systems.

This line of work initially started within the SEIDO laboratory (EDF) is now pursued within the chair CyberCNI [14]. This chair is jointly operated by IMT Atlantique, Télécom ParisTech, Télécom SudParis and is supported by BNP PariBas, EDF, Orange, et cetera. In addition, national collaborations with Airbus, Cogisys, and others (e.g., project MSSTB) have been established. International collaborations with KEIST are, for instance, supported by the STIC-ASIE program (project DYNARIS). The excellence of the team's research has been recognized through a Best Paper Award at GameSec 2017 [24] and even received media coverage through a radio broadcast ("La méthode scientifique").

Besides design improvement, metrics have been proposed to numerically assess the efficacy of security countermeasures with respect to system vulnerabilities. This work takes advantage of attack graphs with symbolic parameters (thesis Vanhulst). It allows multi-dimensional sensitivity analyses of attackers ability to compromise a system. This work is also funded by the chair CyberCNI as a complement to game theory works.

A recently created chair (C3S) is expected to bring the team's activities regarding real-time systems, model-based design, as well as safety and security closer together. The chair aims at developing secure and reliable development platforms for communicating and autonomous cars and is supported by Renault, Valeo, Thales, and others.

Energy Consumption of Computation (Brandner, Memmi)

Another non-functional property is energy consumption, which is becoming highly relevant in almost all computing domains. Based on our expertise in system design, the team explores the use of software techniques to reduce the energy consumption of computations. This is a challenge particularly faced by mobile and battery powered devices, e.g., military gear (Safran) or the surveillance of infrastructure (SNCF). Leveraging existing hardware capabilities, such as voltage and/or frequency scaling, the energy consumption of energy-critical computations can be scaled down considerably at the expense of computing performance. The current work focuses on the development of expressive power models (postdoc Vaddina) of software running under varying power configurations. The team was able to show that the trade-off between energy reductions and execution time on embedded processors results in a convex curve (thesis De Vogeleer), i.e., an

optimal power configuration exists for each application [2]. This work was carried out jointly with P. Jouvelot (MINES ParisTech) and recently received a Best Paper Award at SoftCOM 2017 [35].

2.2.3 Loosely Coupled Systems

In concrete terms, the theme of loosely coupled systems focuses on distributed systems. It includes roughly 2 full professors (P. Kuznetsov, E. Najm) and 4 assistant professors (A. Diaconescu, J. Leneutre, S. Tardieu, S. Vignes). E. Najm and S. Vignes are working on modelling, analysing and synthesizing distributed services (in particular in the context of the Internet of Things). J. Leneutre focuses on security issues of Internet of Things. A. Diaconescu is addressing complex distributed systems and in particular those that interact in an autonomous and adaptative manner (like those present in smart grids and domotic systems). P. Kuznetsov focuses on algorithms for distributed systems and in particular for synchronisation and failure detection. S. Tardieu is getting back to research and is investigating research issues in the domain of the blockchain technologies (smart contracts) with P. Kuznetsov. Very recently, a new position has been opened in our team on algorithms for distributed systems and in particular on blockchain technology. To summarize this theme, the most emblematic systems of this theme, because the most open, are certainly autonomic systems that are characterized by their ability to adapt to various behaviour models, sometimes inspired by human mechanisms. Similar characteristics can also be found in systems fors the Internet of Things (IoT), which also face constraints related to embedded systems.

Distributed services (Diaconescu, Najm, Sharrock)

The main focus of this research work is on safe design and development of services, in two main areas: web-based interactive services and IoT-based autonomous services.

For web-based services, we considered the issue of the safe interaction of the orchestration of loosely coupled and independently designed services. Such services may interact in an inappropriate and incompatible manner resulting in run-time errors. Interaction errors manifest themselves when unexpected messages or when messages containing values with unexpected types are received. To mitigate this problem we investigated a typing approach whereby services that are checked to be well-typed at compile time are guaranteed to be interaction safe at run-time. We revisited and enhanced the well-known industry standard orchestration language WS-BPEL in view of its usage as a web service orchestrator. We defined also a typing algorithm that checks if an orchestrated service behaves according to its declared provided and required types. This work was published in the Journal of Logic and Algebraic Programming [8].

For IoT-based autonomous services, where services deployed, e.g. in a smarthome, may share sensors and actuators, we considered the issue of designing conflict free services with maximised user satisfaction. To address these issues, we define service clusters endowed with orchestrators that manage access conflicts within these clusters. We provided also an algorithm that maximises a utility function that reflects end user satisfaction, and a set of rules to check the consistency and validity of the services and their orchestrators (patent [41]). R. Sharrock worked on extending the autonomic architecture in order to manage misunderstanding situations and facilitate the sensemaking processes in the Autonomic Smart-Home.

Coordination of work on adaptive service compositions for the smart home (part of the SEIDO II Lab) to provide two complementary approaches: E. Najm and R. Sharrock focused on offline service composition, ensuring validity and absence of conflicts in the deployed system and on designing a simulator for detecting these conflicts; and Ada Diaconescu focused on online service composition, aiming to find system adaptation solutions for runtime changes that were not predicted offline.

Note that R. Sharrock got involved in the design of outstanding MOOCs and later on reoriented his research activities on connected objects for computer-human interactions. As a consequence, in september 2017, he joined the newly created DIVA research team.

Complex autonomic systems (Diaconescu)

Ada Diaconescu works on systems that adapt to unpredictable changes in their environments [11]. The increasing development and reliance upon complex adaptive technical systems – such as smart grids, smart cities and the Internet of Things – raise serious technical challenges, with important socio-economic ramifications. Ada takes an interdisciplinary approach, and, from a software engineering perspective, analyses existing complex adaptive systems in nature – including inert physical systems, individual organisms and advanced societies – and aims to identify the reoccurring structures and processes behind their success [12].

The goal is to formalise these core structures and processes via reusable engineering artefacts, including generic principles, architectures, models, design patterns, frameworks, methodologies, platforms, and tools [13, 21]. Providing such engineering artefacts will provide the basis for facilitating the development and maintenance of viable and efficient artificial complex autonomic systems, which are becoming essential for our modern societies. These engineering artefacts are distilled progressively from experience with concrete projects in different application domains. Concrete contributions include four PhD thesis and several research internships on decentralised autonomic controllers in smart grids and smart homes [21], [4] data management in complex [33], collaborations with EDF Labs, VEDECOM, University of Grenoble-Alpes, University of Colombia); a regional MINALOGIC project, MEDICAL (ended in 2014) on self-managing data mediation systems (with University of Grenoble-Alpes, Orange Labs and ScalAgent); and several national and international collaborations resulting in co-authored publications, co-organised events, long stays in Hannover University (04-08/16 and 03-08/17) and 14 invited talks such as [36] or [37].

As a complementary endeavour, Ada Diaconescu also examines the impact on society brought about by such complex technical systems [37], both in the short and long term, and considers viable alternatives [3], [15].

Merging expertise in autonomic systems and communication networks, A. Diaconescu and M. Coupechoux (RMS team) have co-supervised a PhD student financed by VEDECOM (2015-2017) on the topic of self-adaptive clustering of vehicular networks, based on both local wireless and cellular networks.

Security in Internet of Things (Najm, Leneutre)

In the area of loosely-coupled systems, research interests of J. Leneutre lie in security issues of Internet of Things (IoT). Providing security in IoT is a challenging task. In particular, there is a need for protocols providing a secure management of objects in order to add new objects to a local network, to change their administrative domain, or to revoke them. These protocols, usually grouped in a process called *security bootstrapping*, are a pre-requisite for the definition of authentication and access control mechanisms. Such protocols use classical cryptographic mechanisms but also rely on assumptions about physical characteristics (existence of an out-of-band or human assisted channel, location or signal range of the device, shared contextual information, etc.). Formally proving security properties for these protocols becomes a new challenge: most of existing security protocol verification approaches do not, or only partially, take these physical characteristics into account. The thesis of Trung Nguyen [30] proposed a *security bootstrapping* mechanism, parts of which have been verified formally. This work is pursued in the context of the CIFRE thesis of Aida Diop at Orange R&D, co-supervised by Maryline Laurent from Télécom SudParis.

Fault-tolerant and asynchronous distributed computing (Kuznetsov)

Petr Kuznetsov focuses on the foundations of distributed computing, assuming asynchronous or partially synchronous communication and component failures (from crash to Byzantine). A major part of his time over the years of 2013-2015 was devoted to the Marie-Curie ITN project on theoretical foundations of *transactional memory*, a programming paradigm intended to render concurrent system design tractable and efficient. The project enabled a thesis for one doctoral student (Srivatsan Ravi, now with USC) [18, 26, 7].

In 2014 Petr Kuznetsov launched an ANR-DFG (jointed French-German) DISCMAT project on mathematical methods in distributed computing, in collaboration with D. Kozlov, a professor in mathematics at Bremen University, M. Raynal (U Rennes 1), and Achour Mostefaoui (U Nantes). Within the project, T. Rieutord, a doctoral student at Télécom ParisTech, managed to formulate an elegant combinatorial characterization of a large class of distributed computing models, strongly generalizing all previously established characterizations (best paper, [27]).

P. Kuznetsov's work is mostly theoretical [22, 20, 39], though he periodically takes detours to systems research, such as hybrid transactional memory design [17], consistent software-defined networking [10, 19, 38, 40], and blockchain-based services. Recently, he joined the BART project, accumulating blockchain-focused research undertaken by several research institutes of the Parisian metropolia (Inria, Télécom ParisTech, Télécom SudParis, and IRT SystemX). An associate professor position in this topic has been open at the ACES group, to be filled in summer 2018.

Model-Based Testing (Vignes, Memmi, Borde)

Supporting verification activities to validate models is a shared interest of ACES members. Using formal approaches is necessary and sometimes even required. Our research contributions in this field concern *reactive* systems that are permanently interacting with their physical environment and that are subject to external timing constraints. The challenge is to obtain a high-level confidence in Functional Validation of such systems, towards a verification workflow compatible with stringent certification.

The research undertaken by S. Vignes focuses on *Model-Based Testing* of a reactive system in co-simulation with a physical process. The contribution concerns the positioning of model-checking techniques upstream of the development cycle to consolidate the functional validation of a critical system. In collaboration with E. Borde, S. Vignes studied relations between formalized application of Model-Based Systems Engineering and model transformation.

In the period 2013-2017, S. Vignes mainly contributed to the French project CONNEXION and directed the doctoral thesis of Yanjun Sun [34]. This project aimed at improving the development process of the Instrumentation & Control (I&C) system of nuclear power plants. I&C systems were modelled using synchronous data-flow language (Scade, Lustre) and were co-simulated with the physical process model (Modelica). We beneficially interacted with the academic partner CEA-LIST, using its tools towards the verification platform: (i) ARTiMon for real-time observations at execution time and (ii) the model checker GATeL to satisfy test objectives.

2.2.4 Scientific Highlights:

Organization of conferences and workshops

organization of 3 flagship conferences (DISC'16, RTSS'17, SASO'17) ; creation of a new conference (DisCoTec) ; organization of 4 international workshops (2 Dagstuhl seminars, DSDN'14, WCET'18) ; organization of 2 summer schools (ETR'17, SPTCC'17) ; organization of the ACM Student Research Competition at CGO'16 ;

PC chair of conferences and workshops

chairing and co-chairing for international conferences (Euro-Par'18, SEAA since 2015) ; steering committee of SASO (since 2016), of ICAC (since 2015) or DisCoTec (since 2018)

Associate editors of journals

Editorial board members of Technology and Computer Sciences Journal (TSI).

Awards

6 best papers, 1 outstanding paper, best MOOC 2016.

Impact and Attractivity

- 72 publications (43%) with international co-authors
- 3 PhD shared with international supervisors

- Active members of the international standardization AADL committee ; Main editor and authors of annexes of AADL standard (Behavioural Annex, Core Language)

Long stays of faculty members
Ada Diaconescu (Hannover University, DE, 04-08/16 and 03-08/17)

Significant Contracts with Industrials, Chairs

- Chair ISC (Ingénierie des Systèmes Complexes) with THALES, Dassault Aviation, DGA, DCNS, Ecole Polytechnique, Télécom ParisTech, ENSTA ;
- Chair C3S (Connected Cars and Cyber Security), with Renault, Nokia, Valeo, THALES, Wavestone ;
- Project CONNEXION (COntrôle Commande Nucléaire Numérique pour l'EXport et la rénovatION) with CEA, INRIA, CRAN, ENS Saclay, LIG and Télécom ParisTech ;
- Project CORAIL / CORAC (next generation of IMA platforms) with THALES, AIRBUS, AIRBUS HELICOPTERS, DASSAULT AVIATION, SAGEM ...;

Common Lab with Industrial or Universities

- Lab SEIDO (SEcurité et Internet Des Objects), with EDF, Télécom ParisTech ;
- Lab BART (Blockchain Advanced Research and Technologies), with IRT-SystemX, Inria, Télécom ParisTech, Télécom SudParis.

Interaction with Economic and Social Spheres

- "ABC for C language" on platform France Université Numérique, best MOOC 2016 ;
- Invited talk at the UNESCO World Committee about Lifelong Learning (2014)
- Interview at Public Sénat on MOOCs (2014)
- Invited talk to UNESCO african ambassadors on "Online access to Education"
- Lectures at "Ministère de l'enseignement supérieur et de la recherche" on "How to build your MOOC from scratch" (200 attendees) (2015)
- Invited talk at "Assemblée Nationale" and "Sénat" on "Comprendre la Blockchain"
- Co-coordination of the Compilation group of the GDR GPL and the working group OVSTR of the Labex DigiCosme;
- Working group "Sécurité des Réseaux et des Infrastructures" of Pre-GDR Security
- Appearance at the France Culture radio show "La méthode scientifique" (11/2016)

2.3 SWOT analysis

2.3.1 Strengths

A strength of the theme on "Loosely Coupled Systems", in particular Ada Diaconescu and Petr Kuznetsov, is the high international visibility. Members of the theme are regularly visited (over extended periods of time) by renowned researchers from Europe and overseas and maintain a rich set of international collaborations that often result in joint projects as well as joint publications.

A strength of the theme "Strongly Coupled Systems" are the well developed relations with industrial partners, as illustrated by several industrial chairs, joint labs, and projects ("Ingénierie de Systèmes Complexes", C3S, SEIDO, CONNEXION, IRT SystemX, ...). These relations have allowed to carry out a diverse set of research projects that have the potential to generate a high socioeconomic impact for the involved companies. This may be relevant in terms of competitiveness (chair C3S on connected cars), quality of service (project CORAC resulting in joint patents), or cost reductions in terms of development, and testing (chair CyberCNI). It is important to point out that Télécom ParisTech is a school of the Ministry of the Economy, Industry, and Digital Sector. Strong relations with industry represent one of the defining pillars of the school's mission.

2.3.2 Weaknesses

As identified in a previous evaluation of the team, a weakness of the team is a comparatively low level of interaction between team members. This applies in particular to the theme "Loosely Coupled Systems" which covers a broader spectrum of research topics and where team-internal collaboration is less frequent and team members orient themselves towards external collaborations (enabled by and reinforcing the theme's strength related to international visibility). This weakness can be explained through past recruitment practices, where experts in specialized (teaching) areas have been recruited instead of focusing on team building. A recent attempt to build a core team around Isabelle Demeure, by recruiting Ada Diaconescu and Remi Sharrock, ultimately failed, due to the departure of Isabelle Demeure (for personal reasons). Remi Sharrock thereafter joined the newly created DIVA team, whose research focus promises to be a better match for his current work. The interaction among team members across theme boundaries is similarly low. This is due to the fact that the respective context of our research is very different (critical versus non-critical systems), which complicates joint work and joint publications. This fundamental issue can be resolved by reorienting the research agenda of one or both themes. We believe that the BART lab (blockchain) can provide such an opportunity.

2.3.3 Opportunities

As explained below in more detail, the retirement of E. Najm and S. Vignes from theme "Loosely Coupled Systems" poses some risks to the team's stability. At the same time, these departures represent an opportunity to the team in order rebuild a new dynamic team and elaborate a coherent strategy for the development of the theme. It is thus crucial for the theme (and the entire team) to compensate these departures. A first step is an ongoing recruitment complementing the team's strengths in distributed algorithms and theoretical computer science, while opening the path to new topics such as the **blockchain**. This is further supported by the newly started research initiative BART (Inria, Télécom SudParis, Télécom ParisTech, and IRT SystemX).

As the move of Télécom ParisTech to Palaiseau approaches, the repeatedly cited opportunities (c.f. previous evaluations) associated with the new environment at the Plateau of Saclay have to be substantiated and seized. Concrete examples are the possibility to create joint teams and to associate researchers with the team (e.g., from CEA List). École Polytechnique (team Cosynus) and ENSTA ParisTech (team SSH), for instance, currently work towards the creation of a new joint team around **cyber-physical systems**. The ACES team has been consulted in defining the scope of this new team and would be welcome to join. Note that several points of contact between both themes of ACES and these teams exist, including the chair "Ingénierie des Systèmes Complexes", the Labex DigiCosme, the IRT SystemX, as well as ongoing joint PhD students.

2.3.4 Threats

A main threat concerns the departure of R. Sharrock to another team and the retirement of E. Najm and S. Vignes, all within the theme "Loosely Coupled Systems". The departures reduce the manpower of the theme, having considerable impact on teaching, funding, PhD supervision, and, due to increased load, ultimately research. In order to keep the theme stable, competitive, and attractive, the departures need to be compensated. A first recruitment is already in progress (see opportunities).

Another threat concerns the dependence on industrial funding within the theme "Strongly Coupled Systems" (as identified in a previous evaluation). The team currently finds itself in a very comfortable situation in terms of industrial funding, with the risk of facing difficulties of finding other sources of funding. Team members are aware of this issue and currently work on gaining visibility at the national and international level (working group OVSTR and participation in EU COST actions) in order to join and build successful consortia for accessing diverse sets of funding sources – while preserving the long-standing relations with our industrial partners.

2.4 Scientific project for the the next five years

In terms of research trends, as already indicated, we plan to focus on two major research activities.

2.4.1 Project on Blockchain Technologies

The prominent *blockchain* technology aims at implementing a public "ledger": a decentralized consistent history of transactions proposed by an *open* set of participating processes, with no static membership. This problem itself can be seen as an instance of the classical fault-tolerant *state-machine replication*, examples of which are the *crash-tolerant* Paxos protocol by Lamport and the BFT (*Byzantine* fault-tolerant) system by Castro and Liskov. These systems use instances of *consensus* protocols in order to ensure that users get consistent views of the system evolution.

A principal downside of classical consensus protocols is the need for a fixed or properly reconfigurable set of participants out of which only a bounded fraction (up to one third) can be faulty. This can be hard to ensure in an open system, where an arbitrary fraction of participants can be controlled by an adversary (so-called *Sybill attack*). Popular blockchain protocols, such as Bitcoin and Ethereum, achieve (non-deterministic) consistency by assuming that (1) the system is synchronous, (2) participants can use asymmetric cryptography, and (3) the adversary can control at most a minority of computing power. Intuitively, these assumptions are used to overcome the folklore *CAP theorem*, which states that no system can combine Consistency, Availability, and Partition-Tolerance. In particular, these protocols avoid partitioning by enforcing the *proof of work* (PoW) mechanism, i.e., requiring that a participant must solve a time-consuming cryptographic puzzle before updating the ledger. The resulting protocols are notoriously slow and energy-demanding, and an immediate question is whether these costs are unavoidable.

The research agenda of our two themes is to focus on both the algorithmic and the systems side of the blockchain technology. On the one hand, we intend to characterize the model assumptions that enable strong ledger consistency in an open system, such as the assumption of synchrony or energy constraints. On the other hand, we plan to explore the space of consistency definitions that enable solving the *digital currency* problem, addressed, e.g., by the original Bitcoin protocol. Maintaining a total order on all currency transfers may not be necessary: intuitively, non-conflicting transactions may be accepted in parallel without requiring agreement and, thus, costly and slow PoW may be avoided. Theoretical in its nature, these questions are motivated by viable practical concerns. Besides provable complexity and computability bounds, it intends to develop system prototypes that are not only formally proved correct but also studied experimentally. We hope that this work may also help reinforcing the interaction between the two themes, as the technology under study may be instrumental in linking critical and open systems.

2.4.2 Project on Cyber-Physical Systems

Second, we are currently investigating the creation of a joint research team with the COSYNUS team (Ecole Polytechnique, leader Eric Goubault) and the CPS team (ENSTA ParisTech, leader Alexandre Chapoutot). As already mentioned, several researchers from these teams are investigating cyber-physical systems in the context of the chair “Ingénierie des Systèmes Complexes”. The objectives are to strengthen our collaboration and to simplify our interaction in order to facilitate the production and the publication of common contributions. This joint team is also intended to reach a critical mass to compete with teams in computer sciences in the local and national context.

In terms of research activities, the three teams are very complementary. The CPS team focuses on the verification of hybrid systems and control systems, while the COSYNUS team focuses on the verification of concurrent, distributed, and fault-tolerant computing. The ACES team focuses on the design (algorithms, synthesis, middleware, ...) of distributed real-time embedded systems. The three teams can easily collaborate on critical systems. These common activities have already started, as ACES hired a research engineer to integrate several technologies used by COSYNUS into our tool RAMSES, e.g., support for the Robot Operating Systems (ROS). The application domain we are targeting mostly consists in distributed robots, such as a fleet of drones or autonomous cars.

These application domains have also been selected to motivate joint contributions from members of the three NewUni teams. As a matter of fact, the members of both ACES themes may easily contribute, as both topics, distributed systems and embedded systems, would be covered by the research perimeter of the joint team.

2.5 Scientific production (selection)

Articles in Journals

[1] N. Amine, S. Abbaspour, F. Brandner, and M. Jan. Analysis of preemption costs for the stack cache. *Real-Time Systems Journal*, Jan. 2018.

[2] K. De Vogeleer, G. Memmi, and P. Jouvelot. Parameter sensitivity analysis of the energy/frequency convexity rule for application processors. *Sustainable Computing: Informatics and Systems*, 15: 16–27, Sept. 2017.

[3] A. Diaconescu and J. Pitt. Technological impacts in socio-technical communities. values and pathologies. *IEEE Technology and Society Magazine*, Aug. 2017.

[4] X. Gréhant, I. Demeure, and S. Jarp. A survey of task mapping on production grids. *ACM Computing Surveys*, 45(3), June 2013.

[5] Z. Ismail, J. Leneutre, D. Bateman, and L. Chen. A game theoretical analysis of data confidentiality attacks on smart-grid ami. *IEEE Journal on Selected Areas in Communications*, 32(7):1486–1499, July 2014.

[6] Z. Ismail, C. Kiennert, J. Leneutre, and L. Chen. Auditing a cloud provider's compliance with data backup requirements: A game theoretical analysis. *IEEE Transactions on Information Forensics and Security*, 11(8):1685–1699, Aug. 2016.

[7] P. Kuznetsov and S. Ravi. Grasping the gap between blocking and non-blocking transactional memories. *Journal of Parallel and Distributed Computing*, 101:1–16, Feb. 2017.

[8] J. Michaux, E. Najm, and A. Fantechi. Session types for safe web service orchestration. *Journal of Logic and Algebraic Programming*, June 2013.

[9] E. Richa, E. Borde, and L. Pautet. Translation of atl to agt and application to a code generator for simulink. *Software and Systems Modeling*, Aug. 2017.

[10] L. Schiff, S. Schmid, and P. Kuznetsov. In-band synchronization for distributed sdn control planes. *Computer Communication Review*, 46(1):37–43, Feb. 2016.

Books

[11] P. Lalanda, J. McCann, and A. Diaconescu. *Autonomic Computing: Principles, Design and Implementation*. Springer, 2013.

Book Chapters

[12] A. Diaconescu. *Organic Computing – Technical Systems for Survival in the Real World*, chapter Organising Complexity: Hierarchies and Holarchies, pages 89–106. Springer Int. Publishing, 2017.

[13] A. Diaconescu, K. Bellman, L. Esterle, H. Giese, S. Gotz, P. Lewis, and A. Zisman. *Self-Aware Computing Systems*, chapter Generic architectures for collective self-aware computing systems., pages 191–235. Spinger Int. Publishing, 2017.

[14] Z. Ismail, J. Leneutre, D. Bateman, and L. Chen. *Game Theory for Security and Risk Management*, chapter Managing Security Risks Interdependencies Between ICT and Electric Infrastructures: A Game Theoretical Analysis. Birkhäuser, 2018.

[15] J. Pitt and A. Diaconescu. *From Bitcoin to Burning Man and Beyond: The Quest for Identity and Autonomy in a Digital Society*, chapter The Algorithmic Governance Of Common-Pool Resources, pages 133–145. John H. Clippinger and David Bollier, 2014.

Articles in Conference Proceedings

[16] S. Abbaspour, F. Brandner, N. Amine, and M. Jan. Efficient context switching for the stack cache: Implementation and analysis. In *RTNS*, Lille, France, Nov. 2015. **Outstanding paper**.

[17] D. Alistarh, J. Kopinsky, P. Kuznetsov, S. Ravi, and N. Shavit. Inherent limitations of hybrid transactional memory. In *DISC*, Tokyo, Japan, Oct. 2015.

[18] H. Attiya, S. Hans, P. Kuznetsov, and S. Ravi. Safety of deferred update in transactional memory. In *International Conference on Distributed Computing Systems*, pages 601–610, July 2013.
[19] M. Canini, P. Kuznetsov, D. Levin, and S. Schmid. A distributed and robust sdn control plane for transactional network updates. In *INFOCOM*, Apr. 2015.
[20] C. Delporte, H. Fauconnier, P. Kuznetsov, and E. Ruppert. On the space complexity of set agreement. In *PODC*, Paris, France, July 2015.
[21] A. Diaconescu, S. Frey, C. Müller-Schloer, J. Pitt, and S. Tomforde. Goal-oriented holonics for complex system (self-)integration: Concepts and case studies. In *SASO*, 2016.
[22] S. Dubois, R. Guerraoui, P. Kuznetsov, F. Petit, and P. Sens. The weakest failure detector for eventual consistency. In *PODC*, Paris, France, July 2015.
[23] R. Gratia, T. Robert, and L. Pautet. Generalized mixed-criticality scheduling based on run. In *RTNS*, pages Pages 267–276. ACM, New York, NY, USA, Nov. 2015.
[24] Z. Ismail, C. Kiennert, J. Leneutre, and L. Chen. A game theoretical model for optimal distribution of network security resources. In *Conference on Decision and Game Theory For Security*, Oct. 2017. **Best paper**.
[25] X. Jean, M. Gatti, D. Faura, L. Pautet, and T. Robert. A software approach for managing shared resources in multicore ima systems. In *IEEE Digital Avionics Systems Conference*, 2013. **Best paper**.
[26] P. Kuznetsov and S. Ravi. Grasping the gap between blocking and non-blocking transactional memories. In *DISC*, Tokyo, Japan, Oct. 2015.
[27] P. Kuznetsov, T. Rieutord, and Y. He. An asynchronous computability theorem for fair adversaries. In *Symposium on Principles of Distributed Computing*, July 2018. **Best paper**.
[28] V. Legout, M. Jan, and L. Pautet. A scheduling algorithm to reduce the static energy consumption of multiprocessor real-time systems. In *RTNS*, 2013. ISBN 978-1-4503-2058-0. **Best paper**.
[29] R. Medina, E. Borde, and L. Pautet. Availability enhancement and analysis for mixed-criticality systems on multi-core. In *DATE*, 2018.
[30] T. Nguyen and J. Leneutre. Formal analysis of secure device pairing protocols. In *IEEE International Symposium on Network Computing and Applications (NCA)*, Cambridge, USA, Aug. 2014.
[31] S. Rahmoun, E. Borde, and L. Pautet. Multi-objectives refinement of AADL models for the synthesis embedded systems (mu-ramses). In *ICECCS*, pages 21–30, Gold Coast, Australia, Dec. 2015. IEEE.
[32] E. Richa, E. Borde, and L. Pautet. Translating atl model transformations to algebraic graph transformations. In *ICMT*, pages 183–198, L'Aquila, Italy, July 2015. LNCS. **Best paper**.
[33] A. Rodrigues, J. Gomez, and A. Diaconescu. Foraging-inspired self-organisation for terrain exploration with failure-prone agents. In *SASO*, 2015.
[34] Y. Sun, G. Memmi, and S. Vignes. Model-based verification directed by structural coverage and functional requirements. In *International Conference on Software Quality, Reliability and Security*, Vienna, Autriche, Aug. 2016.
[35] K. R. Vaddina, F. Brandner, G. Memmi, and P. Jouvelot. Experimental energy profiling of energy-critical embedded applications. In *SoftCOM*, 2017. **Best paper**.

Invited Talks

[36] A. Diaconescu. An extensible model-driven architecture for controlled self-organisation. In *Dagstuhl seminar on Model-driven Algorithms and Architectures for Self-Aware Computing Systems*, Dagstuhl, DE, Jan. 2015.
[37] A. Diaconescu. Socially-inspired computing: Values and apthomogies. In *Dagstuhl seminar on Social Concepts in Self-organising Systems*, Dagstuhl, DE, Nov. 2015.
[38] P. Kuznetsov. Transactional support for sdn control planes. In *Workshop on the Theory of Transactional Memory 2015*, Donostia-San Sebastián, SP, July 2015.
[39] P. Kuznetsov. Concurrency as an iterated affine task. In *Dagstuhl seminar*, Dagstuhl Schloss, DE, Nov. 2016.
[40] P. Kuznetsov. Parallel combining. In *Dagstuhl seminar*, Dagstuhl Schloss, DE, Nov. 2017.

Patents

[41] R. Baghli, E. Najm, and B. Traverson. Structure informatique perfectionnée d'un objet connecté. (B2665), Sept. 2016.
[42] X. Jean, M. Gatti, D. Faura, and T. Robert. Calculateur comprenant un processeur multicoeur et procédé de contrôle d'un tel calculateur. (3010201), Sept. 2015.

Chapter 3

CCN

Cybersecurity for Communication and Networking

3.1 Presentation of the team

In accordance with the previous HCERES report in 2013, the Network and Information Security (NIS) group has been split into the Cybersecurity for Communication and Networking (CCN) team and the Quantum Information and Applications (QIA) team in 2015.

Team leader:

Patrick Bellot (FP, from 04/2018), Houda Labiod (FP, from 01/2015 to 04/2018).

Faculty:

Patrick Bellot (FP), Rida Khatoun (AP, from 2014), Houda Labiod (FP), Ahmed Serhrouchni (FP), Pascal Urien (FP).

Other permanent members:

Hassane Aissaoui (R&D Eng.), Michel Riguidel (Emeritus).

Sabbatical Professors:

- Dr. Huei-Ru Tseng, Researcher at Industrial Technology Research Institute, Vehicular Control System Division, Taiwan, 07/2014 to 09/2014.
- Ian Aykildiz, Ken Byers Chair Professor at Goergia Institute of Technology, Head of Broadband Wireless Networking Lab, USA, 06/2013 to 07/2013.
- Sherali Zeadally, Associate Professor, University of Kentucky, USA, 2 weeks in 07/2013.

PhD Students (17 defended theses):

Gérôme Bovet (12/2012 - 06/2015), Bruno Dorsemaine (10/2014 - 10/2014), David B. Fotue Fotso (09/2010 - 10/2013), Pengwenlong Gu (02/2015 - 02/2018), Hachem Guerid (11/2010 - 12/2014), Mayssa Jemel (05/2013 - 09/2016), Abdelhamid Makiou (06/2012 - 12/2016), Rim Moalla (05/2011 - 09/2014), Mounira Msahli (12/2011 - 01/2015), Somia Natouri (01/2011 - 03/2014), Mengying Ren (10/2014 - 04/2018), Samih Souissi (06/2012 - 12/2016), Heng-Chuan Tan (04/2014 - 09/2017), Nan Zhao (03/2012 - 09/2015), Ghayet E. M. Zhioua (01/2011 - 05/2014), Badis Hammi (ext., 11/2011 - 09/2015), Mohammad Rmayti (05/2013 - 09/2016).

PhD Students (theses in progress)

Elloh Adja (02/2017), Kodjo E. Agbezoutsi (11/2017), Edouard Bochet (10/2016), Safa Boudabous (10/2017), Zakarya Drias (01/2013), Achraf Fayad (10/2015), Farah Haidar (04/2017), Mohamed T. Hammi (11/2015), Joseph Kamel (10/2017), Katarzyna Kapusta (10/2014), Jean-Philippe Monteuuis (11/2016), Zhenzhe Zhong (09/2016), Zepeng Liu (02/2018).

PostDocs, Research Engineers:

Abdelhamid Makiou , Postdoc, 02/2017 (18 hm), Fouad Guenane, Postdoc, 11/2014 (12 hm), Mounira Msahli, Postdoc, 02/2015 (32 hm), Hassan Noura, Postdoc, 07/2016 (4 hm), Badis Hammi, Postdoc, 10/2015 (36 hm), Walter Bellante, R&D Eng., 10/2012 (12 hm), Dragutin Brezak, R&D Eng., 02/2013 (43 hm), Brahim Djebaili, R&D Eng., 09/2016 (6 hm), Denis Filatov, R&D Eng., 09/2017 (12 hm), Pengwenlong Gu, R&D Eng., 08/2013 (5 hm), Julien Huor, R&D Eng., 10/2015 (6 hm), Pascaline E. Marie, R&D Eng., 09/2013 (8 hm), Jean-Philippe Monteuuis, R&D Eng., 09/2015 (13 hm), Eduardo Salles Daniel, R&D Eng., 04/2016 (5 hm), Omar Shrit, R&D Engineer, 03/2016 (4 hm), Siamak Solat, R&D Eng., 06/2015 (3 hm), Jun Zhang, R&D Eng., 05/2013 (66 hm), Robin Vasseur, Technician, 09/2016 (6 hm), Mohamed T. Hammi, Technician, 03/2015 (6 hm).

Developped Platforms:

- OPC UA ROSA is a M2M communication protocol for industrial automation with specifications developed by the OPC Foundation. It focusses on secure communication with industrial equipment and systems for data collection and control. We have designed an open-source implementation designed during the Cluster Connexion project.
- ITS-Sec is a security plateform for vehicular networks developed by CCN team in the context of SCOOP@F project. ITS-Sec allows to manage a PKI for vehicular networks (VANETs). such as issuing certificates, revoking certificates, creating and publishing CRLs, storing and retrieving certificates and CRLs, and key lifecycle management.

Scientific Production Overview:

The following table represents the scientific production between 2013 and 2018. A selected list of publications is provided in section 14.4 on page 192.

Journal	Articles in Proceedings	Books + Book Chapters	Patents + Normalizations	Keynotes Tutorials	Other Invited Talks
34	136	2+5	1+5	1	7

Defended HDR	Defended Theses	ETP Recherche	Q1 + Q2 Journals	A*, A, B, C Conferences
0	17	2,5	12+6	57

European Contracts	AAP ANR (horsd PIA)	PIA IDEX UPSay	Autres financ. publics	Collectivités territoriales	Contrats industriels
797 205	23 042	40 574	1 833 528	168 941	418 775

3.2 Research Activities

Overview. To face the large and heterogeneous panel of interconnected networks systems as well as devices, there is a need for on demand security and privacy where the underlying mechanisms are tightly linked to the involved services. Security demands could vary greatly based on the supported services. We need security on demand approaches to deal with security requirements variation allowing adaptive security adjusted to the service and environment multi-constraints while taking into account the following properties: scalability, lightness, autonomy, mobility, and interoperability. Aiming to defend against a high number of critical attacks, the challenges that we address are: adaptive end-to-end security architectures with lightweight and scalable security functions and protocols, scalable trust management with lightweight cryptographic functions/mechanisms and crypto-agility, identity management and lightweight authentication mechanisms, blockchain-based solutions for cybersecurity mainly for access control, integrity and resilience. These application domains are declined in several research collaborative activities listed below and separated into

three sections: secutity and trust in information and networking systems, attacks analysis and misbehavior detection and privacy. The last one is a very recent domain research for us.

3.2.1 Security and Trust in Information and Networking Systems

Trusted and Secure Communications in Scalable and Constrained Environments. In the context of cooperative intelligent transportation (C-ITS), connected and autonomous vehicles are considered as connected objects within a highly scalable hybrid meshed vehicular network [56]. Cybersecurity is a key challenge given the risks arising from any one of the different communication modes and from the potential weaknesses of the intra-vehicle system (bugs, incorrect configuration, software flaws etc.). Our aim was to design an end-to-end security architecture focusing on securing exchanged V2X messages, ensuring protection of personal data, designing trust models and trust mechanisms. Our solutions aim at reaching a trade-off between scalability, security, safety, performance and cost. We also address interoperability issues between trusted C-ITS security systems and propose security solutions for real deployment cases [46, 47, 73].
To establish robust and available communication between vehicles in highly scalable dynamic vehicular ad hoc networks, we design efficient mobility-based clustering algorithms to guarantee cluster stability as well as data transmission efficiency with intermittent connectivity. We mainly validate our research work through simulation, analytical modelling and real [52, 54]. Major achievements of our recent activity are illustrated through three important European pilot deployment projects of cooperative intelligent transportation systems SCOOP@F, InterCor and C-Roads [64] in prospecting for a national roll-out.

Trusted digital services based on Secure Elements. We designed innovative paradigms and protocol based on tamper resistant computing resources such as secure elements (SE). We deal with the security for Cloud application, IoT platforms, mobile payments or applications and blockchain transactions. Four IETF drafts were published to push new protocols towards standardization. Four demonstrations addressing security features for the IoT were selected by the IEEE ComSoc society for the CES International Exhibition [77, 78, 81]. An innovative mobile payment project was demonstrated during the annual Orange research days in 2015. In the European project SecFuNet, new research directions were explored in order to store sensitive data such as keys and cryptographic algorithm executions in remote secure elements hosted by dedicated RACS (Remote APDU Call Secure) servers [80]. This approach creates a Virtual Machine identity and secures the VM migrations. The first RACS protocol draft was issued in 2013 and the first open software in 2017 for Raspberry, Linux, and Windows. Security issues for IoT were addressed by considering highly constrained computing nodes embedding communication stack such as TLS in tamper resistant environments. As an illustration, multi modal SE supporting Mifare, ISO7816 and NFC interfaces establish secure bridges between the cloud (for credentials downloading) and Mifare IoT devices such as locks. We designed the original LLCPS (Logical Link Control Protocol Secure) dedicated to NFC peer to peer (P2P) communications [79]. We did pioneer work dealing with the security of Host Card Emulation (HCE) services. In 2017, we deliver a research work for the French governmental agency AFIMB and the ADCET association to evaluate the threats induced by the next generation of Calypso mobile HCE application. In 2017 we release an open software as a first milestone for trusted blockchain transaction.

Securing Communications in Industrie 4.0. Industrie 4.0 is a name for the current trend of automation and data exchange in manufacturing technologies. OPC UA is an open M2M communication protocol for industrial automation developed by the OPC Foundation and normalized under EN/IEC 62541. OPC UA is becoming increasingly important in industrial networks because it has, from the beginning, incorporated safety and security into its principles. In the Cluster Connexion project, we developed a partial C/C++ implementation of OPC UA. We backed up our implementation of the OPC UA stack, responsible of data transfer, with ROSA designed at Telecom ParisTech [55] which is dedicated to path recovery. It allows securing the routing providing we have a large number of nodes in the network [58, 57]. Our OPC UA has been used as the standardized interface of the industrial WSN OCARI. It also has been incorporated in the

INGOPCS project, supported par l'ANSSI, which at providing a totally proved and secured stack for OPC UA: code analyzed by the Frama C software from CEA and certified by Common Criteria at level EAL4 (Evaluation Assurance Level). We changed our stack for the INGOPCS stack.

Secure Access Control in Industrial IoT. We designed a security protocol that meets the IoT requirements. It is made of a lightweight mutual authentication mechanism, the one-time password (OTP) algorithm and an AES-GCM/CCM mechanism for protecting data. It allows authentication of devices and encryption of transferred data on the industrial WSN OCARI. To ensure a secure, flexible and transparent migration of things from a network to another, we created a decentralized authentication mechanism based on private Blockchain (Ethereum) that allows a high mobility of things especially designed for constrained devices [45, 65, 66]. We used a formal validation using AVISPA (Automated Validation of Internet Security Protocols and Applications) from European FET Open and then, using the Scyther tool of Oxford University. We realized a real implementation in C language and TestRPC. We made many experiences to evaluate the time and energy consumption of our approach.

3.2.2 Attacks Analysis and Misbehavior Detection

Attack Analysis and Countermeasure in Information Network. This work focuses on the security of computer networks and services and in the design of security solutions. A lot of work has been done in the study and analysis of attacks in different contexts [59, 60]. Classifications have been produced and specific solutions have been developed for each class of attack. This work has been carried out under contracts in particular bilateral with industry (Schneider, OrangeLabs, Renault). We have defined a suitable risk analysis for service resilience needs [74]. We used architectural, protocol, probabilistic and machine learning approaches. This allowed: 1) to define entities for attacks detection on Web applications, machine learning WAF (Web Application Firewall) based approach [71, 76], 2) to extend existing protocols like TLS for authentication that preserves customers identity while maintaining interoperability, 3) to define and design security architectures and security protocols, including synchronized digital safes integrated into cloud environments [67]; in our approach we rely on standards like HTML5 and the cooperative and secure nature of the Blockchain for the optimization of these solutions [68, 69], and 4) to design new secure approaches in total disruption with Internet Networks, NDN (Named Data Networking). To sustain this approach we proposed new solutions and we defined a specific Blockchain adapted to Information Centric Networking (ICN) [61].

Attacks and Misbehaviors Detection in Wireless Networks. We address the increasingly complex problem of protection against cyber-attacks and misbehaviors in vehicular networks and Ad Hoc networks. We focus on designing cybersecurity architecture for such networks ensuring their protection through cooperative paradigms. To tackle Radio Frequency (RF) jamming attacks, we proposed a cooperative anti-jamming beam forming scheme for the control channel jamming problem in vehicular networks. It takes advantage of the multi-antenna and spatial diversity provided by the RSU (Road Side Unit) and relay vehicles to improve the transmission reliability of the victim vehicles [62, 44]. On the other side, vehicular networks are also vulnerable to Sybil attack. Thus we proposed and validated a Support Vector Machine (SVM) based Sybil attack detection method [63] with three SVM kernels functions based classifiers to distinguish malicious and benign nodes by evaluating the difference of their Driving Pattern Matrices (DPM).

We designed and validated a fully distributed detection mechanism of malicious nodes performing packet dropping attacks to disrupt the routing services in Mobile Ad hoc Networks [50, 75]. To tackle attacks performed by malicious nodes, in context of smart cities [49, 48], we proposed and validated through simulation a prediction framework extending the detection mechanism already mentioned using a Markov chain model to handle the problem of periodic packet dropping attacks [53]. This framework allows keeping track of the evolution of network nodes over a time period in order to predict their stationary states.

Misbehaviors Detection in Cloud Computing. Security of Cloud Computing is often overlooked and that can have disastrous consequences: the conversion of cloud computing into an

attack vector. Botnets supporting Distributed Denial of Service (DDoS) attacks are among the greatest beneficiaries of this malicious use. To tackle this issue, we designed and validated a source-based detection scheme that aims at detecting the abnormal virtual machines behavior [43] through a cooperative system. The detection method is based on Principal Component Analysis (PCA) to detect anomalies that can be signs of botcloud's behavior supporting DDoS flooding attacks. We evaluated our approach using simulations that rely on real workload traces showing the detection system effectiveness and low overhead, as well as its support for incremental deployment in real cloud infrastructures.

3.2.3 Privacy

Privacy is also a challenging issue that aims at mitigating data leakages, user's traceability, unauthorized access to data and to implement anonymization/pseudonymization and accountability functions as required by the European GDPR regulation. We developped a research activity on personal data protection in the context of several application areas: big data, IoT, Cloud and ITS. We aim to propose privacy by design solutions for data storage/generation/processing/transfer while respecting applications and system performances constraints. In the context of ITS-G5 based C-ITS systems, we address pseudonymization/anonymization of V2X messages. In hybrid ITS-G5/LTE networks, we address end-to-end privacy aware-data delivery for V2V, V2I and I2V data communications with mobility based service continuity. We investigate interaction between the system performance and the privacy level [51, 379].

3.2.4 Scientific Highlights

- Startups:
  - EtherTrust (http://ethertrust.com) is a Telecom ParisTech spinof and a FrenchTech partner. It develops and markets SSL/TLS/DTLS middleware for Secure Elements (SE). Its patented technology enables secure communications using SE for on-line payments, physical access, IoT security and remote enterprise access for greater privacy and security. The team includes internationally recognized experts and two employees.
- Significant Contracts with Industry:
  - SCOOP@F is a national and European important project funded by the European Commission and led by the MEDDE/DGITM Ministry. It is the first large-scale pilot deployment project of Cooperative Intelligent Transport Systems (C-ITS) in France with 3000 vehicles and 2000 km of roads. We are the leader of this activity. Security topics: PKI, pseudonymization and anonymization, end-to-end security, privacy preserving mechanisms for ITS-G5 and hybrid communications, risk analysis.
  - Cluster Connexion was a 4 years *Investissement d'Avenir* project. Cluster Connexion partners: All4Tec, Alstom, Areva, Atos Worldgrid, CEA, Corus, CNRS CRAN, EDF (leader), ENS, Esterel, INRIA, INP Grenobble (LIG), Predict, Rolls-Royce Civil Nuclear SAS and Telecom ParisTech from 2012 to 2016. French nuclear industry developped a R&D work program to incorporate major innovations into the design and implementation of control-command of nuclear power plants.
- Chairs:
  - Connected Cars & Cyber Security (C3S) is a research chair launched for a period of five years with five major industry actors: Nokia, Renault, Thales, Valeo and Wavestone. Its goal is to develop cyber security research activities according to five main axes: risk analysis and dependability, data and data flow real time protection, cryptography and agility, authentication, identity management, resilience by design and privacy. Led by two research professors from Telecom ParisTech, one from INFRES/CCN expert in the field of cybersecurity of cooperative intelligent transport systems and one from the COMELEC department specialist in embedded systems safety, the Chair gathers a multidisciplinary team from Telecom ParisTech and other partners.

- Common Lab with Universities:
  - CCN is highly involved in the Joint Research Laboratory between Telecom ParisTech and Shanghai Jiao Tong Univ. It is devoted to Security and Trust in the Future Internet.
  - We participate to BART (Blockchain Advanced Research and Technologies), a lab dedicated to Blockchains with IRT SystemX, Inria and IMT.
- Associate editors of journals:
  - Special issue on Cybersecurity in Networking, Annals of Telecommunications, 2018.
- Standardization activities:
  - 3 ETSI Security Standards and 7 IETF Drafts.
- Interaction with Economic and Social Spheres:
  - *Puces sous la peau, Révolution ou danger ?* M6 (66 minutes), mars 2018.
  - Presentation of the Master spécialisé *Architecte Télécom Orienté Multi-Services* and trhe Master spécialisé *Conception et Architecture de Réseaux*, Campus Channel, 2018.
  - Forum *Véhicule Connecté Et Autonome : Relevez les défis technologies, réglementaires et collaboratifs*, Usine Nouvelle, nov. 2017.
  - *M.S. Smart Mobility : transformation numérique des systèmes de mobilité*, Campus Channel, mars 2017.
  - *Il faut monter une 4ème armée ! Reste à former les soldats*, Usine-Digitale, mai 2017.
  - *La cyberdéfense est une dimension primordiale dans la sécurité d'un État ou d'une entreprise*, Le Figaro Étudiant, mars 2016.
  - *Du simple appel au paiement sans contact, 40 ans d'évolution du téléphone portable*, France Info, sept. 2015.
  - *Mobile, Internet, CB, vidéocaméras : sommes-nous tous sous surveillance ?*, M6 (E=M6), juin 2014.
  - *Le high-tech made in Picardie brille à Las Vegas*, L'Union, jan. 2014.
- Organization of Conferences: SSIC[1] 2016 / CFIP[2] 2015 / NTMS[5] 2014 to 2018 / MobiSecServ[3] 2015 to 2018.
- PC chair of Conferences: CSNET[4] 2017, 2018 / SSIC[1] 2015, 2016 / NTMS[5] 2015.
- Best Papers: SCVT[6] 2014 / SSIC[1] 2015 / CSNET[4] 2017.

3.3 SWOT Analysis

Strength:

- Imminent arrival of a new assistant professor in September 2018.
- The good balance between fundamental research and applied research made on contract.

Weakness:

- Because of the heavy load due to ongoing contractual projects, the reduced number of researchers (5), the team encountered difficulties in achieving its publications objectives and accepting research collaboration with academics and industrial partners.

Opportunities:

- Our skill in Intelligent Transport System (ITS) cybersecurity is an important strength of our current work. It becames a major source of growth of our research activities.

[1]SSIC: International Conference on Security of Smart cities, Industrial Control System and Communications.
[2]CFIP: Colloque francophone sur l'ingénierie des protocoles.
[3]MobiSecServ: International Conference on Mobile and Secure Services.
[4]CSNET:International Conference on Cyber Security In Networking
[5]NTMS: International Conference on New Technologies, Mobility and Security.
[6]SCVT: IEEE Symposium on Communications and Vehicular Technology.

- The quality of our relations with industry, manufacturers, integrators, (Renault, EDF, Thalès, Nokia, Valeo, etc.) and with academic researchers in France and within IMT (Telecom SudParis for instance).
- France's and Europe's strategy on information systems defence and security.
- Future *Plateau de Saclay* collaborations and strong internal collaborations with COMELEC departement and ACES group (on Blockchain) in INFRES departement.
- Industrie 4.0 is the current trend of automation and data exchange in manufacturing techs.

Threats:

- Lack of vision on our future governance. People are worried about our installation at Saclay.

3.4 Scientific project for the the next five years

Our future research projects mainly strengthten the activities that we described in section 3.2 with new domains such as privacy models, Blockchains and protocols for Time Sensitive Network (TSN).

Trusted and secure communications in Scalable ans constrained environments. Our objective is to strengthen our cybersecurity activities in ITS domain which are very diverse and not all investigated for the moment in current projects: privacy models and mechanisms, detection of abnormal behavior of drivers and systems, models and architectures of scalable trust, cryptoagility, revocation, large scale interoperability. Huge opportunities are available thanks to the current and future national and European contexts (EC regulation, national strategy on connected and autonomous vehicles, NFI, H2030, etc.) allowing our team to develop a strong upstream research. The team aims to enhance its partnership within French eco-system (academics, industry, Ministry of Defense, Ministry of Transport, road operators, telecom operators, ...) and to start new collaborations to cover these critical subjects especially on the Plateau of Saclay with l'X, LRI, CentraleSupelec, CEA, TSP, Inria-Saclay, IRT SystemX, VeDeCoM. The newly created C3S Chair with Renault is a perfect example highlighting the urgency of dealing with cybersecurity issues. A complementarity of the team's expertise with the expertise of other teams of the LTCI laboratory exists and could provide opportunities for very interesting collaborations (ACES, DIG, SEN, S2A). A second objective is to participate to the European and international standardization bodies to change standards and to interact with national authorities to show the feasibility of our solutions. Our third objective is to achieve our project to set up two security platforms, ITS-Sec and IoT-Sec, for research and experimentation combined with a Security Test Living Lab.

Security data analytics in large scale networks/systems. The team would like to develop an activity on security data analytics transversal to the other research activities carried out in the different themes. With the increase of networks/systems size, data volume and advancement in artificial intelligence, many useful information can be mined in a crowdsourcing manner. We aim to define approaches for security data analysis in large scale and complex networks/systems. To address this issue, we will investigate methods to combine network and security analysis in order to define a global secure opinion aggregation system, so as to make correct decision according to the data collected from networks and systems as well as to detect malicious or unreliable behavior/entity/data. Many tools will be studied such AI tools (machine learning, ...) .

Attack Analysis and Countermeasure in Information Network. We will focus on the design, specification and validation of authentication models responding to environments with high latency constraint (ICS, IoT, ITS) and/or responding to specific needs such as anonymity, accountability, etc. Model design and mechanism integration such as the Blockchain will be considered. The strong constraint to achieve is to preserve interoperability with the existing. An ongoing approach is the design and realization of public keys (PKI) entirely based on a Blockchain. The integration of pseudonymous certificates into TLS is also being standardized at the IETF. Our previous contributions and results give us some tangible assets. This work will require a study and risk analysis to validate our results.

Cyber Physical Systems and Blockchains. The Blockchain is an emerging paradigm that could solve security and trust issues in information technologies. Telecom Paristech is part of the

Blockchain Advanced Research & Technologies (BART) initiative, started in 2018 with academic partners (Telecom SudParis, Inria and IRT SystemX). We plan to define new IoT protocols dealing with blockchain platforms such as BIoT (Blockchain IoT), whose early concept has been recently introduced in an IETF draft Blockchain Transaction Protocol for Constraint Nodes. These researches could also be applied to Cyber Physical Systems (CPS). Another research direction will be driven thanks to the BART initiative and will focus on the design of trusted architectures for blockchain applications, targeting a security level at least equivalent to the today banking services.

Secure Communications for Industrial Environment. OPC UA & IoT is becoming a field of exploration and research. Implementations of OPC UA that relate to IoT are gateways that allow to switch from one technology to another. We will develop an OPC UA adapted to very small connected objects with little computing power, energy and having very low or even intermittent communications means. This prospective result should make it possible to deploy OPC UA for IoT. The emergence of Time Sensitive Network (TSN) is a major innovative feature of the coming years in the industrial world. Our aim is to explore this TSN technology which must be associated with optimized network communication services such as OPC UA.

3.5 Scientific production (selection)

Articles in Journals

[43] R. Cogranne, G. Doyen, N. Ghadbane, and B. Hammi. Detecting botclouds at large scale: a decentralized and robust detection method for multi-tenant virtualized environments. *IEEE Transactions on Network and Service Management*, 15(1):68–82, 2018.

[44] P. Gu, C. Hua, R. Khatoun, Y. Wu, and A. Serhrouchni. Cooperative anti-jamming relaying for control channel jamming in vehicular networks. *IEEE Transactions on Vehicular Technology (IEEE VTT)*, May 2018.

[45] M. T. Hammi, B. Hammi, P. Bellot, and A. Serhrouchni. Bubbles of trust: a decentralized Blockchain-based authentication system for IoT. *Computers & Security*, 2018.

[46] T. Heng Chuan, M. Ma, H. Labiod, A. Boudguiga, J. Zhang, and P. Chong. A secure and authenticated key management protocol (SA-KMP) for vehicular networks. *IEEE Transactions on Vehicular Technology*, Oct. 2016.

[47] T. Heng Chuan, M. Ma, H. Labiod, P. Chong, and J. Zhang. A non biased trust model for wireless mesh networks. *Wiley International Journal of Communication Systems*, Oct. 2016.

[48] R. Khatoun and S. Zeadally. Smart cities: Basic concepts, architectural issues, and research opportunities. *Communications of the ACM (CACM)*, 59(8):46–57, Aug. 2016.

[49] R. Khatoun and S. Zeadally. Cybersecurity and privacy solutions in smart cities. *IEEE Communications Magazine*, 55(3):51–59, Mar. 2017.

[50] R. Khatoun, Y. Begriche, J. Dromard, L. Khoukhi, and A. Serhrouchni. A statistical trust system in wireless mesh networks. *Annals of Telecommunications*, 71(5):187–199, Dec. 2015.

[51] M. Msahli, A. Serhrouchni, H. Labiod, A. Kaiser, and B. Lonc. TLS for cooperative ITS services. *IOV*, Sept. 2017.

[52] M. Ren, L. Khoukhi, H. Labiod, J. Zhang, and v. Vèque. A mobility-based scheme for dynamic clustering in vehicular ad-hoc networks (VANETs). *Elsevier Vehicular Communications*, Dec. 2016.

[53] M. Rmayti, R. Khatoun, Y. Begriche, L. Khoukhi, and D. Gaïti. A stochastic approach for packet dropping attacks detection in mobile ad hoc networks. *Journal of Computer Networks*, 121:53–64, Apr. 2017.

[54] G. Zhioua, N. Tabbane, H. Labiod, and S. Tabbane. A fuzzy multi-metric QoS-balancing gateway selection algorithm in a clustered VANET to LTE advanced hybrid cellular network. *IEEE Transactions on Vehicular Technology*, Jan. 2015.

Books & Book Chapters

[55] T. Dang, P. Minet, P. Bellot, C. Mozzati, and E. Livolant. *Internet of Things : Novel Advances and Envisioned Applications, A. Acharjya ed. (Springer)*, chapter Industrial IoT : Mobility Support and Service Discovery for Industrial Process Monitoring, pages pp. 57–85. 2016.

[56] H. Labiod and A.-L. Beylot. *Models and algorithms for vehicular networks*. ISTE Publishing Knowledge/John Wiley and Sons Inc., 2013.

Articles in Conference Proceedings

[57] T. Dang, D. Brezak, and P. Bellot. Routing in opc-ua with rosa overlay network. In *OTM'14/CoopIS, Industry Case Studies Program*, Amantea (Italy), Oct. 2014.

[58] C. Devic, E. Livolant, J.-P. Carrié, P. Minet, and P. Bellot. Connexsensors: An open iot solution designed for and by industrials. In *ICSSEA'2017*, Paris, France, May 2017.

[59] Z. Drias, A. Serhrouchni, and O. Vogel. Taxonomy of attacks on industrial control protocols. In *International Conference on Protocol Engineering (ICPE) and International Conference on New Technologies of Distributed Systems (NTDS)*, Paris France, July 2015.

[60] Z. Drias, A. Serhrouchni, and O. Vogel. Analysis of cyber security for industrial control systems. In *IEEE International Conference on Cyber Security of Smart Cities, Industrial Control System and Communications (SSIC'2015)*, Shanghai, China, Aug. 2015.

[61] Z. Drias, A. Serhrouchni, and O. Vogel. Dentity-based cryptography based key management system for industrial control systems. In *1st IEEE-IFIP CSNet*, Rio de Janeiro. Brazil, Oct. 2017.

[62] P. Gu, C. Hua, Y. Wu, R. Khatoun, and A. Serhrouchni. Cooperative anti-jamming relaying for control channel jamming in vehicular networks. In *IEEE GLOBECOM 2017*, Singapore, Dec. 2017.

[63] P. Gu, R. Khatoun, Y. Begriche, and A. Serhrouchni. Support vector machine (svm) based sybil attack detection in vehicular networks. In *Wireless Networks of the IEEE WCNC 2017 conference*, San Francisco, CA, USA, Mar. 2017.

[64] B. Hammi, J.-P. Monteuuis, E. Salles Daniel, and H. Labiod. Asn.1 specification for etsi certificates and encoding performance study. In *18th IEEE International Conference on Mobile Data Management*, pages 291–298, Corée du sud, May 2017.

[65] M. T. Hammi, E. Livolant, P. Bellot, A. Serhrouchni, and P. Minet. Mac sub-layer node authentication in OCARI. In *IFIP PEMWN*, Paris, France, Nov. 2016.

[66] M. T. Hammi, E. Livolant, P. Bellot, A. Serhrouchni, and P. Minet. A lightweight mutual authentication protocol for the iot. In *ICMWT*, Kuala lumpur, Malaisie, June 2017.

[67] M. Jemel and A. Serhrouchni. Content protection and secure synchronization of HTML5 local storage data. In *11th IEEE CCNC*, Las Vegas, Nevada, USA, Jan. 2014.

[68] M. Jemel and A. Serhrouchni. Decentralized access control mechanism with temporal dimension based on blockchain. In *IEEE 14th ICEBE*, Shanghai, China, Nov. 2017.

[69] M. Jemel, M. Msahli, and A. Serhrouchni. Towards an efficient file synchronization between digital safes. In *31st IEEE AINA*, pages 136–143, Sept. 2017.

[70] K. Kapusta, G. Memmi, and H. Noura. Secure and resilient scheme for data protection in unattanded wireless sensor networks. In *1st IEEE-IFIP CSNet*, Rio de Janero, Bresil, Oct. 2017.

[71] A. Makiou and A. Serhrouchni. Efficient training data extraction framework for intrusion detection systems. In *6th IEEE IFIP NOF*, Montreal, Canada, Sept. 2015.

[379] R. Moalla, B. Lonc, H. Labiod, and N. Simoni. CIVAS: Towards a cooperative ITS vehicle application oriented security framework. In *IEEE IV'2014*, Dearborn, Michigan, June 2014.

[73] J.-P. Monteuuis, B. Hammi, E. Salles Daniel, H. Labiod, R. Blancher, E. Abalea, and B. Lonc. Securing PKI requests for C-ITS systems. In *3rd International Workshop on Vehicular Networking and Intelligent Transportation Systems. Held within ICCCN 2017*, Vancouver, Canada, Aug. 2017.

[74] S. Natouri, A. Serhrouchni, and C. Lac. Resilience design using the challenge countermeasure tree (cct) model. In *Applications and Innovations in Mobile Computing*, Kolkata, India, Feb. 2014.

[75] M. Rmayti, Y. Begriche, R. Khatoun, L. Khoukhi, and D. Gaïti. Denial of service (dos) attacks detection in manets using bayesian classifiers. In *The 21st IEEE Symposium on Communications and Vehicular Technology in the Benelux*, Delft, Netherlands, Nov. 2014.

[76] S. Souissi, A. Serhrouchni, L. Sliman, and B. Charroux. Security incident response: Towards a novel decision-making system. In *International Conference on Intelligent Systems Design and Applications*, Porto, Portugal, Dec. 2016.

[77] P. Urien. Llcps: A new security framework based on tls for nfc p2p applications in the internet of things. In *IEEE CCNC'2013*, Las Vegas, USA, 2013.

[78] P. Urien. A secure cloud of electronic keys for nfc locks securely controlled by nfc smartphones. In *IEEE CCNC 2014*, Las Vegas, NV, USA, Jan. 2014.

[79] P. Urien. Llcps: A new secure model for internet of things services based on the nfc p2p model. In *IEEE ISSNIP 2014*, Singapour, Apr. 2014.

[80] P. Urien. Racs: Remote apdu call secure creating trust for the internet. In *IEEE CTS 2015*, Atlanta, USA, 2015.

[81] P. Urien. Securing the IoT with TLS/DTLS server stacks embedded in secure elements: An eplug usecase. In *2017 14th IEEE CCNC*, Las Vegas, USA, Jan. 2017.

Chapter 4

DIG

Data, Intelligence and Graphs

4.1 Presentation of the team

Team Leader: Talel Abdessalem (-05/17), Albert Bifet (05/17-).

Faculty between 2013 and 2018: Talel Abdessalem (FP), Antoine Amarilli (AP, 09/16-), Bogdan Cautis (AP, -8/13), Albert Bifet (FP, 09/15-), Thomas Bonald (FP, 01/17 -), Laurent Decreusefond (FP, 01/17 -), Jean-Louis Dessalles (AP), Pierre Senellart (FP, -08/16), Mauro Sozio (AP), Fabian M. Suchanek (FP).

Invited Professors: Pierre Senellart (Professor, Ecole Normale Supérieure, November 2017 -).

Sabbatical Professors: Gustavo de Veciana (Professor, The University of Texas at Austin, January - April 2018), Joao Gama (Associate Professor, University of Porto, July - December 2017).

PhD Students Defended: Mohamed Khalil EL MAHRSI (supervised by Fabrice ROSSI, Christine POTIER 15/07/09 -30/09/13), Damien MUNCH (supervised by Jean-Louis DESSALLES 05/10/09 - 05/11/13), Imen BEN DHIA (supervised by Talel ABDESSALEM, Mauro SOZIO 01/10/10 - 16/12/13), Ioana ILEANA (supervised by Bogdan CAUTIS, Pierre SENELLART 01/10/11 - 24/10/14), Modou GUEYE (supervised by Talel ABDESSALEM, Samba NDIAYE 01/09/11 - 15/12/14), Muhammad FAHEEM (supervised by Pierre SENELLART 16/08/11 - 17/12/14), Mouhamadou Lamine BA (supervised by Talel ABDESSALEM, Pierre SENELLART 02/04/12 - 30/03/15), Antoine SAILLENFEST (supervised by Jean-Louis DESSALLES 01/10/11 - 25/11/15), Antoine AMARILLI (supervised by Pierre SENELLART 01/09/13 - 14/03/16), Luis GALARRAGA (supervised by Fabian SUCHANEK 03/02/14 - 29/09/16), David MONTOYA (supervised by Pierre SENELLART 01/01/14 - 06/03/17), Oana BALALAU (supervised by Mauro SOZIO 01/11/13 - 17/05/17).

PhD Students Current: Mikaël Monet (supervised by Antoine Amarilli and Pierre Senellart, since 2015), Thomas Pellissier-Tanon (supervised by Antoine Amarilli and Fabian Suchanek, since 2017), Thomas Rebele (supervised by Fabian Suchanek, since 2015), Jonathan Lajus (supervised by Fabian Suchanek, since 2016), Jérôme Dockès (supervised by Fabian Suchanek and Gaël Varoquaux, since 2016), Julien Romero (supervised by Fabian Suchanek and Nicoleta Preda, since 2017), Alexandre Hollocou (co-supervised by Thomas Bonald, since 2015), Céline Comte (supervised by Thomas Bonald, since 2016), Mauro Sardara (supervised by Thomas Bonald, since 2016), Nathan de Lara (supervised by Thomas Bonald, since 2017), Édouard Pineau (supervised by Thomas Bonald, since 2017), Zhihan Zhang (supervised by Laurent Decreusefond and Anaïs Vergne, since 09/2017), Jalal Rachad (supervised by Laurent Decreusefond and Ridha Nasri , since 2017), Jacob Montiel (supervised by Talel Abdessalem and Albert Bifet, since 2015), Dihia Boulegane (supervised by Albert Bifet and

Giyyarpuram Madhusudan, since 2017), Maroua Bahri (supervised by Albert Bifet and Silviu Maniu since 2017), Pierre-Alexandre Murena (supervised by Jean-Louis Dessalles, since 2016).

PostDocs and non-permanent Research Engineers: Thomas Bonis (postdoc with Laurent Decreusefond, since 2017), Camille Bourgaux (Postdoc with Fabian Suchanek, since 2017), Danai Symeonidou (Postdoc with Fabian Suchanek, 2015), Katerina Tzompanaki (Postdoc with Fabian Suchanek, 2016), Maximilien Danisch (Postdoc with Mauro Sozio, 2015-2017), Arnaud Guerqin (research engineer with Mauro Sozio, 2017), Jesse Read (PostDoc with Talel Abdessalem, 2016), Mostafa Haghir Chehreghani (PostDoc with Talel Abdessalem and Albert Bifet, since 2016), Heitor Murillo Gomes (PostDoc with Albert Bifet, since 2017).

Platforms and Software: The team develops the following platforms:

- YAGO is a large open source knowledge base that is built automatically from Wikipedia, WordNet and GeoNames. It won the Test of Time Award of the Web Conference 2018. YAGO is developed jointly with the Max Planck Institute for Informatics and is used in projects such as DBpedia and IBM Watson. `http://yago-knowledge.org/`.
- MOA is the most used data stream machine learning (ML) software, and it is being developed with University of Waikato in New Zealand. It includes a collection of machine learning algorithms (classification, regression, clustering, outlier detection, concept drift detection and recommender systems) and tools for evaluation. `https://moa.cms.waikato.ac.nz/`.
- Apache SAMOA is a distributed streaming machine learning (ML) framework that contains a programing abstraction for distributed streaming ML algorithms for Big Data stream engines on the Hadoop ecosystem `https://samoa.incubator.apache.org/`.
- StreamDM is a distributed streaming machine learning (ML) framework for Spark Streaming that is developed with Huawei Noah's Ark Lab `http://huawei-noah.github.io/streamDM/`. A non distributed version in C++ also exists `http://huawei-noah.github.io/streamDM-Cpp/`.
- `scikit-multiflow` is a multi-output/multi-label and stream data framework implemented in Python developed with Ecole Polytechnique `https://scikit-multiflow.github.io/`.

Scientific Production Overview: Table 7.1 represents the scientific production between 2013 and 2018.

	Journal articles	Books	Book chapters	Articles in proceedings	Patents	Invited talks	PhD Thesis	HdR
2013-18	61	3	13	178	0	11	12	4

Table 4.1: Overall Scientific Production

Scientific Highlights:

- Organization of Workshops and Conferences
  - International Workshop on Big Data, Streams and Heterogeneous Source Mining: Algorithms, Systems, Programming Models and Applications (BigMine) at KDD 2015-2018
  - Workshop on Graph learning 2018
  - ICCBR 2018 (Case-based reasoning)
  - European IoT Analytics Summit (EuroIoTA) 2016-2017
  - Paris-Saclay Junior Conference on Data Science and Engineering 2016
  - IEEE/ACM Int. Conf. on Advances in Social Networks Analysis and Mining (ASONAM 2015)

- PC Chair of Workshops
  - International Workshop on Big Data, Streams and Heterogeneous Source Mining: Algorithms, Systems, Programming Models and Applications (BigMine) at KDD 2015-2018
  - Web DB Workshop at SIGMOD 2015
  - Knowledge Extraction workshop at NIPS 2014
  - Knowledge Extraction workshop at CIKM 2013
  - PhD Workshop at CIKM 2013
  - IoT Large Scale Learning from Data Streams Workshop at ECML-PKDD 2017-2018
  - International Workshop on Energy Efficient Data Mining and Knowledge Discovery (Green Data Mining 2018) at ECML-PKDD 2018
  - Workshop on Real-time & Stream Analytics in Big Data at IEEE Big Data Conference 2016-2017
  - IEEE International Conference on Information Reuse and Integration for Data Science 2018
- Associate Editors of Journals
  - Special issue of the Elsevier Journal of Web Semantics
  - Data Mining and Knowledge Discovery (DAMI) (2018 -)
  - IEEE Transactions on Big Data (IEEE TDB) (2015-2017)
  - Neurocomputing Journal (2016-2017)
- Editorial or program committees
  - SIGKDD 2015, 2016, 2017, 2018
  - ECML-PKDD 2015, 2016, 2017, 2018
  - IEEE Big Data 2015, 2016, 2017, 2018
  - IJCAI 2015, 2017, 2018
  - ICDM 2015, 2016, 2017
  - NIPS 2018
  - Machine Learning Journal
- Keynotes
  - 12th ACM International Conference on Distributed and Event-based Systems (DEBS 2018)
  - KDD Workshop on Mining and Learning from Time Series (MiLeTS 2017)
  - The 6th Brazilian Conference on Intelligent Systems (BRACIS 2017)
  - The 3rd Africa and Middle East Conference on Software Engineering (AMECSE2017)
  - The 16th International Conference on Artificial Intelligence and Soft Computing ICAISC 2017
  - The 8th Asian Conference on Machine Learning (ACML 2016)
  - ACML Workshop on Learning on Big Data 2016
  - International Symposium on Information Management and Big Data SIMBig 2016
  - 1st Workshop on High Velocity Mobile Data Mining MobDM 2016
  - Workshop on Parallel and Distributed Computing for Knowledge Discovery in Data Bases (PDCKDD 2015) at ECML-PKDD 2015
  - Workshop on Mining Ubiquitous and Social Environments (MUSE 2015) at ECML-PKDD 2015
  - WikiData Conference 2017
  - WSDM Cup Workshop at WSDM 2017
  - KET Workshop at WWW 2015
  - EGC Conference 2014
- Tutorials in international conferences
  - SIGMOD 2013, ICDE 2013

  - VLDB 2014
  - WWW 2015
  - SIGKDD 2016, CIKM 2016
  - SIGKDD 2017, AAAI 2017, SDM 2017, IJCAI 2017
- Awards
  - Seoul Test of Time Award of the The Web Conference 2018
  - Honorable Mention Award of the The Web Conference 2018
  - Prominent Paper Award of the Artificial Intelligence Journal
  - SIGMOD Dissertation Award Honorable mention 2018 (for one of our PhD students)
  - E. W. Beth Dissertation Prize in 2017 (joint winner)
  - Best talk award at Highlights'16
  - Outstanding Reviewer Award at the WSDM 2014 conference
  - Best student paper award at the WWW 2013 conference
- Fundings
  - Labex DIGICOSME, Emergence Projects
  - 1 ANR contract (1 PhD + 1 postdoc)
  - 1 DigiCosme contract (1 PhD + 1 postdoc)
- Evaluation and scientic committees
  - Members of evaluation board of national or international projects (ANR, ERC starting grant, national agencies – New Zealand, Belgium, Austria, Chile, ...).
  - Member of the evaluation committee of Inria
  - Member of the HCERES evaluation committee of the ICube Lab
- Vulgarization
  - Book chapter in the "Les Big Data à découvert", 2017
  - Interview with 01Net 2016-07 (France): "A la poursuite du cerveau artificiel" (p. 58)
  - Interview with Le Monde 2016-01-11 (France): "Wikipédia, quinze ans de recherches"
  - Interview with CBC Radio 2014-09-28 (Canada): "Knowledge bases"
- Contribution to higher level and research education
  - Masters in computer science: joint accreditation with Universite Paris-Saclay (coordination tasks, courses and student supervision)
  - M2 Data&Knowledge: a joint master's program with Paris-Sud University in the frame of Paris-Saclay University, of which we are the main organizers.
  - M2 COMASIC Conception & Management des Systèmes Informatiques Complexes
  - Master Parisien de Recherche en Informatique (MPRI)
- Industrial Chairs
  - Big Data & Market Insights: Telecom ParisTech Research Chair with the support of Groupe Rocher, SNCF, Deloitte and Groupe BPCE
  - Data Engineering and Artificial Intelligence for Banking and Insurance: Telecom ParisTech Teaching Chair with the support of Groupe BPCE
- Industrial collaborations
  - Google, Nokia, Huawei, Cisco, Thales, Safran

4.2 Research Activities

The core expertise of the DIG team is data management, artificial intelligence modelling and graph mining. The team deals with applied collaborations with Internet companies as Google, telecommunication companies as Orange, Nokia, Huawei and Cisco, and others as Safran, Thales

and Deezer. The team has a strong expertise in Big Data management, Artificial Intelligence, IoT Machine Learning, and Natural Language.

The scientic animation of the team is done at two different levels. A team seminar is organized periodically with invited researchers; it covers a wide range of subjects. At a more specic level, research meetings have been organized on different topics, involving only a sub-part of the team.

The main contributions of the team are described next, and are organized into knowledge base management, foundations of data management, mining of large dynamic graphs, random graphs and hypergraphs, natural language and relevance, and machine learning for data streams.

4.2.1 Knowledge Base Management

The work in this area falls into two domains: the creation of knowledge bases, and the mining of the data. Together with the Max Planck Institute for Informatics in Germany, we develop the YAGO knowledge base [158] – one of the largest general purpose knowledge bases on the Semantic Web. YAGO consolidates information from several semi-structured Web sources (Wikipedia, WordNet, Geonames, and others), and has a manually verified accuracy of 95%. We have recently developed methods to extract information also from unstructured sources: One method can extract commonsense knowledge from Web corpora [168]. We find, e.g., that apples can be sweet, and that people can be sweet, but that these are two different meanings of "sweet". In another work, conducted with Google research, we automatically detect named entities on the Web, and cluster together different names for the same entity. In the context of extracting information, we have proposed a method for repairing faulty regular expressions automatically [163]: Given a regular expression, and given a word that the expression does not match, we generalize the expression so that it matches the missing word and other similar words.

Our second domain of research is the mining of knowledge bases. The basis of this research axis is mining knowledge bases for Horn rules [98]. We find, e.g., that if someone lives in a city and is married, then their partner most likely also lives in the same city. This information helps us to complete and correct the knowledge base. We have expanded this work to mine also conditional keys [167]. Our most recent contribution determines where a knowledge base is missing information. We can determine with high precision whether a person graduated from a university in the real world, even if this is not stated in the knowledge base [99]. In a variation of this theme, we can determine whether an attribute is obligatory for a class in the real world, even if it is sparse in the knowledge base [153]. One of the applications of our knowledge base is to trace historical trends over time. We can trace, e.g., the life expectancy of people over the centuries in different countries. In the same spirit, we have extracted commercial products from the Web, and traced the global flow of trade between countries.

Finally, we have also ventured into alternative collections of knowledge. We have worked on private knowledge bases, as well as on automatically generated, creative knowledge [166]. We have also proposed methods that can automatically gather knowledge about the brain from fMRI scans [145]. To query these knowledge bases efficiently, we have developed a query engine that can scale effortlessly to the largest knowledge bases in existence [162]. We disseminate our work in tutorials, book chapters, vision papers, and articles for the general public.

4.2.2 Foundations of Data Management

Some of DIG's research deals with foundational questions related to data management problems, and we have shown a number of theoretical results on various topic. One main research topic is the management of data under uncertainty. For probabilistic data, we have proposed a way to evaluate queries on tree-shaped data [122], and connected this to the study of provenance and knowledge compilation [124], also proving new bounds in this area [131]. We have also shown that provenance could be represented as circuits and used these factorized representations to enumerate query results efficiently [127], including under updates [130]. We have also shown results for probabilistic query evaluation under the angle of combined complexity [129]. Last, we have proposed a framework to capture the new question of uncertainty on the order of data [126].

We have also proposed new ways to reason logically about incomplete data, in particular under finiteness assumptions [119], connecting together the research approaches of existential rules and description logics [118], or extending expressive fixpoint logic formalisms [123]. We have also used this approach for efficient query evaluation and connected them to provenance [128]. Last, we have studied the related problem of reformulating queries on restricted access methods, and shown new results in the context where result bounds are imposed on the methods [120].

We have also worked on probabilistic XML and connected it to probabilistic relational databases, and intensional Web data. Another topic is crowdsourcing: reformulating queries to evaluate them through a crowd of users. We have proposed ways to perform data mining tasks using the crowd [121], to evaluate top-k queries on constrained crowd data [125], and to estimate the reliability of the users for data labeling tasks [139]. We have also worked on data pricing, and on the resource allocation of data centers [86, 85].

4.2.3 Graphs

Graph Clustering

We have developped a number of algorithms for graph clustering, aiming at finding the best partition of the set of nodes without any information but the graph itself. As such, this is an unsupervised learning problem. This is a key problem in graph analysis, with many applications like data visualization, content recommendation, link prediction, label propagation and anomaly detection, to quote a few. In [103], we extend classical spectral algorithms to cope with overlapping communities. We prove the consistency of the algorithm on a random graph model called the stochastic blockmodel with overlap, using the geometric properties of the spectrum of the expected adjacency matrix. In [150], we propose a local algorithm that discovers the communities around some target nodes without requiring the exploration of the full graph. In [151], we design an online algorithm that returns a clustering of the nodes when edges are streamed, with a minimal complexity of $O(1)$ per edge.

Mining of Large Dynamic Graphs

We develop several algorithms for making sense of large real-world graphs evolving over time. We aim at developing efficient algorithms with strong theoretical guarantees both on the quality of the solution and their running time. We focus on the following theoretical models of computations: sequential, streaming, dynamic, parallel as well as on the following systems and architectures: MapReduce, Spark, Pregel, MPI, and multicore architectures. In [104] and [147], we adapt classical algorithms for matching and facility location into the MPI and Pregel systems, respectively. In [141, 135, 146], we develop algorithms for finding dense regions in the input graph. In particular, the algorithm developed in [141] can find an optimum solution for a large constrained convex optimization problem in graphs containing up to 20 billions edges. In [146], we develop an algorithm for maintaining an approximation of the densest subgraph in an evolving graph, while requiring poly-logarithmic amortized cost. Our experimental evaluation on real-world graphs show that a densest subgraph can be maintained while requiring microseconds per update operation, on average. In [142], we develop an algorithm for enumerating all k-cliques in graphs containing tens of millions of edges, while our algorithm enumerates all 10-cliques in graphs containing up to two billions edges. Such an algorithm leverages the fact that real-world graphs are relatively sparse. In [140], we develop an algorithm for maintaining a $2+\epsilon$-approximation solution for the k-center clustering problem, where input points can be added or removed arbitrarily. Such a problem consists of partitioning a set of points given input into k clusters with minimum maximum diameter. Our algorithm boasts poly-logarithmic amortized cost, while our experimental evaluation on data collected from Twitter shows that such a clustering can be maintained while requiring a few milliseconds per update operation, on average. Our algorithm can also be used to cluster an undirected graph into k clusters with minimum maximum diameter, with the distance between two nodes being measured as the shortest path distance between the two nodes in the input graph.

Our achievements in this research direction include additionally a patent [100], a nomination to the best paper award at the Web conference 2018, as well as, a Google Faculty Award.

Random Graphs and Hypergraphs

When data are geometric, it is often useful to analyze them through their proximity graphs and more generally from the simplicial complexes which can be built upon them. For randomly distributed points, we developped and analyzed several algorithms based on these representations [373, 374, 294, 295, 375]. These results are based on theoretical analysis of some random point processes with dependence between points [230, 114, 288, 113].

4.2.4 Machine Learning and Predictive Analytics

Machine Learning for Data Streams

We developed new efficient machine learning methods for data streams [110]. In the data stream model, data arrives at high speed, and algorithms that process it must do so under very strict constraints of space and time, especially if environment and energy concerns are under consideration (*green* AI). Consequently, data streams pose several challenges for data mining algorithm design. First, algorithms must make use of limited resources (time and memory). Second, they must deal with data whose nature or distribution changes over time. We proposed an adaptive version of Random Forests for data streams [102] as the new state-of-the-art method in ensemble methods [101] in the MOA data stream mining software [172], the most popular software of data stream mining, that we are developing with University of Waikato. For Big Data systems, we developed a novel distributed streaming decision tree [935] for Apache SAMOA, a software that we are also co-leading [171]. Apache SAMOA is a distributed streaming machine learning (ML) framework that contains a programing abstraction for distributed streaming ML algorithms. Apache SAMOA enables development of new ML algorithms without directly dealing with the complexity of underlying distributed stream processing engines (DSPEe, such as Apache Storm, Apache Flink, and Apache Samza). Apache SAMOA users can develop distributed streaming ML algorithms once and execute them on multiple DSPEs.

We proposed new methods in dynamic feature selection [936] and deep learning methods for streaming data [937, 105]. We presented two new open source tools for Big Data stream mining that we are managing with Huawei: StreamDM C++ [138] and StreamDM Spark Streaming [137]

The *Internet of Things (IoT)* is the network of physical objects, that contain embedded technology to communicate and sense or interact with their internal states or the external environment; a large network of sensors and actuators connected by networks to computing systems. Data produced by the IoT is dynamic and arrives as a stream [173, 174].

We are co-leading 4 open source projects on data stream mining: MOA, Apache SAMOA, StreamDM C++, and StreamDM Spark Streaming.

Recommender Systems

The purpose of recommender systems is to predict user preferences on a large selection of items, i.e. find items that are likely to be of interest for the user. The scalability of the proposed techniques and the quality of the recommendations remain two of the most important challenges in this domain. Aiming at improving the accuracy of recommender systems, we proposed in [116] a cluster-based matrix factorization technique that enables online integration of new ratings. Thus, we significantly enhance the obtained predictions between two matrix factorizations. Then, we tried to focus on these issues in two specific applications, namely Points of Interest (POI) Recommendation [148] and Hotel Bookings [83]. Recently, we opened a new direction with online recommendation, where we try to design online recommender systems that are able to handle user feedback and the availability of new items in real-time. The idea is to adapt recommender systems to the drifts when a change in the data distribution is detected [117].

4.2.5 Natural Language and Relevance

Simplicity Theory (ST) was developed in the previous period. ST is based on Kolmogorov complexity (minimal description length). It captures relevance as complexity drop: relevant situations or arguments must highlight a complexity gap between causal complexity and description complexity [143]. Its applications have been explored in domains such as incremental learning [161], analogy making, creativity [106], subjective probability [164], responsibility and moral judgment. For instance responsibility is analyzed as the difference of causal complexity with and without the action. These results support the claim that Simplicity Theory is able to make non-trivial predictions in a broad range of domains. More theoretical results about relevance [144, 115, 143] have been found. We also addressed two issues in semantics: predication based on contrast, and a dynamic model of Aspect. Besides, our model of Social Signaling [97] has been further applied to explain the emergence of language (see also [111]) The point is to re-interperet behaviors usually described as cooperative and instead present them as costly social signals.

4.3 SWOT analysis

4.3.1 Strengths

- High international visibility: team members regularly publish in the top tier journals and conferences.
- Strong research collaborations with industrial partners: Google, Safran, Cisco, Orange, Huawei, Nokia.
- Strong international collaborations with academic institutions from many different countries (US, UK, Germany, China, Israel, New Zealand,Italy, Hong Kong).
- Research funding from diverse sources: European Commission, French ANR, local programs (Digicosme) and industry (CIFRE programs).

4.3.2 Weaknesses

- Members of the team do not work and publish a lot together as there is a low interaction between their mains topics of interest. The departures of some members of the team and the recent arrival of others also mean that new interactions have to be built.
- There is no academic entrepreneurship inside the team yet. We plan to collaborate more with startups to improve this.

4.3.3 Opportunities

- The team has strong expertises in Artificial Intelligence (Machine Learning, Knowledge Bases, cognitive science ...). Following the ambitious French program in AI (#FranceIA), the team will benefit from our collaborations with academic and industrial partners in artificial intelligence.
- New University. The team will be able to benefit from the synergy of the move of Télécom ParisTech to Palaiseau, and the incorporation of Télécom ParisTech to the new University created around École Polytechnique.

4.3.4 Threats

- Attractiveness of industry for researchers, with access to large quantities of data, favorable conditions for the development of their research, and attractive salaries.

4.4 Scientific project for the next five years

Our project for the next period is to consolidate the work of the team around its main expertise (data Management and Mining, Knowledge Extraction and Artificial Intelligence). The goal is to maintain and push for a quality of research at the highest level which, in return, will help us in improving our visibility and attractiveness.

As we pointed out in the SWOT, our research domain is at the heart of today's major scientific and technological concerns around AI and its applications. The team intends to participate in tackling the scientific challenges related to its areas of expertise and to contribute fully to the innovation and transfer effort expected from the scientific community around these issues.

We give below some orientations and ideas that we plan to develop in our future work.

Smarter Knowledge Bases

We have spent the last 10 years building up YAGO, one of the largest knowledge bases (KBs) on the Semantic Web. There are thousands of other KBs as well. And yet, all of these KBs contain only binary facts, i.e., relations between a subject and an object. With this, they ignore a wide area of knowledge that is not binary, but n-ary, or even causal, narrative, hypothetical, or procedural. We aim to investigate how such knowledge, too, can be represented and collected.

Knowledge Compilation for Database Query Evaluation

We are investigating how we can evaluate queries on databases using so-called knowledge compilation techniques: compute a circuit-based representation from the query and database, and use this to produce the answers. We have used this technique successfully to show new results when evaluating expressive queries on trees and tree-like structures, especially on probabilistic structures, or when computing provenance information. Our goal is to understand more generally the connections between database theory and knowledge compilation and its applications for expressive queries, in particular to show new results on the complexity of enumerating query answers.

Online Graph Learning

Many problems of Artificial Intelligence (AI) rely on data structured as a graph. For instance, most recommender systems use the underlying graph linking products to customers. Typical learning tasks consist in labeling, ranking and clustering nodes, as well as predicting new links. The focus of our research will be on *online* learning techniques, where the links of the graph arrive (and possibly leave) as a stream. Both supervised and unsupervised learning tasks will be addressed. The algorithms developed within this project will be tested on real data and made available through a Python library.

From Graphs to Hypergraphs

Graphs are everywhere in artificial intelligence and data analysis. We intend to generalize some well-known techniques for graphs to hypergraphs. These structures are already used in the topological analysis of data. We would like to investigate what would be hypergraph clustering or hyper-pagerank. We already began this line of thought by defining a new kind of random walk on hypergraphs which seems very promising.

Artificial Intelligence for Data Streams

We plan to work on intelligent agents (IA), entities that are autonomous and that observe through sensors and act using actuators on their environment, and direct their activity towards achieving goals. They should accommodate new problems solving rules incrementally, adapting online and in real time, learning quickly from large amounts of data, and having parameters to represent

short and long term memory, age, and forgetting. We will extend out machine learning techniques for data streams to build powerful new systems of intelligent agents. We plan also to work on a new open source software, `scikit-multiflow`, to perform machine learning for data streams, multi-label and multi-target classification. As more data scientists are using Python, we think that having a software system that extends `scikit-learn` will allow us to have a strong impact on the community of researchers working on machine learning for data streams.

Artificial Relevance

Analyzing and producing relevant communication and acts will appear essential for artificial systems to appear intelligent. We will build on Simplicity Theory (ST) to analyze and detect relevant events, and on the conflict-abduction-negation (CAN) method to analyze and generate relevant argumentation. ST can also be used to compute responsibility (e.g. for autonomous machines). Relevant action will be modeled within the framework of social signal ling, as a way to increase the actor's social desirability. This analysis can be applied in the context of social networks or to non-utilitarian approaches to economy (e.g. cooperation in open-source communities or conspicuous consumption).

4.5 Scientific production (selection)

Articles in Journals

[82] S. Abiteboul, Y. Amsterdamer, D. Deutch, T. Milo, and P. Senellart. Optimal probabilistic generation of xml documents. *Theory of Computing Systems*, 57(4):806–842, Nov. 2015.

[83] M. Al-Ghossein, T. Abdessalem, and A. Barré. Open data in the hotel industry: leveraging forthcoming events for hotel recommendation. *Information Technology & Tourism*, 2018.

[293] L. D. Alvarez-Corrales, A. Giovanidis, P. Martins, and L. Decreusefond. Analysis of static cellular cooperation between mutually nearest neighboring nodes. *Transactions on Mobile Computing*, 2016.

[85] T. Bonald and C. Comte. Balanced fair resource sharing in computer clusters. *Performance Evaluation*, 2017.

[86] T. Bonald, C. Comte, and F. Mathieu. Performance of balanced fairness in resource pools: A recursive approach. *Proceedings of the ACM on Measurement and Analysis of Computing Systems*, 1(2), Dec. 2017.

[87] M. H. Chehreghani and T. Abdessalem. Upper and lower bounds for the q-entropy of network models with application to network model selection. *Information Processing Letters*, 119:1–8, Mar. 2017.

[88] M. H. Chehreghani, A. Bifet, and T. Abdessalem. Discriminative distance-based network indices with application to link prediction. *Comput. J.*, 61(7):998–1014, 2018.

[89] R. Cheng, S. Maniu, and P. Senellart. Guest editorial: Special issue on databases and crowdsourcing. *Distributed and Parallel Databases*, 33(1):1–2, Mar. 2015.

[262] L. Coutin and L. Decreusefond. Stein's method for {B}rownian approximations. *Communications on Stochastic Analysis*, 7(3):349–372, Sept. 2013.

[249] L. Coutin and L. Decreusefond. Higher order expansions via stein's method. *Communications on Stochastic Analysis*, 8(2):155–168, May 2014.

[236] L. Decreusefond. The {S}tein-{D}irichlet-{M}alliavin method. *ESAIM : proceedings and surveys*, 51:49–59, Oct. 2015.

[258] L. Decreusefond, I. Flint, and K. C. Low. Perfect simulation of determinantal point processes. *Submitted*, Nov. 2013.

[296] L. Decreusefond, P. Martins, and F. Yan. Accuracy of homology based coverage hole detection for wireless sensor networks on sphere. *IEEE Transactions on Wireless Communications*, 13(7): 3583–3595, July 2014.

[288] L. Decreusefond, I. Flint, and A. Vergne. A note on the simulation of the ginibre point process. *Journal of Applied Probability*, 52(4), Oct. 2015.

[230] L. Decreusefond, M. Schülte, and C. Thäle. Functional {P}oisson approximation in {K}antorovich-{R}ubinstein distance with applications to {U}-statistics and stochastic geometry. *Annals of probability*, 44(3):2147–2197, June 2016.

[97] J.-L. Dessalles. Optimal investment in social signals. *Evolution*, 68(6):1640–1650, June 2014.

[98] L. Galárraga, C. Teflioudi, K. Hose, and F. M. Suchanek. Fast rule mining in ontological knowledge bases with amie+. *VLDB journal*, Aug. 2015.
[99] L. Galárraga, S. Razniewski, A. Amarilli, and F. M. Suchanek. Predicting completeness in knowledge bases. *WSDM*, Jan. 2017.
[100] A. Gionis, G. De Francisci Morales, and M. Sozio. System and method of matching content items and consumers. (US8660975 B2), Feb. 2014.
[101] H. M. Gomes, J. P. Barddal, F. Enembreck, and A. Bifet. A survey on ensemble learning for data stream classification. *ACM Computing Surveys (CSUR)*, 50(2):23, June 2017.
[102] H. M. Gomes, A. Bifet, J. Read, J. P. Barddal, F. Enembreck, B. Pfharinger, G. Holmes, and T. Abdessalem. Adaptive random forests for evolving data stream classification. *Machine Learning*, June 2017.
[103] E. Kaufmann, T. Bonald, and M. Lelarge. A spectral algorithm with additive clustering for the recovery of overlapping communities in networks. *Journal of Theoretical Computer Science (TCS)*, 2017.
[104] F. Makari Manshadi, B. Awerbuch, R. Gemulla, R. Khandekar, J. Mestre, and M. Sozio. A distributed algorithm for large-scale generalized matching. *PVLDB (Proceedings of the VLDB Endowment)*, Aug. 2013.
[105] D. Marrón, J. Read, A. Bifet, and N. Navarro. Data stream classification using random feature functions and novel method combinations. *Journal of Systems and Software*, 127:195–204, June 2017.
[106] A. Saillenfest and J.-L. Dessalles. Can believable characters act unexpectedly? *Literary & Linguistic Computing*, 29(4):606–620, Oct. 2014.
[107] P. Senellart. Provenance and probabilities in relational databases: From theory to practice. *SIGMOD Record*, 46(4), Dec. 2018.
[294] A. Vergne, L. Decreusefond, and P. Martins. Simplicial homology for future cellular networks. *IEEE Transactions on Mobile Computing*, 14(8):1712–1725, Aug. 2015.
[295] F. Yan, A. Vergne, P. Martins, and L. Decreusefond. Homology-based distributed coverage hole detection in wireless sensor networks. *IEEE/ACM Transactions on Networking*, 23(6):1705–1718, June 2015.

Books

[110] A. Bifet, R. Gavaldà, G. Holmes, and B. Pfahringer. *Machine Learning for Data Streams with Practical Examples in MOA*.
[111] J.-L. Dessalles, C. Gaucherel, and P.-H. Gouyon. *Le fil de la vie - La face immatérielle du vivant.* Odile Jacob, Paris, France, 2016.
[112] R. Missaoui, T. Abdessalem, and M. Latapy. *Trends in Social Network Analysis - Information Propagation, User Behavior Modeling, Forecasting, and Vulnerability Assessment.* Springer International Publishing, New York, USA, 2017.

Book Chapters

[113] L. Decreusefond and A. Vasseur. Asymptotics of superposition of point processes. In *Geometry of Science Information*, pages 187–194. Springer, Palaiseau, 2015.
[114] L. Decreusefond, I. Flint, N. Privault, and G. L. Torrisi. Determinantal point processes. In *Stochastic analysis for Poisson point processes Malliavin calculus, Wiener-Itô chaos expansions and stochastic geometry*. Springer, 2016.
[115] J.-L. Dessalles. *Principles and Practice of Multi-Agent Systems, LNAI 9935*, chapter A Cognitive Approach to Relevant Argument Generation, pages 3–15. Springer, 2016.
[116] M. Gueye, T. Abdessalem, and H. Naacke. Dynamic recommender system: Using cluster-based biases to improve the accuracy of the predictions. In *Advances in Knowledge Discovery and Management Volume 5*, pages 79–104. Springer, 2015.

Articles in Conference Proceedings

[117] M. Al-Ghossein, P.-A. Murena, T. Abdessalem, A. Barré, and A. Cornuéjols. Adaptive collaborative topic modeling for online recommendation. In *12th ACM Conference on Recommender Systems (RecSys 2018)*, Vancouver, Canada, Oct. 2018.

[118] A. Amarilli and M. Benedikt. Combining existential rules and description logics. In *IJCAI 2015*, pages 2691–2697, Buenos Aires, Argentine, July 2015.

[119] A. Amarilli and M. Benedikt. Finite open-world query answering with number restrictions. In *LICS 2015*, pages 305–316, Kyoto, Japon, July 2015.

[120] A. Amarilli and M. Benedikt. When can we answer queries using result-bounded data interfaces? In *PODS*, June 2018.

[121] A. Amarilli, Y. Amsterdamer, and T. Milo. On the complexity of mining itemsets from the crowd using taxonomies. In *ICDT (International Conference on Database Theory)*, pages 15–25, Athens, Greece, Mar. 2014.

[122] A. Amarilli, P. Bourhis, and P. Senellart. Provenance circuits for trees and treelike instances. In *ICALP 2015*, pages 56–68, Kyoto, Japan, June 2015.

[123] A. Amarilli, M. Benedikt, P. Bourhis, and M. Vanden Boom. Query answering with transitive and linear-ordered data. In *IJCAI*, June 2016.

[124] A. Amarilli, P. Bourhis, and P. Senellart. Tractable lineages on treelike instances: Limits and extensions. In *PODS (Principles of Database Systems)*, pages 355–370, San Francisco, USA, June 2016.

[125] A. Amarilli, Y. Amsterdamer, T. Milo, and P. Senellart. Top-k queries on unknown values under order constraints. In *ICDT 2017*, Venice, Italy, Mar. 2017.

[126] A. Amarilli, M. L. Ba, D. Deutch, and P. Senellart. Possible and certain answers for queries over order-incomplete data. In *TIME 2017*, Mons, Belgique, Oct. 2017.

[127] A. Amarilli, P. Bourhis, L. Jachiet, and S. Mengel. A circuit-based approach to efficient enumeration. In *ICALP 2017*, Varsovie, Pologne, July 2017.

[128] A. Amarilli, P. Bourhis, M. Monet, and P. Senellart. Combined tractability of query evaluation via tree automata and cycluits. In *ICDT 2017*, Venice, Italy, Mar. 2017.

[129] A. Amarilli, M. Monet, and P. Senellart. Conjunctive queries on probabilistic graphs: Combined complexity. In *PODS 2017*, Chicago, États-Unis, May 2017.

[130] A. Amarilli, P. Bourhis, and S. Mengel. Enumeration on trees under relabelings. In *ICDT*, Mar. 2018.

[131] A. Amarilli, M. Monet, and P. Senellart. Connecting width and structure in knowledge compilation. In *ICDT*, Mar. 2018.

[132] Y. Amsterdamer, Y. Grossman, T. Milo, and P. Senellart. Crowd mining. In *SIGMOD (Special Interest Group on Management of Data)*, pages 241–252, New York, USA, June 2013.

[133] Y. Amsterdamer, Y. Grossman, T. Milo, and P. Senellart. Crowd miner: Mining association rules from the crowd. In *VLDB (Very Large Data Bases)*, pages 241–252, Riva del Garda, Italy, Aug. 2013.

[134] M. L. Ba, T. Abdessalem, and P. Senellart. Uncertain version control in open collaborative editing of tree-structured documents. In *DocEng (Document Engineering)*, pages 27–36, Florence, Italy, Sept. 2013.

[135] O. D. Balalau, F. Bonchi, T. H. Chan, F. Gullo, and M. Sozio. Finding subgraphs with maximum total density and limited overlap. In *Proceedings of the Eighth ACM International Conference on Web Search and Data Mining, WSDM*, pages 379–388, 2015.

[936] J. P. Barddal, H. M. Gomes, F. Enembreck, B. Pfahringer, and A. Bifet. On dynamic feature weighting for feature drifting data streams. In *Joint European Conference on Machine Learning and Knowledge Discovery in Databases*, pages 129–144, June 2016.

[137] A. Bifet, S. Maniu, J. Qian, G. Tian, C. He, and W. Fan. Streamdm: Advanced data mining in spark streaming. In *IEEE International Conference on Data Mining Workshop, ICDMW 2015, Atlantic City, NJ, USA, November 14-17, 2015*, pages 1608–1611, Feb. 2015.

[138] A. Bifet, J. Zhang, W. Fan, C. He, J. Zhang, J. Qian, G. Holmes, and B. Pfahringer. Extremely fast decision tree mining for evolving data streams. In *Proceedings of the 23rd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, Halifax, NS, Canada, August 13 - 17, 2017*, pages 1733–1742, 2017.

[139] T. Bonald and R. Combes. A minimax optimal algorithm for crowdsourcing. In *NIPS*, Los Angeles, United states, 2017.

[140] T. H. Chan, A. Guerqin, and M. Sozio. Fully dynamic k-center clustering. In *Proceedings of the 2018 World Wide Web Conference on World Wide Web, WWW 2018, Lyon, France, April 23-27, 2018*, pages 579–587, 2018.

[141] M. Danisch, T. H. Chan, and M. Sozio. Large scale density-friendly graph decomposition via convex programming. In *Proceedings of the 26th International Conference on World Wide Web, WWW*,

pages 233–242, 2017.

[142] M. Danisch, O. D. Balalau, and M. Sozio. Listing k-cliques in sparse real-world graphs. In *Proceedings of the 2018 World Wide Web Conference on World Wide Web, WWW 2018, Lyon, France, April 23-27, 2018*, pages 589–598, 2018.

[143] J.-L. Dessalles. Algorithmic probability and friends. In *Solomonoff 85th*, volume LNAI, pages 119–130, Berlin, Germany, Dec. 2013. Springer.

[144] J.-L. Dessalles. Conversational topic connectedness predicted by simplicity theory. In *Proceedings of the 39th Annual Conference of the Cognitive Science Society*, pages 1914–1919, Austin, TX, July 2017. Cognitive Science Society.

[145] J. Dockès, D. Wassermann, R. Poldrack, F. M. Suchanek, B. Thirion, and G. Varoquaux. Text to brain: predicting the spatial distribution of neuroimaging observations from text reports . In *MICCAI*, 2018.

[146] A. Epasto, S. Lattanzi, and M. Sozio. Efficient densest subgraph computation in evolving graphs. In *Proceedings of the 24th International Conference on World Wide Web, WWW 2015*, pages 300–310, 2015.

[147] K. Garimella, G. D. F. Morales, A. Gionis, and M. Sozio. Scalable facility location for massive graphs on pregel-like systems. In *Proceedings of the 24th ACM International Conference on Information and Knowledge Management, CIKM, pages = 273–282, year = 2015,*.

[148] J.-B. Griesner, T. Abdessalem, and H. Naacke. POI Recommendation: Towards Fused Matrix Factorization with Geographical and Temporal Influences. In *9th ACM Conference on Recommender Systems (RecSys 2015)*, pages 301–304, Vienna, Austria, Sept. 2015.

[149] M. Gueye, T. Abdessalem, and H. Naacke. A parameter-free algorithm for an optimized tag recommendation list size. In *RecSys '14 Proceedings of the 8th ACM Conference on Recommender systems*, pages 233–240, Oct. 2014.

[150] A. Hollocou, T. Bonald, and M. Lelarge. Multiple local community detection. In *Performance Evaluation*, New York City, United states, 2017.

[151] A. Hollocou, J. Maudet, T. Bonald, and M. Lelarge. A streaming algorithm for graph clustering. In *NIPS 2017 - Wokshop on Advances in Modeling and Learning Interactions from Complex Data*, pages 1–12, Long Beach, United states, Dec. 2017.

[935] N. Kourtellis, G. D. F. Morales, A. Bifet, and A. Murdopo. Vht: Vertical hoeffding tree. In *Big Data (Big Data), 2016 IEEE International Conference on*, pages 915–922, June 2016.

[153] J. Lajus and F. M. Suchanek. Are all people married? determining obligatory attributes in knowledge bases. In *WWW*, Lyon, France, Apr. 2018.

[375] N.-K. Le, P. Martins, L. Decreusefond, and A. Vergne. Simplicial homology based energy saving algorithms for wireless networks. In *IEEE ICC*, London, United kingdom, 2015.

[374] N.-K. Le, A. Vergne, P. Martins, and L. Decreusefond. Distributed simplicial homology based load balancing algorithm for cellular networks. In *IEEE VTC 2017 Fall*, Toronto, Canada, Sept. 2017.

[373] N.-K. Le, A. Vergne, P. Martins, and L. Decreusefond. Optimize wireless networks for energy saving by distributed computation of Čech complex. In *IEEE WiMob 2017*, Rome, Italy, Oct. 2017.

[157] S. Lei, S. Maniu, L. Mo, R. Cheng, and P. Senellart. Online influence maximization. In *KDD*, pages 645–654, Sydney, Australia, Aug. 2015.

[158] F. Mahdisoltani, J. Biega, and F. M. Suchanek. Yago3: A knowledge base from multilingual wikipedias. In *CIDR*, Jan. 2015.

[937] D. Marrón, J. Read, A. Bifet, T. Abdessalem, E. Ayguadé, and J. Herrero. Echo state hoeffding tree learning. In *Asian Conference on Machine Learning*, pages 382–397, June 2016.

[160] C. Meng, R. Cheng, S. Maniu, P. Senellart, and W. Zhang. Discovering meta-paths in large heterogeneous information networks. In *WWW*, Florence, Italy, May 2015.

[161] P.-A. Murena, A. Cornuéjols, and J.-L. Dessalles. Incremental learning with the minimum description length principle. In *International Joint Conference on Neural Networks (IJCNN 2017)*, Anchorage, Alaska USA, July 2017.

[162] T. Rebele, T. P. Tanon, and F. M. Suchanek. Bash Datalog: Answering Datalog Queries with Unix Shell Commands. In *ISWC*, 2018.

[163] T. Rebele, K. Tzompanaki, and F. M. Suchanek. Adding Missing Words to Regular Expressions. In *PAKDD*, 2018.

[164] A. Saillenfest and J.-L. Dessalles. Some probability judgments may rely on complexity assessments. In *37th Annual Conference of the Cognitive Science Society*, Pasadena, CA, USA, July 2015. Cognitive Science Society.

[165] A. Souihli and P. Senellart. Optimizing approximations of dnf query lineage in probabilistic XML.

In *ICDE (International Conference on Data Engineering)*, pages 721–732, Brisbane, Australie, Apr. 2013.

[166] F. M. Suchanek, C. Menard, M. Bienvenu, and C. Chapellier. What if machines could be creative? *ISWC (demo)*, Jan. 2017.

[167] D. Symeonidou, L. Galárraga, N. Pernelle, F. Saïs, and F. M. Suchanek. Vickey: Mining conditional keys on knowledge bases. In *ISWC*, Dec. 2017.

[168] N. Tandon, G. de Melo, F. M. Suchanek, and G. Weikum. Webchild: Harvesting and organizing commonsense knowledge from the web. In *International Conference on Web Search and Data Mining (WSDM)*, New York, USA, Nov. 2014.

[377] A. Vergne, L. Decreusefond, and P. Martins. Reduction algorithm for simplicial complexes. In *IEEE INFOCOM*, pages 475–479, Turin, Italy, Apr. 2013.

[376] A. Vergne, I. Flint, L. Decreusefond, and P. Martins. Disaster recovery in wireless networks: A homology based algorithm. In *ICT 2014, best paper award*, Lisbon, Portugal, May 2014.

Invited Talks

[171] A. Bifet. Mining Big Data Streams with Apache SAMOA. In *Proceedings of the 6th International Workshop on Mining Ubiquitous and Social Environments (MUSE 2015) co-located with the 26th European Conference on Machine Learning / 19th European Conference on Principles and Practice of Knowledge Discovery in Databas*, page 55, Feb. 2015.

[172] A. Bifet. Massive Online Analytics for the Internet of Things (IoT). In *The 8th Asian Conference on Machine Learning*, Hamilton, New Zealand, Nov. 2016.

[173] A. Bifet. Massive Online Analytics for the Internet of Things (IoT). In *The 6th Brazilian Conference on Intelligent Systems (BRACIS 2017)*, Uberlandia, Brazil, Oct. 2017.

[174] A. Bifet. Internet of Things (IoT) Analytics. In *The 16th International Conference on Artificial Intelligence and Soft Computing ICAISC 2017*, Zakopane, Poland, May 2017.

Chapter 5

DIVA

Design, Interaction, Visualization & Applications

5.1 Presentation of the team

Team leader: Eric Lecolinet (09/17-)

Faculty: Gilles Bailly (JRS, 10/13-09/16), James Eagan (AP), Yves Guiard (SRS, -01/14), Eric Lecolinet (AP), Remi Sharrock (AP, 09/17-)

Associated Members: Annie Gentès (AP, I3 Lab., 07/17-), Samuel Huron (AP, I3 Lab., 07/17-)

Invited Professors: Yves Guiard (Emeritus, 01/14-)

Sabbatical Professors: Fumio Mizuno (08/15-03/16, Tohoku Institute of Technology)

Permanent Research Engineers: Gérard Mouret (RE)

PostDocs, non-permanent Research Engineers: Nadia Boukhelifa (10/15-08/16), Aurélie Cohé (11/13-06/15), Bastien Liutkus (01/14-09/15), Minzhi Luo (10/12-10/13), Simon Perrault (05/13-10/13), Marc Teyssier (02/16-12/16), Julie Wagner (10/12-04/13)

PhD Students: Emeline Brulé* (10/14-, A. Gentès & G. Bailly), Jonathan Diehl (07/11-11/14, J. Eagan & J. Borchers (RWTH Aachen)), Bruno Fruchard (10/15-, E. Lecolinet & O. Chapuis (LRI)), Hind Gacem (10/12-04/16, E. Lecolinet & J. Eagan), Julien Gori** (15-, O. Rioul & Y. Guiard), Emmanouil Giannisakis (12/15-, G. Bailly), Thibaut Jacob (11/13-09/17, E. Lecolinet & G. Bailly), Can Liu (10/12-12/15, E. Lecolinet, O. Chapuis (LRI), M. Beaudouin-Lafon (LRI)), Jiali Liu (11/17-, J. Eagan), Wanyu Liu** (11/15-, O. Rioul, M. Beaudouin-Lafon (LRI) & Y. Guiard), Rafael Moralès (12/15-10/17, G. Bailly & C. Appert (LRI), Simon Perrault (09/09-04/13, Y. Guiard & E. Lecolinet), Quentin Roy (05/12-12/15, E. Lecolinet & Y. Guiard), Marc Teyssier (01/17-, E. Lecolinet, C. Pelachaud, G. Bailly), Dong-Bach Vo (11/09-09/13, E. Lecolinet & Y. Guiard)

(*) Co-supervised student of the I3 Lab., (**) Co-supervised students of the ComNum team.

Platforms: The team exploits the following platforms:

- Digiscope, an EquipeX project, is a network of high-performance platforms for interactive visualization of large datasets and complex computation that is distributed throughout the University of Paris-Saclay. The DIVA team is in charge of the PIXLS and IRIS platforms. http://www.digiscope.fr/
- The Télécom Fab Lab is co-managed by the DIVA and IMAGE teams. https://fablabtp.wp.imt.fr/
- Télécom "Studio Design" is co-coordinated by S. Huron, who is an associate member of the team. http://ses.telecom-paristech.fr/studio-design/

- Webstrates (webstrates.net) is a web-based platform based around the fundamental concepts of sharing, malleability, and collaboration. It is a testbed environment to re-invision the way that people build and interact with software. Initial developed in collaboration between Aarhus University, Télécom ParisTech, and LRI, it has spawned research projects at UC San Diego, Univ. of Maryland, Konstanz Univ., and others.
- Codecast, Taskgrader and Weblinux: three platforms for online education. http://codecast.info

Scientific Production Overview: Table 5.1 represents the overall scientific production between 2013 and 2018. The detailed bibliography is listed in the dedicated accompanying document.

Journals	Articles in Proceedings	Patents	Keynotes and Tutorials	Other Invited Talks	Habilitation thesis	Completed PhD
5	52 *	1	3	10	1 **	8

Table 5.1: Overall Scientific Production

(*) Including 26 articles at ACM CHI and 2 at ACM UIST, two high-quality conferences with the best scientific impacts in the domain (CHI is ranked A in the CORE classification, respective Google Scholar h5-medians are 106 and 65). (**) Defended by G. Bailly after he left LTCI.*

5.2 Research activities

5.2.1 Overview

The DIVA team is devoted to fundamental and applied research on human-computer interaction (HCI), design and data visualization. It focuses on novel interaction techniques, technology-mediated environments and on the challenge of representing more and more data, not only on standard computers but also on small, very large, and non-traditional devices. It also aims to establish models of behavior in interactive situations and to exploit these models for the design of interactive objects.

The DIVA team was created in September 2017 following the reorganization of LTCI. This description includes the research activities of the DIVA members in their previous team. The DIVA team also includes two associate members of the I3 Laboratory, S. Huron and A. Gentes, whose expertise lies on Design, a thematic that is very complementary to DIVA's activities.

Scientific animation is performed in several ways. The internal team seminar occurs approximatively every two weeks. A larger audience seminar, named GRID, was created in 2017. This seminar is conducted in collaboration with colleagues of the I3 UMR working in related domains (design, psychology, sociology, ergonomics, etc.). Finally, the team has been strongly involved in the seminar of the ACM SIGCHI Paris local chapter (J. Eagan is currently chair and both he and E. Lecolinet have been chair and vice chair). This seminar, which gathers HCI researchers of the larger Paris area, generally takes places in Paris-Saclay. http://paris.sigchi.acm.org.

The main contributions of the team during the period take place in the below-described domains.

5.2.2 Novel interactions: techniques, physical artifacts and software paradigms

This research axis focuses on developing novel ways of interacting with user interfaces. It addresses complementary aspects of this process by leveraging new principles and methods for interacting with devices while considering their physical characteristics and studying how they are being used and deployed. It also includes the development of novel interaction and design paradigms, which

act as a ground for implementing new interaction techniques.

New forms of interaction. This field of research aims at developing novel techniques allowing for more natural and effective ways of interacting. In recent years, it has led us to explore various modalities of gestural interaction, with an emphasis on leveraging overlooked input dimensions, in order to increase the interaction bandwidth between users and their devices [190, 194, 181]. During the period, we have more specifically focused on methods for interacting with small and large devices and on alternate input/output modalities. We have also contributed to the domain by proposing design spaces in several papers and by publishing a comprehensive review of menu techniques [175].

This branch of research lead to the conception, implementation and evaluation of various innovative techniques such as for instance WatchIt [192], for interacting eyes-free with smartwatches, Multi-finger Chords [190] for selecting commands with multi-touch gestures, or MarkPad [181] (a research project held in collaboration with LRI), which allows using a very large set of gestural commands on a small touch-sensitive surface.

We have also leveraged novel input modalities, such as head movements, to facilitate 3D interaction, combined gestures with other modalities [193] to allow performing quick "micro-interactions", and developed methods for interacting with an augmented reality system dedicated to training. In a collaboration with LRI in the context of the DIGISCOPE Equipex project, we have also focused on the interaction with large wall screen displays. This study, which was focusing on collaborative interaction between multiple users using has also demonstrated the benefits of using such devices compared to the desktop even when only one user is interacting with them [189].

Physical Artifacts and Tangible Interaction. This theme completes the previous one by considering how the physical characteristics of the objects manipulated by the user can make the human-system interaction more fluid and closer to the usual ways of interacting. Material design has an important place in these works that require both the creation of objects (using the Telecom FabLab, which is co-managed by the team) and the realization of embedded electronics.

Design is another central aspect of this theme, not only for making the form of the objects adequate with their function, but also for studying them in-situ, in the environment where these technical devices are being deployed (codesign). Recent works in this field include the development of on-body touch Sensors [187], shape-changing interfaces which automatically adapt to the context; of "SmartTokens" and "TouchTokens" that combine tangible and gestural interaction to enrich the interaction with tablets; of various communicating objects (pens, watches, interactive jewelery), which tangibility helps user interaction in everyday tasks; and also of design artifacts specifically designed for visually impaired people [184]. Most of these studies have been conducted in collaboration with various teams (I3, LRI, CRISTAL, Max Planck Saarbrücken, etc.)

Novel interaction and design paradigms. The appearance of new types of devices (mobile devices, communicating objects, wall screen displays, etc.) requires a thorough review of design techniques and software paradigms, which were essentially designed at a time when a user was interacting with a single computer, a keyboard and possibly a mouse. With this in mind, we are exploring how to give users the opportunity 1) To work collaboratively with several devices located in various locations. The Digiscope project focuses on the hardware side of this challenge by creating the infrastructure for multi-device, multi-surface interactions and collaborations across physical locations; 2) To make interactive software "malleable". The Webstrates [185] and Scotty projects focus on this aspect by making software more soft so as to allow the user to personalize their interactions and their functionalities (Scotty project, Grab'n Drop [179], etc.); 3) To give programmers the means to better express these interactions when traditional paradigms are no longer sufficient (Webstrates and Codestrates [178], two projects held in collaboration with LRI and Aarhus University).

5.2.3 "Homo numericus": visualization, "sense-making" and behavior models

Ultimately, the various forms of exploring new ways for users to interact with the machine and to express themselves align around "homo numericus", where humans interact with data, content, and other humans as mediated through the human-computer interface. This branch of our work focuses on understanding the relationship between human and tool and investigates large-scale, technology-mediated environments such as learning environments with many learners and few experts to guide them.

Data Visualization and sense-making. During the last 20 years, the production of digital data has massively increased which makes it crucial for the industry as for all the actors of the society, to be able to manipulate, analyze, and understand these masses of data. Visualization of interactive data makes it possible to perform a set of tasks of analysis, comprehension and communication. This theme aims to design and understand new graphical representation systems (e.g., SchemeLens [176]) or physical representation of data (Pedagogy & Physicalization, Constructive Visualization) in contexts of production of meaning (Data workers & uncertainty [180]). Another approach is to design specific visualization tools for sense-making in learning environments (Codecast project). In this spirit, we are jointly exploiting computer, art and design knowledge to explore new design spaces.

Behavior models. The goal here is to understand and model user behavior in order to predict the performances and to provide theoretically sound guidelines for the optimization of interfaces. Our work focuses in particular on 1) Predictive models of performance for command selection and for optimizing menu systems [191]; 2) Optimization of navigation in multiscale interfaces, using Bayesian modeling of information gain (the BIGNav and the BIGFile projects); 3) The basic study of pointing (Fitts' law) - an overwhelming concern in human-machine interfaces - by reconsidering this research topic from the angle of information theory [421, 430]. The two later research themes are carried out in collaboration with LRI and the ComNum team, and in particular O. Rioul who cosupervises, jointly with Y. Guiard, two PhD students, Abby Waniu Liu and Julien Gori). A detailed description is given in the section "Tools for statistics and information theory" (subsection "Human-Computer Interaction") of the ComNum team.

Novice / Expert Transition. This axis complements the previous themes by relying both on the study of user's behaviors and cognitive abilities and on the implementation of visualization and interaction techniques answering these needs. It aims to facilitate the transition from a novice to an expert use of human-machine interfaces by promoting the discovery, the learning and the memorization of commands. In this context, we are particularly interested in the resources offered by the exploitation of spatial memory and of semantic aids [188, 181]. Another way was to promote implicit learning through visual adaptive representations (IconHK project). Finally, the novice / expert transition goal is the enhancement of human learning and its analysis using a variety of proxy measures for learning, including measures of participation, persistence, completion, satisfaction, and activity.

5.2.4 Scientific Highlights

- Organization of Workshops and Conferences:
  - Workshop on online education at the ACM SIGCSE 2018 conference.
  - Program committee of the ACM CHI 2013 conference (+200 people) and strong contribution to the organization of the CHI'13 conference (3400 attendees)
  - International Instrumental Interaction workshop (2013)
  - Journée Visu workshop (2014)

- Program Chair of Workshops or Conferences:
  - Program co-chair of the IHM conference (2015), of the EIT ICT Labs Smart Spaces Workshop (2013) and of the IHM/IA workshop (2015, 2017)
  - Associate chair at CHI 2017 and 2018, Mobile HCI 2016, ITS 2014, EICS 2018, IHM 2014, 2015, 2016 & 2017 and publicity chair at IHM 2013
- Associate editors of journals:
  - Y. Guiard is associate editor of ACM Transactions on Computer-Human Interaction (TOCHI) since 2009
- Awards:
  - Y. Guiard was elected member to the ACM SIGCHI Academy in 2016
  - Best paper award (top 1%) at ACM CHI (ACM Conference on Human Factors in Computing Systems) in 2015 and 2104 and at ACM UIST (ACM User Interface Software and Technology Symposium) in 2015
  - Honorable mention award (top 5%) at ACM CHI in 2017, 2016, 2015 and 2014 (twice) and at MobileHCI in 2014
  - Honorable Mention Poster Award at IEEE VAST in 2016
  - Best MOOC of the year in 2016 (ABC du langage C) on FUN-MOOC
  - Outstanding Review Award at ACM UIST in 2014 (J. Eagan)
- Evaluation and Steering committees:
  - E. Lecolinet was an elected member of the 7th section of "Comité National de la Recherche Scientifique" (CoNRS) from 2012 to 2016
  - E. Lecolinet is president of Association Francophone d'Interaction Homme-Machine (AFIHM) (elected in Sept. 2017) and was a permanent member of the steering committee of the IHM conference (CPPMS) (before Sept. 2017)
  - Y. Guiard is a member of the Scientific and Strategic Advisory Board of the Human-IST Institute (Fribourg University) and of the Advisory council of the International Association for the Study of Attention and Performance
  - E. Lecolinet and J. Eagan have both been chair and vice chair of the ACM SIGCHI Paris Chapter
  - J. Eagan participated in the creation of the Comité d'Éthique pour la Recherche, Paris-Saclay (CER-PS) and is a member of the CER-PS ethics review board (2014-, official launch Sept. 2018).
  - Several members of the team have been involved in the AFIHM board, committees of the DigiCosme Labex and the Digiscope Equipex, and the board of the LTCI lab
- Interaction with Economic and Social Spheres:
  - Demonstrations in public events (Futur en Seine 2013, open seminar EDF Connexion 2015)
  - Public inaugurations of the DIGISCOPE and FabLab platforms
- Significant Contracts:
  - EquipeX *DIGISCOPE* with LRI and 8 other partners throughout Univ. Paris-Saclay
  - BGLE2 *CONNEXION* (with CEA, INRIA, CNRS/CRAN, ENS Cachan, LIG)
  - ITEA-3 *TWIRL* (with Cassidian, Pertimm, Lille 1, TSP and 8 other partners)
  - ANR projects: *EDISON3D* (with Sonic Emotion Lab, Radio France, Ecole Polytechnique, UBO); *Accessimap*; *SocialTouch* (leader, with I3, ISIR, HEUDIASYC)

  - Other projects: FUI *PresAge*; DIGITEO *DigiZoom* and *MemSpace* ; *GE Healthcare*; *Fondation Telecom* for On line Education

- Invited talks:

  - Plenary Keynote at the International Joint Conference on Computer Vision, Visualization and Computer Graphics Theory and Applications (2016)
  - Plenary Keynote at Forum sur l'Interaction Tactile et Gestuelle (FITG) (2014)
  - Invited talk at the Wearable Technologies Conference (150 attendees) (2013).
  - Multiple invited talks on on-line education and learning at scale environments at Stanford University, Boston University, MIT, Harvard University, Dartmouth College, Berkley University, University of Adelaide (2017, 2018).
  - Invited talks on HCI in various universities (Saarland Univ., Aarhus Univ., RWTH Aachen, UCLIC at Univ. College of London, Univ. of Toulouse, Univ. of Birmingham, NUS Singapore), at Google (Mountain View, CA) and at the French symposium for Junior Researcher in HCI.

- Sabbatical Stays of faculty members:

  - Rémi Sharrock, Dartmouth College, NH, USA, in 2017 (3 weeks) and 2018 (2 months)
  - James Eagan, four one-week stays at Aarhus University over 2013–2017.

- Collaborations:

  The DIVA team collaborates with many other groups: 1) at Télécom ParisTech, 2) at Paris-Saclay, 3) with other national or international research teams:

  - Télécom ParisTech: We have strong collaborations with the ComNum team (as said above, Y. Guiard and O. Rioul supervises two PhD thesis) and with colleagues of the I3 UMR working in related domains (A Gentès and G. Bailly also supervise a PhD candidate). A. Gentès and S. Huron are associate members of DIVA. We also collaborate with F. Detienne, M. Baker, S. Safin, D. Diminescu in various projects (e.g. ANR SocialTouch) and we have a common seminar (GRID seminar).
  - Paris-Saclay: DIVA has a long time collaboration with LRI, which has been particularly significant during the period: five Ph-D theses have been cosupervised with collegues of the EX-SITU or ILDA groups (M. Beaudouin-Lafon, O. Chapuis, C. Appert).
  - National and international teams: various collaboration have taken place with ISIR (Paris), CRISTAL (Lille), IRIT (Toulouse), RWTH (Aachen), Aarhus University, Max Planck (Saarbrücken), UCL and University of Birmigham (UK), NUS (Singapore), Univ. of Toronto (Canada), Dartmouth College, Harvard and Stanford (USA).

- Contribution to Higher Education for Research:

  - Teaching and administrative responsibilities in the following Masters: *HCI - Interaction* (Université Paris-Saclay); *ANDROIDE* (P. & M. Curie/Sorbonne Université)
  - Teaching and Co-responsibility of the *IGR* program (Filière 3D et Systèmes Interactifs), of the *SLR* program (Filière Systèmes Logiciels Répartis) and of the *Big Data* "Mastère Spécialisé" at Télécom ParisTech
  - Creation of 10 Massive Open Online Courses both on Fun-MOOC (3 in French) and edX (7 in English)
  - Scientific co-responsibility (E. lecolinet) and technical management (G. Mouret) of the Télécom Fab Lab (used by students and PhD students)

5.3 SWOT analysis

5.3.1 Strength

- The team members have recognized expertise in the domain and many collaborations inside or outside Télécom ParisTech
- The team benefits from top-tier hardware infrastructures: Fab Lab, Studio Design, Digiscope collaborative screen walls, etc.

5.3.2 Weakness

- The main weakness of the group is its limited staff combined with a significant involvement in education (modules with a large number of students, significant participation in the administration of education)

5.3.3 Opportunities

- The "NewUni" project offers collaboration opprtunities with ENSTA colleagues working in robotics (and, more particularly, in social robotics)
- The HCI research community is opening a new specific track on education which will fit the learning at scale and education technologies new field of research of the team.

5.3.4 Threats

- Given its relatively small size, the team was particularly weakened by the CNRS de-association: G. Bailly had to leave the team and another researcher could not join the team. This affected the development of two promising themes we wanted to investigate in more depth: tangible interaction and mixed reality.
- Leaving the Paris-Saclay University may be a risk given our high level of involvement in this environment, both for education and research (cf. the numerous collaborations with LRI)

5.4 Scientific project for the next five years

The DIVA Group intends to continue its work in the above-mentioned domains while strengthening its collaborations with its academic partners (LRI, INRIA Saclay, IRIT, University of Aarhus, ISIR, Calgary, etc.), the industrial actors involved in the projects in which the group participates (Air Liquide, Aktronika, etc.) and other research teams at Télécom ParisTech, both in the LTCI and the I3 Labs. We also wish to develop the following topics in the years to come:

Novel techniques and devices for social interaction. This new topic, investigated in collaboration with ISIR, UTC and I3, examines how the sense of touch can be integrated into interactive systems to take advantage of emotional channels. It focuses on a modality much less studied than vision or verbal communication and addresses innovative topics such as as the role of social touch and the techniques to simulate it in a credible way. Two contexts will be studied: mediated interpersonal communication and communication with a conversational agent in a virtual reality environment.

Reinventing the programming paradigms of interactive systems. The aim of this project, carried out in collaboration with LRI and the University of Aarhus, is to explore new programming paradigms to make interactive systems more malleable, flexible and reusable. Collaborative interactions in a situation of mobility in virtual or augmented reality environments require, for example, other abstractions and paradigms of expression than current models. In this context, we pursue the creation of environments that enable new ways to design interactive systems, such as by creating software that breaks away from the traditional models of application

and document to provide support for robust, asymmetric collaboration and richer malleability of interactions.

Analysing learning at scale environments metrics and computer science education outcomes. The goal is to capitalize on the success of one of the team members in designing interactive software for teaching and its involvement in major conferences such as *ACM SIGCSE* (Computer Science Education) and *ACM Learning at Scale* (committee member of both conferences; workshop organizer at SIGCSE). He will benefit from the group's expertise in various fields (interaction paradigms, behavioral models, novice/expert transition) to develop new approaches in the fields of self-explaining systems and outcome analysis of large-scale learning environments.

Such environments are extremely diverse and there are countless communities of (formal or informal) learners with different characteristics. These systems, which common purpose is to increase human potential, either depend upon large numbers of learners or are enriched through the use of data collected from previous experience. Building on our previous expertise on large scale systems our goal is to apply this expertise to improve large-scale learning environments. We plant to study the outcome of standard proxy measures for learning (measures of participation, persistence, completion, satisfaction and activity) and we aim to produce data allowing to measure student learning and the effect of instructional techniques, technological infrastructures, learning habits, and experimental interventions that improve learning.

Interestingly, the HCI research community recently announced that a specific track on education and learning technologies would be opened in 2019 in order to increase exchanges between the SIGCSE and SIGHCI communities. This constitutes a perfect opportunity for the DIVA team.

Data visualization for novices & experts. Our work on data visualisation pushes on the two extremes of users: novices and expers. As an extension of our work on data visualization, we want to explore its application for use by novice users as well as for citizen or personal applications. Most of the recent work in visualization has focused on manipulating, understanding and communicating data for industrial or scientific experts. The democratization of personal computing opens this field to new uses and applications.

On the expert end of the spectrum, today's visualisation tools are built around the assumption that users are either programming illiterate or that they will construct their visualisations entirely in code. We push on this assumption to explore the hybrid space in the middle, where data analysts construct rich visualizations that blend the scaffolding of general-purpose interfaces with the rich flexibility of code.

Interaction techniques evaluation based on information theory. Input techniques serving, quite literally, to allow users to send information to the computer, the information theoretic approach seems tailor-made for their quantitative evaluation. This project capitalizes on collaboration between Y. Guiard and O. Rioul, an expert in information theory who is a member of the ComNum team. Shannon's framework makes it straightforward to measure the performance of any technique as an effective information transmission rate, in bits/s. Apart from pointing, however, evaluators of input techniques have generally ignored Shannon, contenting themselves with less rigorous methods of speed and accuracy measurements borrowed from psychology. We plead for a serious consideration in HCI of Shannon's information theory as a tool for the evaluation of all sorts of input techniques. We discuss how Shannon's concepts of entropy and mutual information should be applied to the input techniques evaluation problem and we work at developing two concrete methodologies, one focused on the discrete timing and the other on the continuous time course of information gain by the computer.

Mixed reality. The team would also like to develop its expertise in the domain of Augmented/Virtual/Mixed Reality. This domain which will certainly play a major role in the next coming years, both because affordable and efficient technologies ar now available and because of the strong involvement of major players in the computing industry. Interacting with these devices is currently one of the main problems to be solved to make these technologies truly usable and accessible, especially for industrial applications. Because of its long expertise in interaction techniques, the team is well placed for investigating this field. Moreover, mixed reality also opens up new perspectives for data visualization and the interaction with Big Data, which is one of the main resarch topic of team.

5.5 Scientific production (selection)

Articles in Journals

[175] G. Bailly, E. Lecolinet, and L. Nigay. Visual menu techniques. *ACM Computer Surveys*, 49(4):41 pages, Jan. 2017.

[176] A. Cohé, B. Liutkus, G. Bailly, J. Eagan, and E. Lecolinet. Schemelens: A content-aware vector-based fisheye technique for navigating large systems diagrams. *Transactions on Visualization & Computer Graphics (TVCG)*, 22(1):330–338, Jan. 2016.

Articles in Conference Proceedings

[421] J. Gori, O. Rioul, Y. Guiard, and M. Beaudouin-Lafon. The perils of confounding factors: How fitts' law experiments can lead to false conclusions. In *ACM Conference on Human Factors in Computing Systems (CHI'18)*, Montréal, Canada, April 2018.

[178] J. Eagan, R. Rädle, M. Nouwens, K. Antonsen, and C. Klokmose. Codestrates: Literate computing with webstrates. In *The 30th Annual ACM Symposium on User Interface Software and Technology*, Québec City, Canada, October 2017.

[179] J. Eagan. Grab 'n' drop: User configurable toolglasses. In *16th IFIP Conference on Human-Computer Interaction (INTERACT 2017)*, volume 10515, pages 315–334, Mumbai, India, September 2017. Springer.

[180] N. Boukhelifa, M.-E. Perrin, S. Huron, and J. Eagan. How data workers cope with uncertainty: A task characterisation study. In *CHI'17: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*, pages 3645–3656. ACM, May 2017.

[181] B. Fruchard, E. Lecolinet, and O. Chapuis. Markpad: Augmenting touchpads for command selection. In *CHI'17: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*, pages 5630–5642, Denver, Colorado, Etats-Unis, May 2017. ACM.

[429] W. Liu, R. Lucas DOliveira, M. Beaudouin-Lafon, and O. Rioul. Bignav: Bayesian information gain for guiding multiscale navigation. In *CHI'17: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*, pages 5869–5880, Denver, Colorado, USA, May 2017. ACM.

[430] J. Gori, O. Rioul, and Y. Guiard. To miss is human: Information-theoretic rationale for target misses in fitts' law. In *CHI'17: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*, pages 260–264, Denver, USA, May 2017. ACM.

[184] E. Brulé, G. Bailly, A. Brock, F. Valentin, G. Denis, and Ch. Jouffrais. Mapsense: Multi-sensory interactive maps for children living with visual impairments. In *CHI'16: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*. ACM Press, May 2016.

[185] C. Klokmose, J. Eagan, S. Baader, W. Mackay, and M. Beaudouin-Lafon. Webstrates: Shareable dynamic media. In *UIST '15: Proceedings of the ACM Symposium on User Interface Software and Technology*, page 11, Charlotte, NC, USA, October 2015. ACM.

[457] Y. Guiard and O. Rioul. A mathematical description of the speed/accuracy trade-off of aimed movement. In *British HCI*, Lincoln, Royaume Uni, July 2015. Association for Computing Machinery.

[187] M. Weigel, T. Lu, G. Bailly, A. Oulasvirta, C. Majidi, and J. Steimle. iskin: Flexible, stretchable and visually customizable on-body touch sensors for mobile computing. In *CHI'15: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 2991–3000, Seoul, Korea, April 2015. ACM.

[188] S. T. Perrault, E. Lecolinet, Y. Guiard, Y. Bourse, and S. Zhao. Physical loci: Leveraging spatial, object and semantic memory for command selection. In *CHI'15: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*, pages 299–308, Seoul, Korea, April 2015. ACM.

[189] C. Liu, O. Chapuis, M. Beaudouin-Lafon, E. Lecolinet, and W. Mackay. Effects of display size and navigation type on a classification task. In *CHI'14: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*, pages 4147–4156. ACM, April 2014.

[190] J. Wagner, E. Lecolinet, and T. Selker. Multi-finger chords for hand-held tablets: Recognizable and memorable. In *CHI'14: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*, pages 2883–2892, Toronto, Canada, April 2014. ACM.

[191] G. Bailly, A. Oulasvirta, D. P. Brumby, and A. Howes. Model of visual search and selection time in linear menus. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*, Toronto, Canada, April 2014. ACM.

[192] S. T. Perrault, E. Lecolinet, J. Eagan, and Y. Guiard. Watchit: Simple gestures and eyes-free interaction for wristwatches and bracelets. In *CHI'13: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*, pages 1451–1460, Paris, France, April 2013. ACM.

[193] M. Serrano, E. Lecolinet, and Y. Guiard. Bezel-tap gestures: Quick activation of commands from sleep mode on tablets. In *CHI'13: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*, pages 3027–3036, Paris, France, April 2013. ACM.

Patents

[194] J. Robinson, M. Ribière, M. Baglioni, E. Lecolinet, and J. Daigremont. Servers, display devices, scrolling methods and methods of generating heatmaps. (8994755), March 2015.

Chapter 6

IQA

Quantum Information and Applications

6.1 Presentation of the team

Team leader: Isabelle Zaquine (Prof, $< 1995- >$)

Faculty: Romain Alléaume (AP), Eleni Diamanti (JRS,$< -09/2016 >$), Elham Kashefi (JRS, $< 09/2014 - 09/2016 >$), Damian Markham (JRS, $< -09/2016 >$), Filippo Miatto (AP,$<$ $10/2017- >$),), Isabelle Zaquine (FP)

PhD Students: M. Bozzio (10/16- , E. Diamanti, I. Zaquine), M. Cordier (10/2015- I. Zaquine), L. Disilvestro (10/13-9/17, D. Markham), J. Ghalbouni (10/10 -11/13, I. Zaquine), P. Jouguet (09/10—09/13), Niraj Kumar, (03/15- , E. Diamanti), A. Marie (08/13-06/17, R. Alléaume), A. Marin (10/09-09/13, D. Markham), A. Pappa (11/10—07/14, E. Diamanti), M. Persechino (10/14-10/17, E. Diamanti), H. Qin (11/11-07/15, R. Alléaume), A. Sohbi (11/13–12/16 ,I. Zaquine), J. Trapateau (10/14-, I. Zaquine), N. Vyas (09/17-, R. Alléaume).

PostDocs, Research Engineers: H. Qin (09/15-11/15), M. Kaplan (02/12-12/15), T. Lawson (10/11—11/14), A. Marie (02/13-08/13), A. Marin (11/13-02/14), A. Orieux (02/15-10/16), A. Pappa (09/14-11/14), R. Parapatil (05/12-10/15), W. Plick (10/14-07/16), T. Prammanik (01/14-12/15), L. Trigo Divarte (09/15-09/16), R. Ragunathan (05/17-05/18)

Scientific Production Overview: The detailed bibliography is listed in the dedicated accompanying document.

Journals	Articles in Proceedings	Books and Book Chapters	Patents	Other Invited Talks	PhD defenses	HDR defenses
34	25	1	4	19	9	3*

Table 6.1: Overall Scientific Production;* Please note that two of the HDR defenses were those of CNRS JRS D. Markham and E. Kashefi after the splitting with CNRS

6.2 Research activities

6.2.1 Overview

The research activity of the group IQA is centered on applications of quantum information science, with a focus on quantum cryptography and components for quantum communications. An important characteristic of IQA, is to combine theoretical and experimental approaches in quantum

information with "classical" expertise such as optical communications or network security, working toward bringing quantum technologies closer to applications.

6.2.2 Quantum cryptography systems and protocols:

Quantum cryptography and more specifically quantum key distribution is the most developed application in quantum information, already offering commercial products and even recently satellite-based experiments. Many limitations remain nevertheless to be investigated and both experiments and protocols can be improved. Our experimental platform is based on photonic systems, with the advantage of simplicity and flexibility and mostly at telecom wavelengths for a good compatibility and possible integration in current communication systems and networks. Two classes of experiments have been developed: the first one is based on nonlinear optics, in order to generate entangled photon pairs, through spontaneous down conversion in nonlinear crystals or through four wave mixing in microstructured fibers [205, 195]. It is noteworthy that such photonic systems, can also provide a legitimate path to performing small-scale quantum computations. The second aspect of this experimental platform is based on continuous variable cryptography for which the expertise of our group has enabled the creation of the spin-off Sequrenet and is still internationally recognized [197] with the realization of advanced implementations of the most celebrated quantum cryptographic protocol enabling unconditionally secure secret message exchange [210], as well as the investigation of quantum hacking [200], and the problem of phase reference sharing [196, 211].

Demultiplexing techniques are used for instance to distribute entangled pairs to a network of users for discrete variable cryptography applications [198] and also for the investigation of coexistence of continuous variable QKD with intense DWDM classical channels [208]. We have contributed to the implementation of suitable protocols tailored to multiparty applications [201]. We have conducted theoretical studies and achieved the practical development of a wide range of quantum cryptographic and communication tasks with a provable advantage over classical protocols in terms of performance, security, or efficiency[209, 206].

More recently we have proposed and developed a novel approach to quantum cryptography. This approach relies on a hybrid quantum-computational (hqc) model that combines the noisy storage assumtion [KWW12] with an extra assumption, namely the short-term security of computational one-way functions. The advantage of the hqc model is to allow to build protocols with everlasting security (unreachable with computational schemes) with performance (rate-loss behavior) and functionality that go beyond what is possible with "standard" quantum cryptography. A first key distribution protocol in the hqc model has been presented at QCrypt 2015, based on a multimode coherent state encoding. It allowed a rate increase scaling like $\sqrt{N}$, where N is the number of modes of the encoding. We have filed 3 patents [214, 213, 212] this work and now intend to develop quantum key distribution schemes compatible with weakly trusted classical repeaters. This could allow to increase the range of secure quantum communication to very long ($>$ 1000 km) distances and therefore have an important impact on the real-world development of quantum cryptography.

We are also involved in the international instance for Quantum Key distribution certification: ETSI QKD-ISG, and act as rapporteur on the Work Item "QKD deployment parameters".

A new axis in our activity in quantum communications concerns the quantum repeater, an essential ingredient for the quantum communication infrastructure of tomorrow in order to overcome the distance limitations. A very innovative "one-way" solution is being explored, which does not require quantum signals to travel in both directions at each node. This should simplify the protocols and increase the bandwidth. Reinforcement learning will be used in order to optimize the design of the optical implementation.

6.2.3 Quantum computing and fundamental aspects

Although large-scale quantum computer are still out of reach technologically, key research challenges consist in developing a better understanding of logical transformation, noise and of the scalability of quantum computing systems. Moreover, quantum computing can be studied as an

extension of computer science shedding a new light on fundamental questions related to information and computational resources and their interplay.

Our group also investigates models of quantum computing rooted in the formal theory of computer science, to design Universal Blind quantum computing protocols together with their appropriate verification schemes. New applications, algorithms and cryptographic protocols for quantum information processing devices are explored [204, 203, 202].
A better undestanding of fundamental quantum properties such as entanglement, non locality or contextuality has also been at the heart of the research activity of IQA and will be essential to the future development of our domain. For instance, the permutation symmetry of multiparty entangled states and the related properties of non-locality has several immediate concequences in terms of communication complexity and non-local games [199]. Another example is the investigation of graph states; in collaboration with the experimental group of John Rarity in Bristol we have implemented several protocols with graph states including error correction[207]. We have also developed and implemented protocols for verifying entanglement [201].

6.2.4 Scientific Highlights:

- Significant Projects
  - Ile-de-France Region SESAME project "Sécurité Quantique", 350 000euros, 2010 – 2014
  - Ville de Paris Emergences Programme project CiQWii "Cryptography in a Quantum World : from inception to implementation", 220 000euros, 2012 - 2015, Collaboration with IRIF, Univ. Paris Diderot.
  - ANR project QRYPTOS "Quantum cryptography on silicon", 137 280euros, 2014 - 2017, Collaboration with C2N, Univ. Paris Sud and LCFIO.
  - ANR Emergence project QUANTUM-WDM, Wavelength Division Multiplexing enabled Quantum Key Distribution, 245 419 euros. Telecom PArisTech Coordinator (2013-2015).
  - ANR project COMB "Continuous-variable measurement based quantum computing", 111072 euros, 2014 - 2017, Collaboration with MPQ, Univ. Paris Diderot and LKB, Univ. Pierre et Marie Curie.
  - ANR Blanc-International France-Canada project FREQUENCY "Fundamental research in quantum networks and cryptography", 160 715 euros, 2010 - 2013, Collaboration with University of Waterloo/Institute for Quantum Computing, University of Calgary, Université de Montréal, ENS Cachan, and SeQureNet.
  - EPSRC Established Career Fellowship, 2015 - 2020, "Verification of Quantum Technology"; £1.2M; EPSRC Quantum Technology Hub, 2014 - 2019, "Networked Quantum Information Technology"
  - H2020 ITN Project QCALL (2017-2020): Quantum Communication for All, 262875 euros (2017-2020).
  - Partner University Fund France - USA project CRYSP "Quantum cryptography with silicon photonics", 77000$, 2015 - 2018, Collaboration with Columbia University and LCFIO.
  - Coordinator for French partners : CHISTERA European Coordinated project HIPERCOM: "High performance coherent quantum communications", 150 176euros, 2011 - 2014, Collaboration with Université Libre de Bruxelles, Max Planck Institute for the Science of Light, University of York, LCFIO, and SeQureNet
  - European Union FP7 Marie-Curie IAAP project QCERT "Quantum key distribution certification", 180keuros, 2010 - 2014, Telecom ParisTech coordinator, Collaboration with Univ. de Genève and IDQuantique.
- Creation of the federation of Parisian labs: Paris Center for Quantum Computing in January 2014 with CNRS

- Coordinated MOU between the department of informatics (U. Edinburgh) and Télécom ParisTech.
- Organization of Workshops and Conferences Physics and Information 2013 Workshop, Paris, France, April 2013, Quantum Physics and Computer Science (QPSC) school, 15-20 June 2014 in Sevres, Qcrypt 1-5 Sept 2014 220 participants, GdRIQFA in Nov 2016, Participation to the organizing committee of Frontiers Of Quantum Safe Cryptography (FOQUS) 29-30 April 2017, Univ. Pierre et Marie Curie, Paris; Program Chair of Qcrypt 1-5 Sept 2014
- Associate editors of journals
  Eleni Diamanti is: Editorial Board member of Nature Scientific Reports, since June 2016; Editorial Board member of IOP Quantum Science and Technology, since March 2016; Guest Editor for Special Issue on Quantum Cryptography, MDPI Cryptography, 2016 - 2017; Guest Editor for Special Issue on Quantum Communications and Cryptography, IEEE Photonics; Society Journal of Selected Topics in Quantum Electronics (JSTQE), 2014 – 2015Journal 1;
- Scientific dissemination
  - Romain Alléaume ; France Culture, La Méthode Scientifique, "Cryptographie quantique, la nouvelle machine à chiffrer ?", (25 Octobre 2017); Le Monde, La Chine leader des communications quantiques (14 Aout 2017) ; blog recherche de l'IMT "Ordinateur Quantique", (18 avril 2017); La Recherche "Cryptographie quantique, la confiance retrouvée" (juillet 2015) ; Horizon Magazine "The keys to your secrets in quantum states of light", (March 2015).
  - Eleni Diamanti: France-Culture radio emission "La méthode scientifique" on quantum computing, with Daniel Estève (SPEC, CEA), (November 2016); Bar des Sciences on quantum entanglement and quantum cryptography, with Alexei Grimbaum (LARSIM, CEA), (November 2016); Interview with Les Echos and La Recherche regarding the launching of a quantum enabled satellite in China, (August 2016); "Vers des réseaux ultrasécurisés", with Sébastien Tanzilli, Dossier "Les révolutions quantiques", La Recherche, (July-August 2015). "Les communications dans le monde quantique du futur", Invited talk at the SNCF Meeting on "Telecommunications de l'avenir", December 2014; Interview "L'heure du cryptage quantique a sonné", Science et Vie, (December 2013); Interview "Une sécurité maximale sur des plus longues distances", La Recherche, (June 2013).
  - Eleni Diamanti and Isabelle Zaquine: Participation in the conception and realization of a short film on the principle of quantum cryptography for the Cité des Sciences, produced by CNRS Images, 2014
  - Elham Kashefi: Invited Lecturer for The Times Cheltenham Science Festival, 2015; Live BBC Scotland Interview on quantum verification, 2014

6.3 SWOT analysis

6.3.1 Strength

- Complementarity of expertise in quantum information, quantum cryptography and experimental quantum communications
- Experimental platform and capacity to build experimental demonstrators for quantum communications.
- Thematic connectivity with other domain in the school: cryptography, digital communications, optical communications, machine learning
- Industrial experience (start-up) and collaborations with quantum technology companies

6.3.2 Weakness

- 3 IQA colleagues affiliated with CNRS had to move to LIP6 where they started a new quantum information group, after CNRS stopped the agreement with LTCI

6.3.3 Opportunities

- New colleague Filippo Miatto, novel thematics : quantum repeater, quantum machine learning
- We have one project selected in the Quantum Technology Flagship, CiViQ on continous variable quantum communications (2018-2021).
- Environment: Regional network in quantum information: SIRTEQ (Science et Ingénierie en Région Ile-de-France pour les Technologies Quantiques) ; Quantum technologies announced as strategic theme in NewUni.
- Paris Centre for Quantum computing (being founding members)
- Industrial interest and student attraction for the subject

6.3.4 Threats

- Obstacles for the development of cross-discplinairy research (computer science / physics / communication engineering) in quantum information.
- Resistance to the building of common projects between NewUni and Univ. Paris Saclay.

6.4 Scientific project for the next five years

6.4.1 Quantum and hybrid approaches for the security of communication systems

One axis is the development and experimental demonstration of sources of non classical states of light (entangled photon pairs, photon triplets) ; a project has been submitted to ANR (Quantum Technologies) in collaboration with XLIM in Limoges and LCF in Palaiseau. We intend to investigate hollow core photonic crystal fibers for photon pair or photon triplet generation and use the numerous design parameters available to engineer the spectral correlations of the generated photons.

A second axis will be related to the convergence of classical and quantum communications. This work will be lead within the Quantum Technology flagship project CiViQ , that gathers a 21 European partner consortium (including Orange and Nokia in France) . Within Telecom ParisTech, we will work in close collaboration with the GTO group in COMELEC department. We aim at demonstrating that classical and quantum coherent communication can be operated on the same fiber with partially-shared hardware at the endpoints (in particular low-noise coherent receivers). We expect to develop new techniques based on customized classical-quantum modulation format and signal processing, combined with multiplexing and switching to allow for the joint deployment and operation of quantum and classical coherent communications. CV-QKD happens to be a very promising platform in order to demonstrate such convergence, as illustrated by some recent work [196],[208]).

6.4.2 Complex quantum systems and application to quantum computing and simulation

The motivation for the investigation of quantum computing is twofold: i) the simulation of large quantum systems (dimension greater than 50) is out of reach of a classical computer and ii)hard problems such as the factorization of composite numbers [Shor P.W. 1994 Proceedings., 35th Annual Symposium on. Ieee] or the solving of linear equation systems could be accelerated using

a large universal quantum computer implying application to cryptanalysis and also to machine learning. The corresponding research axes in our team are:

- A project on Machine Learning for quantum unitary synthesis: it consists in developing a Reinforcement Learning AI that learns how to break down a multi-qubit unitary into an arrangement of quantum gates from a fixed set. Once we understand how this kind of AI learns and performs, we can apply it to the larger space of optical unitary interactions. The difference is that quantum circuits are made of qubits, with 2-dimensional state spaces and quantum optical systems are made of optical modes, with infinite-dimensional state spaces. The main goal of applying the AI to optical interactions is developing realistic realizations of a one-way quantum repeater [F. Miatto et al. *Quantum* **2**, 75 (2018)].
- Modeling decoherence and characterizing the noise model of a complex quantum system with Machine Learning. This project aims at modeling the unwanted behavior of quantum chips in order to invent better error correction schemes. The idea is that instead of using general quantum error correction procedures, it is possible to let an artificial intelligence understand which procedures are better suited from real-time calibration data.
- A new project on frequency multimode quantum communications associates experimental quantum optics and quantum cryptography. It consists in encoding information in a large frequency mode basis to enable the use of new protocols of hybrid cryptography offering a better rate/distance compromise than pure quantum protocols. The actual experimental implementation will allow to validate the feasibility and assess i) the performance gain with respect to single mode quantum key distribution and ii) the technological complexity increase required by the multimode encoding.

6.5 Scientific production (selection)

Articles in Journals

[195] M. Cordier, A. Orieux, R. Gabet, Th. Harlé, N. Dubreuil, E. Diamanti, Ph. Delaye, and I. Zaquine. Raman tailored photonic-crystal-fiber for telecom band photon-pair generation. *Optics Letters*, 42 (13):2583–2586, July 2017.

[196] A. Marie and R. Alléaume. Self-coherent phase reference sharing for continuous-variable quantum key distribution. *Physical Review A*, 95(1):012316, February 2017.

[197] Eleni Diamanti, Hoi-Kwong Lo, Bing Qi, and Zhiliang Yuan. Practical challenges in quantum key distribution. *npj Quantum Information*, 2:16025, 2016.

[198] C. Autebert, J. Trapateau, A. Orieux, A. Lemaître, C. Gomez-Carbonnel, E. Diamanti, I. Zaquine, and S. Ducci. Multi-user quantum key distribution with entangled photons from an AlGaAs chip. *Quantum Science and Technology*, 1:1, December 2016.

[199] A. Sohbi, I. Zaquine, E. Diamanti, and D. Markham. Logical and inequality based contextuality for qudits. *Physical Review A*, 94(3):32114, September 2016.

[200] H. Qin, R. Kumar, and R. Alléaume. Quantum hacking: Saturation attack on practical continuous-variable quantum key distribution. *Physical Review A*, 94(1):012325, February 2016.

[201] W. McCutcheon, A. Pappa, B. Bell, A. McMillan, A. Chailloux, T. Lawson, M. Mafu, D. Markham, E. Diamanti, I. Kerenidis, and others. Experimental verification of multipartite entanglement in quantum networks. *Nature communications*, 7:13251, February 2016.

[202] P. S. Turner and D. Markham. Derandomizing quantum circuits with measurement-based unitary designs. *Physical review letters*, 116(20):200501, February 2016.

[203] S. Barz, V. Dunjko, F. Schlederer, M. Moore, E. Kashefi, and I. A. Walmsley. Enhanced delegated computing using coherence. *Physical Review A*, 93(3):032339, February 2016.

[204] A. Gheorghiu, E. Kashefi, and P. Wallden. Robustness and device independence of verifiable blind quantum computing. *New Journal of Physics*, 17(8):083040, February 2015.

[205] M. Barbier, I. Zaquine, and Ph. Delaye. Spontaneous four-wave mixing in liquid-core fibers: towards fibered raman-free correlated photon sources. *New Journal of Physics*, 17:053031, May 2015.

[206] A. Pappa, N. Kumar, Th. Lawson, M. Santha, S. Zhang, E. Diamanti, and I. Kerenidis. Nonlocality and conflicting interest games. *Physical Review Letters*, 114:020401, January 2015.

[207] B. A. Bell, D. A. Herrera-Martí, M. S. Tame, D. Markham, W. J. Wadsworth, and J. G. Rarity. Experimental demonstration of a graph state quantum error-correction code. *Nature Communications*, 5(3658), April 2015.
[208] H. Qin, R. Kumar, and R. Alléaume. Coexistence of continuous variable QKD with intense DWDM classical channels. *New Journal of Physics*, February 2015.
[209] A. Pappa, P. Jouguet, Th. Lawson, A. Chailloux, M. Legré, P. Trinkler, I. Kerenidis, and E. Diamanti. Experimental plug and play quantum coin flipping. *Nature Communications*, 5:3717, April 2014.
[210] P. Jouguet, S. Kunz-Jacques, A. Leverrier, Ph. Grangier, and E. Diamanti. Experimental demonstration of long-distance continuous-variable quantum key distribution. *Nature Photonics*, 7:378, April 2013.

Patents

[211] R. Alléaume and A. Marie. Phase reference sharing schemes for continuous-variable quantum cryptography. (16305551), May 2016.
[212] R. Alléaume. Communications with everlasting security from short-term-secure encrypted communication,. (15305017.4), January 2016.
[213] R. Alléaume. Practical quantum cryptography with everlasting security. (15187905.3), October 2015.
[214] R. Alléaume. Hybrid classical-quantum cryptography. (69606EP), January 2015.

Chapter 7

MC2

Discrete Mathematics, Coding and Cryptography

7.1 Presentation of the team

Team leader: Olivier Hudry (-2015), Laurent Decreusefond (2015-2016), Gérard Cohen (2016-2017), Hugues Randriambololona (2017-)

Faculty: Gérard Cohen (Prof., -2017 / Emeritus 2017-), Laurent Decreusefond (Prof., -2017), Olivier Hudry (Prof.), Antoine Lobstein (CR, -2016), David Madore (MCF), Bertrand Meyer (MCF), Hugues Randriambololona (MCF), Jacques Sakarovitch (Emeritus), A. Süleyman Üstünel (Prof., -2015)

Associated Researchers: Antoine Lobstein (CR, LRI, 2016-), Sihem Mesnager (MCF, LAGA)

PhD Students: Eustache Besançon (2016-, supervised by L. Decreusefond and P. Moyal (UTC)), Ian Flint (2010-2013, supervised by L. Decreusefond), Hélène Halconruy (2016-, supervised by L. Decreusefond), Kevin Hartmann (2013-2016, supervised by A.S. Ustunel), Estelle Marie (2014-, supervised by O. Hudry and S. Elloumi (CNAM/ENSTA)), Franck Maunoury (2014-2018, supervised by L. Decreusefond and E. Eisenbaum (P7)), Victor Marsault (2012-2015, supervised by J. Sakarovitch), Alain Patey (2011-2014, supervised by G. Cohen and H. Chabanne (Morpho)), Matthieu Rambaud (2014-2017, supervised by H. Randriambololona), Lionel Rivière (2012-2015, supervised by G. Cohen and H. Chabanne (Morpho)), Edouard Rousseau (2017-, supervised by H. Randriambololona and L. De Feo (UVSQ)), Aurélien Vasseur (2014-2017, supervised by L. Decreusefond), Anaïs Vergne (2010-2013, supervised by L. Decreusefond), Zizhu Wang (2009-2013, supervised by G. Cohen and D. Markham)

PostDocs, Research Engineers and Sabbatical Professors: Janos Körner (Visitor, roughly 1 month p. year), Julia Pieltant (PostDoc, 2014-2016)

Scientific Production Overview: Table 9.1 represents the overall scientific production between 2013 and 2018. The detailed bibliography is listed in the dedicated accompanying document.

	Journal	Book	Book Chapters	Articles in Proceedings	Patents	Invited talks
2013-18	60		5	38	1	3

Table 7.1: Overall Scientific Production

7.2 Research activities

7.2.1 Overview

The MC2 team has its research activities in fundamental mathematics (algebraic geometry, number theory, combinatorics), and in areas at the frontier between mathematics and computer science (automata, coding theory, cryptography, computational complexity) but still with a predominantly mathematical perspective.

During the period 2013-2017 it also had members interested in probability theory and its applications.

7.2.2 Algebraic geometry and applications

We studied various problems in algebraic geometry, motivated first by their own mathematical interest, but also by their applications in theoretical computer science and information theory, e.g. in coding theory, combinatorics, complexity, computability, or cryptography.

In [242] we proved that étale cohomology mod ℓ is computable.

Combining methods from algebraic geometry, classical coding theory, and bilinear algebra, we developed the theory of *$*$-products and powers of codes* and obtained several results on them, such as asymptotic bounds on their parameters [257, 267, 240].

Still related to $*$-products, in [263] we introduced an optimal method for the contruction of auxiliary divisors on a curve needed in several problems in extremal combinatorics and combinatorial geometry [229], in bilinear complexity theory, and in information-theoretically secure multi-party computation.

The theme of bilinear complexity was reinforced with J. Pieltant's PostDoc and M. Rambaud's PhD. Using various optimization methods, and solving deep geometric problems on Shimura curves, allowed to produce the best symmetric and non-symmetric bilinear algorithms known at this time for most finite fields [248].

All these works fit in the scope of our ANR project Manta (2016-2019), joint with Inria Saclay and Toulouse University.

7.2.3 Automata theory

We pursued our work on automata theory with an emphasis, during V. Marsault's PhD, on problems raised by rational base numeration systems [226]. On a more classical side of automata theory, we have proposed a new approach and definition of the validity of weighted automata [273].

The Vaucanson Project consists in several pieces of sofware related to finite automata. The main one is a platform for computing with automata and transducers with multiplicity taken in all classical semirings of weights. The version Vaucanson2 has been supported by an ANR project involving Epita, Bordeaux University and Telecom ParisTech from March 2011 to August 2014. A new version of the platform, called Awali, is now developed in a cooperation between Bordeaux University and Telecom ParisTech.

7.2.4 Combinatorial coding theory

Coding theory borrows methods from many branches of mathematics, especially from algebra, geometry, and combinatorics. This last point of view is used in our works relating coding theory with boolean functions and cryptography [250, 221, 223, 216], minimal codes and their variants [232], and zero-error information theory and extremal combinatorics [259, 261, 260, 219].

7.2.5 Graph theory, complexity, and combinatorial optimization

In graph theory we studied several variants of the dominating set problem, and more precisely, we focused on the notions of *locating-dominating codes* and *identifying codes*. We studied certain combinatorial properties of these objects [269, 255, 245, 238, 234, 220], the complexity of some

related optimization problems [231, 227, 225, 217], and their generalization to a new concept we called *watching systems* [268, 254]. Some of these works are in the continuity of D. Auger's PhD, defended in 2010.

In a second direction, other problems related to complexity theory were studied: this includes the study of median orders [265, 246], or the unicity of optimal solutions in classical problems [228, 217]. Some of these problems seem not to fall in the usual complexity classes, e.g. $\mathcal{NP}$, but higher in the polynomial or boolean hierarchy, such as classes Θ_2, Δ_2, $F\Delta_2$, $\mathcal{DP}$ (a.k.a. $\mathcal{BH}_2$), etc.

A third direction concerns combinatorial optimization for various problems in operational research. In the continuity of L. Denoeud-Belgacem's PostDoc, we studied the routing and wavelength assignment problem in optical networks [253, 243]. Other articles continued our previous works on the determination of median relations [265, 246, 218]. Following a conference we organized on applications of mathematics to psychology, we also studied preference analysis [264, 266]. Last, E. Marie's PhD applies combinatorial optimization to sensor deployment in a wireless network, thanks to which she obtained the *Best paper award* in the 4th International Conference on Control, Decision and Information Technologies (Barcelona, Apr. 2017).

7.2.6 Stochastic analysis

We continued the work about singular differential equations using stochastic calculus of variations [256, 271]. Quantifying the rate of convergence in stochastic algorithms and more generally in limit theorems, is a crucial step in the validation of approximation methods. We started a line a research based on the so-called Malliavin-Stein method [262, 249, 236]. With applications to modelisation of mobile systems in mind, we developped the stochastic analysis of point processes with dependence [288, 258].

However in 2015 A.S. Üstünel retired, and in 2017 L. Decreusefond went to the DIG team. Hence, this theme is no longer in the scope of MC2.

7.2.7 Highlights

- Distinctions and awards: Gérard Cohen became IEEE Fellow in 2013
- Organization of conferences:
  - CohenFest 2016
  - (conf. d'Olivier)
- Editorial responsabilities in journals:
  - Advances in Mathematics of Communications
  - International Journal on Information and Coding Theory
- Publicly funded projects:
  - ANR Vaucanson 2 (2011-2014)
  - ANR Gardio (2015-2018)
  - ANR Manta (2016-2019)
- Common lab with industrial: Identity and Security Alliance, with Morpho
- Other: Bertrand Meyer was one of the organizers of the 2017 South Western Europe Regional Contest of the ACM International Collegiate Programming Contest.

7.3 SWOT analysis

7.3.1 Strength

Despite the small size of the team, its research interests encompass a very broad range of topics, including but not limited to: algebraic geometry, number theory, combinatorics, theoretical computer science... Actually, this is true not only at the level of the team, but also at the individual level. Each member of the team is a versatile mathematician with a very wide spectrum. This allows one to work in an agile and opportunistic way, not being bound to a specific subject or application, but instead shifting interest wherever one encounters something with enough mathematical relevance to be worth investing time and resources.

7.3.2 Weakness

Most members of the team come from the community of pure mathematics. As such they share a cultural background that is quite different from that of other teams in LTCI, who come e.g. from applied mathematics, computer science, etc. While cultural diversity is certainly a positive thing, sometimes it can be a source of misunderstandings, especially at the organizational level: importance of project-oriented research, number of PhD students, publication habits, etc.

7.3.3 Opportunities

Last year the team proposed opening a position in cryptography. The aim was to have someone: (1) interested in the mathematical aspects, able to interact with the current team members especially on algebraic geometry, number theory, and coding theory, but also (2) with a good knowledge of the usages and applications, in order to build bridges with other teams, for instance in cybersecurity, secured distributed computing, or in lightweight cryptography for embedded systems. Our proposition did not succeed, but still we think it would be a good opportunity to reinforce the research of the team, and at the same time to strengthen its integration in LTCI.

Considering the relocation of Telecom ParisTech in Saclay, we observe MC2 already has regular collaborations with the Grace team at LIX/Inria.

7.3.4 Threats

After the departure of its CNRS researchers, three retirements, and the move of L. Decreusefond to another team, MC2 only remains with four permanent members. Any further loss would certainly be very prejudicial for the visibility of the team as a collective entity (although probably less so for the research of its individual members).

7.4 Scientific project for the the next five years

MC2 is first a collection of individuals gathered together by the fact that they see themselves as mathematicians. Still, we can identify the following three structuring themes, in the continuity of our past research activities:

7.4.1 New interfaces in coding theory

In coding theory, our interest often goes to "non-classical" problems, in the sense that they depart from the usual questions of minimization of the error rate and practicality of decoding. A sample of the topics we are considering is:

- study of new classes of codes motivated by specific applications (locally decodable codes, private information retrieval, broadcast...)

- study of codes as abstract mathematical objects (algebraic, combinatorial, geometric, or metric properties...)
- application of methods from coding theory to other branches of mathematics.

7.4.2 Efficient arithmetic for cryptography and computer algebra

A second research direction covers problems in algorithmic number theory and computer algebra. In particular we consider questions of algebraic complexity, such as bilinear complexity of multiplication in finite fields; index calculus for the discrete logarithm problem; implementation of lattices of finite fields in computer algebra systems. These are fundamental questions in algorithmics, with a potential impact in all branches of computer science, and first of all in cryptography and cryptanalysis.

7.4.3 New problems in complexity theory and in graph combinatorics

Last, in graph theory, one of our main themes is the study of identifying codes and related problems. The team already obtained numerous results on this topic in the past, which we plan to study further; but it also allowed to introduce new questions in complexity theory, such as the complexity of decision for existence of a *unique* solution. This last question seems very natural and fundamental, and studying it in a more general setting should be a promising new research direction for us.

7.5 Scientific production (selection)

Articles in Journals

[215] I. Charon and O. Hudry. How different can slater's solutions and kemeny's solutions of tournaments be? *soumis pour publication*, 2018.
[216] S. Mesnager, F. Ozbudak, A. Smak, and G. Cohen. On q-ary (partially) bent and plateaued functions over f_q. *European Journal of Combinatorics*, 2018.
[217] O. Hudry and A. Lobstein. Complexity of unique (optimal) solutions in graphs: Vertex cover and domination. *Journal of Combinatorial Mathematics and Combinatorial Computing*, 2018.
[218] O. Hudry. Application of the "descent with mutations" metaheuristic to a clique partitioning problem. *RAIRO - Operations Research*, 2018.
[219] G. Cohen, E. Fachini, and J. Korner. Path separation by short cycles. *Journal of Graph Theory*, 85 (1):107–114, May 2017.
[220] O. Hudry and A. Lobstein. Some results about a conjecture on identifying codes in complete suns. *International Transactions in Operational Research*, April 2017.
[221] J.-P. Flori and G. Cohen. On a generalised combinatorial conjecture involving addition mod 2ˆk -1. *Int. J. Information and Coding Theory*, 4(2/3):107–115, April 2017.
[222] O. Hudry and A. Lobstein. Some complexity considerations on the uniqueness of solutions for satisfiability and colouring problems. *soumis pour publication*, April 2017.
[223] S. Mesnager and G. Cohen. Fast algebraic immunity of boolean functions. *Advances in Mathematics of Communications*, 11(2):373–377, April 2017.
[224] m. rambaud and G. Memmi. Note sur la cryptanalyse de diffie-hellman. *Génie Logiiel*, (120):56–60, March 2017.
[225] O. Hudry and A. Lobstein. More results on the complexity of domination problems in graphs. *International Journal of Information and Coding Theory*, 4(2/3):129–144, 2017.
[226] V. Marsault and J. Sakarovitch. The signature of rational languages. *Theoretical Computer Science*, 658:216–234, 2017.
[227] O. Hudry and A. Lobstein. Unique (optimal) solutions: Complexity results for identifying and locating-dominating codes. *soumis pour publication*, 2017.
[228] O. Hudry and A. Lobstein. On the complexity of determining whether there is a unique hamiltonian cycle or path. *Journal of Combinatorial Mathematics and Combinatorial Computing*, 2017.

[229] H. Randriambololona. On metric convexity, the discrete hahn-banach theorem, separating systems and sets of points forming only acute angles. *Int. J. of Information and Coding Theory*, 4(2/3): 159–169, 2017.

[230] L. Decreusefond, M. Schülte, and Ch. Thäle. Functional {P}oisson approximation in {K}antorovich-{R}ubinstein distance with applications to {U}-statistics and stochastic geometry. *Annals of probability*, 44(3):2147–2197, June 2016.

[231] O. Hudry and A. Lobstein. More results on the complexity of identifying problems in graphs. *Theoretical Computer Science*, 626:1–12, May 2016.

[232] G. Cohen, S. Mesnager, and H. Randriambololona. Yet another variation on minimal linear codes. *Advances in mathmatics of Communications*, 10(1):53–61, February 2016.

[233] G. Cohen, E. Fachini, and J. Korner. Zero-error capacity of binary channels with memory. *IEEE Transactions Information Th.*, 62:3–7, January 2016.

[234] I. Honkala, O. Hudry, and A. Lobstein. On the ensemble of optimal identifying codes in a twin-free graph. *Cryptography and Communications - Discrete Structures, Boolean Functions and Sequences*, 8:139–153, 2016.

[288] L. Decreusefond, I. Flint, and A. Vergne. A note on the simulation of the ginibre point process. *Journal of Applied Probability*, 52(4), October 2015.

[236] L. Decreusefond. The {S}tein-{D}irichlet-{M}alliavin method. *ESAIM : proceedings and surveys*, 51:49–59, October 2015.

[294] A. Vergne, L. Decreusefond, and Ph. Martins. Simplicial homology for future cellular networks. *IEEE Transactions on Mobile Computing*, 14(8):1712–1725, August 2015.

[238] I. Honkala, O. Hudry, and A. Lobstein. On the ensemble of optimal dominating and locating-dominating codes in a graph. *Information Processing Letters*, 115:699–702, May 2015.

[239] L. Decreusefond, I. Flint, N. Privault, and G. L. Torrisi. Stochastic dynamics of determinantal processes by integration by parts. *Communications on stochastic analysis and applications*, April 2015.

[240] H. Randriambololona. On products and powers of linear codes under componentwise multiplication. *Contemporary Mathematics*, April 2015.

[241] F. Maunoury. Necessary and sufficient conditions for the existence of α-determinantal processes. *Séminaire de probabilités*, April 2015.

[242] D. Madore and F. Orgogozo. Calculabilité de la cohomologie étale modulo ℓ. *Algebra Number Theory*, 9(7):1647–1739, April 2015.

[243] L. Belgacem, I. Charon, and O. Hudry. Resolution of the routing and wavelength assignment problem by independent sets in conflict graphs. *Computers and Operations Research*, February 2015.

[244] H. Randriam, L. Sok, and P. Solé. Lower bounds on the minimum distance of long codes in the lee metric. *Designs, Codes and Cryptography*, 74(2):441–452, February 2015.

[245] I. Honkala, O. Hudry, and A. Lobstein. On the number of optimal identifying codes in a twin-free graph. *Discrete Applied Mathematics*, 180:111–119, January 2015.

[246] O. Hudry. Complexity results for extensions of median orders to different types of remoteness. *Annals of Operations Research*, 225:111–123, 2015.

[247] O. Hudry. Characterization of the majority matrices of profiles of equivalence relations. *Mathematics and Social Sciences*, 2015.

[248] J. Pieltant and H. Randriam. New uniform and asymptotic upper bounds on the tensor rank of multiplication in extensions of finite fields. *Math. of Computation*, 84(294):2023–2045, 2015.

[249] L. Coutin and L. Decreusefond. Higher order expansions via stein's method. *Communications on Stochastic Analysis*, 8(2):155–168, May 2014.

[250] G. Cohen and S. Mesnager. On construction of semi-bent funvtions from bent functions. *AMS Contemporary Mathematics*, 625:141–154, May 2014.

[251] L. Decreusefond and I. Flint. Moment formulae for general point processes. *Journal of Functional Analysis*, 267(2):452–476, April 2014.

[252] D. Auger, G. Cohen, and S. Mesnager. Sphere coverings and identifying codes. *Designs, codes and cryptography*, 70:3–7, March 2014.

[253] L. Belgacem, I. Charon, and O. Hudry. A post-optimization method for the routing and wavelength assignment problem applied to scheduled lightpath demands. *European Journal of Operational Research*, 232:298–306, January 2014.

[254] D. Auger, I. Charon, O. Hudry, and A. Lobstein. Maximum size of a minimum watching system and the graphs achieving the bound. *Discrete Applied Mathematics*, 164:20–33, January 2014.

[255] I. Charon, I. Honkala, O. Hudry, and A. Lobstein. Minimum sizes of identifying codes in graphs

differing by one edge. *Cryptography and Communications - Discrete Structures, Boolean Functions and Sequences*, 6(2):157–170, 2014.

[256] A. S. Ustunel. Variational calculation of laplace transforms via entropy on wiener space and applications. *J. Funct. Anal.*, (8):3058–3083, 2014.

[257] H. Randriambololona. An upper bound of singleton type for componentwise products of linear codes. *IEEE Trans. Inform. Theory*, 59(12):7936–7939, December 2013.

[258] L. Decreusefond, I. Flint, and K. Ch. Low. Perfect simulation of determinantal point processes. *Submitted*, November 2013.

[259] G. Cohen and C. Malvenuto. Cyclic colliding permutations. *ENDM*, 40:223–227, November 2013.

[260] G. Cohen, S. Mesnager, and A. Patey. On minimal and quasi-minimal linear codes. *Springer-verlag LNCS*, 8308:85–98, November 2013.

[261] G. Cohen, E. Fachini, and J. Korner. More on connector families. *ENDM*, 44:23–29, November 2013.

[262] L. Coutin and L. Decreusefond. Stein's method for {B}rownian approximations. *Communications on Stochastic Analysis*, 7(3):349–372, September 2013.

[263] H. Randriambololona. (2,1)-separating systems beyond the probabilistic bound. *Israel Journal of Mathematics*, 195(1):171–186, June 2013.

[264] I. Charon and O. Hudry. Lexicographic decomposition of preferences. *Electronic Notes in Discrete Mathematics*, 42:25–32, June 2013.

[265] O. Hudry. Complexity of computing median linear orders and variants. *Electronic Notes in Discrete Mathematics*, 42:57–64, June 2013.

[266] O. Hudry. Contributions to mathematical psychology. *Electronic Notes in Discrete Mathematics*, 42:1–7, June 2013.

[267] H. Randriambololona. Asymptotically good binary linear codes with asymptotically good self-intersection spans. *IEEE Trans. Inform. Theory*, 59(5):3038–3045, May 2013.

[268] D. Auger, I. Charon, O. Hudry, and A. Lobstein. Watching systems in graphs: an extension of identifying codes. *Discrete Applied Mathematics*, 161:1674–1685, April 2013.

[269] I. Charon, I. Honkala, O. Hudry, and A. Lobstein. Minimum sizes of identifying codes in graphs differing by one vertex. *Cryptography and Communications - Discrete Structures, Boolean Functions and Sequences*, 5:119–136, March 2013.

[270] J. Bringer, H. Chabanne, and A. Patey. Privacy-preserving biometric identification using secure multiparty computation: An overview and recent trends. *Signal Processing Magazine, IEEE*, 30(2): 42–52, March 2013.

[271] R. Lassalle and A. S. Ustunel. Local invertibility of adapted shifts on wiener space and related topics. *Malliavin Calculus and Stochastic Analysis Springer Proceedings in Mathematics & Statistics Volume 34, 2013, pp 25-76*, 34:25–76, January 2013.

[272] L. Decreusefond. Time reversal of volterra processes driven stochastic differential equations. *International Journal of Stochastic Analysis*, 2013:13, 2013.

[273] S. Lombardy and J. Sakarovitch. The validity of weighted automata. *International Journal of Algebra and Computation*, 23:863–913, 2013.

[274] F. Ezerman, B. Meyer, and P. Solé. On polynomial pairs of integers. *Journal of Integer Sequences*, 18, 2015.

Chapter 8

RMS

RMS full Title

8.1 Presentation of the team

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Rossi), Enguehard Marcel (2016−, Dario Rossi), Gong Yixi (2012 − 2016, Dario Rossi), Green Thomas (2017−, Dario Rossi), Imbrenda Claudio (2012 − 2016, Dario Rossi), Rossini Giuseppe (2010 − 2014, Dario Rossi), Samain Jacques (2016−, Dario Rossi), Misseri Xavier (2010 − 2013, Jean-Louis Rougier), Obadia Mathis (2014 − 2017, Jean-Louis Rougier, Luigi Iannone), Ruty Guillaume (2016−, Jean-Louis Rougier), Shao Wenqin (2014 − 2017, Jean-Louis Rougier, Luigi Iannone), Sorokin Roman (2013−2017, Jean-Louis Rougier), Ayadi Ines (2011 − 2014, Noémie Simoni), Hammani Ali Roman (2010 − 2013, Noémie Simoni), Shen Qing Roman (2010 − 2014, Noémie Simoni, Gérard Memmi), Araldo Andrea (2013 − 2016, Dario Rossi), Dieng N'Deye Amy (2009 − 2014, Claude Chaudet), Krolikowski Jonathan (2015−, Anastasio Giovanidis), Mangili Michele (2013 − 2015, Dario Rossi), Vu Thuang Van (2011 − 2014, Nadia Boukhatem).

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Platforms: The team exploits the following platforms:

- FIT Equipex and evolution towards European SILECS platform: FIT Equipex is a national platform funded by the PIA investment plane and designed jointly by several major academic partners in the IoT field. It provides a large scale IoT infrastructure and a software development environment to the IoT research community. This platform has merged in 2016 with Grid 5000 Equipex. The objective was to create a new platform adapted for the design of experiments of complete IoT systems (communications, data analytics and security aspects). This platform named SILECS has reached the TGIR (Très grande infrastructure de recherche) status in France in 2017. An ESFRI project has been submitted to European commission in September 2017 to obtain the status of European platform.
- LISP-Lab: Future Internet Research Platform. The LISP-Lab project built an open platform, based on the LISP (Locator/Id Separation Protocol) architecture, providing the environment to perform high quality research and support the design, development, and thorough assessment of new services and use-cases. The range of technical tasks planned in the LISP-Lab project, from cloud networking, to access technology, through inter-domain connectivity, traffic engineering, and mapping management, has a larger scope than the LISP beta network, boosting innovation beyond the LISP technology itself. The platform allowed to develop the most advanced open source implementation of LISP, which is the only alternative to proprietary implementations with respect to control-plane functionalities.

Scientific Production Overview: Table 8.1 represents the overall scientific production between 2013 and 2018. The detailed bibliography is listed in the dedicated accompanying document.

Journals	Articles in Proceedings	Books and Book Chapters	Patents	Keynotes and Tutorials	Other Invited Talks
69	226	6	8	x	3

Table 8.1: Overall Scientific Production

8.2 Research activities

8.2.1 Overview

RMS research interests lie in the design and study of future emerging networking technologies.

In the past four years, research efforts have been concentrated around three main directions:

1. Cloud and virtualization,

2. Mobile networks and communications,

3. Future Internet and Internet of Things

Research issues covered address both low layers (access, resource allocation, energy harvesting, radio handover, radio mobility management, data transmission reliability, infrastructure resilience) and higher layers (routing, ICN, Network Functions Virtualization (NFV), Software Defined Networks (SDN), block chains, IP mobility, network metrology).

RMS has a strong expertise in protocol and architecture design. It is involved in the design of major research platforms (LISP, FIT, SILECS, ...) for the networking community. RMS is also involved in standardization activities (IETF, 3GPP). RMS has several cooperations with international Laboratories (Europe, China, India, MENA region).

Research activities are also undertaken in the context of national (ANR, FUI) and international research projects (European projects), in tight cooperation with major industrials of the field. RMS has also joint labs with companies such as Cisco (NewNet@Paris research and education chair), EDF (SEIDO Lab) and The LINCS (Laboratory for Information, Networking and Communication Sciences).

8.2.2 Cloud and virtualization

Software Defined Networks We conducted research on SDN networks, in particular in the context of the ANR REFLEXION project and a CIFRE Ph.D. with Thales. In the Software Defined Network (SDN) ecosystem, the controller remains the cornerstone of the architecture and the critical point of its success. That is why performance concerns have existed throughout the history of SDN and controller development. We worked on evaluating and comparing existing SDN controllers, also exploring system wide settings that allow to boost performance in a virtualized environment [305].

Robustness of the SDN control plane is also of paramount importance: it is usually preferable to have several SDN controllers. In this context, We defined several failover [330] and server placement mechanisms in [369].

Cloud and Network Function Virtualization In collaboration with Thales, we address network function virtualization and, more particularly, the "service chaining" problem. Our goal is to optimize the placement of the different service functions, requested by the user in the different servers and data centers, in order to maximize network usage while meeting the customers potential requirements (traffic, workload, delays). A Novel approach based on game theory was introduced [364], which proved to be computationally cheaper than existing algorithms. One of the main benefit of the proposal is also that the algorithm could be fully distributed (while most approach requires a centralized management approach). This work has been awarded the best paper award

at IEEE SDN-NFV'16. We also defined an auction mechanism which would allow one NFV provider to sell available resources (i.e. that were not reserved in advance by customers) to customers to build their chain services. The computational complexity of service chaining makes this task challenging, all the more since the auction system must meet several interesting economic properties (stability, incentives to reveal true valuations, ...). We were able to propose a mechanism which is computationally tractable while meeting several "good properties" [365].

In relation with ALE International, we explored new videoconfering architectures [360] based both on the Cloud and P2P ("Fog") approaches. The "Fog" approach allows a company to use its unused equipments (desktop computers, servers) to perform tasks required to implement the videoconference services (such as video mixing, transcoding, relaying, etc.) We evaluated the potential benefits [366] and issues [360] of the proposed solution.

Multi-resource fairness. Designing efficient and fair algorithms for sharing multiple resources between heterogeneous demands is becoming increasingly important in the context of the cloud and Network Function Virtualization. RMS has proposed a new resource allocation called Bottleneck Max Fairness that differs significantly from the usual allocation known as Dominant Resource Fairness (DRF), leading to a much more favorable efficiency-fairness tradeoff [307, 276, 308]. Practical algorithms to realize this allocation have been designed and analyzed by simulation and queueing analysis.

Network Distributed Storage In collaboration with Cisco, we concentrated on distributed storage for large data centers. A novel "ipv6 centric" architecture has been proposed [362]. The storage system is thus fully integrated with the network, taking advantage of the high capacity and scalability of the network equipments. The architecture is also solving some scalability issues that affect some solutions currently deployed.

Some work have been initiated on erasure coding adapted for distributed storage systems. The method allows to reduce significantly the overhead induced by the repair of failed disks, in particular in terms of bandwidth used. A patent application has been filed by Telecom ParisTech.

Confidentiality management in Cloud environment The number of actors providing Infrastructure as a Service (IaaS) remains limited, while the number of PaaS (Platform as a Ser-vice) and SaaS (Software as a Service) providers is rapidly increasing. In this context, all the stakeholders need to collaborate. However, Cloud Service providers (CSP) need to guarantee a minimum of confidentiality of their proper instrastructure. We have formulated this confidentiality problem and proposed a strategy based on graph theory and a MILP formulation to find a tractable solution to this minimum confidentialy problem [285].

Cloud resiliency In case of failure of the cooling system of a data center (DC), all the VMs running on this DC need to be migrated from one datacenter to another one. In general, different DCs of a large Cloud Service Provier (CSP) are distant from thousands of kilometers. Very few studies have been dedicated to this massive migration problem. Our preliminary investigations have been presented in several papers ([345], [341]). In [335], we propose an innovative strategy named "Kumori" that facilitates such a massive datacenter restoration. The efficiency of the Kumori technique has been demonstrated through real cases under a limited number of VM migrations. This work has been graduated by a best paper award at IEEE RNDM 2015.

Cloud brokering and Cloud federation. The market of Cloud Services is largly dominated by a few major actors (Google, Amazon, Facebook, OVH etc.) that manage their own, large, datacenters. We have been involved in two successive research projects: Compatible-One (FUI) and Easi-Clouds (ITEA), aiming to favour the emergence of smaller competitors. Within these two porojects, both architectural aspects and software tools in charge of managing data migration and dynamic CPU, RAM and disk resource allocation have been proposed. A specificity of the Compatible-One and Easi-Clouds projects associating private companies and academics is the

open source nature of the code developed during each of these projects. We have designed and evaluated the efficiency of innovative pricing strategies suited to this type of environment, mainly in terms of fairness and infrastructure optimization ([351], [350], [349]). We then concentrated on Cloud Federation that consists in a cooperation between small or medium size Cloud Service Providers offering complementary services. We have proposed an innovative pricing strategies aiming to equilibrate fairly the income of each partner proportionally to the usage of its own hardware and software resources to the global benefit of the community [347], [349], [346], [344]).

8.2.3 Mobile networks and communications:

Wireless networks - Network coding for transmission reliability With the increasing demand for multimedia services over wireless communication systems, new technical challenges has been raised, due to the lossy and unpredictable nature of wireless links, as well as the high end-user expectations in terms of service quality.
In this general context, the group has investigated solutions to enhance transmission reliability in wireless networks by the use of network coding techniques.
A first focus has been on the adjustment of network coding redundancy level. A minimal redundancy bound as a tradeoff between network overhead and application requirements as been derived. Additionally, a deployable and distributed algorithm has been developed [325, 320, 329] to guarantee a minimum decoding ratio at destination while keeping the coding overhead relatively low.

A second focus has been put on the efficient transmission of *scalable video* over wireless links thanks to video coding. A comprehensive simulation environment has been built for an extensive analysis on how adaptive network coding techniques combined with multi-layer video can improve end-user quality. New network coding schemes based on layer discrimination, which offer a better protection to base layer packets, have been developed [324, 322, 323, 319].

The group also considered the deployment of network coding across networks and in particular its interaction with TCP. By masking link losses, network coding can prevent useless congestion window decrease and thus enhance TCP performance over lossy wireless links. In this context, the fairness issue between coded TCP flows and non-coded TCP flows has been addressed. A new and appropriate fairness index has been defined and demonstrators of coded TCP (and MP-TCP) versions have been developed as a proof of concept and a practical environment for the analysis of coded TCP behavior [328, 321, 326, 327].

This work has been partially funded by DGA and IDEX Digicosme, OPUS FUI-16 research project and with the collaboration of UCLA/NRL (USA) and UPMC/LIP6 (France).

Stochastic geometry and simplicial homology applications to wireless networks RMS has developed several original models based on stochastic geometry and point process theories to address the issues of planning, dimensioning and performance evaluation of cellular networks. The first category of models introduce closed form expressions used in the dimensioning process of an OFDMA network. A first group of models provides expressions of the outage probability in terms of resource blocks for downlink and uplink, taking into account the impact of several system features such as radio resource management and the use of MIMO [378]. The second category of models evaluate analytically the performance of the COMP feature in cellular networks by deriving closed form expressions of the SINR distribution [293][286]. Stochastic geometry is also used to evaluate the performance of millimeter wave and full duplex networks. New algorithms relying on simplicial homology theory have also been designed to address the issues of coverage hole detection and self coverage recovery in wireless networks [377][295][294][296]. These algorithms have also been adapted to define energy consumption saving algorithms in mobile networks (cell zooming approach). The performance of the cellular networks in presence of relay has been extensively studied. A simulated annealing based approach has been proposed to optimize the relay placement and we have shown how relays could save energy in a cellular network [800]. A new algorithm has been proposed to optimize on-line the trajectory of D2D users in a cellular network so that their

throughput is maximized under the constraint of achieving their final destination within a given delay [331].

Game theory and control for wireless networks RMS has developed an expertise in the field of game theory applied to wireless networks. One trend in todays networks is indeed to distribute computations and optimizations among different network elements. Distributed approaches are desirable for scalability reasons and game theory offers a good framework for the design of new resource allocation algorithms. As a consequence, distributed learning strategies have been designed, studied and evaluated for cognitive networks, load balancing in WLANs [279], load balancing in heterogeneous cellular networks [282] and channel allocation in D2D networks [333].

On the contrary, when a single agent has to take sequential decisions in a dynamic system, Markov Decision Processes provides the right framework to optimize its policy with respect to average or discounted rewards. This approach has been adopted and developed for various problems arising in Internet of Things and wireless networks, such as the on-line deployment of relay in a IoT network [280], the optimal power allocation in hybrid base stations fueled by the electric grid and renewable energy, or the optimal pilot allocation in multiple antenna systems.

Advanced scheduling for cellular networks. A number of coordination techniques have been proposed in LTE-Advanced networks for higher data rates. A key issue that is often neglected in the literature is the extra resource consumption incurred by the joint transmission from several base stations, in the context of a dynamic traffic with mobile users. RMS has addressed this issue in [312, 309, 306, 318, 316, 314, 313, 311], where new scheduling schemes have been proposed and analyzed through traffic models and system-level simulations. These works have been conducted in collaboration with Orange.

8.2.4 Future Internet and Internet of things :

Future Internet Architectures Part of envisioning the Future Internet means revising the key architectural aspects of the current legacy architecture. One of the cornerstones future network architectures, including the upcoming 5G, is the separation of *who* and the *where*, i.e., who is entity communicating vs. where the entity is placed in the network topology. Such paradigm nicely fit the SDN and NFV approaches. We performed extensive work on the Locator/Identifier Separation Protocol (LISP), the main example of this new paradigm, trying at the same time to transcend protocol peculiarities aiming at more abstract architectural properties. LISP is based on a map-encap mechanism to split the who and the where of the current IP addresses. Although LISP is currently under standardization in IETF and is deployed in the wild, it lacks the thorough measurement work showing its realistic performance in the large-scale networks and for its improvement. We assessed LISP from the different aspects. We measured the public deployment [304, 303]. The work performed allowed to have industrial impact with several published RFCs [298, 299]. The know-how in the field has been recognized by RIPE NCC (Réseaux IP Européens - Network Coordination Center), who invited for a LISP tutorial at 70th RIPE Meeting [380].

Path diversity is a key element of traffic engineering, enabling many advanced services (such as load balancing, QoS routing, ...). While the Internet connectivity graph displays vast inherent path diversity, the current protocols (in particular the Border Gateway Protocol, BGP) restrict the use of multiple paths. We propose a backwards compatible and incrementally deployable mechanism which allows for diverse inter-domain paths to be propagated among carriers and used for packet forwarding [371]. We show through simulation based on real Internet measurements the potential benefits of this approach. The alternate routes could be sold ("Route as a service") and we proposed an auction mechanism [370]. This work was conducted in collaboration with the University of Vienna (Austria) and university of Paris Daupine.

Information centric networks (ICN) is among the key new paradigms for the Future Internet, exposing application semantic (e.g., names) directly at the lower layer of the networking infrastructure. The RMS team has extensively worked in this domain, in part in collaboration with Cisco, by

focusing on crucial aspects of the content distribution chain. Part of the work focused on caching, such as proposing stochastic cache partitioning techniques that allow Internet Service Providers (ISP) to cache encrypted content without revealing business-critical information of Content Service Providers (CSP)[289]. Notably, the scientific work has modeled, simulated and implemented ways to make network caches "cost-aware", i.e., by caching the more costly items (e.g., those traveling expensive customer-provider links) to reduce ISPs operational expenditures.[292]. Other than analyzing ICN benefits from an economic viewpoint, several technical work has been carried out as well. At a system level, a smart hierarchical cache has been proposed which, leveraging peculiar stochastic properties of the ICN request arrival process, is able to break a technological barrier, by offering TeraByte-scale caches operating at line-rate.[357]. At a network level, we have porposed, modeled, simulated and implemented an optimal forwarding algorithms able to find the closest cached replicas without incurring the cache pollution problem[356]. At a simulation level, RMS implemented and open sourced ccnSim[359], which, to our knowledge, has become the most known and scalable simulator for ICN networks, with several thousands of downloads so far.

Internet measurement To redesign the Future Internet, understanding limits of the current Internet is of paramount importance. Along this spirit, RMS has proposed a ground-breaking methodology for the detection, enumeration and geolocation of IP anycast replicas [291]. The methodology is phrased as an (Maximum Independent Set) optimization problem, coupled to a maximum likelihood estimation, and is so lightweight that was amenable to run several censuses over the whole Internet[353]. These work received important awards (Google Faculty Research Award in 2015 and IETF Applied Network Research Prize in 2016) and are now in process of being transferred to the industry, as RIPE (the organization that federates all European Autonomous Systems and ISPs) has decided to use this technology for its Internet mapping service (RIPE Atlas).

We also concentrated on multihomed sites in a collaboration with Border6[1]. Even if multihoming has been studied and deployed for more than a decade, management of the route selection process appeared to be very subtle. We concentrated particularly on the metrology aspects and studied the following questions: how to select the most relevant routes [368], how to get insightful measures of the path performances to make the best route choices [367, 363, 361].

Quality of User Experience Networks are defined to, ultimately, serve its users, and especially to serve them well. As such, it is important to be able to assess users quality of experience for different applications such as video streaming [290] and Web browsing [354].

In particular, whether faithful interactions may arise between different networking protocols and apparatuses, such as for instance end-to-end congestion control and local scheduling at a router [358], then it is important to be able to model, confirm via simulation and experiments, and solve these issues. In particular, a control theoretic study of these issues has been carried out in [358] (runner-up for best paper award).

Similarly, at times where the dominant application-layer protocol (i.e., HTTP) is being redesigned (e.g., SPDY QUIC and HTTP/2), the ability to define metrics able to capture user satisfaction is of uttermost importance: our work in this context [354] (best paper at the conference) defined classes of integral metrics that do not just take a single measurement of a page lifetime (i.e., the page load time, which is by definition a statistical outlier) but that rather has an integral form and that naturally weights all events in a page (more precisely: the complementary of the cumulative visual rendering completion integrated over time). Transfer to the industry is in progress with the IPlabel company.

Optical networks. A key challenge in today's transport networks is to bridge the gap between high-speed optical transmission and limited electronic processing. This can be achieved by enabling payload to be switched directly in the optical domain, at subwavelength granularity. RMS has proposed several solutions enabling subwavelength switching in optical networks

[1]Border6 was a start-up company incubated at Telecom ParisTech. It has been acquired by Expereo in 2017.

[310, 315, 454, 277, 278]. The proposed solutions have been analyzed through simulations and appropriate queueing models. This work was done in collaboration with Orange and Nokia Bell LAbs. A patent has also been filled [384]. Protection and restoration are two important operations that need to be preplaned in the design of long-haul all-optical WDM networks. We have proposed a two-stage protection procedure taking into account quality of transmission of the optical signal. For that purpose, the impact of both attenuation and chromatic dispersion are considered during the connection establishment step in considering Shared Risk Link Group (SRLG) constraints ([337], [338]).

Cloud Radio Access Network (CRAN) and Mobile Edge Computing . In dense urban areas, the rapid increase in radio-mobile and IoT traffic necessitates the introduction of pico-cells within macro-cells to increase network's capacity. However, such a densification has a strong impact on the CAPEX/OPEX cost of the backhaul infrastructure. Digitized Radio-over-Fiber (D-RoF) appears as the best alternative and begins to be adopted by operators by means of CRAN architecture. In [284], we propose an optimized backhauling strategy using genetic algorithms and a Pareto front technique to demonstrate the efficiency of D-RoF in realistic LTE scenarios.
In parallel, we have also investigated the problem of energy starvation of radio-mobile terminals. In the perspective of Mobile Edge Computing (MEC), we have designed the Mobile Applications Offloading (MAO) algorithm that decides to export the most energy consuming applications from an handset terminal to a remote MEC server. Two factors may activate the usage of the MAO algorithm: a low level of available energy of the battery, or an unacceptable processing speed of the current active tasks. Our numerical analysis considers three benchmark applications that differ from each other by their real-time constraints and their computing complexity (chess game, speach recognition and virus scanning). We have demonstrated the efficiency of the MAO algorithm through an analytical modeling, and, thanks to a collaboration with Prof. Sandeep Gupta (Arizona State Univ.-USA), on a real testbed [339].

IoT data provisioning Due to the exponential increase in the amount of data from IoT devices, how to provision the data to users becomes a new challenge. Generally, provisioning of raw time-series data (i.e. without any data treatment) incurs large network overhead. This is especially a problem during the visualization of time-series data on IoT devices, where high resolutions of raw data are provisioned even though the screen resolutions of IoT devices do not have the capabilities to represent the whole data, leading to wastage of network bandwidth. Various data aggregation protocols exist to reduce the amount of data transfer from data server to users, but will generally result in distortion of data. To cope with this problem, the RMS group has focuses on enhancing lossless data aggregation, which is based on finding and eliminating redundant data in the visualization phase, which reduces network overhead while maintaining the integrity of the visualized data [287].

IoT applications: Smart grids Our research activities in smart grids mainly focus on demand side management (DSM). DSM is becoming a key component of future energy systems as it helps power grids' operators to balance the demand for power with intermittent renewable energy sources (such as wind and solar units). DSM consists in optimizing/adapting the power consumption to meet the production through various methods, namely energy response (e.g. energy efficient appliances) and demand response (e.g. time-variable pricing, energy market, etc.). We proposed a multi-objective home energy management system (HEMS) that takes advantage of the demand flexibility to optimize the energy consumption while meeting the household comfort constraints, under time-variable pricing schemes [388, 372]. However, if all households of a neighborhood behave according to the same pricing scheme, the demand response solution may result in rebound peak without achieving the expected benefit. We thus proposed a coordinated management of energy consumption at the neighborhood level [389]. The aim is to encourage households to collaborate to achieve a global goal for the grid.

The limited capacity of distribution grids for hosting renewable generation is one of the main challenges towards the energy transition. Local energy markets, enabling direct exchange of energy blocks between prosumers is a promising solution to overcome this limitation, In [332], we proposed an architecture that enables households to autonomously exchange energy blocks and flexibility services with neighbors and other market actors. The solution is based on a blockchain transactive platform where households can trade energy with their neighbors, aimed to locally balancing renewable energy production. The aforementioned contributions are part of SEIDO Lab.

IoT applications: Electric Vehicle (EV) charging infrastructures EVs are considered as the best approach to reduce carbon emissions in dense urban areas. The main technical and economical challenge to enable a smooth transition from combustion engine to EVs is the speed and cost of deployment of charging infrastructures. We have been involved in two sucessive research projects financially funded by ADEME: Telewat and GreenFeed. In the context of the Telewat project, we have demonstrated the feasibiity to reuse existing public lighting networks to power EV charging stations. Various scheduling policies have been proposed for this original context. This work has driven to the design of a digital simulator that describes in the very details the behavior of the electrical circuitry. This work has been at the origin of two patents for the European market (EP15726156.1), and for the North-American market (FR1455042) respectively. Various papers outlining the potentialities of our approach have been published [342], [343], [348], [336].

Today, each large city of France hosts its dedicated Charging Service Operator (CSO) to manage its EV charging infrastructures. In the context of the Greenfeed project, we have considered the case of electro-mobility service providers (EMSP). An EMSP can be viewed as a technical and business intermediator between independent CSOs operating in distinct cities. It offers charging services at a national or international scale. We have contributed to the design and performance evaluation of pricing strategies aiming at a fair and efficient share of the revenues between different CSOs operating in competition. Game theory has been extensively used for that purpose [334], [340]. Our research activities have been mainly focused in two directions: the design of innovative scheduling charging strategies optimizing energy consumption and the design of pricing strategies for EMSPs.

8.2.5 Scientific Highlights:

- Organization of Workshops and Conferences
  - ACM SIGCOMM Reproducibility (Workshop Organisation) 2017 [275]
  - WiOpt 2017 (General chairing)
  - ANR NETLEARN Workshop on Learning and Networks, 2015.
  - TMA PhD School'18 IFIP Network Traffic Measurement and Analysis Conference, 2018, Vienna, Austria (co-Chairing)
  - IFIP TMA'18 IFIP Network Traffic Measurement and Analysis Conference, June 2018, Vienna, Austria (Sponsorship Chairing)
  - ACM SIGCOMM PhD School on TMA, 4th PhD School on Traffic Monitoring and Analysis, London, UK, 14-16 April 2014 (General Chairing)
- Steering Committees
  - The International Teletraffic Conference Steering committee, 2014 onward
  - ACM SIGCOMM AINTEC Steering committee, 2015 onward
  - IEEE Reliable Networks Design and Modeling (RNDM) conference Steering committee, 2015
  - IEEE High Performance Switching and Routing Steering committee, 2015
- Program Chair of Workshops or Conferences

  - WiOpt 2017, TPC co-chairing
  - MEDHOCNET 2017, TPC chairing
  - GAMENETS 2018, TPC chairing
  - ITC29, 29th ITC conference 2017, Area Chairing
  - ACM SIGCOMM - 3rd ACM Conference on Information-Centric Networking (ICN 2016) 2016, TPC Chairing
  - ACM AINTEC - 10th Asian Internet Engineering Conference (AINTEC) held in cooperation with ACM SIGCOMM, 2014 TPC Chairing
- Associate editors of journals
  - IEEE/ACM Transactions on Networking
  - Elsevier Computer Networks Journal
  - IEEE Transactions on Green Communications and Networking
  - IEEE Journal on Selected Areas in Communications (Associate Editor for Green Communications and Networking Series)
  - IEEE Transactions on Networks and Service Management
- Awards
  - Best dataset award at PAM 2018[352]
  - Best Paper Award in the IEEE International Conference on Smart Grid Communications 2017, Dresden, Germany [332]
  - Best Paper Award in the IEEE Conference on Network Function Virtualization and Software Defined Networks 2016, Palo-Alto, USA [364]
  - Best paper award in the IEEE Design of Reliable Communications Networks (DRCN-2016) Conference, Paris-France [335]
  - Best Paper Award recipient of the IEEE ComsSoc/ISOC Internet Technical Committee, 2016-2017
  - Best paper of the ACM SIGCOMM Internet-QoE workshop (2016)[354]
  - Best paper award at the 6th International Workshop on TRaffic Analysis and Characterization(TRAC 2015)[355]
  - Best paper award IEEE ICT conference 2014, Lisbon, Portugal [376]
  - Runner-up for best paper award at the 25th International Teletraffic Congress (ITC 2013) [358]
  - Phd Thesis : 1st prize "GTTI Award" (Enrico Bocchi, 2017).
  - Phd Thesis : 2nd prize "Prix de thèse de la Fondation Mines - Télécom" (Amal Ellouze, 2017).
  - Phd Thesis : 1st prize "Prix de thèse de la Fondation Mines - Télécom" (Anaïs Vergne, 2014)
  - IBM Faculty Award (Gagnaire Maurice, 2015)
  - Receipient of the IETF Applied Network Research Prize (Dario Rossi, 2016)
  - ACM Senior member (Dario Rossi, 2015)
  - Receipient of the Google Faculty Research Award (Dario Rossi, 2015)
  - Finalist at the IEEE INFOCOM Innovation Challenge (Enrico Bocchi, 2016)
  - MSc thesis - 2nd prize of IEEE ComSoc (Danilo Cicalese, 2016)
  - Distinguished Member of the IEEE INFOCOM TPC (Dario Rossi, 2015, 2016 and 2017)
  - HIJACK-2 team won the CAIDA BGP hackaton (Danilo Cicalese, 2016)
- Significant Contracts with Industrials, Chairs

- NewNet@Paris Chair funded by Cisco`https://newnet.telecom-paristech.fr`. The chair organized around three main pillars:

  Research: lay out new solid scientific basis for this new dawn of the network, as well as to build and innovate on its top.

  Teaching: to educate the new generation of leaders, managers and engineers, in the context of their research and innovation work and beyond.

  International development: to disseminate these theories and experience to the scientific and industrial communities, and more broadly to the international public at large.

- LTE4PMR projects is a FUI project funded by BPI France. It involves the major stakeholders specialized in space and public safety communications. This project is devoted to the design of a new 4G/5G standard for public safety communications in France.
- LCI4D is a FUI project aiming at developing local 4G operators in developing countries.
- OPUS is a FUI project aiming at improving the transmission of multimedia contents over auto-organised wireless networks. It relies on new and annovative technologies such as recent video standards (HEVC) and network coding techniques to optimise the transmission of multimedia content in lossy and constrained wireless environments.
- NETLEARN is a ANR project aiming at showing the benefits of learning and game theory in networks.
- LISP-Lab is an ANR project aiming with a strong experimental aspect demonstrating the potential benefits of the LISP architecture.
- REFLEXION

- Common Lab with Industrial/Universities

  - **SEIDO Lab** The power grid has been organized in a centralized architecture connecting thousands of consumers to a few large production centers. Tomorrow, it will integrate more and more multiple renewable and sporadic energy sources and will handle a growing proportion of decentralized micro-production units. End-users are also expected to become active consumers managing and even producing their own energy ("prosumers"). The power grid needs to adapt to these evolutions. Telecom ParisTech and EDF R&D have created since 2012 SEIDO Lab as a joint laboratory dedicated to the Internet of things and cybersecurity, and to their utilization in the power grid to overcome the challenges arising from the advent of smart grids. In 2016, it has been decided to renew SEIDO Lab for another five years and to associate new partners, namely CNRS LASS and Télécom SudParis as well as Department Comelec; but also to sign a framework contract between EDF, Telecom Paristech, and Telecom Sud Paris enabling a large cooperation between these three organizations.
  - **LINCS** The LINCS (Laboratory for Information, Networking and Communication Sciences) is a joint research and innovation lab created as a partnership between Alcatel-Lucent Bell Labs France (ALU), Inria (INRIA), Institut Mines-Telecom (IMT), SystemX (SX) and Université Pierre et Marie Curie (UPMC).

    The main objective of the LINCS is to create knowledge and value by promoting and facilitating synergies and collaboration between academia and industry, facilitating the transfer between both worlds as an accelerator of the innovation chain.

    The main organization principles are based on the co-location in the same premises of researchers and experts from all the partners (full or partial time) together with high level invited experts from all over the world (around 20 invited researches, from main Universities like, for 2017, Berkeley, EPFL, Max Plank, Princeton, Stanford, and Technion, among others), providing an eco-system that facilitates reaching the cited general objectives. SystemX as a cluster brought to the LINCS researchers from Orange and Cisco. The methodology combines fundamental and experimental approaches, the high level competences in both research approaches is one of the key differentiators of the LINCS.

LINCS organizes every year a weekly seminar with invited researchers from all over the world, 3 workshops on various topics for motivating collaboration internally and with external organizations, as well as other activities. As an example of LINCS' outcomes, the number of joint publications (2 or more partners involved) has grown exponentially following the creation of the Lab. and LINCS has been recognized as a key international player in topics like Content Centric Networks. LINCS will host an ERC allocated to Prof. François Beccelli, covering in particular future wireless networks, starting in January 1st, 2019..

8.3 SWOT analysis

8.3.1 Strength

- Strong expertise in mathematical modeling and algorithm design applied to networking
- Strong expertise in Architecture and protocol design
- Strong expertise in Network measurements and metrology
- Participation and contribution in standardization bodies
- Tight Cooperation with the major industrial stakeholders of the field and transfer to industry
- Involvement in major research and academic platforms
- Several solid international cooperations (Joint lab agreement with NCRL/Nanjing)

8.3.2 Weakness

- Lack of permanent research engineering staff to support long term development of research projects and platforms.

8.3.3 Opportunities

- NewUni will ease cooperation with historical partners such as LiX
- Complementary of NewUni research teams will create positive synergies to address new challenges.

8.3.4 Threats

- Difficulty of transfer to Palaiseau of existing research platforms
- UPSAy and NewUni duality. Need to carry on existing collaborations with other Upsay partners, even while we quit UpSay.

8.4 Scientific project for the the next five years

8.4.1 Protocol and architecture design

SDN and NFV in the upcoming 5G

Future access networks aim at providing very low latency and personalized network services, especially context-based, as well as highly flexible and efficient use of resources. Based on virtualization, it also aims at making flexible and agile management of services possible (eg video analytics, augmented reality, video customization, etc.), content (eg, based on location) and resources (calculation, storage network). ETSI's Multi-Access Edge Computing (MEC) group structures this approach, including early architectural elements. H2020 5G research projects have also begun to address this topic.

To this end, it is important to explore the combination of MEC and NFV approaches in order to provide massively distributed services to the closest users in a flexible, resource efficient and resilient way.

Aircrafts' Networking

The aviation industry is nowadays looking at and adopting the IP technology for current and especially future aircrafts. The aviation environment, from a network perspective is quite peculiar. On the one hand, the overall network is based on a plethora of lower layers' technology ranging from optic fiber, to WiFi and Ethernet, but also PLC (Power-Line Communication) and real-time deterministic networks. On the other hand, different physical networks serve different purposes, hence, having different requirements and needing to be segregated and secured. All in all, it represents a pretty fragmented environment, where every fragment tackles robustness, resiliency, and performance independently from each other, leading to replication of functionalities as well as useless duplicated functions.

The SDN technology may help in coping with the above challenges by providing an easily adaptable management substrate, additionally providing a future proof solution, easy to enhance, extend and improve. However, deployments of current SDN networks are centralized at the level of a "controller". If this centralization is desired, as in a data center for example, it is not adapted for all deployment cases. For sure it is not adapted to an aviation environment, where the scale is smaller, the services are limited in number, but robustness and resiliency are of paramount importance.

Beyond 5G Initiative

As the standardization of 5G has already started, several research initiatives are currently launched in leading international universities and companies for the definition of beyond 5G networks. The group is involved in the structuration of this research in Paris-Saclay. This 'Beyond 5G Initiative' project is led by CentraleSupelec and Telecom ParisTech and is expected to be launched in 2018. Some faculty members of the group are directly involved in the gouvernance of the project. Its aim is to gather all the teams of Paris-Saclay working on next generation networks (143 researchers from 12 labs and 8 institutions) and to organize/structure research efforts in this domain. Its scientific objective is to design, develop, evaluate algorithms, technologies and architectures for future communication networks, focusing on upstream research in partnership with industrial partners (Nokia, Thal‘es, Orange).

8.4.2 Modeling and Algorithms design

AI revolution and impact on future networks technologies design

The rapid development of AI will have strong impacts in the design of many algorithms used in current networking technologies. In mobile communications, handover algorithms can benefit from AI to design more performant and more proactive algorithms taking into account user mobility. New radio resource algorithms taking into account the evolution of traffic patterns can also be envisioned. In IP networks, there is an on-going trend towards network automation and telemetry. AI algorithms can thus be easily integrated into networking management and control planes to detect anomalies and variations, adapt the network configuration and topology automatically to these events, etc.

Stochastic geometry and optimal transport theory applications

Stochastic geometry has already been successfully applied to model the performances of mobiles networks. It is commonly used to model SINR distribution in downlink and uplink, network capacity and dimensioning process. Current models are not adapted for very high densities of users/sensors. With the development of very dense networks such as IoT or 5G, new models are

required to predict the performances of such new systems. New resource management strategies at the network level need to be specified to cope with higher density of users. Optimal transport theory based models can be designed to provide new cooperation schemes at the network level while integrating at the same time geometry and coverage constraints.

Stochastic and robust optimization applications in smart grids

Along with the increasing penetration of decentralized renewable resources (DER) in the medium- and low-voltage grid, utilities are increasingly taking advantage of the demand flexibility to maintain demand-supply equilibrium. These trends have led to the development of new concepts such as home energy management system (HEMS) and neighborhood energy management system (NEMS). However, most developed approaches do not take into account the uncertainties of loads and intermittent renewables (e.g. photovoltaic panels, wind turbines). In the context of smart grids, stochastic and robust optimization methods can be applied in order to provide reliable solutions for demand side management under load and production uncertainties.

8.4.3 Experimental platforms and testbeds

Evolution of FIT Equipex towards SILECS platform

FIT Equipex will evolve from a national testbed to an international testbed named SILECS (ESFRI European project). It will integrate new IoT technologies such as LORA/SigFox, NB-IoT and 5G air interfaces. It will also provide integration with NFV/SDN servers in order to provide a full integrated IoT systems for experimentation purposes.

Design of future IoT application testbeds

Research on future IoT require implementation of practical testbeds that can be used to implement designed algorithms and acquire experimental results. This includes new application of embedded hardware/software platforms that will be used to emulate specific service scenarios in IoT applications. Using such IoT platforms triggers experimental studies of heterogeneity in the case of co-existence of present and future Wi-Fi (IEEE 802.11ac, ax), Bluetooth (LE, mesh), and Sensor networks (802.15.4), as well as their interoperation with existing cloud platforms such as AWS and Azure. These testbeds can also be used for various examples of protocol testing, one future example being an on-board design and experimentation of network security protocols such as data fragmentation and distributed authentication on sensor testbeds such as FIT/IoT-Lab and future microcontrollers.

HARVEST collaborative Chaire on on digital agriculture

Our group is heavily involved in the creation of the HARVEST research Chaire, initiated by both Agro Paristech and Telecom Paristech. It benefits from the financial and technical support of "Terres Inovia" and "Interchanvre", non-profit French organizations assembling major French actors in the field of research and development for vegetable oils, proteins and hemp. The goal of the chair is to develop interdisciplinary projects between agriculture and digital data processing. Expert researchers from the Networks and Computer Science department and the Image, Data and Signal department of Telecom Paristech will be involved in this new chaire. Telecom Paristech will contribute to the chair introducing innovative technologies, ranging from sensor networks, radio-mobile networks, data analytics, signal processing and Cloud computing.

8.5 Scientific production (selection)

Articles in Journals

[275] Damien Saucez and Luigi Iannone. Thoughts and Recommendations from the ACM SIGCOMM 2017 Reproducibility Workshop. In *ACM SIGCOMM Computer Communication Review (CCR), ISSN 0146-4833*. 2018.

[276] Th. Bonald and J. Roberts. Enhanced cluster computing performance through proportional fairness. *Performance Evaluation*, 79:134–145, September 2014.

[277] Th. Bonald, D. Cuda, R.-M. Indre, and L. Noirie. Building optical packet networks without buffering, signalling or header processing. *Journal of Optical Communications and Networking*, January 2013.

[278] A. Bianco, Th. Bonald, D. Cuda, and R.-M. Indre. Cost, power consumption and performance evaluation of metro networks. *Journal of Optical Communications and Networking*, 5(1):81–91, January 2013.

[279] M. Touati, R. Elazouzi, M. Coupechoux, E. Altman, and J.-M. Kélif. A controlled matching game for wlans. *IEEE Journal on Selected Areas in Communications, Special Issue on Game Theory for Networks*, 35(3):1–14, March 2017.

[280] A. Chattopadhyay, A. Sinha, M. Coupechoux, and A. Kumar. Deploy-as-you-go wireless relay placement: An optimal sequential decision approach using the multi-relay channel model. *IEEE Transactions on Mobile Computing*, 16(2):341–354, February 2017.

[777] M. Minelli, M. Ma, M. Coupechoux, J.-M. Kélif, M. Sigelle, and Ph. Godlewski. Uplink energy-delay trade-off under optimized relay placement in cellular networks. *IEEE Transactions on Mobile Computing*, 15(9):2376–2387, September 2016.

[282] M. S. Ali, P. Coucheney, and M. Coupechoux. Load balancing in heterogeneous networks based on distributed learning in near-potential games. *IEEE Transactions on Wireless Communications*, 15 (7):5046–5059, July 2016.

[800] M. Minelli, M. Ma, M. Coupechoux, J.-M. Kélif, M. Sigelle, and Ph. Godlewski. Optimal relay placement in cellular networks. *IEEE Transactions on Wireless Communications*, 13(2):998–1009, February 2014.

[284] A. Haddad and M. Gagnaire. Optimized radio-over-fiber-based cellular backhauling strategy using genetic algorithms and pareto fronts. *Telecommunication systems (Springer)*, March 2015.

[285] R. Aoun, E. A. Doumith, M. Gagnaire, and et al. Towards an optimized abstracted topology design in cloud environment. *Elsevier Future Generation Computer Systems (FGCS)*, 29(1):46–60, January 2013.

[286] F. Baccelli and A. Giovanidis. A stochastic geometry framework for analyzing pairwise-cooperative cellular networks. *IEEE Trans. on Wireless Communications*, 14(2):794–808, February 2015.

[287] P. Bae, K.-W. Lim, W.-S. Jung, and Y.-B. Ko. Practical implementation of m4 for web visualization service. *Journal of Communications and Networks*, 19(4):384–391, August 2017.

[288] L. Decreusefond, I. Flint, and A. Vergne. A note on the simulation of the ginibre point process. *Journal of Applied Probability*, 52(4), October 2015.

[289] A. Araldo, G. Dan, and D. Rossi. Caching encrypted content via stochastic cache partitioning. *IEEE/ACM Transactions on Networking*, 26(1):548–561, January 2018.

[290] J. Samain, G. Carofiglio, L. Muscariello, M. Papalini, M. Sardara, M. Tortelli, and D. Rossi. Dynamic adaptive video streaming: Towards a systematic comparison of icn and tcp/ip. *IEEE Transactions on Multimedia*, 19(10):2166–2181, October 2017.

[291] D. Cicalese, D. Joumblatt, D. Rossi, J. Augé, M.-O. Buob, and T. Friedman. Latency-based anycast geolocalization: Algorithms, software and datasets . *IEEE Journal on Selected Areas of Communications,*, 34(6):1889–1903, June 2016.

[292] A. Araldo, D. Rossi, and F. Martignon. Cost-aware caching: Caching more (costly items) for less (isps operational expenditures). *IEEE Transactions on Parallel and Distributed Systems*, February 2015.

[293] L. D. Alvarez-Corrales, A. Giovanidis, Ph. Martins, and L. Decreusefond. Analysis of static cellular cooperation between mutually nearest neighboring nodes. *Transactions on Mobile Computing*, 2016.

[294] A. Vergne, L. Decreusefond, and Ph. Martins. Simplicial homology for future cellular networks. *IEEE Transactions on Mobile Computing*, 14(8):1712–1725, August 2015.

[295] F. Yan, A. Vergne, Ph. Martins, and L. Decreusefond. Homology-based distributed coverage hole detection in wireless sensor networks. *IEEE/ACM Transactions on Networking*, 23(6):1705–1718, June 2015.

[296] L. Decreusefond, Ph. Martins, and F. Yan. Accuracy of homology based coverage hole detection

for wireless sensor networks on sphere. *IEEE Transactions on Wireless Communications*, 13(7): 3583–3595, July 2014.

Books

[297] Marceau Coupechoux and Philippe Martins. *Vers les systèmes radiomobiles de 4e génération - De l'UMTS au LTE.* Collection IRIS. Springer, 2013. ISBN 978-2-8178-0084-4. doi: 10.1007/978-2-8178-0085-1.

Book Chapters

[298] Damien Saucez, Luigi Iannone, Albert Cabellos, and Florin Coras. *LISP Impact.* RFC 7834. Internet Engineering Task Force - (IETF), April 2016.

[299] Damien Saucez, Luigi Iannone, and Olivier Bonaventure. *LISP Threats Analysis.* RFC 7835. Internet Engineering Task Force - (IETF), April 2016.

[300] M. Coupechoux, I. Davydov, and S. Iellamo. Tabu search heuristic for competitive base station location problem. In G. Pflug G. Tragler K. Doerner, I. Ljubic, editor, *Operations Research Proceedings 2015*, pages 325–330. Springer, Vienna, Austria, March 2017.

[301] C. Chaudet and Y. Haddad. Software defined mobile networks (sdmn): Beyond lte network architecture. chapter Wireless Software Defined Networking, pages 45–60. Wiley, 2015.

[302] M. Gagnaire. Fiber-wireless convergence in next-generation communications networks. chapter 4: Analog and Digitized Radio-over-Fiber, pages 99–126. Springer-International Publishing, Cham, Switzerland, 2017.

Articles in Conference Proceedings

[303] Yue Li, Damien Saucez Luigi Iannone, and Benoit Donnet. Stability and Consistency of the LISP Pull Routing Architecture. In *10th IEEE Workshop on Network Measurements (WNM'16)*, Dubai (UAE), November 2016.

[304] Yue Li, Akram Abouseif, Luigi Iannone, and Damien Saucez. LISP-Views: Monitoring LISP at Large Scale. In *29th International Teletraffic Conference (ITC 29)*, Genova (IT), September 2017.

[305] Yimeng Zhao, Luigi Iannone, and Michel Riguidel. On the performance of sdn controllers: A reality check. In *Network Function Virtualization and Software Defined Network (NFV-SDN), 2015 IEEE Conference on*, pages 79–85. IEEE, 2015.

[306] N. Abbas, Th. Bonald, and B. Sayrac. Mobility-aware scheduler in comp systems. In *PIMRC*, Valencia, Spain, September 2016.

[307] Th. Bonald and J. Roberts. Multi-resource fairness: Objectives, algorithms and performance. In *ACM Sigmetrics*, Portland, United states, 2015.

[308] Thomas Bonald, James Roberts, and Christian Vitale. Convergence to multi-resource fairness under end-to-end window control. In *IEEE INFOCOM*, Proceedings of IEEE INFOCOM, Atlanta, United States, 2017.

[309] N. Abbas, Th. Bonald, and B. Sayrac. How mobility impacts the performance of inter-cell coordination in cellular data networks. In *Globecom*, San Diego, United states, 2015.

[310] N. Benzaoui, Y. Pointurier, Th. Bonald, B. Uscumlic, Q. Wei, and S. Bigo. Mobility support in optical slot switching-based next-generation mobile backhaul networks. In *ECOC*, Valencia, Spain, 2015.

[311] A. Khlass, Th. Bonald, and S.-E. Elayoubi. Analytical modeling of downlink comp in lte-advanced. In *VTC*, Glasgow, United kingdom, 2015.

[312] N. Abbas, Th. Bonald, and B. Sayrac. Opportunistic gains of mobility in cellular data networks. In *WiOpt*, Bombay, India, 2015.

[313] A. Khlass, S. El Ayoubi, and Th. Bonald. Multi-flow transmission and carrier aggregation interoperation in hspa+ advanced. In *Vehicular Technology Conference*, pages 1–5, Vancouver, Canada, September 2014. IEEE.

[314] A. Khlass, Th. Bonald, and S. El Ayoubi. Flow-level modeling of multi-user beamforming in mobile networks. In *Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt), 2014 12th International Symposium on*, pages 70–77, Hammamet , Tunisia, May 2014.

[315] P. Delesques, Th. Bonald, G. Froc, Ph. Ciblat, and C. Ware. Analyse de performances d'un commutateur de bursts optiques à mémoire électronique partagée. In *Journées nationales d'optique guidée ({JNOG})*, number 179, Villetaneuse, France, July 2013. Poster.

[316] Th. Bonald, A. Khlass, and S. El Ayoubi. Flow-level performance of intra-site coordination in cellular networks. In *WiOpt*, volume 1, pages 1–8, Tsukuba, Japan, May 2013.

[454] P. Delesques, Th. Bonald, G. Froc, Ph. Ciblat, and C. Ware. Enhancement of an optical burst switch with shared electronic buffers. In *International Conference on Optical Networking Design and Modeling (ONDM)*, pages 136–141, Brest, France, April 2013. Poster.

[318] Th. Bonald, S. El Ayoubi, and A. Khlass. Capacity gains from multipoint single frequency transmission in hspa+. In *WCNC*, April 2013.

[319] H. Baccouch, P.-L. Ageneau, N. Tizon, N. Boukhatem, and Th. M. T. Nguyen. Bounded network coding redundancy for multi-layer video streaming. In *IWCMC*, Valencia, Spain, June 2017.

[320] P.-L. Ageneau, N. Boukhatem, and M. Gerla. Constraint-aware multi-path intra-flow network coding in wireless mesh networks. In *IWCMC 2017*, Valencia, Spain, June 2017.

[321] P.-L. Ageneau, N. Boukhatem, and M. Gerla. Practical random linear coding for multi-path tcp : Mpc-tcp. In *ICT 2017*, Cyprus, May 2017.

[322] H. Baccouch, P.-L. Ageneau, N. Tizon, and N. Boukhatem. Network coding schemes for multi-layer video streaming on multi-hop wireless networks. In *WCNC*, San Francisco, USA, March 2017.

[323] H. Baccouch, P.-L. Ageneau, N. Tizon, and N. Boukhatem. Prioritized network coding scheme for multi-layer video streaming. In *CCNC*, Las Vegas, USA, January 2017.

[324] H. Baccouch, P.-L. Ageneau, and N. Boukhatem. Adaptive redundancy scheme for scalable video traffic using network coding. In *NOF*, BUZIOS, Brésil, November 2016.

[325] P.-L. Ageneau, Ch. Wu, N. Boukhatem, and M. Gerla. Redundancy adaptation for multi-path intra-flow network coding in wireless mesh networks. In *VTC Fall 2016*, Montréal, September 2016.

[326] P.-L. Ageneau and N. Boukhatem. Multi-path tcp over network coding for wireless networks. In *IEEE CCNC 2016*, Las Vegas, January 2016.

[327] N. Boukhatem, Th. M. T. Nguyen, and Th. V. Vu. Dynamic coding for tcp transmission reliability in multi-hop wireless networks. In *WoWMoM 2014*, Sydney, Australie, June 2014.

[328] P.-L. Ageneau, N. Boukhatem, and M. Gerla. Fairness evaluation of pipeline coded and non coded tcp flows. In *Communications (ICC), 2014 IEEE International Conference on*, pages 2754–2760, Sydney, Australia, June 2014. IEEE.

[329] Th. V. Vu, N. Boukhatem, and Th. M. T. Nguyen. Adaptive redundancy control with network coding in multi-hop wireless networks. In *IEEE WCNC'13*, Chine, January 2013.

[330] M. Obadia, M. Bouet, J. Leguay, L. Iannone, and K. Phemius. Failover mechanisms for distributed sdn controllers. In *1st Workshop on Smart Cloud Networks and Systems*, Paris (France), December 2014.

[331] A. Singh Bedi, K. Rejawat, and M. Coupechoux. An online approach to d2d trajectory utility maximization problem. In *IEEE International Conference on Computer Communications (INFOCOM)*, pages 1–9, Honolulu, USA, April 2018.

[332] J. Horta, D. Kofman, D. Menga, and A. Silva. Novel market approach for locally balancing renewable energy production and flexible demand. In *IEEE International Conference on Smart Grid Communications (SmartGridComm)*, Dresden, Germany, October 2017.

[333] M. S. Ali, P. Coucheney, and M. Coupechoux. Optimal distributed channel assignment in d2d networks using learning in noisy potential games. In *IEEE Infocom 5G & Beyond Workshop*, pages 1–6, Atlanta, US, May 2017.

[334] I. Amigo and M. Gagnaire. Electric vehicle recharge pricing under competition, a game theoretic approach. In *ENERGYCON*, Leuven, Belgium, April 2016. Leuven University.

[335] A. Fressancourt, C. Pelsser, and M. Gagnaire. Kumori: Steering cloud traffic at ixps to improve resiliency. In *12th International Conference on the Design of Reliable Communication Networks (DRCN)*, Paris, France, February 2016. IEEE Communications Society.

[336] M. Alvarado-Ruiz, F. Abi Abdallah, and M. Gagnaire. Minimum driving distance warranty for ev charging over public lighting systems. In *IEEE International Conference on Computer as a Tool (EUROCON)*, pages 1–6, Salamanca, Spain, September 2015.

[337] M. Bakri, M. Koubaa, A. Bouallegue, and M. Gagnaire. A two-stage qot-aware protection procedure for dependable connection establishment in survivable srlg-constrained wdm translucent networks. In *7th IEEE International Workshop on Reliable Networks Design and Modeling (RNDM)*, Munich-Germany, October 2015. IEEE.

[338] M. Bakri, M. Koubaa, A. Bouallegue, and M. Gagnaire. An integrated qot-aware traffic grooming heuristic for multi-granularity d-connection establishment in survivable srlg-constrained translucent networks. In *IEEE Conference on Wireless and Optical Communications Networks (WOCN)*, (Bengalore, India), September 2015. IEEE.

[339] M. Gagnaire and A. Ellouze. Toward an optimized servers placement for mobile applications offloading. In *IEEE International Conference on Ubiquitous Wireless Broadband (ICUWB)*, Montreal, February 2015. IEEE.

[340] I. Amigo and M. Gagnaire. Online electric vehicle recharge scheduling under different e-mobility operator's pricing models. In *IEEE Symposium on Computers and Communication (ISCC)*, Larnaca, Cyprus, February 2015. IEEE.

[341] A. Fressancourt and M. Gagnaire. A sdn-based network architecture for cloud resiliency. In *12th Annual IEEE Consumer Communications and Networking Conference (CCNC)*, Las Vegas-Nevada USA, January 2015. IEEE.

[342] M. Alvarado-Ruiz, F. Abi Abdallah, and M. Gagnaire. Improving energy distribution for ev charging over public lighting systems. In *IEEE International Conference on Connected Vehicles and Expo (ICCVE)*, pages 408–415, Vienna, Austria, November 2014.

[343] M. Alvarado-Ruiz, F. Abi Abdallah, and M. Gagnaire. On-line scheduling policies for electric vehicle charging over public lighting systems. In *IEEE International Electric Vehicle Conference (IEVC)*, pages 1–8, Florence, Italy, December 2014.

[344] B. El Zant, I. Amigo, and M. Gagnaire. Game theoretic approaches for revenue sharing in federated cloud. In *Cloud Networking (CloudNet), 2014 IEEE 3rd International Conference on*, pages 300–306, Luxembourg, October 2014.

[345] A. Fressancourt and M. Gagnaire. A dynamic offer/answer mechanism encompassing tcp variants in heterogeneous environments. In *International Conference on Advanced Networking Distributed Systems and Applications (INDS)*, volume 1, pages 7–12, Béjaia, June 2014. IEEE.

[346] F. Diaz, S. Al Zahr, M. Gagnaire, J.-P. Laisné, and I. J. Marshall. Compatibleone: Bringing cloud as a commodity. In *IEEE International Conference on Cloud Engineering*, pages 397–402, Boston (USA), March 2014. IEEE.

[347] I. Amigo, B. El Zant, and M. Gagnaire. Federation and revenue sharing in cloud computing environment. In *Cloud Engineering (IC2E), 2014 IEEE International Conference on*, pages 446–451, March 2014.

[348] M. Alvarado-Ruiz, F. Abi Abdallah, M. Gagnaire, and Y. Lascaux. Telewatt: An innovative electric vehicle charging infrastructure over public lighting systems. In *IEEE International Conference on Connected Vehicles and Expo (ICCVE)*, pages 741–746, Las Vegas, NV, USA, April 2013.

[349] F. Diaz, S. Al Zahr, and M. Gagnaire. An exact placement approach for optimizing cost and recovery time under faulty multi-cloud environments. In *IEEE International Conference on Cloud Computing Technology and Science*, pages 138–143, Bristol (UK), December 2013. IEEE.

[350] F. Diaz, M. Gagnaire, and et al. Cosched: A scheduling agent maximizing cloud broker's revenues under the compatibleone architecture. In *IEEE ISPA conference*, Melbourne-Australia, October 2013.

[351] F. Diaz and M. Gagnaire. Cloud brokering placement: Taxonomy and survey. In *IEEE Network of the Future 2013.*, Pohang, South Korea, October 2013. IEEE.

[352] Th. Green, A. Lambert, C. Pelsser, and D. Rossi. Leveraging inter-domain stability for bgp dynamics analysis. In *International Conference on Passive and Active Network Measurement (PAM)*, Berlin, Germany, March 2018.

[353] D. Cicalese, J. Augé, D. Joumblatt, T. Friedman, and D. Rossi. Characterizing ipv4 anycast adoption and deployment. In *ACM CoNEXT*, Heidelberg, Germany, December 2015.

[354] Enrico Bocchi, Luca De Cicco, and Dario Rossi. Measuring the quality of experience of web users. In *ACM SIGCOMM Workshop on QoE-based Analysis and Management of Data Communication Networks (Internet-QoE 2016), selected as best paper in the workshop for reprint in ACM SIGCOMM Comput. Commun. Rev.*, Aug 2016.

[355] E. Bocchi, A. Safari, S. Traverso, A. Finamore, V. Di Gennaro, M. Mellia, M. Munafo, and D. Rossi. Impact of carrier-grade nat on web browsing. In *6th International Workshop on TRaffic Analysis and Characterization (TRAC)*, pages 532–537, Dubrovnik, Croatia, August 2015.

[356] G. Rossini and D. Rossi. Coupling caching and forwarding: Benefits, analysis, and implementation. In *ACM SIGCOMM Conference on Information-Centric Networking (ICN-2014)*, pages 127–136, Paris, France, September 2014.

[357] G. Rossini, D. Rossi, M. Garetto, and E. Leonardi. Multi-terabyte and multi-gbps information centric routers. In *IEEE INFOCOM*, pages 1–9, Toronto, Canada, April 2014.

[358] Y. Gong, D. Rossi, and E. Leonardi. Modeling the interdependency of low-priority congestion control and active queue management. In *25th International Teletraffic Congress (ITC25)*, Shanghai, China, September 2013.

[359] R. Chiocchetti, D. Rossi, and G. Rossini. ccnsim: an highly scalable ccn simulator. In *IEEE International Conference on Communications (ICC)*, pages –, Budapest, Hungary, June 2013.

[360] R. Sorokin, J.-L. Rougier, P.-V. Ricardo, and T. Nicolas. Impact of cpu load on video conferencing quality. In *Principles, Systems and Applications of IP Telecommunications (IPTComm)*, volume 2017, Chicago, IL, USA, September 2017. IEEE.

[361] S. Wenqin, J.-L. Rougier, A. Paris, F. Devienne, and M. Viste. One-to-one matching of rtt and path changes. In *Teletraffic Congress (ITC 29), 2017 29th International*, Genoa, Italy, September 2017.

[362] G. Ruty, A. Surcouf, and J.-L. Rougier. Collapsing the layers: 6stor, a scalable and ipv6-centric distributed storage system. In *Software Defined Systems (SDS), 2017 Fourth International Conference on*, Valencia, Spain, May 2017.

[363] S. Wenqin, J.-L. Rougier, F. Devienne, and M. Viste. Missing measurements on ripe atlas. In *CoNEXT Student Workshop 2016*, Irvine, California, USA, December 2016.

[364] M. Obadia, J.-L. Rougier, L. Iannone, V. Conan, and M. Bouet. Revisiting nfv orchestration with routing games. In *Network Function Virtualization and Software Defined Networks (NFV-SDN), IEEE Conference on*, Palo Alto, CA, USA, November 2016.

[365] M. Obadia, M. Bouet, V. Conan, L. Iannone, and J.-L. Rougier. Elastic network service provisioning with vnf auctioning. In *Teletraffic Congress (ITC 28), 2016 28th International*, Würzburg, Germany, September 2016.

[366] R. Sorokin and J.-L. Rougier. Video conference based on enterprise desktop grid. In *Telecommunications (ICT), 2016 23rd International Conference on*, Thessaloniki, Greece, May 2016.

[367] W. Shao, J.-L. Rougier, F. Devienne, and M. Viste. Improve round-trip time measurement quality via clustering in inter-domain traffic engineering. In *Network Operations and Management Symposium (NOMS), 2016 IEEE/IFIP*, Istanbul, Turkey, April 2016.

[368] W. Shao, L. Iannone, J.-L. Rougier, F. Devienne, and M. Viste. Scalable bgp prefix selection for effective inter-domain traffic engineering. In *Network Operations and Management Symposium (NOMS), 2016 IEEE/IFIP*, Istanbul, Turkey, April 2016.

[369] M. Obadia, M. Bouet, J.-L. Rougier, and L. Iannone. A greedy approach for minimizing sdn control overhead. In *Network Softwarization (NetSoft), 2015 1st IEEE Conference on*, London, UK, June 2015.

[370] X. Misseri, J.-L. Rougier, and S. Moretti. Auction-type framework for selling inter-domain paths. In *Network and Service Management (CNSM), 2013 9th International Conference on*, Zurich, Switzerland, October 2013.

[371] X. Misseri, I. Gojmerac, and J.-L. Rougier. Idrd: Enabling inter-domain route diversity. In *ICC 2013*, Budapest (Hungary), June 2013.

[372] S. Al Zahr, E. Doumith, and Ph. Forestier. Advanced demand response considering modular and deferrable loads under time-variable rates. In *IEEE Globecom*, Singapour, Singapour, December 2017.

[373] N.-K. Le, A. Vergne, Ph. Martins, and L. Decreusefond. Optimize wireless networks for energy saving by distributed computation of Čech complex. In *IEEE WiMob 2017*, Rome, Italy, October 2017.

[374] N.-K. Le, A.ıs. Vergne, Ph. Martins, and L. Decreusefond. Distributed simplicial homology based load balancing algorithm for cellular networks. In *IEEE VTC 2017 Fall*, Toronto, Canada, September 2017.

[375] N.-K. Le, Ph. Martins, L. Decreusefond, and A. Vergne. Simplicial homology based energy saving algorithms for wireless networks. In *IEEE ICC*, London, United kingdom, 2015.

[376] A. Vergne, I. Flint, L. Decreusefond, and Ph. Martins. Disaster recovery in wireless networks: A homology based algorithm. In *ICT 2014, best paper award*, Lisbon, Portugal, May 2014.

[377] A. Vergne, L. Decreusefond, and Ph. Martins. Reduction algorithm for simplicial complexes. In *IEEE INFOCOM*, pages 475–479, Turin, Italy, April 2013.

[378] F. Z. Kaddour, Ph. Martins, L. Decreusefond, E. Vivier, and L. Mroueh. Outage probability upper bound for multi-class qos in the uplink of lte networks. In *2013 IEEE Global Communications Conference, GLOBECOM 2013, Atlanta, GA, USA, December 9-13, 2013*, pages 4129–4134, Atlanta,USA, March 2013.

[379] R. Moalla, B. Lonc, H. Labiod, and N. Simoni. Civas: Towards a cooperative its vehicle application oriented security framework. In *IEEE Intelligent Vehicles Symposium (IEEE IV'2014)*, Dearborn, Michigan, June 2014.

Invited Talks

[380] Luigi Iannone. Locator/id separation protocol (lisp) tutorial. 70th RIPE Meeting, 2015.
[381] Thomas Bonald. Bandwidth sharing models for the internet. INFORMS Telecommunications Conference, 2014.
[382] Thomas Bonald. Resource sharing in data networks. Workshop on Stochastic Networks, 2014.

Patents

[383] Th. Bonald and A. Famulari. Procédé de traitement de données de géolocalisation. (PCT/EP2014/066206), February 2014.
[384] Th. Bonald, D. Cuda, and R.-M. Indre. Dispositif et procédé de fusion de composantes optiques associées à une longueur d'onde en une composante optique fusionnée. (EP 2549773 (A1)), January 2013.
[385] D. Perino, G. Carofiglio, D. Rossi, and G. Rossini. Device and method for organizing forwarding information in nodes of a content centric networking. (EPO13161714.4), June 2014.
[386] D. Rossi and G. Rossini. Method for managing packets in a network of information centric networking (icn) nodes . (EPO14305866.7), 2014.
[387] G. Rossini, D. Rossi, M. Garetto, and E. Leonardi. Information centric networking (icn) router. (Patent EPO14305639.8), 2014.
[388] S. Al Zahr, M. Rousselle, and Ph. Forestier. Procede de gestion d'un ensemble d'appareils consommateurs d'energie electrique, et module gestionnaire d'energie electrique. (1562001), June 2017.
[389] S. Al Zahr, Ph. Forestier, and M. Rousselle. Coordination de gestion de consommation d'énergie électrique. (1662727), December 2016.
[390] F. Abi Abdallah and M. Gagnaire. Procédé et dispositif de détermination de tensions et/ou de puissances disponibles dans un réseau électrique de recharge. (14455042), June 2014.

Part II

Detailed activities: Communications and Electronics

Chapter 9

C2S

Circuits and Communication Systems

9.1 Presentation of the team

Team leader: Patricia Desgreys (Professor, 07/13 – *now*), Patrick Loumeau (Professor, 01/13 – 06/13)

Faculty: Paul Chollet (AP, 12/17 – *now*), Patricia Desgreys (FP, 10/00 – *now*), Chadi Jabbour (AP, 05/15–*now*), Patrick Loumeau (FP, 10/76–01/18), Van Tam Nguyen (AP, 04/05–*now*), Hervé Petit (AP, 11/75 – 10/17)

Sabbatical Professors: José Ramon Garcia Oya (06/17 – 07/17), Yvon Savaria (07/14 – 12/14)

Permanent Research Engineers: Hussein Fakhoury (04/09 – 11/16), Dang Kien Germain Pham (11/17 – *now*)

PostDocs, non-permanent Research Engineers: Alexandre Asselin (10/14 – 10/15), Han Le Duc (01/16 – 01/17), Seyed Majid Homayouni (11/12 – 11/14), Chadi Jabbour (10/10 – 10/14), Venkata Narasimha Manyam (12/14 – 09/15), Minh Tien Nguyen (02/14 – 11/16), Thanh Nhan Nguyen (07/13 – 07/17), Dang Kien Germain Pham (01/13 – 01/14 & 04/15 – 10/17)

PhD Students: Hussein Fakhoury (09/13 – 12/14, Patrick Loumeau), Yosra Gargouri (09/14 – 11/17, Patrick Loumeau), Olivier Jamin (10/11 – 03/13, Patrick Loumeau), Gaël Kamdem De Teyou (09/12 – 08/15, Patrick Loumeau, Hervé Petit), Sandeep Kowlgi Srinivasan (10/08 – 04/13, Patrick Loumeau), Han Le Duc (12/12 – 12/15, Van Tam Nguyen, Patricia Desgreys), Mirko Maldari (03/17 – *now*, Patricia Desgreys), Venkata Narasimha Manyam (10/15–*now*, Patricia Desgreys), Arnaud Meyer (05/13–05/16, Patricia Desgreys, Hervé Petit), Minh Tien Nguyen (07/11 – 09/15, Van Tam Nguyen), Tuan Anh Nguyen (09/16 – *now*, Van Tam Nguyen), Dang-Kièn Pham (01/10 – 01/13, Patrick Loumeau), Duc Tuyen Ta (11/14 – *now*, Van Tam Nguyen), Kelly Tchambake (10/14 – *now*, Patricia Desgreys, Chadi Jabbour), Raphaël Vansebrouck (11/12 – 01/16, Patricia Desgreys, Chadi Jabbour)

Scientific Production Overview: Table 9.1 represents the overall scientific production between 2013 and 2018. The detailed bibliography is listed in the dedicated accompanying document

Journals	Articles in Proceedings	Books and Book Chapters	Patents	Keynotes and Tutorials	Other Invited Talks	Habilitation thesis	Completed PhD
21	44	2	1	1	3	1	10

Table 9.1: Overall Scientific Production

9.2 Research activities

The C2S team is devoted to the design of Radio-Frequency (RF) communication chips and is specialized in Analog-and-Mixed-Signal (AMS) interfaces for 5G and IoT Systems. It specifically concentrates on the critical interface between radio communication and digital processing, combining analog electronics efficiency with digital flexibility in optimal trade-offs.

Our historical expertise in AMS circuit design span Analog-to-Digital Converters (ADCs), receivers and samplers. For these sub-systems, we have designed solutions for the ever-increasing data rate demand while limiting power consumption. ASICs have been implemented in CMOS technology to demonstrate the efficiency of our solutions [part 1.2.1].

We have then broadened our theoretical approach with the development of new algorithms and digital processing dedicated to AMS systems performance. Our added-value lies in specific pre- and post-processing algorithms dedicated to the linearity improvement of AMS communication interface [part 1.2.2].

Recently, we have pushed further the concept towards "Smart" AMS Systems by developing Compressed Sensing (CS) algorithms and Cognitive Radio (CR) algorithms useful to drastically reduce the power consumption and to increase CR security [part 1.2.3].

9.2.1 High performance reconfigurable communication systems

High performance reconfigurable ADCs
One of the main expertise of the C2S team is the design of high performance reconfigurable ADCs. During the last five years, we have designed and taped out three ADCs in a CMOS 65 nm technology from ST-Microelectronics.

The first work is a general purpose Continuous-Time (CT) Delta Sigma($\Delta\Sigma$) ADC which was designed in the framework of European Projects ENIAC ARTEMOS and CATRENE CORTIF in collaboration with NXP-france (Fig **??** Left). Thanks to its reconfigurable bandwidth 10/20/40 MHz, its high resolution (>11 bits of Dynamic Range (DR)), its high linearity (>12 bits of measured Total harmonic distortion), its good power consumption (<100 mW of measured power consumption) and its inherent filtering, this ADC could target a diversity of applications such as Zigbee Moderator, DVB-T receivers and Bio-Medical Imaging. It is worth mentioning that the designed chip is midway between a lab prototype and a product since it integrates a digital decimation filter, a bandgap and several automatic calibrations for quantizer offset and integrator time-constants. The aforementioned functions are commonly performed off chip. Based on the very promising results of this work, our colleague Hussein Fakhoury founded SCALINX in 2015 as a spin-off of Telecom ParisTech.

The second work is being developed in the framework of the STAR project in collaboration with the Paris Observatory (LESIA). It targets the observations of long wavelength radio astronomy which need a receiver with a minimum DR of 120 dB over 100 MHz bandwidth. This extremely high DR is not achievable with one single ADC for the considered bandwidth. Currently, the European Space Agency satellites use a variable gain amplifier to cover all the DR. This solution consumes 1 W and takes 4 seconds for gain adjustment which leads to a very degraded temporal resolution. To overcome these problems, we proposed a new architecture based on stacked ADCs where the input signal is split into multipath, each with different gain amplifier before the ADC. The output signal is selected from the channel with the largest magnitude without saturation. The proposed architecture comprises four 60-dB ADCs preceded by gains of 0, 30, 60 and 90 dB. The architecture hence is able to track a 120 dB dynamic range with a Signal-to-Noise Ratio (SNR) higher than 30 dB. The STAR project is organized into two phases, the first which finished in February 2018 consisted in the design, the tapeout and the test of the amplifier chain [398] (Fig **??** Center). The measured results are aligned with the specifications. The second phase which started in parallel since june 2017 is the design of the full prototype. The complete solution is expected to consume 250 mW (150 mW for the amplifiers and 100 mW for the ADC) with a temporal resolution of 5 ns.

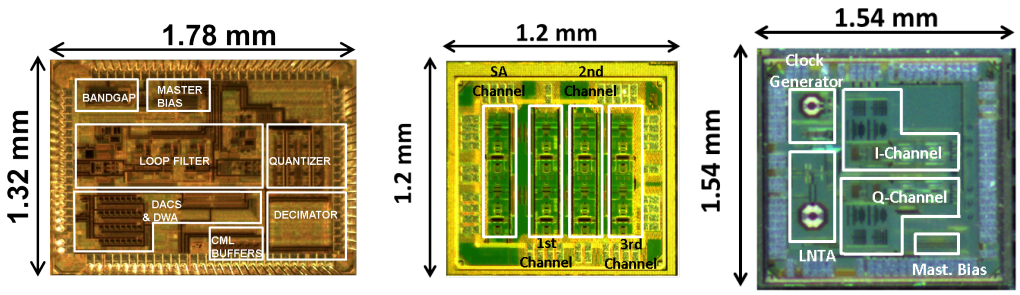

FIGURE 9.1: Left) General Purpose 5^{th} order $\Delta\Sigma$ CT ADC. Center)STAR receiver for astrophysical observations. Right) 0.4 - 6 GHz Direct $\Delta\Sigma$Receiver.

The third work is a novel architecture of ADC, called Multi-Stage Noise Band Cancellation (MSNBC), suited for digitizing the distorted output of Power Amplifiers (PA). This is a key step in the implementation of digital pre-distortion systems. It is becoming more and more challenging for new standards such as LTE and 5G since the ADC needs in practice to handle 5 times the signal bandwidth due to the non-linear terms with a resolution around 10 to 12 bits [403]. The MSNBC solution, which has been patented by the C2S team in 2011, can overcome this challenge thanks to a multi-band processing of the signal. In this architecture, a main channel digitizes the useful signal and adjacent channels digitize the power amplifiers non-linearities whose power is usually 30 to 50 dB lower than the main signal. This multi-band processing allows to adjust the resolution for each channel and as the multi-band decomposition uses an inherent property of $\Delta\Sigma$ modulators, it thus avoids using bulky power hungry filters [399]. Based on this idea, a multi-channel continuous time $\Delta\Sigma$ ADC has been designed and sent to fabrication in november 2017. The ADC uses a 2^{nd} order modulator for the main channel and a 4^{th} order modulator for the adjacent channels. Electrical simulation results showed that the Adjacent Channel Power Ratio (ACPR) of the PA could be improved from 40 dB to 60 dB for a LTE 20 MHz signal. This work has been carried out in the framework of project LIFLEX in collaboration with Centrale-Supelec.

Frequency-agile and reconfigurable receiver for Cognitive Radio System (CRS)
During the last few years, the C2S team has developed a research activity on a novel family of receivers, the Direct $\Delta\Sigma$ Receivers (DDSR). The specificity of these receivers is that in contrast to a conventional receiver in which the RF stages and the BaseBand (BB) stages are cascaded, a DDSR is a direct RF-to-digital receiver with RF feedback connecting the output BB stages to the RF stages. This RF feedback relaxes the linearity requirements of the RF amplifiers and also increases the $\Delta\Sigma$ modulator loop order. However, the RF feedback poses several challenges, especially making the design methodology more complex since the blocks of the DDSR receiver cannot be designed, analyzed, and simulated independently. To overcome this problem, the C2S team has developed a new design methodology suited for this family of receivers. The proposed methodology covers simulation approaches, system design, and non-ideality impacts on the receiver [393]. It has been used to propose several architectures suited for GSM, WCDMA and LTE standards in both continuous and discrete time. It was also used to design and tape-out in a CMOS 65 nm process a flexible 4^{th} order discrete time DDSR. Electrical post-layout simulations showed that the designed receiver achieves a Noise Figure of 9 dB, a Dynamic range of 77 dB for a conversion bandwidth of 20 MHz, a center frequency range of 0.4 to 6 GHz and an average power consumption of 40 mW (Fig **??** Right). If the measurements, which are planned for July 2018, confirm the electrical simulation results, this work would constitute an impressive improvement of the state of the art of DDSR both in terms of noise figure and frequency range.

Highly linear samplers for wideband ADC for military applications
Today, receivers for radar and electronic warfare systems need to operate with larger bandwidths

or at higher frequencies. Because of the limited bandwidth of common ADC, classical heterodyne receivers need numerous costly stages in order to down convert the upper frequency into baseband. A solution to cope with this problem is to directly transpose the signal into baseband using subsampling. This method allows to reduce the cost, the complexity and the size of receivers chains. In this context, in collaboration with Thales S.A., we realized a highly linear sample-and-hold circuit (THD of -39dB@20 GHz) in 130nm SiGe BiCMOS technology with a large bandwidth (>26GHz), which permits to use an ADC at its full dynamic range [404][400].

9.2.2 Digitally enhanced mixed signal systems

Digital pre-distortion

Digital correction techniques are increasingly used to correct imperfections in analog/mixed and RF circuits[403]. In particular, Digital PreDistortion (DPD) offers powerful solutions for correcting the power amplifiers (PA) at the transmitter. This correction has two beneficial effects on telecommunications systems: first, the power consumption of the equipment can be reduced because the efficiency of the PA can be improved; second, signal quality is better, allowing for finer spectrum management and higher communications rates. New challenges are emerging today for broadband systems. Indeed, the RF front-end transmitting and receiving circuits must cover bandwidths at least equal to five times the useful band in order to have a suitable correction.

The C2S team proposes new algorithms and architectures, at both system and circuit level, of power amplifier linearization minimizing implementation complexity and overall system consumption. The first contribution was done in collaboration with ESIEE in the framework of the IMT project REFLEX. In connection with the work on MSNBC ADCs, a new DPD architecture has been proposed using different quantization on each subband. This DPD architecture optimizes the design constraints of the ADCs of the feedback path. We have shown that by allocating sufficient resolution to adjacent bands, the resolution of the main band could be reduced by at least 2 bits, while maintaining almost the same correction performance for a classical predistortion algorithm. We have also proposed a sub-sampling algorithm based on a subband DPD architecture which enables to reduce computational speed constraints of the digital part and thus to reduce the energy consumption[402]. It was shown that the subsampled architecture at 15 MHz could divide the power consumption of the digital part by 27 in comparison with the initial case at 75 MHz.

As part of the IDEX project LIFLEX (Flexible Linearisation), we have proposed another predistortion architecture that also takes advantage of the low-rate subband decomposition. In this architecture, the subband signals are sampled at the Nyquist frequency of the transmission channel which is much smaller than the regular approach using the full bandwidth of the distorded signal. These subband signals are then used to construct a Discrete Fourier Transform (DFT) estimate of the fullband distorted signal. The predistortion parameters are then directly calculated from the DFT data without having to reconstruct the high frequency sampling signal. The performance of the algorithm has been shown to be as good as the regular approach while dividing the sampling frequencies by the nonlinear order of the system.

Finally, we are currently studying a new type of so-called hybrid corrections based on both digital and analog processing to generate the predistorted signal. This approach makes it possible to maintain a great flexibility in the predistortion parameters and also to reduce the bandwidth constraints of the transmission Digital-to-Analog Converters (DACs)[395].

Digitally assisted ADCs and receivers

The C2S team aims at integrating new digital algorithms into AMS and RF Systems-on-Chip in order to achieve both wideband and high linearity communication systems, a must for 5G applications.

We have had three outstanding contributions in this domain recently.

Our first development, in collaboration with Renesas, consists in adaptive and blind background calibration of the channel mismatches in Time-Interleaved ADCs (TI-ADCs). In this work, a new digital blind calibration technique for TI-ADCs is used to correct the gain, time-skew, bandwidth and offset mismatches. The technique can be divided into two independent steps. The

first step (estimation) consists in identifying the mismatches from the measurements. The second step (compensation) consists in reducing the errors due to channel mismatches. This technique was tested on 14 bits ADCs from Analog Devices. The achieved results show a channel mismatch errors reduction by up to 38 dB.)[401]
The second development was part of the European project named Applications Gateway for Open Platform combining set-top box and residential gateway and integrating multiple home applications. In collaboration with NXP semiconductor, we were in charge of improving the performance of the Full Spectrum Transceiver (FST). We proposed a new background correction of the frequency-independent channel mismatches of the TI-ADC employed in the FST. The main achievements of our solution are: all digital background calibration solution with blind algorithm, configurable functionality and flexibility, direct benefits of CMOS technology scaling, sensitivity to analog noise reduction. in a second step, we added a polyphase decomposition in order to reduce the clock frequency and we performed ASIC Synthesis of the proposed technique with ST-28nm FD-SOI process. Our achieved results outperformed that of the existing state-of-the-art [392].
The third development addresses a more general challenge that is blind correction of wideband receiver's non linearity. Following a precursor path, we aimed at 1 GHz bandwidth linearization by analyzing the non-linearity in the RF chain, by studying the post-processing blind correction techniques and by designing a new digital blind post-distortion technique with an implementation on FPGA. Instantiation was achieved with a multi-channel receiver suited for DVB-T applications based on a 1-GHz bandwidth RF front-end followed by a 2.7-GHz 13-bit analog-to-digital converter. Two digital post-distortion approaches were demonstrated by measurements: for the first approach, the correction in the band shows around 18 dB of linearity improvement and for the second approach, 10 dB of distortion reduction is observed.[391].

9.2.3 Signal Processing for Smart AMS systems

Compressed sensing
Following our past works on Non Uniform Sampling (NUS), we engaged in Compressed Sensing (CS) by digitalizing less data than the Nyquist rate. In the frame of our collaboration with the LESIA, we studied the application of compressed sampling for the acquisition of spatial astrophysical signals in the frequency band [1 kHz to 50 MHz]. Based on the characteristic properties of the signals of interest, we progressively and methodologically constructed our acquisition scheme: from the study of signals compressibility, to the choice of the AIC architecture and the signal reconstruction algorithm. For a real Jovian signal with a bandwidth of 40 MHz, we demonstrated its compressibility in the frequency domain and chose the CS based Non Uniform Sampler (CS-NUS) as an appropriate AIC architecture. We showed that this signal could be sensed by taking only 20% of samples at random, while still recovering the scientific information. We also proposed a new, flexible and programmable implementation of the selected Analog-to-Information Converter (AIC) in a 65nm CMOS technology using a double-tail sense amplifier, a binary-weighted capacitive array with an attenuation capacitor and a SAR control-logic. This practical implementation of CS-NUS has highlighted the reduction in energy consumption with a gain factor of 5 compared to a conventional ADC [396].

Cognitive radio algorithms
For secure cooperative sensing algorithms, to mitigate the primary user emulation attacker, who prevents other secondary users from accessing radio resources and interferes with nearby primary users, we have investigated the channel surveillance process to mitigate the selfish Primary User Emulation (PUE) in the multi-channel attack context [394] [397] . By monitoring the occupied channels, the network manager can detect the selfish PUE attacker. Determining surveillance strategies, particularly in multi-channel context, is necessary for ensuring network operation fairness. Since a rational attacker can learn to adapt to the surveillance strategy, the question is how to formulate an appropriate modeling of the strategic interaction between a defender and an attacker. The relationship between the selfish PUE and the surveillance process are analyzed by game-theoretic approaches in the multi-channel attack context. We investigated two scenarios

where the defender acts as a regular player (the non-commitment case), i.e., not commits to its surveillance strategy, or a leader (the commitment case), i.e., commits to its surveillance strategy and force the attacker to be a follower by play the best response regarding the observed strategy. In the commitment model, the network manager takes the leadership role by committing to its surveillance strategy and forces the attacker to follow the committed strategy. The relevant strategy is analyzed through the strong Stackelberg equilibrium. Compared with the non-commitment case, analytical and numerical results show that the network manager significantly improves its utility with respect to playing a Nash equilibrium strategy, hence obtains a better protection against selfish PUEs. Moreover, the computational effort to compute the strong Stackelberg equilibrium strategy is lower than to find a Nash equilibrium strategy. We concluded that the defender must exploit the leader position in the game by committing its defense strategy to get the higher expected payoff. This method can be generalized to deal with the other types of PUE such as the malicious and the unknown attacking type ones.

9.3 Scientific Highlights:

Editorial activities

- Guest Editor in Springer Analog Integrated Circuits and Signal Processing in 2013 & 2014

Conferences organization

- General Chair of IEEE International Conference NEWCAS in June 2013 in Paris
- General Chair of GDR SOC2 National Symposium in June 2014 in Paris
- Technical Program Chair of IEEE International Conferences, NEWCAS in 2013 & ICECS in 2016

Business creation, start-ups

- The company SCALINX was founded in 2015 as a spin-off of Telecom ParisTech

Responsibilities in learned societies

- IEEE CAS France Chapter Chair since 2015

Best papers and awards

- Best Student Papers at IEEE International Conference NEWCAS in 2014 & 2016
- IEEE Circuits and Systems Society Student Travel Awards in 2013 & 2015

Stays in foreign laboratories

- NICT Rank A Guest Researcher, University of Aizu, Jul 2012 - Jun 2013
- Visiting Scholar & Senior Marie Curie Fellow, UC Berkeley College of Engineering, Apr 2013 - Dec 2016
- Visiting Associate Professor, Stanford University, Jul 2016 - Present

9.4 SWOT analysis

9.4.1 Strength

- Young team with three senior replacements in the last three years with a solid and dynamic organization
- Collaborations with several LTCI teams: ComNum, SSH
- Numerous industrial partnerships: STM, NXP, Livanova, CEA, THALES
- National, European and international collaborations

9.4.2 Weakness

- Small team size which sets a limit to chip production and makes competition with circuit designers large teams very harsh
- The typical thesis duration required for producing an outstanding performance circuit goes beyond the three years doctoral school limit, a rule which is not internationnally enforced

9.4.3 Opportunities

- Starting collaborations with LTCI teams outside COMELEC: S2A, RMS
- University Paris-Saclay : C2S is involved in the 'Integrated Circuits and Systems' master program, with opportunities to attract outstanding PhD students
- Future collaborations with our spin-off SCALINX
- High increase in microelectronics industrial production
- As detailled in Table 9.2, three PhD are planned to start in October 2018, reinforcing some existing collaborations and starting new ones.

Topic	Funding	Collaborations
High speed DAC converters in 28FDSOI technology	CIFRE STM	STMicroelectronics, ISEN Lille
Outphasing PA For 5G	CEA internal funding	CEA-DACLE, ESIB-USJ Beirut
Flexible A2F converter for smart sensors	Telecom ParisTech ALUMNI	S2A team LTCI, Cornell University

Table 9.2: PhDs starting in 2018

9.4.4 Threats

- Reduction in European projects opportunities with the end of CATRENE program which benefited from significative French financial support
- Circuit designers are less and less present among academic decision authorities (CNRS, IMT, our future university) weakening the supervision of our research topics.

9.5 Scientific project for the the next five years

Nowadays, networked computer systems are ever more present in our daily lives and electronic systems are moving into stronger and stronger interaction with the physical world, so that the computer and physical worlds are merging to evolve towards Cyber Physical Systems. This transformation aims to increase adaptive capacity, autonomy, efficiency, functionality, reliability and security of the future systems. Our objective is the development of hardware elements for interfacing the system of connected objects on one side with the physical world via sensors and on the other side with the system core via wireless communications. Taking into account and managing consumption drives the design of AMS&RF circuits towards more modularity and agility. Intelligent communication interfaces designed for this purpose by C2S use real-world interaction (smart sensors, energy recovery), network knowledge, digital power (adaptation, correction), and knowledge of the usage for which the data are intended.

9.5.1 High-performance reconfigurable acquisition and communication systems

The fifth generation of mobile communications (5G) will provide more diversity in terms of spectral bands, data rates and operation modes in order to cover efficiently all the user demands going from sub-Hz IoT applications to very high data rates video applications. To answer these constraints, 5G transceivers will need to be highly flexible in many aspects such as central frequency, filtering and noise figure in order to satisfy the specifications while keeping low power consumption. On the other hand, nowadays conventional bulk CMOS technology has reached its limits. Two new approaches are used to implement sub 40 nm transistors, the fully depleted Silicon on Insulator (FDSOI) and the Fin Field-effect transistor (FinFET). These new technologies open promising perspectives for analog and RF design especially the FDSOI technology, thanks to its back biasing gate, provides an additional knob for reconfigurability. Our objective for the coming years is to implement in 28 nm FDSOI technology several architectures that we have been developping during the last years such as Direct Delta Sigma Receivers, Npath filters and Mixed signal pre-distorters.

Digital correction techniques are increasingly used to correct imperfections in analog/mixed and RF circuits. In particular, digital predistortion offers powerful solutions for correcting the power amplifiers (PA) at the transmitter. However, the RF front-end transmitting and receiving circuits must cover bandwidths at least equal to five times the useful band for making a suitable correction. In the context of 5G, millimeter waves open the field at bandwidths of at least 100MHz requiring RF frontends supporting at least 500MHz for predistortion. This today requires highly energy-consuming systems. In addition, with the advent of new telecommunications standards such as LTE Advanced, new transmission scenarios are to be considered, including the case of aggregation of non-contiguous carriers. This situation requires novel predistortion approaches to model and correct these non-contiguous band signals efficiently.

9.5.2 Signal processing for low-power SMART AMS Systems

The Internet of Things (IoT) is currently experiencing huge developments in fields such as healthcare, transportation, military, infrastructure management or consumer applications. IoT includes lots of different devices such as Wireless Sensors Networks (WSN) or wearable electronics that rely on wireless communications. The main constraint on the IoT sensors, along with data security, is energy consumption. To reduce this energy consumption, our goal is to work towards smart AMS systems that can adapt the processing done (signal detection, signal classification, full signal processing) to the context. To achieve this, both the communication and sensing part of the sensors should be considered. The sensing part consists in acquiring only the relevant data by adding intelligence into the sensor. This can be done by combining recent sensing techniques (analog-to-information and analog-to-feature) with machine learning to optimize power consumption and reduce the amount of data to be transmitted. The communication part aims at proposing new smart wake-up receivers that can detect the signal presence in several steps to maximize the time spend in sleep mode and thus reduce the energy consumption.

Wake up receivers are key components in IoT devices as they consume a high percentage of the overall power consumption. Similarly to classical receivers, in wake up receivers, there is a tradeoff between power consumption and sensitivity. To break this tradeoff, we are developping a multi-step approach that reduces power consumption while keeping constant misdetection/false alarms rates. The first theoretical analysis and calculation prove that the proposed approach is very promising. However the practical implementation faces several challenges that we are planning to address in the near future. Our objective is to develop a proof of concept to demonstrate the soundness of our proposal.

9.6 Scientific production (selection)

Articles in Journals

[391] R. Vansebrouck, C. Jabbour, O. Jamin, and P. Desgreys. Fully-digital blind compensation of non-linear distortions in wideband receivers. *Transactions on Circuits and Systems I*, 64(8):2112–2123, August 2017.

[392] H. Le Duc, D. M. Nguyen, C. Jabbour, P. Desgreys, O. Jamin, and V. T. Nguyen. Fully digital feedforward background calibration of clock skews for sub-sampling tiadcs using the polyphase decomposition. *Transactions on Circuits ans Systems I*, 64(6):1515–1528, June 2017.

[393] M. T. Nguyen, C. Jabbour, S. M. Homayouni, D. Dupperay, P. Triaire, and V. T. Nguyen. System design for direct rf-to-digital delta sigma receiver. *IEEE Transactions on Circuits and Systems I: Regular Papers*, August 2016.

[394] N. Nguyen-Thanh, Ph. Ciblat, A. T. Pham, and V. T. Nguyen. Surveillance strategies against primary user emulation attack in cognitive radio networks. *IEEE Transaction on Wireless Communications*, 14(9):4981–4993, September 2015.

Articles in Conference Proceedings

[395] V. N. Manyam, D.-K. G. Pham, C. Jabbour, and P. Desgreys. A wideband mixed-signal predistorter for small-cell base station power amplifiers. In *IEEE International Symposium on Circuits and Systems (ISCAS)*, Florence, Italy, May 2018.

[396] Y. Gargouri, H. Petit, P. Loumeau, B. Cecconi, and P. Desgreys. Analog-to-information converter design for low-power acquisition of astrophysical signals. In *IEEE International New Circuits and Systems Conference (NEWCAS)*, pages 113–116, Strasbourg, France, June 2017.

[397] D.-T. Ta, N. Nguyen-Thanh, P. Maillé, Ph. Ciblat, and V. T. Nguyen. Mitigating selfish primary user emulation attack in multi-channel context : a game-theoretic approach. In *IEEE Global Telecommunications Conference (GLOBECOM)*, Washington DC (USA), December 2016.

[398] r. mohellebi, C. Jabbour, B. Cecconi, H. Petit, M. Dekkali, M. Maksimovic, and P. Loumeau. A cmos 65nm 120 db stacked a/d converters receiver for long wavelength radio astronomy observations. In *IEEE ICECS Conference*, Monaco, December 2016.

[399] K. Tchambake, D.-K. G. Pham, C. Jabbour, P. Desgreys, and P. Loumeau. A multi-channel sigma delta modulator for subband digital predistortion with lte signals. In *IEEE International NEWCAS Conference*, Vancouver, Canada, June 2016.

[400] A. Meyer, P. Desgreys, H. Petit, B. Louis, and R. Corbière. Single-ended/differential 2.5-gs/s double switching track-and-hold amplifier with 26ghz bandwidth in sige bicmos technology. In *IEEE MTT-S International Microwave Symposium (IMS)*, San Francisco, Californie, May 2016.

[401] G. K. De Teyou, H. Petit, and P. Loumeau. Adaptive and digital blind calibration of transfer function mismatch in a time-interleaved adcs. In *IEEE NEWCAS 2015 Conference*, Grenoble France, June 2015.

[402] D.-K. G. Pham, G. Gagnon, F. Gagnon, P. Desgreys, P. Loumeau, M. Abi Hussein, and O. Venard. A subsampled adaptive subband digital predistortion algorithm. In *IEEE International NEWCAS Conference*, Trois-Rivières, Canada, June 2014. IEEE.

Invited Talks

[403] P. Desgreys, V. N. Manyam, K. Tchambake, D.-K. G. Pham, and C. Jabbour. Wideband power amplifier predistortion: Trends, challenges and solutions. In *IEEE International Conference on ASIC*, Guiyang, China, October 2017.

Patents

[404] A. Meyer, B. Louis, R. Corbière, V. Petit, P. Desgreys, and H. Petit. Dispositif échantillonneur-bloqueur de signal électrique. (FR1700025), January 2017.

Chapter 10

ComNum

Digital Communications

10.1 Presentation of the team

Team leader: Philippe Ciblat (FP)

Faculty between 2013 and 2018: Jean-Claude Belfiore (FP, – 10/15), Philippe Ciblat (FP), Walid Hachem (SRS, – 12/16), Ghaya Rekaya-Ben Othman (FP), Olivier Rioul (FP), Georges Rodriguez (AP, – 06/18), Patrick Solé (SRS, – 12/16), Aslan Tchamkerten (AP), Michèle Wigger (FP)

Invited Professors: Karime Zayana (2017-, IGEN)

Sabbatical Professors: Roy Timo (2014, Ericsson, Sweden) Jose Carlos Magossi (2015, Unicamp, Brazil) Roy Yates (2017, Rutgers University, USA), Aylin Yener (2016, PennState University, USA), Ofer Shayevitz (2017, Tel Aviv University, Israel), Haim Permuter (2013, Ben Gurion University, Israel), Max Costa (2017, University of Campinas, Brazil), Yossef Steinberg (2014, Technion, Israel).

PhD Students: Akram Abouseif (2017-), Aymen Askri (2017-), Abdelkerim Amari (2013-2016), El Mehdi Amhoud (2014-2017), Apostolos Avranas (2017-), Laure Aptel (2017-), Selma Belhadj Amor (2012-2015), Abir Ben Hadj Fredj (2015-), Eloi de Cherisey (2015-), Vincent Corlay (2017-), Ehsan Ebrahimzadeh (2014-), Pierre Escamilla (2016-), Ibrahim Fawaz (2016-), Samet Gelincik (2016-), Julien Gori (2015-), Annelie Heuser (2014-2016), Franck Iutzeler (2010-2013), Fanny Jardel (2012-2016), Sarah Kamel (2013-2017), Mohamed Achraf Khsiba (2014-2017), Alaa Khreis (2015-), Xavier Leturc (2015-), Longguang Li (2016-), Wanyu Liu (2015-), Raphaël Massin (2012-2016), Sébastien Marcille (2010-2013), Asma Mejri (2010-2013), Hamed Mirghasemi (2013-2016), Homa Nikbakht (2017-), Adil Salim (2015-), Alexander Schaub (2017-), Seyed Milad Sefidgaran (2009-2013), Lin Sok (2010-2013), Julia Vinogradova (2011-2014), Youlong Wu (2012-2015)

PostDocs: Thomas Courtat (2013-2015), Jihad Fahs (2016), Sarah Kamel (2017-), Nassar Ksairi (2013-2014), Asma Mejri (2013-2014), Seyed Mirghasemi (2014), Manuj Mukherjee (2018-), Nhan Nguyen-Thanh (2013-2015), Buket Ozkaya (2015), Sadaf Salehkalaibar (2015-2017), Lin Sok (2013), Chien-Yi Wang (2016), Qifa Yan (2017-)

Scientific Production Overview: Table 10.1 represents the scientific production between 2013 and 2018. More details are given in chapter 10.6

Journal	Book Chapter	Proceedings	Patents	Invited talks	Faculty MM	Funding over 2013-2017
73	5	184	25	40	302.5	2.35M€

Table 10.1: Overall Scientific Production

10.2 Research activities

10.2.1 Overview

Communication networks involve a variety of communication media (*e.g.*, wireless, wired, optical) for information transmission, information retrieval, and information processing. These tasks must typically be performed under constraints which take into consideration an array of performance metrics including complexity, reliability, latency, and secrecy. Moreover, depending on the nature of the network, these constraints should be met in a centralized or decentralized way.

The main thrust of the Digital Communication team's research effort has been on providing a better understanding of the fundamental limitations of communication networks and on providing means to achieve these limits. Accordingly, our contributions span the areas of information theory, coding, optimization, and signal processing.

Main results were obtained in the context of multi-user cellular networks (one-to-many or many-to-one communication), wireless ad hoc networks (many-to-many communication), and optical communications (one-to-one communication). For these settings, the team has developed

- fundamental limits and related coding techniques for information transmission and storage over networks;
- resource optimization for wireless networks ;
- fundamental limits and related estimation techniques for centralized or distributed contexts.

Over 2013-2018, the team had a high publication rate in leading journals and conferences—about 2.8 journals/year/member and 7.3 conferences/year/member—and obtained a few Best Paper Awards. The team has also written 25 patents. Our research activities are supported by European, national, or industrial fundings. One Faculty is recipient of an ERC starting grant.

In addition to its research activities, the team is on the editorial board of the IEEE Transactions on Information Theory, the IEEE Transactions on Signal and Information Processing over Networks, and the IEEE Communications Letters, is part of technical committees of flagship conferences (*e.g.*, ISIT, ITW, GLOBECOM, ICC, ICASSP, ...).

In addition, the joint scientific life of the team is organized through PhD's internal seminars (around 8 seminars per year) and seminars with external visitors (around 10 seminars per year).

10.2.2 Topic 1: Point-to-point communications

Asynchronous communications In monitoring or sensor networks, communications between a transmitter and a receiver typically occur once in a while, non-periodically, which results in asynchronous communication. The receiver, without knowing when transmission occurs must therefore both detect the sent message and decode it. We investigated the scenario where the receiver is energy constrained. As the energy consumption of practical systems scales roughly linearly in the sampling rate, the receiver sampling rate design is of a crucial importance. We showed that there exists receiver sampling strategies that operate at a vanishing sampling rate and yet achieve the same detection delay as the best detection schemes operating under full sampling [419, 442, 443, 452, 456].

In the above work, asynchronism is due to a bursty source of information at the transmitter. In a different line of works, we investigated the scenario where asynchronism is caused by the channel itself (typically missynchronization) which can be modeled by the insertion and deletion channels [426]. Communication over such channels still represents a formidable challenge as virtually all

known coding techniques (algebraic and modern) assume perfect synchronization. In this work, we provided a means to import certain algebraic coding techniques (lattices) to handle both insertions and deletions [405, 453].

Lattice based MIMO decoders The huge increase in demand for real-time data and the diversification of services promoted in 5G networks induce different challenges. High reliability and ultra-low latency are among key requirements for new communication systems. MIMO technology has been a great answer for high reliability and high throughput issues as well as latency. But, best performance is offered at the expense of high complexity decoding techniques, preventing them to take advantage of the full potential it offers. We proposed several decoding algorithms to handle large-scale MIMO systems with affordable complexity and latency cost due to computation. Each algorithm is adapted to different system setting such as dimension and different requirements in terms of latency and reliability. These decoders can be used on their own or as components of a decoding chain. Two main results that concern the early termination problem and the recursive decoding have been established: i) Early termination problem occurs when for real time decoding a threshold on complexity or running time is imposed. This forces to have permanently, during decoding time, an output- ready solution to deliver when threshold is reached or output order is given. We have proposed new early termination techniques. ii) We have proposed a recursive sub-block decoding for MIMO systems to reduce complexity, with a flexibility on the desired diversity order and SNR gain, while offering an important reduction on the overall decoding complexity. We derive an upper bound of the error probability function of the sub-blocks sizes, the desired diversity order and the SNR gain. The Block Decoding scheme is perfectly suitable to a parallelization of block processing for a further decrease of decoding latency [424, 460, 462].

Optical communications Due to emergence of new applications (*e.g.*, video streaming, cloud computing), the amount of data in the optical core networks has strongly increased. To handle the saturation of the core network, advanced digital communication tools have to be applied to the optical communications field. The way to increase the data rate is to use all the available degrees of freedom. Polarization and Phase have been already used in the last decade. Space (through a multi-mode and/or multi-core fiber) is a promising way. Therefore, space-division multiplexing (SDM) has received a lot of attention recently. In the same fiber, interactions between spatial channels are inevitable. These interactions, if not compensated, degrade the system performance. We have focused on recent optical MIMO schemes based on polarization division multiplexing (PDM) and space division multiplexing (SDM) through mode multiplexing. In both scenario, we assess the performance penalties induced by non-unitary crosstalk and loss disparities among the channels arising from imperfections in the optical components (fibers, amplifiers, multiplexers...), and introduce novel modern MIMO coding solutions known as Space-Time (ST) codes, initially designed for wireless multi-antenna channels, to mitigate them [417]. Through numerical simulation results we have shown that ST codes allow to mitigate very efficiently (almost completely) the loss effects for PDM and SDM systems. We also derived analytically the error probability upper bound to explain the specific behavior of ST codes for both channels. Finally, an experimental validation has been carried out [438]. We have also studied the concatenation of ST coding and FEC (error correcting codes), shown a coding gain summation through simulations and analytically proven [411]. We also proposed other optical and digital signal processing solutions to increase the capacity of multi-mode fibers, like the random and deterministic mode scrambling [441]. Given a amount of degree of freedoms, another way to increase the data rate is to increase the constellation size which implies to increase the transmit power to keep the same reliability [425]. Unfortunately, increasing the transmit power leads to an additional impairment due to the fiber non-linearity. Actually the non-linearity with the fiber can be well modeled by a Volterra series expansion. We proposed two new receivers structure to compensate for the nonlinearities. The first proposed receiver relied on the fifth-order Inverse Volterra Series Transfer Function (IVSTF) for ultra high data rate optical fiber communications using either OFDM or Nyquist-Wavelength Division Multiplexing (WDM) waveform. Compared to the third-order IVSTF, we significantly

improved the performance in terms of Bit Error Rate (BER) and/or transmission distance. Due to nonlinearities, crosstalk between adjacent wavelengths occurs as well. Therefore, we also proposed a second receiver consisting in detecting the adjacent subcarriers, regenerating them thanks to the Volterra series model of optical fiber, and removing them from the subcarrier of interest. This new receiver, called Inter-subcarrier Nonlinear and linear Interference Canceler (INIC), significantly outperform well-known techniques such as digital back propagation (DBP) and Volterra based nonlinear equalizer (VNLE) implemented in a subcarrierwise manner [448]. These works have been done in close collaboration with Optical Telecommunications team (GTO).

In addition, we also focused on Free-Space Optical (FSO) communications which is a promising technique for short bakchaul and fronthaul. Particularly attractive are simple intensity-modulation direct- detection (IM-DD) systems, where the transmitter modulates the intensity of optical signals coming from light emitting diodes (LEDs) or laser diodes (LDs), and the receiver measures incoming optical intensities by means of photodetectors. We introduced several upper and lower bounds on the capacity that are close in the finite SNR regime and that asymptotically match in the high-SNR and low-SNR regimes. A key observation in our work is that for any SNR value, capacity is achieved by a LED cooperation scheme where each input antenna is switched on only if all stronger antennas operate at their maximum allowed peak power [423].

10.2.3 Topic 2: Network optimization

Coding and Allocation for Caching-Enabler networks Placing popular contents closer to the end users by sharing backhaul is a new paradigm in wireless networks in order to reduce the traffic and the latency. Finally it is a manner to take benefit of broadcasting factorization for multi-cast communications.

One way for placing these contents is to wait for periods of low network congestion (e.g., at nights) while the contents are consulted during peak-traffic time (e.g., during evenings). The main challenge is that the contents have to be cached before knowing which files the users will request at peak-traffic times. It has been shown that by carefully placing different contents at different users, coding techniques can be used which allow the transmitters to simultaneously serve multiple users during peak-traffic times and thus improve performance compared to traditional caching systems. In our works we showed that further gains are possible in asymmetric situations where some receivers have worse channel conditions than others, for example, because they are in deep fades or because they are further away from the transmitter and thus receive their packets with larger erasure probabilities. These further gains can be achieved with the previously proposed cache placement strategies, but they require a new design for the peak-traffic phase that directly incorporates the multi-cast opportunities into channel coding. This new approach yields significant gains, sometimes more than doubling the gains in data rates offered by caching. We also present fundamental converse results showing that the proposed coding techniques often perform close to optimal [413, 428].

Previous works considered a static cache which was updated each night because it is assumed that the popular contents do not change along with the day. We have also considered a different setup where the contents are dynamic (for instance, consider a popular newspaper website) and so have to be updated during the rush hours too in order to be still relevant. We proposed a quasi-optimal updating policy (from the server to the local cache) refreshing a cached item in proportion to the square root of its popularity [427].

Resource allocation for wireless networks In the context of Device-to-Device (D2D) communications , a network manager may handle the resource allocation with few information on the network. Therefore we consider that only statistical Channel State Information (CSI) is available. Then we proposed a set of algorithms for different channel models (Rayleigh or Rice) to maximize the energy efficiency of the network or of each user of the network when Hybrid Automatic ReQuest (HARQ) are carried out in order to improve each link reliability. These algorithms typically allocated jointly the bandwidth proportion and power of each user [418, 450, 432].

When the network manager has more information on each link (typically in a cellular network rather than in a D2D network), the resource allocation setup can be partially modified. For instance, based on Markov Decision Process (MDP) tool, we found out the best modulation and coding scheme at each retransmission round of the HARQ when partially outdated channel state information is available at the transmitter. We also addressed the problem of adapting power among users and their packet retransmissions in a downlink OFDMA context for optimizing a weighted sum throughput, once again based on a Constrained MDP approach [436].

If we consider mobile networks where mobile devices have both information to transmit and application computation to perform, the resource allocation issue is to find a relevant tradeoff between the computation done locally and remotely. We also considered that the application is strict delay constrained and that the device has energy harvesting (EH) ability. Therefore our objective was to minimize the packets' loss due to buffer overflow or delay violation of the queued packets at the device. We formulated this problem as a Markov Decision Process (MDP) and exhibited an optimal deterministic offline scheduling-offloading policy. We showed through numerical results that the proposed policy can significantly improve the successfully received packets' rate and the energy consumption compared to other policies, such as immediate scheduling or only local processing or only offloading policies [420].

Finally, analysis of feedback availability at the transmitters has been extensively done for multi-user communication systems, and this is a first pavement for joint uplink and downlink resource allocation [415].

Physical-Layer Network coding Practical wireless communication systems, such as cellular or sensor ones, are inherently multiuser networks where several transmitters and receivers share the available wireless resources. An important issue is then the multiple access interference resulting from the superposition and broadcast properties of the wireless medium. A new technique termed Physical-Layer Network Coding (PLNC) revealed the advantages of interference in enabling more efficient and reliable transmissions. Using PLNC, intermediate nodes in a wireless multi-hop relay network treat interference as useful information to decode and forward functions of the original source signals. This new management technique is shown to essentially provide higher transmission rates among other significant benefits. We studied the performance of PLNC strategies in practical multiuser network configurations when the PLNC protocol termed the Compute-and-Forward (CF) is used. We focused on PLNC applied with lattice-based channel coding and studied the end-to-end implementation and performance. Three network topologies have been investigated: the Two-Way Relay Channel (TWRC), the Multi- Source Multi-Relay (MSMR) Channel and the distributed Multiple-Input Multiple-Output (MIMO) Channel [455]. We showed that MAP decoding is equivalent to MMSE-GDFE preprocessed minimum euclidean distance decoding. Given the new metric, we developed a practical decoding algorithm and showed by numerical simulations its effectiveness and gains over the standard decoding scheme for the CF protocol. Moreover, we proposed an approximation of the ML decoder which reduces to solve an Inhomogenous Diophantine Approximation of reals and proposed a practical algorithm based on the Cassel's algorithm. Numerical results demonstrate the gain of the proposed algorithm over the traditional decoding scheme for the CF particularly at high signal-to- noise ratio range [416].

Distributed processing One of the important reasearch fields related with the distributed processing [412] is the distributed optimization, where a set of processing agents connected through a network seek to collectively solve an optimization problem. The working assumption in this context is that there is no central processor (or a so-called fusion center). In many distributed statistical estimation problems, target tracking problems, or distributed learning problems, the agents are decentralized and asynchronous. The research in this field is in fact at a crossread between optimization theory and stochastic approximation theory. Indeed, the distributness and the asynchronism can be modelled as a random process on the graph involving the nodes (agents) and the edges (communication channels among agents). To this randomness, one can also add the randomness that is inherent to the data received by the agents in many statistical or leaning

applications. From the standpoint of optimization theory, we explored the powerful theoretical framework of the monotone operator theory, and we focused on primal-dual optimization algorithms such as the popular ADMM (Alternate Direction Method of Multipliers) [414]. In order to address the statistical nature of our problems, we created the concept of random monotone operator, which revealed to be a powerful tool for designing random optimization algorithms. This work has been done in collaboration with the Signal, Statistics, and Learning team (S2A).

In the context of D2D communications, node clustering is a well known solution for handling the scalability issue. Thanks to the coalition game theory, we derived a novel generic distributed node clustering algorithm converging to Nash-stable partitions where the nodes only share information with their neighbors. This generic algorithm is then tailored to both structured and unstructured networks. Based on extensive simulations, we show that our proposed solutions outperform the existing ones especially in terms of cluster size and stability [409].

Cooperative Detection In the context of cognitive radio, the cooperative spectrum sensing issue has been analyzed by taking into account that the sensors have to report their sensing data (I.e. their decentralized soft decision) to a fusion center in order to make the final decision on the channel occupancy. We optimized the number of sensing samples at the sensors and the number of reporting bits for quantizing local sensing data by maximizing the network throughput constrained to a target detection probability for this decentralized decision issue.

Decreasing costs of sensors and improved hardware technologies facilitate a rapid increase of sensor applications, in particular as part of the future Internet of Things (IoT). Our focus is on sensor networks with multiple sensors collecting correlated data that they communicate to decision centers so as to facilitate detection of certain hazardous events at these centers. We studied the quality (in terms of error exponents) of these detections taken at the centers in function of the underlying network characteristics. More specifically, we derived the optimal exponents for various multi-hop network configurations, for networks with multiple decision centers and concurrent detections, and noisy multi-access channels. In this last setup, we showed, for example, the benefits of unequal error protection codes as a tool to limit the degradation in performance caused by the channel noise [410].

Cooperative Communication Cooperative communication will be an inherent building block of future 5G cellular networks. A prominent example are cloud radio access networks (C-RANs) where base stations (BSs) mainly consist of basic remote radio heads (RRH) and connect to a common central processor through digital fronthaul links. In the downlink communication of such a C-RAN architecture, the central processor pre-computes and coordinates the signals sent by the BSs to the mobiles in their cells. For this setup, we proposed a new coding scheme that improves over the previously proposed schemes in some parameter ranges. We also analyzed the gains that can be attained in a slighly more complex architecture where the BSs keep their ability to communicate over connecting backhaul links. In another work we completely focused on this more classical architecture with backhaul links connecting BSs but without fronthaul links or central processor. In this latter work we analyzed the impact of complexity constraints on the fundamental limits (high-SNR asymptotic capacity) of the networks. Our results reveal that when the backhaul rates are of relatively small rates, then even simple single-round backhaul cooperation protocols can achieve the first-order high-SNR capacity, i.e., the degrees of freedom. In contrast, when the backhaul links are of very high rates, the degrees of freedom of such networks scale linearly with the number of cooperation rounds.

10.2.4 Topic 3: Security

Lattice-based Cryptography Personal data is being daily exposed online through the Internet while achieving some critical private activities such as paying bills, banking and completing governmental processes. Therefore, there is a real need to strengthen the communication security and especially to enforce confidentiality of personal data while they are transmitted. Data

security protocols are used for that purpose. However, due to advances in quantum computing technology, new attacks are about to emerge that will require changes in these protocol designs. Hence, post-quantum security solutions are being extensively studied. Yet, current post-quantum cryptography algorithms are too heavy to be usable, mainly because of their huge key sizes compared to classical cryptosystems. This problem is further aggravated if one considers the device computation constraints. This emphasizes the necessity for low complexity and small key size post- quantum algorithms. We have studied lattice-based public-key cryptography, which is one of the most promising techniques for the post-quantum cryptography systems. In particular, we focused on the Goldreich-Goldwasser-Halevi (GGH) cryptosystem, for which we propose a new scheme using GLD lattices (generalized low density lattices). While guarantying the same level of security, our cryptosystem significantly reduces the complexity compared with previous GGH schemes. In dimension 1000, the key can be represented by approximately 100 KBs whereas the key size of previous GGH systems was in the order of MBs. Moreover, since HNF (Hermit Normal Form) is used for the design of the lattice generator matrix, the complexity of the public key generation reduces by 1300 times compared to Micciancio and LDLC based GGH systems. Finally, the GLD lattice iterative decoding offers a better performance than Babai's algorithms and decreases the decryption complexity compared to LDLCs iterative decoding [434]

Physical-Layer Security with cache-enabler networks Wiretap channels model communication channels where external passive eavesdroppers overhear the communication and wish to learn something about the transmitted data. The legitimate transmitters and receivers are required to code in a way that prevents such information leakage. We studied wiretap erasure broadcast channels with cache memories at the receivers. Cache memories close to end-users can be used to pre-store fragments of popular contents or secret keys during periods of low network congestions with the goal to reduce and secure network traffic during peaktraffic periods. For the described scenario we presented various secure coding schemes and show, by means of converse results, that these schemes often perform close to the fundamental limits of the system. Our result also shows that when some users have no cache memories, then the imposed secrecy constraint causes a significant loss in the data rates that can be achieved. For more balanced cache configurations the loss in data rate seems to be small. However, allocating equal cache sizes to all receivers seems to perform poorly except when all receivers have identical channel conditions [433].

Security issue in cognitive radio We investigated the primary user emulation (PUE) attack which is a serious security problem in cognitive radio networks since the wrong primary user prevents to deploy a secondary system. There exist three types of PUE attackers: i) selfish one which aims at maximizing its selfish usage of channel resource, ii) malicious one which points for obstructing the operation of CR network, and iii) mixed between selfish and malicious PUE attacker. For combating a selfish PUE attacker, a channel surveillance process has to be implemented in order to determine active user's identification and so selfish PUE attacker. An extra-sensing process has to be implemented for observing new opportunities to access the channel and so for mitigating the malicious PUE attacker's effect. Relevant strategies for deploying the above processes are obtained through a game theory-based analysis and the exhibition of Nash equilibrium [446]. This work has been done in collaboration with the Circuits and Communication Systems team (C2S).

Hardware Security: Side-channel attacks and protections Any embedded system that contains secrets used in cryptographic algorithms is prone to side-channel attacks. Such attacks are based on physically observable unintentionally emitted information such as power consumption during computation. They exploit the relationship between this leakage information and sensitive data that is processed in the device. The state-of-the-art consists in various statistical tools called distinguishers which have been compared on various measurements or simulated data. We have provided information-theoretical tools to compare side-channel distinguishers. We first carried out a mathematical comparison of two distinguishers based on the Kolmogorov-Smirnov distance for one-bit leakage [449]. This gives a deeper understanding of the influencing parameters on the

distinguisher's performance. However, the analysis in a standard side-channel setting is very much intricate. Therefore, a new path of investigation was found by deriving mathematical expressions for optimal side-channel distinguishers, many of which being novel. In this framework, the side-channel is seen as a digital communication channel and the chosen optimality criterion is the maximization of the probability of success in a given scenario. In an unprotected scenario, we derive optimal distinguishers for three different types of leakage models and various types of noise [406, 407]. In a protected scenario with masking countermeasures, we derive optimal distinguishers for second-order and higher-order masking schemes as well as for masking table recomputations. In addition, optimal dimension reduction techniques are derived, which are of particular interest for profiled side-channel distinguishers. It is found that the optimal dimension reduction technique in additive Gaussian noise asymptotically reduces to a known state-of-the-art method known as linear discriminant analysis. Returning to the question of comparing state-of-the-art side-channel distinguishers we focused on the first-order exponent of the probability of success. It is shown that such an approximation is tight even for a moderately low number of measurements. Closed-form expressions for success exponents are derived for correlation power analysis, difference of means, mutual information analysis, and optimal distinguishers, which highlight the relevant parameters influencing the success of the attacks [447, 440].

Web applications are also subject to side-channel attacks which consist in performing a statistical analysis of the web traffic to gain sensitive information about a client. We investigated how side-channel leaks can be used on search engines such as Google or Bing to retrieve the client's search query. In contrast to previous works, due to payload randomization and compression, it is not always possible to uniquely map a search query to a web traffic signature and hence stochastic algorithms must be used. They yield, for the French language, an exact recovery of search word in more than 30% of the cases. We deduced some methods to mitigate such side-channel leaks. These works have been done in collaboration with the Secure and Safe Hardware team (SSH).

Hardware Security: Physically Unclonable Functions A physically unclonable function (PUF) is a hardware device that can generate intrinsic responses from challenges. The responses serve as unique identifiers and it is required that they be as little predictable as possible. Having a unique identifier for each electronic chip allows to use them in a secure way. If, for example, the chip is used in a smartphone, the identifier can be used to associate the device with a specific service. The identifier can also be used to thwart overbuilding since it can be recorded at fabrication and can later be checked against a whitelist—in this way, overproduced or counterfeited chips can be detected. A loop-PUF is an architecture where n single-bit delay elements are chained. Each PUF generates one bit response per challenge. We modelled the relationship between responses and challenges in a loop-PUF using Gaussian random variables and gave a closed-form expression of the total entropy of the responses. It is shown that n bits of entropy can be obtained with n challenges if and only if the challenges constitute a Hadamard code. Contrary to a previous belief, it is shown that adding more challenges results in an entropy strictly greater than n bits. A greedy code construction was provided for this purpose [435].

10.2.5 Topic 4: Tools for statistics and information theory

Large random matrix theory Born in the mid-fifties of the previous century, the large random matrix theory has deep connections with many branches of mathematics and mathematical physics. This is a very active field of research, with applications in the analysis of quantum disordered systems, number theory, large dimensional statistical estimation, economy and finance, biological networks, signal processing, and communication theory.

Our results were first devoted to the mutual information analysis of MIMO systems. Second, we have been interested in the applications related with the statistical estimation for wireless multiple antenna systems (or, more generally, multivariate time series), the fault diagnosis in wireless networks and the detection for cognitive radio. Statistical estimation problems are related with the spectral estimation of a population covariance matrix from the observation of the empirical covariance matrix in the regime where the time series dimension and the observation window

length converge to infinity at the same pace. The latter two applications are related with the analysis of the extreme eigenvalues of large random matrices, and the detection and estimation of low rank perturbations of such matrices. Our mathematical results go beyond the field of wireless communications, and can be useful in time series analysis at large or in statistical physics.

Information-Theoretic Inequalities We performed a simple proof of the entropy-power inequality using an optimal transportation argument which takes the form of a simple change of variables. The same argument yields a reverse inequality involving a conditional differential entropy which has its own interest. It can also be generalized in various ways, for linear transformations (Zamir-Feder EPI) and for Rényi entropies. The equality case is easily captured by this method and the proof is formally identical in one and several dimensions [408].

We determined the corner points of the capacity region of the two-user Gaussian interference channel under strong or weak interference using the notions of almost Gaussian random vectors, almost lossless addition of random vectors, and almost linearly dependent random vectors. In particular, the "missing" corner point problem was solved in a manner that differs from previous works in that it avoids the use of integration over a continuum of SNR values or of Monge-Kantorovitch transportation problems [431].

Human-Computer Interaction (HCI) Target clicking having proved an indispensable building block of interface design, the speed/accuracy trade-off of aimed movement has always been a keen concern of HCI research. Taking mean movement time as our speed measure and relative spread as our accuracy measure, we have shown that a small set of obvious mathematical axioms predict not only the data from the Fitts and the Schmidt paradigms but also the data from the more recent dual-minimisation paradigm of Guiard et al. The new mathematical framework encourages a more complete understanding. The proposed approach may help HCI practitioners obtain from their experimental data more reliable and more complete information on the comparative merits of design options. The trade-off between speed/accuracy can be analyzed through the Fitts' law which is either a logarithmic law or a power law. We showed that the claim done on Meyer & al. paper (the power model encompasses the logarithmic model as a limiting case, when the number of movements grows large) is mathematically questionable [457].

In the most common view of HCI, users communicate with computers through a series of inputs, and receive feedback from the computer for information exchange. We are familiar with the notion that we, as humans, extract information from the computer. However, the information sent by users to computers has received little attention. We usually think in terms of users giving inputs (or commands) to the computer, not information. Yet these inputs reflect users' intentions, letting the computer know what is the users' goal, therefore, they represent information. This leads to a number of questions: How much information is there in these input commands? Can we quantify the information? If we can, what can we do with it and what does it imply? We proposed a Bayesian Information Gain approach (BIG), based on Bayesian Experimental Design. It uses the criterion of information gain, related to a conditional mutual information, to quantify the information sent by the user to the computer in the interaction loop. By leveraging the amount of information gain, we can gain some insights on who is in control, and hence, further understand the notion of human-computer partnership [429, 422]. These works have been done in collaboration with the Design, Interaction, Visualization, and Applications team (DIVA).

10.3 Scientific Highlights

- Organization of Workshops, Summer Schoool and Conferences:
  - IEEE Information Theory Workshop (ITW2016)
  - Digiscome Summer School on "IoT" (2017)
  - Institut Henri Poincaré (IHP) "Nexus of Information and Computation Theories" 2016

- Associate editors of journals
  - 3 for IEEE Transactions on Information Theory
  - 1 for IEEE Transactions on Signal and Information Processing over Networks
  - 1 for IEEE Communications Letters
- Technical Programme Committee (TPC) of flagship IEEE conferences (every year): IEEE Information Theory Society (ISIT, ITW), IEEE Communications Society (ICC, GLOBECOM), and IEEE Signal Processing Society (ICASSP, SPAWC)
- Awards
  - IEEE ICMCIS Best Paper Award 2016: Xavier Leturc
  - Best PhD award of Télécom ParisTech 2016: Annélie Heuser
  - Best PhD award from Telecom Foundation 2016: Annélie Heuser
  - IEEE ICMCIS Best Paper Award for Young Scientist 2017: Xavier Leturc
  - Best PhD award of Thales Group 2017: Raphaël Massin
  - Best Scientific Contribution PhD award of Université Paris-Saclay 2017: Mehdi Amhoud
  - CHI Best Paper Award (top 1%) 2017
  - CHI Best Paper Honorable Mention Award (top 5%) 2018
- Significant sources of fundings
  - ERC starting grant (CTO Com)
  - ANR International grant (SIERRA)
  - ANR young investigator grant (BSC)
  - France Brevet fundings
  - Google European Fellowship Award
- Invited talks, Keynotes: about 40 (Globalsip, European School of Information Theory, Chalmers, Berkeley, TU Delft, Unicamp, ETH, Technion, Google Zürich, etc)
- Sabbatical stays for Faculty members
  - One-year sabbatical stay in Stanford University (2014) : Aslan Tchamkerten
  - Five-months sabbatical stay in UNICAMP (2014 and 2016) : Olivier Rioul
  - One-month sabbatical stay in UCLouvain (2015 and 2016) : Philippe Ciblat
  - One month sabbatical stay in UIRabat (2018) : Philippe Ciblat
  - Four-months sabbatical stay in ETH Zürich (2016) : Michèle Wigger
- Service in IEEE-style Society
  - Board of Governers (BoG) in IEEE Information Theory Society
  - Member of Technical Committee on "Signal Processing for Communications and Networking" for IEEE Signal Processing Society
  - Secretary and BoG in GRETSI
  - Deputy Director for GDR ISIS, Deputy Scientific Director for GDR ISIS
- Education
  - New M2 degree on Optical Communications of Université Paris-Saclay (ROSP)
  - Integration in M2 degree on Wireless Communications of Université Paris-Saclay (SAR)
  - New track in Digital Communicatinos for Shanghai Jiao-Tong ParisTech-Elite Institute of Technology (SPEIT)

10.4 SWOT analysis

10.4.1 Strengths

- The team members are well established in their scientific community and have strong research achievements according to their publication records (IEEE Transactions and conferences).
- The team members collaborate on a number of project (see publications). To foster interaction the team organizes Ph.D. seminars and talks on a monthly basis.

10.4.2 Weaknesses

- The team lost two CNRS members due to the split between CNRS and Telecom ParisTech.
- Machine learning establishes itself as a dominant area and absorbs many Ph.D. students. This competition requires to constantly question our own research and teaching in order to attract good students.

10.4.3 Opportunities

- We have great funding opportunities on each below-defined project's topics at different levels: European Commission (one ERC in the team), national level (several ANR projects despite of the low acceptance rate), industrial funding (a lof of CIFRE with an effective collaboration between the industrial partner and ourself).
- We have many inter-disciplinary collaborations abroad, in France and Telecom ParisTech.

10.4.4 Threats

- The institutional environment is always moving (CNRS accreditation loss, Université Paris-Saclay integration stop, Creation of NewUni). Researchers need a stable organization to focus on their research and education missions.
- Although we succeed to obtain fundings, this task is very time-consuming due to the low acceptance rate and the moving environment (Rules for proposals are not stable especially for internal calls).

10.5 Scientific project for the the next five years

For many applications (health, grid, autonomous vehicle, public transportation, logistic, public safety), theere is a huge increasing demand for data sharing: these data may require either very high data rate (high speed cellular networks or local networks) or very low data rate but with strigent low energy and low latency constraints (Internet of Things –IoT–). Whichever the context, the next wireless communication generation (5G) has to be able to handle both kinds of traffic. Therefore the technical challenges are numerous. One can mention i) scalability issue due to multiple communicating devices with different Quality of Experiment, ii) network archictecture in order to minimize the number of relevant information exchange, iii) low latency communications issue, highlighted with the autonomous Vehicle to Vehicle communications, and iv) data exchange safety and privacy.

Consequently, intensive researchs on wireless communications (which gather the MAC and Physical layers) will be done in next decade, and the Digital Communications team (ComNum) plans to play a world-level academic role.

10.5.1 Resource optimization for IoT and 5G

We plan to expand this axis since the number of challenges in this area is growing rapidly. Indeed, the network structures become so complex that the Physical and MAC layers are now completely intrincated with these structured networks (Fog-network, Cache-enabler network, D2D network, Overlayed network, etc). Moreover dependance on State Information exchange will rise the number of unresolved issues (centralized, decentralized, partially-distributed, distributed networks, etc). Optimization techniques (distributed optimization, machine-learning based optimization, non-convex optimization) will therefore become a rich playground for our research.

10.5.2 Data coding and processing for IoT and 5G

For large network with high level of interference, new coding techniques based on the network structure have to be created: one can mention massive MIMO coding, coding with cache-enabler network, coding for interference (network coding). One can also mention coding for low latency constraint. Obviously, related decoding techniques have to be created as well, at time based on deep learning. The team plans to continue and enhance its works on these hot topics.

10.5.3 Security issue in wireless networks

We plan to reinforce the axis on infrastructure security as well as embedded systems security by completing the work on side-channel and leakage issue, with post-quantum homomorphic cryptography. One goal is to achieve multi-hop communications with advanced processing at each node without loosing privacy.

10.5.4 Optical Communications

We plan to continue our research activities on optical fiber MIMO communications when the number of active cores and modes significantly increase in order to reach very high data rates. The project is strongly related to the decoding part of the project 2.

10.6 Scientific production (selection: 20%)

Articles in Journals

[405] A. Tchamkerten and L. Aptel. Bits through queues with feedback. *IEEE Transactions on Information Theory*, May 2018.

[406] N. Bruneau, S. Guilley, A. Heuser, D. Marion, and O. Rioul. Optimal side-channel attacks for multivariate leakages and multiple models. *Journal of Cryptographic Engineering*, 7(4):331–341, November 2017.

[407] N. Bruneau, C. Carlet, S. Guilley, A. Heuser, E. Prouff, and O. Rioul. Stochastic collision attack. *IEEE Transactions on Information Forensics & Security*, 12(9):2090–2104, September 2017.

[408] O. Rioul. Yet another proof of the entropy power inequality. *IEEE Transactions on Information Theory*, 63(6):3595–3599, June 2017.

[409] R. Massin, C. Le Martret, and Ph. Ciblat. A coalition formation game for distributed node clustering in mobile ad hoc networks. *IEEE Transactions on Wireless Communications*, 16(6):3940–3952, June 2017.

[410] S. Salehkalaibar, M. Wigger, and R. Timo. On hypothesis testing against conditional independence with multiple decision centers. *IEEE Transactions on Communications*, May 2017.

[411] E. M. Amhoud, G. Rekaya-Ben Othman, and Y. Jaouën. Concatenation of space-time coding and fec of optical mimosystems. *IEEE Photonics Technology Letters*, 29:603–606, April 2017.

[412] M. Sefidgaran and A. Tchamkerten. Distributed function computation over a rooted directed tree. *IEEE Transactions on Information Theory*, December 2016.

[413] R. Timo, S. Saeedi Bidokhti, M. Wigger, and B. Geiger. A rate-distortion approach to caching. *IEEE Transactions on Information Theory*, September 2016.

[414] F. Iutzeler, P. Bianchi, Ph. Ciblat, and W. Hachem. Explicit convergence rate of a distributed alternating direction method of multipliers. *IEEE Transactions on Automatic Control*, 61(4):892 – 904, April 2016.

[415] S. Belhadj Amor, Y. Steinberg, and M. Wigger. Mimo mac-bc duality with linear-feedback coding schemes. *IEEE Transactions on Information Theory*, November 2015.

[416] A. Mejri and G. Rekaya-Ben Othman. Efficient decoding algorithms for the compute-and-forward strategy. *IEEE Transactions on Communications*, June 2015.

[417] E. Awwad, G. Rekaya-Ben Othman, and Y. Jaouën. Space-time coding schemes for mdl-impaired mode-multiplexed fiber transmission systems. *Journal of Lightwave Technology*, 33(24):5084–5094, 2015.

[418] N. Ksairi, Ph. Ciblat, and C. Le Martret. Optimal resource allocation for type-ii harq based ofdma ad hoc networks under rate and power constraints. *IEEE Transactions on Wireless Communications*, 13(10):5621–5634, October 2014.

[419] A. Tchamkerten, D. Tse, and V. Chandar. Asynchronous capacity per unit cost. *IEEE Transactions on Information Theory*, March 2013.

Articles in Conference Proceedings

[420] I. Fawaz, Ph. Ciblat, and M. Sarkiss. Optimal resource scheduling for energy harvesting communications under strict delay constraint. In *IEEE International Conference on Communications (ICC)*, Kansas City (USA), May 2018.

[421] J. Gori, O. Rioul, Y. Guiard, and M. Beaudouin-Lafon. The perils of confounding factors: How fitts' law experiments can lead to false conclusions. In *ACM Conference on Human Factors in Computing Systems (CHI'18)*, Montréal, Canada, April 2018.

[422] W. Liu, O. Rioul, J. McGrenere, W. Mackay, and M. Beaudouin-Lafon. Bigfile: Bayesian information gain for fast file retrieval. In *ACM Conference on Human Factors in Computing Systems (CHI'18)*, Montréal, Canada, April 2018.

[423] S. M. Moser, L. Wang, and M. Wigger. Asymptotic high-snr capacity of miso optical intensity channels. In *ITW*, Taiwan, November 2017.

[424] M.-A. Khsiba and G. Rekaya-Ben Othman. Sphere decoder with dichotomic search. In *PIMRC 2017*, Montreal, CANADA, October 2017.

[425] E. M. Amhoud, G. Rekaya-Ben Othman, L. Bigot, M. Song, E.-R. Andresen, G. Labroille, M. Bigot-Astruc, and Y. Jaouën. Experimental demonstration of space-time coding for mdl mitigation in few-mode fiber transmission system. In *ECOC 2017*, volume paper M.1.D.2, Goteborg (Suède), September 2017.

[426] A. Tchamkerten and L. Li. Infinite dispersion in bursty communication. In *International symposium on information theory*, Aachen, Germany, June 2017.

[427] R.Y. Yates, Ph. Ciblat, A. Yener, and M. Wigger. Age-optimal constrained cache updating. In *IEEE International Symposium on Information Theory (ISIT)*, Aachen/Aix-la-Chapelle, Germany, June 2017.

[428] S. Saeedi Bidokhti, M. Wigger, and A. Yener. Benefits of cache assignment in degraded bcs. In *ISIT 2017*, Aix-La-Chapelle, June 2017.

[429] W. Liu, R. Lucas DOliveira, M. Beaudouin-Lafon, and O. Rioul. Bignav: Bayesian information gain for guiding multiscale navigation. In *CHI'17: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*, pages 5869–5880, Denver, Colorado, USA, May 2017. ACM.

[430] J. Gori, O. Rioul, and Y. Guiard. To miss is human: Information-theoretic rationale for target misses in fitts' law. In *CHI'17: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*, pages 260–264, Denver, USA, May 2017. ACM.

[431] O. Rioul. At every corner: Determining corner points of two-user gaussian interference channels. In *IEEE International Conference on Communications (ICC'17)*, Paris, France, May 2017.

[432] X. Leturc, C. Le Martret, and Ph. Ciblat. Energy efficient resource allocation for harq with statistical csi in multiuser ad hoc networks. In *IEEE International Conference on Communications (ICC)*, Paris, France, May 2017.

[433] S. Kamel, M. Sarkiss, and M. Wigger. Achieving joint secrecy with cache-channel coding over erasure broadcast channels. In *ICC*, Paris, France, May 2017.

[434] S. Kamel, M. Sarkiss, and G. Rekaya-Ben Othman. Improving ggh cryptosystem using generalized low density lattices. In *2016 International Conference on Advanced Communication Systems and Information Security*, Marrakech, Maroc, October 2016.

[435] O. Rioul, P. Solé, S. Guilley, and J.-L. Danger. On the entropy of physically unclonable functions. In *2016 IEEE International Symposium on Information Theory (ISIT'16)*, Barcelona, Spain, July 2016.

[436] R. Tajan and Ph. Ciblat. Information-theoretic multi-user power adaptation in retransmission schemes. In *IEEE Signal Processing Advances in Wireless Communications (SPAWC)*, Edinburgh (Scotland), July 2016.

[437] A. Lapidoth and M. Wigger. A necessary condition for the transmissibility of correlated sources over a mac,. In *ISIT 2016*, Barcelona, Spain, July 2016.

[438] E. M. Amhoud, G. Rekaya-Ben Othman, and Y. Jaouën. Design criterion of space-time codes for sdm optical fiber systems. In *International Conference on Telecommunications (ICT 2016)*, volume Session S25, Thessaloniki, Greece, May 2016.

[439] F. Jardel, J. Boutros, M. Sarkiss, and G. Rekaya-Ben Othman. Spatial coupling for distributed storage and diversity applications. In *The Fifth International Conference on Communications and Networking (ComNet'2015)*, HAMMAMET, November 2015.

[440] N. Bruneau, S. Guilley, A. Heuser, D. Marion, and O. Rioul. Less is more: Dimensionality reduction from a theoretical perspective. In *17th Workshop on Cryptographic Hardware and Embedded Systems (CHES 2015)*, Saint-Malo, France, September 2015.

[441] E. Awwad, G. Rekaya-Ben Othman, and Y. Jaouën. Space-time coding and optimal scrambling for mode multiplexed optical fiber systems. In *ICC 2015*, volume session ONS-05, London, June 2015.

[442] A. Tchamkerten and V. Chandar. Asynchronous capacity per unit cost under a receiver sampling constraint. In *ISIT 2015*, Hong-Kong, June 2015.

[443] A. Tchamkerten and E. Ehsan. Sequential detection of transient changes in stochastic systems under a sampling constraint. In *ISIT 2015*, Hong-Kong, June 2015.

[444] R. Timo, M. Wigger, and S. Shamai. Slepian-wolf coding for broadcasting with cooperative base-stations. In *International Symposium on Information Theory 2015*, Hong Kong, Chine, June 2015.

[445] A. Bracher and M. Wigger. Feedback and partial message side-information on the semideterministic broadcast channel. In *International Symposium on Information Theory 2015*, Hong Kong, Chine, June 2015.

[446] N. Nguyen-Thanh, A. T. Pham, Ph. Ciblat, and V. T. Nguyen. Channel surveillance against selfish primary user emulation attack in cognitive radio networks. In *IEEE GlobalSIP 2014*, Atlanta, USA, December 2014.

[447] N. Bruneau, S. Guilley, A. Heuser, and O. Rioul. Masks will fall off: Higher-order optimal distinguishers. In *International Conference on the Theory and Application of Cryptology and Information Security (AsiaCrypt)*, volume 8874, pages 344–365, Kaoshiung, Taiwan, December 2014. Springer LNCS.

[448] A. Amari, Ph. Ciblat, and Y. Jaouën. Fifth-order volterra series based nonlinear equalizer for long-haul data rate optical fiber communications. In *Asilomar Conference on Signals, Systems, and Computer*, Pacific Grove (USA), November 2014.

[449] A. Heuser, O. Rioul, and S. Guilley. Good is not good enough: Deriving optimal distinguishers from communication theory. In *16th Workshop on Cryptographic Hardware and Embedded Systems (CHES 2014)*, volume LNCS 8731, pages 55–74, Busan, Korea, September 2014. Springer LNCS.

[450] N. Ksairi, Ph. Ciblat, and C. Le Martret. Optimal resource allocation for type-ii harq based ofdma ad hoc networks under individual rate and power constraints. In *ICASSP*, Florence (Italy), May 2014.

[451] Th. Laich and M. Wigger. Utility of encoder side information for the lossless kaspi/heegard-berger problem. In *International Symposium on Information Theory 2013*, Istanbul, Turkey, July 2013.

[452] A. Tchamkerten, G. Caire, and V. Chandar. Energy and sampling constrained asynchronous communication. In *IEEE International Symposium on Information Theory*, Istanbul (Turkey), July 2013.

[453] A. Tchamkerten, P. Solé, and L. Sok. Lattice based codes for insertion and deletion channels. In *IEEE International Symposium on Information Theory*, Istanbul (Turkey), July 2013.

[454] P. Delesques, Th. Bonald, G. Froc, Ph. Ciblat, and C. Ware. Enhancement of an optical burst switch with shared electronic buffers. In *International Conference on Optical Networking Design and Modeling (ONDM)*, pages 136–141, Brest, France, April 2013. Poster.

[455] A. Mejri and G. Rekaya-Ben Othman. Practical physical layer network coding in multi-sources relay channels via the compute-and-forward. In *IEEE Wireless Communications and Networking Conference (WCNC 2013)*, Shanghai, Chine, April 2013.

[456] V. Chandar, G. Caire, and A. Tchamkerten. Energy and sampling constrained asynchronous com-

munication (invited paper). In *Information Theory and Applications*, San Diego, US, January 2013.
[457] Y. Guiard and O. Rioul. A mathematical description of the speed/accuracy trade-off of aimed movement. In *British HCI*, Lincoln, Royaume Uni, July 2015. Association for Computing Machinery.

Patents

[458] G. Rekaya-Ben Othman, A. Mejri, and M.-A. Khsiba. Methods and devices for sub-block data decoding, December 2016.
[459] Th. Courtat, P. Bianchi, and Ph. Ciblat. Identification conjointe de signaux confondus, September 2016.
[460] G. Rekaya-Ben Othman, E. M. Amhoud, and Y. Jaouën. Space-time coding methods and devices for optical mimo systems, May 2016.
[461] O. Rioul and S. Guilley. Secret key estimation methods and devices, April 2016.
[462] G. Rekaya-Ben Othman and A. Mejri. Tree search-based decoding, February 2015.

Chapter 11

GTO

Optical Communications

11.1 Presentation of the team

Team leader: Didier Erasme (-09/15), Yves Jaouën (10/15-)

Faculty: Didier Erasme (FP), Renaud Gabet (AP), Frédéric Grillot (FP since 10/15), Yves Jaouën (FP), Mansoor Yousefi (AP from 03/16), Cedric Ware (AP)

Invited Professors: Lilin YI (FP Jiao Tong University of Shanghai, since 02/18)

Sabbatical professors: L. Yi (02/14-10/14), M. Osinski (10/14-12/14)

Permanent Research Engineers: Mengdi SONG (since 06/16)

PostDocs, non permanent Research Engineers: I. Bertoldi Martins (05/12-07/13), T.C. Newell (04/16), A. Le Breton (11/16-07/17), X. Yangzhang (06/16-07/16), T. Gui (09/17-10/17), J. Fahs (12/16-01/17), M. Amhoud (01/18-08/18)

PhD Students: V. Henry (10/11-12/2014), E. Lucas (01/11-12/14), E. Awwad (10/11-01/15), C. Wang (co-supervision, registered at INSA Rennes 09/11-03/15), M. Chaibi(10/12-11/15), X. Zou 10/12-11/15), M. Song (10/12-10/16), A. Amari (03/13-07/16), H. Huang (08/13-03/17), W. Samoud (10/13-10/16), L. Jumpertz (10/13-11/16), G. Simon (10/13-12/16), D. Maraval (11/13-05/17), M. Amhoud (09/14-12/17), B. Han (12/14-05/18), J.-M. Sarraute (10/14-05/18), W. Wei (jointly with the Univ. JiaoTong of Shanghai, 05/15-05/18), J. Konopacki (10/14-), C. Romano (12/14-), J.-W. Goossens (06/15-), A. Gallet (10/15-), H. Chouman (11/15-), Sandra Gomez (01/16-), W. Gemechu (jointly with the U. of Brescia, 03/16-), O. Spitz (09/16-), S. Barthomeuf (10/16-), A. Minakhmetov (10/16-), P. Clément (11/16-), A. Abouseif (01/17-), L. Paillier (09/17-), A. Luay (11/17-), J. Duan (10/17-), C. Sauvage (10/17-), C. Catanese (11/17-)

Plateforms: High-bit rate coherent transmission systems[1]
GTO has developed a high bitrate system platform based coherent detection combined with digital signal processing for evaluating the performance of 100Gb/s and 400Gb/s fiber transmission systems and subsystems. The digital signal processing is done "off-line" from recorded time traces.

Scientific Production Overview: Table 11.1 shows the overall scientific production between 2013 and 2018. The detailed bibliography is included in a separate accompanying document.

11.2 RESEARCH ACTIVITY

The Optical Communications Group (GTO) is home to the research programs of six faculty members and a state-of-the-art laboratory on optical fiber transmission. We conduct advanced research

[1]Website: `https://www.comelec.telecom-paristech.fr/index.php?id=230&L=1`

Journals	Articles in Proceedings	Books and Book Chapters	Patents	Keynotes and Tutorials	Other Invited Talks	Habilitation Thesis	Completed PhD
107	186	7	7	8	17	0	17

Table 11.1: Overall Scientific Production at GTO.

in six categories: fiber-optic transmission, short-reach communication, network architectures, advanced lasers for communications, integrated photonics, and optical sensors. The GTO closely collaborates with the Digital Communications Group (ComNum) at Télécom ParisTech, as well as with world-renown international research groups in photonics and communications. These collaborations has led to many joint PhD projects and has made our position in inter-disciplinary research privileged and perhaps unique in France.
Experimental demonstration of novel concepts in optical communication is of strategic importance to the GTO. Thanks to a state-of-the-art experimental platform, we have demonstrated high-speed transmission experiments using sophisticated DSP and advanced mathematical algorithms for the compensation of the channel impairments.
A short summary of each research axis is provided below.

11.2.1 Axis 1: High-speed optical fiber data transmission

Faculty: Yves Jaouën, Mansoor Yousefi and Mengdi Song

The exponential increase in data traffic is putting an escalating pressure on fiber-optic networks. As a result, optical communication rapidly progressed in the past decade in order to keep pace with the demand for high data rates. Important advances include application of digital signal processing (DSP) for compensation of channel impairments, advanced communication algorithms for spectrally-efficient transmission, and space-division multiplexing using multi-mode and multi-core fiber. The GTO has made valuable contributions to these research frontiers.

1) Capacity of models of optical fiber. The propagation of a signal in optical fiber is governed by the stochastic nonlinear Schrödinger (NLS) equation. The NLS equation models chromatic dispersion, Kerr nonlinearity, and amplified spontaneous emission (ASE) noise. Because of the analytic difficulties that nonlinearity brings about, half a century since the introduction of the optical fiber, determining the capacity of this channel has remained a formidable challenge. At GTO, we made several breakthroughs on the capacity problem. First, we proved that the channel capacity is upper bounded by log(1+SNR), where SNR is the signal-to-noise ratio (in collaboration with researchers from TU Munich and U. of Toronto) [495]. This is the only known capacity upper bound for this important channel. Second, we established the asymptotic capacity as the input power tends to infinity, thereby resolving a long-standing vexing conundrum about the ultimate capacity of the optical fiber to carry information. Third, we proved that the optimal input that achieves the maximum transmission rate is surprisingly discrete, even though the signal at the fiber input is generally a continuous-time waveform (in collaboration with ComNum).

2) DSP for mitigating channel impairments. Coherent detection makes it possible to compensate channel impairments (such as chromatic dispersion) using digital signal processing, giving way to spectrally-efficient transmission with higher-order modulation formats and signal shaping. At GTO, we have applied DSP for mitigating fiber nonlinearity based on digital back-propagation and Volterra series. We designed a successive interference cancellation scheme for WDM, termed inter-subcarrier nonlinear interference canceler (INIC) [463]. The INIC consists of detecting the symbols of adjacent subcarriers, regenerating them using the Volterra series model of fiber, and removing their interference on the subcarrier of interest. Finally, we addressed the polarization-dependent loss (PDL), a non-unitary stochastic linear effect in dual polarization systems. We designed space-time codes for long-haul optical fiber systems impaired by PDL.

3) Transmission based on the nonlinear Fourier transform. The achievable data rates of the con-

ventional methods in optical communication vanish at high input powers. This singular effect has become known as the "capacity crunch" or the "nonlinear Shannon limit" in fiber. A focal research direction at GTO is the application of *nonlinear Fourier transforms (NFTs)* to overcome the limitation that fiber nonlinearity sets on the transmission rates of the fiber-optic networks. We have proposed a novel transmission method termed *nonlinear frequency-division multiplexing (NFDM)* based on the NFT that is fundamentally compatible with the nonlinear optical fiber. NFDM can be viewed as a generalization of the orthogonal frequency-division multiplexing (OFDM) in linear channels to the nonlinear optical fiber. In NFDM, in the absence of noise, inter-channel and inter-symbol interference are simultaneously zero for all users of a network. The GTO played a pivotal role in advancing the NFDM research in the past few years. Importantly, we showed that the achievable rates of NFDM are higher than the achievable rates of WDM in ideal simplified models. We established this result for fiber with negative [512] and positive dispersion [511], as well as for dual-polarization systems [465] and realistic systems with non-idealities and perturbations [466]. These contributions spurred NFDM research to faster progress, giving way to a series of experimental demonstrations of the transmission based on the NFT, including experiments at the GTO lab [498].

4) Space-division multiplexing. The interaction between transmission modes in multi-mode or multi-core fiber degrades the system performance considerably. For example, a non-unitary cross-talk distortion in few-mode fibers (FMFs) is mode-dependent loss (MDL) that is known to substantially increase the bit error rate. Intensive research has been carried out in recent years to compensate the cross-talk in SDM using multiple-input multiple-output (MIMO) DSP. Over the Ph. D. thesis of Elie Awwad and El-Mehdi Amhoud, we have designed space-time codes to mitigate MDL in FMFs, obtaining an appreciable net coding gain in numerical simulations [467], and validated that in the lb [499]. In addition, we explained this improvement analytically by computing an upper bound on the probability of error [468].

11.2.2 Axis 2: Cost-effective systems and enhanced spectral efficiency modulation for access and metro networks

Faculty: Didier Erasme, Mengdi Song, Frédéric Grillot

Short reach optical communication systems are prone to an uninterrupted run for data rate enhancement while cost constraints limit the adoption of the most highly efficient solutions deployed in long haul. The access communication segment must provide ubiquitous solutions allowing convergence between business, residential and mobile (front and back hauling) networks. Low energy consumption, low cost and stringent latency limitations constitute typical constraints that forbid so far using coherent reception, external modulation, optical amplification and advanced digital signal processing. Most practical solutions remains in the scope of IM/DD meaning: intensity modulation, direct detection. In addition, normalization generate standards that specify the objective for systems and restrict flexibility by fixing, for example, the wavelength plan for transmission.

In the field of passive optical access networks, NGPON2 standard was published in 2013, consisting on a 4 to 8 channel WDM overlay on a XGPON (10Gbit/s) TDM solution. This proposal, although apparently rather conservative, proved to be difficult to fulfil by equipment providers. Gaël Simon demonstrated such blockage in his PhD (see for example [500]). Operators then backtracked to simple TDM IM/DD solutions with enhanced bit rates. This was shown possible using 10Gbit/s capable emitters and receivers by using spectrally efficient modulation formats such as duobinary, which was studied by Justine Konopacky, and PAM4 or PAM8 being presently studied by Sylvain Barthomeuf [501]. (These 3 PhDs are done in collaboration with Orange Labs in Lannion).

On the other hand, Cheng Wang and Heming Huang studied enhancing the modulation characteristic (high bandwidth and low phase amplitude coupling) of semi-conductor lasers (see Axis 4, the section on semi-conductor lasers). The performance of all the above-proposed solutions remained very limited in terms of bit-rate versus distance when the emission wavelength is in the C-Band around 1550 nm. We demonstrated earlier that single-side-band or vestigial-side-band modulation

could solve this drawback. Using a special emitting device called a dual-electroabsorbtion modulated laser [469], we could push up the limit when using orthogonal-frequency division multiplexing (OFDM) or carrier-less amplitude-phase modulation (CAP) to high rate (Up to 36Gbit/s) and/or long distances (above 200km repeater-less) [470].
Optical access networking can be addressed also through free space optics. A new activity exploring solutions for kilometer-range connection in hostile surroundings has recently started in 2017 in collaboration with ONERA.

11.2.3 Axis 3: Cross-layer optical networking, optical switching

Faculty: Cédric Ware, Yves Jaouën

While it boosts their data rate, data networks' ballooning energy consumption must be curbed while also meeting stringent latency requirements brought by 5G. This requires cutting across network layers to leverage optics' huge bandwidth and low energy per bit processed [497, 510].
An example of such cross-layer approaches is our activity on optical packet switching (OPS). While it avoids wasteful optical-to-electronic-to-optical (O-E-O) conversions, it is vulnerable to contention because there are no practical optical buffering techniques. Thus, in pure OPS, contending packets are lost, leading to an unacceptable packet loss ratio (PLR).
We study 3 approaches to make OPS a deployable solution. First, over the Ph. D. thesis of Wiem Samoud (10/2013–10/2016, jointly with Télécom SudParis), a hybrid opto-electronic packet switch (HOPS) couples an OPS switch with a shared electronic buffer; just a few input/output ports to the buffer can bring the PLR to acceptable levels—especially when traffic is split along service classes: only a fraction of the traffic needs ironclad reliability [471]. Our simulations show that HOPS has an acceptable PLR and cuts down considerably on energy-wasting O-E-O conversions.
Second, in data-center networks (a large part of the energy consumption of the IT sector) the high PLR of OPS can be mitigated at a higher network level, by reconfiguring the transfer control protocol (TCP) used in most network connections. Over the Ph. D. thesis of Artur Minakhmetov (10/2016–present, jointly with the RMS team), we have shown that HOPS works even better for this application [502]. Preliminary simulations indicate an up to 4-fold gain in energy efficiency.
Third, contention can be sidestepped by timing the packets' arrival into the switches. We participate in the ANR N-GREEN project, led by Nokia Bell Labs France: an OPS-based synchronous network architecture in the 5G context [517]. An integrated OPS has been realized by our partners, to be tested by us experimentally system-wise using our transmission platforms. Also, part of the PhD thesis of Bing Han (11/2015–10/2018, jointly with Orange Labs) studied "TIme and Spectral optical Aggregation" (TISA): a purely optical aggregation with a fine granularity comparable to packet switching, thanks to the combination of temporal and spectral domains.
In addition to OPS, we also work on WDM circuit switching: the reconfigurable optical add-drop multiplexer (ROADM) function. In the Ph. D. thesis of Wei Wei (joint with Jiao Tong University) we realized an ultra-selective ROADM using stimulated Brillouin scattering (SBS). A frequency-sweeping depolarized SBS pump allows a sharply rectangular filter, polarization independent, with a 2-GHz bandwidth (the state of the art is ∼10 GHz) [472, 473, 474]. On a Multi-band polarization-multiplexed QPSK-OFDM signal, with guard bands as low as ∼300 MHz, the filter-induced penalty is only ∼1 dB at a bit error rate of 10^{-3}. We also proposed cost-effective GHz-wide arbitrary-shaped microwave photonic filters based on SBS using a directly-modulated laser [475].
In the longer term, to integrate additional optical functionalities into practical networks, we are looking for more awareness of the network's physical layer at higher-layer levels. Over the Ph. D. of Hussein Chouman (11/2015–present, in collaboration with Télécom SudParis), we have developed a physical-layer-aware network simulator that we are using to quantify the benefits of functionalities such as all-optical wavelength conversion using various network design heuristics.

11.2.4 Axis 4: Novel in-plane semiconductor lasers

Faculty: Frédéric Grillot, Didier Erasme, Mengdi Song

In this research, we aim at developing novel-in plane semiconductor lasers for high-speed and direct modulation operation, wavelength conversion, optical switching, and coherent communications [506]. To do so, we essentially rely on quantum dot (QD) as the active laser medium which are one of the best practical examples of emerging nanotechnologies. Owing to the atom-like discrete energy levels, QDs exhibit various properties resulting from the three-dimensional confinement of carriers, like a high stability against temperature variation and a low-threshold lasing operation, which are in favor for the reduction of the energy consumption [514], [482].
Nowadays, direct-detection systems implemented with directly modulated semiconductor lasers remain a simple and compact solution for fiber-optic communications. In these systems, the electro-optic 3-dB modulation bandwidth of a directly modulated laser is the most important figure-of-merit that determines the maximum data rate achievable. To keep increasing the data rate, the enhancement of the electro-optic 3-dB modulation bandwidth without causing other impairments is highly desired. Such improvements are obtained from the development of novel in-plane semiconductor materials and nonlinear architectures like the optical injection-locked gain lever laser (OILGL). Over the PhD of J. M. Sarraute (collaboration with Université Laval, Canada), we showed that the OILGL which is made of a short modulation section and a long gain section continuous wave biased can produce a strong increase of the electro-optic 3-dB bandwidth that is pushed close to 100 GHz without being affected by gain nonlinearities unlike any other directly modulated semiconductor laser[484]. Over the PhD of H. Huang (collaboration with TU Berlin), we investigated the potential of non-linear and dynamic properties of InAs/GaAs QD lasers [493], [508]. We demonstrated an efficient nonlinear conversion with possible THz bandwidth and a symmetrical response between up- and down-converted signals. As compared to semiconductor optical amplifiers, the conversion does not require large pump/probe powers and bias currents which is of first importance for the development of QD-based all-optical wavelength converters.
Secondly, we also demonstrated the first chaos-free operation in an InAs/GaAs QD laser, emitting solely in the ground state transition. This proves the ability of such lasers to operate without an isolator, which is vital in the future fiber optics and silicon photonics communication systems [487].
Lastly, the combination of advanced modulation formats and coherent detection require the use of local oscillators with narrow lines. Our research also reported on the spectral linewidth of QD distributed feedback lasers [509], [476]. A narrow line of 160 kHz (80 kHz intrinsic) with a low sensitivity to temperature is demonstrated [491] [477]. These results confirm the high potential of QD lasers for increasing transmission capacity in future coherent communication systems.

11.2.5 Axis 5: Nonlinear dynamics for chaos based communications and disruptive technologies

Faculty: Frédéric Grillot

First part of this research is focused on the influence of optical feedback and/or optical injection [485] for extreme optical pulse generation (known as optical rogue waves). Our work has recently proposed a novel technique for controlling the generation of extreme events that match the criterion for rogue waves [507]. By using an oscillatory behavior constituted of pulses of fixed amplitude, we have used the system's noise to operate the laser in between two states: a pulsation regime and a stable injection-locked one. Under these conditions, the average number of pulses can be indirectly controlled by moving the laser closer to one state or the other. We found that the threshold for rogue waves is roughly proportional to the square root of the number of pulses, hence it becomes possible to estimate whether the pulses are "rare" by simply counting them [507]. While this technique was presented for a particular quantum well based laser, it can be applied to any laser that exhibits a similar behavior.
We are also interested in studying the dynamics of hybrid III-V semiconductor lasers for integrated silicon photonics [478]. The integration of optical functions on a microelectronic chip brings many innovative perspectives, along with the possibility to enhance the performances of photonic integrated circuits (PIC). However, unintentional reflections originating from various possible inter-

faces (active/passive transitions) induce unwanted feedback effects to the laser. Our results showed that the lasers are strongly affected by sub-cavities in the silicon waveguides which translates into complex modal behaviors. If such lasers were to be used in a PIC, any component reflecting light towards it within the microchip would thus greatly affect its behavior. The results will be useful for the development of integrated photonics applications since parasitic feedback sources must be identified and controlled, as the laser cannot be protected from those using external isolators.
In 2016, we also unveil the first-ever source of deterministic temporal chaos at mid-infrared wavelength [479]. The research contradicts 35 years of knowledge of laser diode destabilization, by demonstrating a unique sequence of bifurcations to chaos that involve self-pulsation at the external cavity frequency, so far only observed in gas lasers. The result of the research makes a significant breakthrough for the photonics community working in these wavelengths. This first observation of temporal chaos in a quantum cascade laser (QCL) under optical feedback have several consequences for the everyday use of the QCLs. Parasitic feedback must indeed be avoided in experimental setups. It is therefore necessary to develop compact and low-cost mid-infrared optical isolators, that could be integrated in QCL packages. Until now, although some companies offer mid- infrared isolators, they remain custom-made, cumbersome, expensive and not suitable for systematic use. Furthermore, the fabrication of mid-infrared optical fibers must be carefully controlled to limit parasitic reflections and Rayleigh backscattering, similarly to near-infrared fibers [489]. On the other hand, a chaotic light source at mid-infrared wavelength could lead to new applications of QCLs, as for interband laser diodes [483]. Chaotic QCLs could be efficient for optical counter-measures, as they are unpredictable sources. One could also imagine chaotic mid-infrared LIDAR that would provide high-resolution and jamming-resistant sensors. For cryptography in the mid-infrared range, chaotic QCLs could provide random bit generation or secured communications using chaos modulation for the message encryption and synchronized chaos for the message transmission.

11.2.6 Axis 6: Optical sensors and applications

Faculty: Renaud Gabet, Yves Jaouën

Optical Fiber Sensors. In the past few years, we have studied distributed strain sensors (DSS) based on the Brillouin scattering, a non-linear effect in the single mode optical fiber, to determine the local variation of temperature and strain. The conventional B-OTDA solution presents higher performances compared to B-OTDR, but required to access to the two end of fiber-under-test. However, a single-end monitoring system is of great interest to many industrial applications.
We studied through the PhD thesis of Damien Maraval (09/13-05/2017, in a CIFRE agreement with the Cementys company) the development of a dynamic interrogator. We proposed a novel real-time distributed strain sensor in the B-OTDR configuration using a slope-assisted acquisition technique for recovering the Brillouin frequency shift [480]. We implemented a 10 m prototype pipe to demonstrate the performance of the proposed distributed dynamic strain-and-displacement monitoring system. A strain resolution of $\pm 40\mu$m, and a displacement resolution of ± 1.2 cm, was achieved with an acquisition rate of 7.6 Hz in a 100 m fiber sensor [503]. The system is limited in real-time dynamic range to $600\mu/m$ with an acquisition rate of over 100 Hz. Ongoing equipment upgrade will extend the dynamic range (by real-time BFS tracking during the acquisition) and speed up the acquisition and transfer of data.
Since September 2017, we collaborate with Febus Optics, a young startup based in Pau, France, to build innovative B-OTDR solutions to dynamically detect the strain variation. We have also started to expand our research to distributed acoustic sensor (DAS), based on the Rayleigh backscattering, and distributed pressure measurement.
Single-frequency fiber laser for coherent LIDAR applications. We have collaborated with the Keopsys Group and ONERA to develop advanced coherent lasers. We built a laser with 1 kW peak-power and 110 ns pulse duration using triangular strain gradient along the fiber, to mitigate stimulated Brillouin scattering. [481]. We developed a three-level model taking into account ion-ion interactions, that is important for systematic design of Thulium fiber amplifiers. In col-

laboration with the Cybel company in the USA, we developed an efficient simulation model based on precise measurements of the cross-section and other parameters [504]. The model agrees well with experiment in several single- and multi-stage amplifier topologies, and in different operating conditions [505].

11.2.7 Scientific highlights

Organization of workshops and conferences

- ISPALD conferences 2014-2018
- Research day on Challenges of Optical Networking (2017, Digicosme)
- P. Gallion serves as the Chairman of the IEEE Photonics French Chapter

Program Chairs of Workshops and conferences

TPC member of ECOC 2015–2018, CLEO Europe 2015 & 2017, ACP 2015 & 2018, SPIE Photonics West 2015–2018, and IEEE Rapid conference 2018

Associate editors of journals

- Associate Editor Optics Express

Awards

- L. Jumpertz, Outstanding thesis "Nonlinear Photonics in Mid-infrared Quantum Cascade Lasers" by the University Paris Saclay in 2017.
- W. Wei, Best student paper Award at conference MicroWave Photonics in november 2017.
- ERC Starting Grant 2018 (Mansoor YOUSEFI)

Significant contracts

- 2012-2015: Safe and secure European routing (SASER-SIGFRIED), celtic-plus project within the program security in energy-efficient, flexible and resilient data networks;
- 2013-2016: ANR APTE – Joint laboratory between APex Technologies and Télécom ParisTech
- 2013-2015: Silicon Optoelectronics, NanoDesign, IdEX Paris-Saclay;
- 2014-2016: Phase-Amplitude Coupling in Complex Semiconductor Lasers with External Control, International Franco-Taiwanese Program PhC Orchid;
- 2014-2017: Nanostructured Lasers for microwave, millimeter-wave and terahertz generation, European Office of Aerospace Research & Development;
- 2016-2018: N-GREEN - New-Generation of Routers for Energy Efficient Network, ANR;
- 2016-2019: EFFLAM - Evolution of fiber optic network infrastructures using multi-core fiber amplification, FUI-21
- 2017-2019: SCODE - Offshore fiber monitoring during deployment and operation
- 2017-2020: Photonic Integrated Circuits Accessible to Everyone, H2020;
- 2018-2021: Communications à base de détecteurs et lasers à cascades quantiques, ANR DGA Maturation -;
- 2018–2022: FONTE - Fiber Optic Nonlinear Technologies, ITN, H2020
- 2018–2022: REAL-NET, Real-time Monitoring and Mitigation of Nonlinear Effects in Optical Networks, ITN, H2020

Sabbatical stays

- Frédéric Grillot, Visiting Professor at the University of California Los Angeles (since 04/17)
- Frédéric Grillot, Research Professor at the University of New Mexico (since 09/15)
- Yves Jaouën, Sabbatical stay at the University Jiao Tong of Shanghai (02/17-05/17)

11.3 SWOT Analysis

11.3.1 Strengths

- Faculty members regularly publish in the top tier journals and conferences (IEEE Transactions, OSA journals, AIP journals, Nature Publishing Group, etc)
- Close collaboration and joint projects with parters in France (Huawei, Orange Labs, Nokia Bell Labs, ONERA, Keopsys), in European universities (UK, Germany, ...), USA/Canada (Colombia, UC Davis, Virginia Tech, Université Laval, NRC Ottawa ...), China (SJTU Shanghai, Tongji Shanghai, SWJTU Chengdu)
- Research at GTO has been recognized internationally, through invited papers and talks at major journals, conferences and workshops
- A state-of-the-art laboratory in the optical communication, maintained by a full-time engineer
- Broad and inter-disciplinary research, covering all aspects of communications from photonics to transmission and networks
- Attracting excellent students for PhD at GTO, by coordinating masters' programs
- Securing research funding from diverse sources: European Commission (H2020), USA government, France ANR, local programs (Digicosme, IMT and COMELEC scholarships) and the private sector (CIFRE programs)

11.3.2 Weaknesses

- Small group (6 professors). Moreover, D. Erasme will leave TPT in 09/2018
- Attractivity of the communications engineering for students has been reduced in the past years

11.3.3 Opportunities

- Strong collaboration with world-renown international research groups (Shanghai Jiao Tong U., Colombia, ...), as well as with European companies (Orange, Nokia, Huawei)
- The GTO collaborates with the SAMOVAR lab at Télécom SudParis (TSP)

11.3.4 Threats

- Difficulty in obtaining external funding for upgrading the GTO lab
- COMELEC funding at "NewUni" is uncertain, given restructuring and growing reliance on external funding
- Optical communication is not among subjects promoted by NewUni

11.4 Scientific Projects in the Next 5 Years

In this section, we describe the projects that the GTO expects to carry out in the next five years.

11.4.1 High rate communications and networking

Transmission based on the nonlinear Fourier transform. As discussed in Section 11.2.1, the achievable information rates of the conventional communication methods in optical communication vanish at high input powers. To address this problem, researchers at the GTO proposed NFDM. The GTO has shown that the achievable rates of NFDM are higher than that of WDM, in ideal

simplified models. However, the merit of NFDM in practical systems with non-idealities and perturbations, and with realistic signal and system parameters, is still open research. At the GTO, we plan to further explore this research direction in the future.
DSP for single- and multi-mode multi-core fiber. The capacity of the optical fiber networks can be maximized by using spatial degrees-of-freedom (multiple-input multiple-output communication using orthogonal modes or fiber cores), advanced modulation formats (e.g., higher-order QAM), spectrally-efficient signaling (e.g., super-channel transmission) as well as DSP. At the GTO, we will continue to design DSP for single- and multi-mode fiber-optic transmission systems. These advanced DSP algorithms will be examined at our high-baud-rate transmission platform.
Free-space optical communication. Communication between the earth and space satellites using laser sources is a key technology in the future wireless communication systems. In this approach, a good spatial signal coherence is needed in order to maximize the coupling efficiency. However, the coherence is impaired by the channel distortions, notably by the atmospheric turbulence. We plan to study this problem.
Cross-layer optimization in optical networks. Today's OSI-layer-model networks face the critical challenge of unsustainable energy consumption growth. Solving it will require a drastic redesign, new network architectures optimized globally, beyond the artificial barriers imposed by network layers. Our current activities toward this end include the design of an efficient and versatile metropolitan/access network architecture based on optical switching in collaboration with the industry; as well as more upstream research such as the practical use of all-optical switching, wavelength conversion and other optical functionalities into networks by a judicious adaptation of network protocols.

11.4.2 Optical devices and systems performance for context driven applications

Optical sources for access, metro and radio-over-fiber networks (radio front and back hauling) must combine integration for both light generation and modulation. Cost driven system solutions capitalize on low-cost well-grounded devices, high-efficiency modulation formats (such as duo-binary, PAM OFDM, CAP) and pre- and post-equalization. Likewise free-space optical communication is finding many new applications in all sort of environment such as RF-saturated areas, vehicle-to-ground or vehicle-to-vehicle communication as well as spatial applications. Circumstance dependent solutions have to be envisaged adjusting all parameters from the transmission wavelength down to the digital communication algorithms.

11.4.3 Quantum confined devices and semiconductor laser dynamics

We will improve the performance of optical communication systems, and develope advanced solutions for optical computing or optics-based information security. To do so, we will develop the next generation of photonic oscillators and quantum confined devices using new materials such as quantum dots and intersubband transitions based quantum cascade structures. Our work also will focus on studying nonlinear dynamical properties and optical chaos of semiconductor lasers as well as microwave and silicon photonics applications [487]. We plan to establish ultra-narrow linewidth operation ($\leq$100 kHz) from quantum dot lasers for coherent communications [477], [485], high purity photonic microwave generation and on chip atomic clocks systems. We will investigate the intersubband dynamics from quantum cascade lasers (mid-infrared and terahertz domains) with the objective of developing novel encrypted atmospheric communication line and unpredictable optical counter-measures systems [492].

11.4.4 Application of Brillouin and Raman effects to sensing and characterization

By analyzing the Rayleigh, Brillouin or Raman backscattered spectra, local information about temperature, strain, loss or acoustic environment of the optical fiber can be derived. Since September

2017, we collaborate with the Febus Optics, a young startup based in Pau, France, to build innovative B-OTDR solutions to detect temperature variations due to strain. Brillouin distributed optical fiber strain sensors are often limited to static events because of the long acquisition time due to the classic frequency sweep technique. We investigate advanced DSP solutions for dynamic distributed strain monitoring with over 100 Hz vibration. We have also started to expand our research to distributed acoustic sensor (DAS) and distributed pressure measurement.

11.5 Scientific production (selection)

Articles in Journals

[463] A. Amari, O. Dobre, R. Venkatesan, O. Kumar, Ph. Ciblat, and Y. Jaouën. A survey on fiber nonlinearity compensation for 400 gbps and beyond optical communication systems. *IEEE Communications Surveys & Tutorials*, October 2017.

[464] E. Awwad, Y. Jaouën, and G. Rekaya-Ben Othman. Polarization-time coding for pdl mitigation long-haul polmux ofdm systems. *Optics Express*, 21(19), October 2013.

[465] J.-W. Goossens, H. Hafermann, M. Yousefi, and Y. Jaouën. Polarization-division multiplexing based on the nonlinear fourier transform. *Optics Express*, 25:, 26437–26452, November 2017.

[466] X. Yangzhang, D. Lavery, P. Bayvel, and M. Yousefi. Impact of perturbations on nonlinear frequency-division multiplexing. *IEEE Journal of Lightwave Technology*, 36(2), January 2018.

[467] E. Awwad, G. Rekaya-Ben Othman, and Y. Jaouën. Space-time coding scheme for MDL-impaired mode-multiplexed fiber transmission systems. *Ligthwave Technology*, June 2015.

[468] E. M. Amhoud, G. Rekaya-Ben Othman, and Y. Jaouën. Concatenation of space-time coding and FEC of optical MIMOsystems. *IEEE Photonics Technology Letters*, 29:603–606, April 2017.

[469] D. Erasme, Th. Anfray, M. E. Chaibi, K. Kechaou, J.-M. Petit-Ferrufino, G. Aubin, K. Merghem, Ch. Kazmierski, J.-G. Provost, Ph. Chanclou, and Ch. Aupetit-Berthelemot. The dual-electroabsorption modulated laser, a flexible solution for amplified and dispersion uncompensated networks over standard fiber. *IEEE/OSA Journal of Lightwave technlogy.*, 32(21):1558–2213, November 2014.

[470] M. E. Chaibi, H. T. Nguyen, Ch. Gosset, F. Grillot, and D. Erasme. Time resolved chirp measurement based on a polarization-maintaining fiber. *IEEE Photonics Technology Letters*, 27(14): 1557–1560, June 2015.

[471] W. Samoud, C. Ware, and M. Lourdiane. Performance analysis of a hybrid optical- electronic packet switch supporting different service classes. *IEEE/OSA Journal of Optical Communications and Networks (JOCN)*, 7(9):952–959, September 2015.

[472] W. Wei, L. L. Yi, Y. Jaouën, and W. Hu. Bandwidth-tunable narrowband rectangular optical filter based on stimulated brillouin scattering in fiber. *Optics Express*, 22:23249–23460, September 2014.

[473] W. Wei, L. L. Yi, Y. Jaouën, and W. Hu. Software-defined microwave photonic filter with high reconfigurable resolution. *Scientific Reports*, 6:35621, October 2016.

[474] L. L. Yi, W. Wei, Y. Jaouën, M. Shi, B. Han, M. Morvan, and W. Hu. Polarization-independant rectangular microwave photonic filter based on stimulated brillouin scattering. *Journal of Lightwave Technology*, 34(2):669–675, January 2016.

[475] W. Wei, L. L. Yi, Y. Jaouën, and W. Hu. Arbitrary-shaped brillouin microwave-photonic filtering by manipulating directly-modulated pump spectrum. *Optics Letters*, 42:4083–4086, October 2017.

[476] Ch. Wang, K. Schires, M. Osinski, Ph. Poole, and F. Grillot. Thermally insensitive determination of the linewidth broadening factor in nanostructured semiconductor lasers using optical injection locking. *Scientific Reports*, (6):27825, October 2016.

[477] J. Duan, H. Huang, Z. Lu, Ph. Poole, and F. Grillot. Narrow spectral linewidth in inas/inp quantum dot distributed feedback lasers. *Applied Physics Letters*, 112:121102, April 2018.

[478] K. Schires, S. Gomez, A. Gallet, G. H. Duan, and F. Grillot. Passive chaos bandwidth enhancement under dual-optical feedback with hybrid III–V/si DFB laser. *Journal of Selected Topics in Quantum Electronics, IEEE*, 23(6):1801309, September 2017.

[479] L. Jumpertz, K. Schires, M. Carras, M. Sciamanna, and F. Grillot. Chaotic light at mid-infrared wavelength. *Light Science and Applications*, Vol. 5(e16088), October 2016.

[480] D. Maraval, R. Gabet, Y. Jaouën, and V. Lamour. Dynamic optical fiber sensing with brillouin optical time domain reflectometry: application to pipeline vibration monitoring. *Journal of Lightwave Technology*, 35(16):3296–3302, October 2016.

[481] E. Lucas, L. Lombard, Y. Jaouën, S. Bordais, and G. Canat. 1 kW peak power, 100 j single-frequency thulium fiber amplifier at 2050 nm. *Applied Optics*, 53:4413–4419, July 2014.

[482] Ch. Wang, M. Osinski, J. Even, and F. Grillot. Phase-amplitude coupling characteristics in directly modulated quantum dot lasers. *Applied Physics Letters*, 105(22):221114, October 2014.

[483] L. Jumpertz, K. Schires, M. Carras, and F. Grillot. Regimes of external optical feedback in 5.6 μm distributed feedback mid-infrared quantum cascade lasers. *Applied Physics Letters*, 105(13):131112, July 2014.

[484] J.-M. Sarraute, K. Schires, S. Larochelle, and F. Grillot. Enhancement of the modulation dynamics of an optically injection-locked semiconductor laser using gain lever. *IEEE Journal of Selected Topics in Quantum Electronics*, 21(6), December 2015.

[485] Ch. Wang, R. Raghunathan, K. Schires, S.-Ch. Chan, L. Lester, and F. Grillot. Optically injected inas/gaas quantum dot laser for tunable photonic microwave generation. *Optics Letters*, 41(6):1153, October 2016.

[486] Ch. Wang, J.-P. Zhuang, F. Grillot, and S.-Ch. Chan. Contribution of off-resonant states to the phase noise of quantum dot lasers. *Optics Express*, 24(26):29872, December 2016.

[487] H. Huang, D. Arsenijevic, K. Schires, T. Sadeev, D. Bimberg, and F. Grillot. Multimode optical feedback dynamics of inas/gaas quantum-dot lasers emitting on different lasing states. *AIP Advances*, 6:125114, 2016.

[488] H. Huang, K. Schires, Ph. Poole, and F. Grillot. Non-degenerate four-wave mixing in an optically injection-locked inas/inP quantum dot fabry–perot laser. *Applied Physics Letters*, 106(14):143501, December 2014.

[489] L. Jumpertz, C. Caillaud, G. Clément, S. Ferré, K. Schires, L. Brilland, T. Johann, M. Carras, and F. Grillot. Estimating optical feedback from a chalcogenide fiber in mid-infrared quantum cascade lasers. *AIP Advances*, 6:105201, October 2016.

[490] Ch. Wang, K. Schires, M. Osinski, Ph. Poole, and F. Grillot. Thermally insensitive determination of the linewidth broadening factor in nanostructured semiconductor lasers using optical injection locking. *Scientific Reports*, 6:27825, June 2016.

[491] Ch. Redlich, B. Lingau, H. Huang, R. Raghunathan, K. Schires, Ph. Poole, F. Grillot, and K. Lüdge. Linewidth rebroadening in quantum dot semiconductor lasers. *IEEE Journal of Selected Topics in Quantum Electronics*, 23(6):1901110, September 2017.

[492] S. Ferré, L. Jumpertz, M. Carras, R. Ferreira, and F. Grillot. Beam shaping in high-power broad-area quantum cascade lasers using optical feedback. *Scientific Reports*, 7:44284, September 2017.

[493] C.-H. Lin, C.-Y. Chen, H. Huang, D. Arsenijevic, D. Bimberg, F. Grillot, and F.-Y. Lin. Comparison of optical feedback dynamics of inas/gaas quantum-dot lasers emitting solely on ground or excited states. *Optics Letters*, 43:210, January 2018.

[494] F. Grillot, Ch. Wang, N. Naderi, and J. Even. Modulation properties of self-injected quantum dot semiconductor diode lasers. *Journal of Selected Topics in Quantum Electronics, Invited paper*, 19 (4):1900812, May 2013.

Articles in Conference Proceedings

[495] M. I. Yousefi, G. Kramer, and F. R. Kschischang. Upper bound on the capacity of the nonlinear Schrödinger channel. In *IEEE Canadian Workshop on Information Theory (CWIT)*, pages 1–5, St. John's, Newfoundland, Canada, July 2015.

[496] E. Awwad, Y. Jaouën, G. Rekaya-Ben Othman, and E. Pincemin. Polarization-time coded OFDM for PDL mitigation in long-haul optical transmission systems. In *ECOC 2013*, page paper P3.4, Londres, September 2013.

[497] C. Ware, M. Lourdiane, and W. Samoud. Can software-defined networks turn impractical optical functionalities into network-savers? In *International Conference on Transparent Optical Networks (ICTON)*, number We.C1.3, Graz, Austria, July 2014.

[498] B. Han, P. Gavignet, E. Pincemin, Th. Guillossou, M. Cresseaux, D. Le Brouster, B. Haentjens, and Y. Jaouën. Low phase noise CO-MB-OFDM optical burst transmitter for time and spectral optical aggregation. In *OFC 2017*, page paper TU3F.6, Los Angeles USA), March 2017.

[499] E. M. Amhoud, G. Rekaya-Ben Othman, L. Bigot, M. Song, E.-R. Andresen, G. Labroille, M. Bigot-Astruc, and Y. Jaouën. Experimental demonstration of space-time coding for MDL mitigation in few-mode fiber transmission system. In *ECOC 2017*, volume paper M.1.D.2, Goteborg (Suède), September 2017.

[500] G. Simon, F. Saliou, Ph. Chanclou, B. Le Guyader, L. Guillo, L. Anet Neto, and D. Erasme. TWDM-

PON ONUs optical frequency drift versus tuning. In *European Conference on optical communication ECOC'16*, page Th.2.P2.SC7.4, Düsseldorf, Germany, September 2016.

[501] S. Barthomeuf, F. Saliou, L. Anet Neto, B. Le Guyader, Ph. Chanclou, and D. Erasme. Real-time downstream 25 gbps PAM4 for high speed TDM-PONs with both 25 and 12.5 gbps ONUs. In *Optical Networking and Communication Conference - OFC'18*, San Diego - USA, March 2018.

[502] A. Minakhmetov, C. Ware, and L. Iannone. Optical networks throughput enhancement via tcp stop-and-wait on hybrid switches. In *The Optical Networking and Communication Conference (OFC)*, San Diego, CA, USA, March 2018.

[503] D. Maraval, R. Gabet, Y. Jaouën, and V. Lamour. Slope-assistedBOTDR for pipeline vibration measurements. In *OFS 2017*, pages paper 10323–56, Jeju City (Korea), April 2017.

[504] C. Romano, R. E. Tench, J.-M. Delavaux, and Y. Jaouën. Characterization of the 3F4-3H6 transition in thulium-doped silica fibres and simulation of a 2μm single clad amplfier. In *ECOC 2017*, page paper P1.SC1.1, Goteborg (Suède), September 2017.

[505] C. Romano, R. Tench, Y. Jaouën, and G. Williams. Simulation and design of a multistage 10W thulium-doped double clad silica fiber amplifier at 2050nm. In *Photonics West*, pages 10083–16, San Franscisco, January 2017.

[506] F. Grillot. Stability, instability and chaos of inas/gaas semiconductor quantum dot lasers emitting exclusively on single lasing states. In *International Symposium on Nanostructures: Physics and Technology*, Minsk, Bielorussie, June 2018.

[507] F. Grillot and K. Schires. Controllable optical extreme events in the semiconductor laser output power. In *Photonics North*, Montreal, Canada, June 2018.

[508] H. Huang, K. Schires, L.-C. Lin, C.-Y. Chen, D. Arsenijevic, D. Bimberg, F.-Y. Lin, and F. Grillot. Dynamics of excited-state inas/gaas fabry-perot quantum-dot lasers under optical feedback. In *CLEO*, San José, October 2016.

[509] Ch. Wang, Ch. Wang, K. Schires, M. Osinski, Ph. Poole, J. Even, and F. Grillot. A novel method for extracting the linewidth broadening factor of semiconductor lasers. In *Frontiers in Optics*, San Jose, USA, October 2015.

[510] C. Ware, W. Samoud, Ph. Gravey, and M. Lourdiane. Recent advances in optical and hybrid packet switching. In *ICTON*, Trento, Italia, July 2016.

[511] X. Yangzhang, M. Yousefi, A. Alvarado, D. Lavery, and P. Bayvel. Nonlinear frequency-division multiplexing in the focusing regime. In *Optical Fiber Communication Conference (OFC)*, March 2017.

[512] M. Yousefi and X. Yangzhang. Linear and nonlinear frequency-division multiplexing. In *42nd European Conference on Optical Communication (ECOC)*, September 2016.

Books

[513] Ph. Gallion. *Basics of Incoherent and Coherent Digital Optical Communications*. Academics Press/Elsevier, New York, 2nd edition edition, 2016.

[514] J. Even, Ch. Wang, and F. Grillot. *Semiconductor Nanocrystals and Metal Nanoparticles*, chapter From Basic Physical Properties of InAs/InP Quantum Dots to State-of-the-Art Lasers for 1.55 μm Optical Communications An Overview. CRC Press, 2016.

Invited Talks

[515] F. Grillot, D. Arsenijevic, H. Huang, and D. Bimberg. Ultrafast and nonlinear dynamics of inas/gaas semiconductor quantum dot lasers. In *SPIE Photonics West*, San Francisco, USA, January 2018.

[516] T. Gui, W. A. Gemechu, J.-W. Goossens, M. Song, M. Yousefi, H. Hafermann, A. P. Tao Lau, and Y. Jaouën. Polarization-division-multiplexed nonlinear frequency division multiplexing. In *The European Conf. Lasers Electro-Optics*, page paper STu4C.3, San Jose, CA, USA, May 2018.

[517] C. Ware and D. Chiaroni. Towards WDM slot switching for aggregation access and metropolitan applications: the ANR N-GREEN project. In *ICTON*, number Mo.B2.4, Girona, Spain, July 2017.

[518] M. Yousefi. Nonlinear frequency-division multiplexing in the focusing regime. In *Optical Fiber Communication Conference (OFC)*, Los Angeles, CA, USA, March 2017.

[519] L. Jumpertz, S. Ferré, M. Carras, and F. Grillot. Beam steering in quantum cascade lasers with optical feedback. In *Photonics West*, San Francisco, USA, February 2017.

[520] M. Yousefi. Linear and nonlinear frequency-division multiplexing. In *42nd European Conference on Optical Communication (ECOC)*, Dusseldorf, Germany, September 2016.

[521] M. Yousefi. Linear and nonlinear frequency-division multiplexing. In *International Conference on Nonlinear Waves – Theory and Applications,*, Beijing, China, June 2016.

[522] Y. Jaouën, E. M. Amhoud, and G. Rekaya-Ben Othman. Optical MIMO techniques for MDL mitigation in few-mode fiber transmission systems. In *Asia Communications and Photonics Conference (ACP)*, Wuhan, China, November 2016.

[523] F. Grillot, L. Jumpertz, K. Schires, and M. Carras. Deterministic temporal chaos from a mid-infrared quantum cascade laser subjected to external optical feedback. In *Photonics West*, San Francisco, February 2016.

Patents

[524] F. Grillot and M. Osinski. Light-emitting device having iii-v semiconductor gain section coupled to whistle- geometry tunable filter. (15174743.3), May 2015.

[525] G. Rekaya-Ben Othman, E. M. Amhoud, and Y. Jaouën. Scrambler for a multimode optical fiber and optical transmission system using such scrambler. (EP 16305925.6 déposé), July 2016.

[526] G. Rekaya-Ben Othman, E. M. Amhoud, and Y. Jaouën. Joint space-time and fec coding in multimode fiber optical transmission systems. (EP 16305926.4 déposé), July 2016.

[527] G. Rekaya-Ben Othman, E. M. Amhoud, and Y. Jaouën. Space-time coding methods and devices for optical mimo systems. (EP 16305565.0 déposé), May 2016.

Chapter 12

LabSoC

12.1 Presentation of the team

Team leader: Renaud Pacalet (→ dec. 2014), Ludovic Apvrille (jan. 2015 → now)

Faculty: Rabéa Ameur Boulifa (AP), Ludovic Apvrille (AP), Sophie Coudert (AP), Renaud Pacalet (FP), Tullio Tanzi (FP)

Permanent research engineers: Dominique Blouin (Ing. half time, since Aug. 2016)

PhD Students: Lilia Belabed, 2016-2019 (T. Tanzi) Matteo Bertolino, 2017-2020 (L. Apvrille, R. Pacalet) Maciej Bielski, 2016-2019 (Renaud Pacalet) Giovanni Camurati, 2017-2020, (L. Apvrille, A. Francillon (Eurecom)) Adrien Canuel, 2014-2017 (R. Pacalet, L. Apvrille) Benjamin Dauphin, 2017-2020 (R. Pacalet, L. Apvrille) Andrea Enrici, 2012-2015 (L. Apvrille, R. Pacalet) Emna Gharbi, 2017-2020 (L. Apvrille, A. Enrici (Nokia)) Letitia Li, 2015-2018 (L. Apvrille) Florian Lugou, 2014-2017 (L. Apvrille, A. Francillon (Eurecom)) Gabriel Pedroza, 2009-2013 (L. Apvrille, R. Pacalet) Hui Zhao, 2016-2019, (F. Mallet (Université Côte Azur), L. Apvrille) Maysam Zoor, 2017-2020 (L. Apvrille, R. Pacalet) Salaheddine Ouaarab, 2012-2016 (R. Pacalet, G. Duc)

PostDocs: Neslihan Kose (2014, L. Apvrille) Bassem Ouni (2013-2014, R. Pacalet) Daniel Camara (2013-2015, R. Pacalet) Alexandre Becoulet (2013, R. Pacalet)

Platforms: The team exploits the following platforms:

- **TTool**: Formal modeling and verification. ttool.telecom-paristech.fr.
- **Alligator**: Meta-classification tool. alligator.telecom-paristech.fr.
- **Embb**: Signal Processing Hw/SW architecture. embb.telecom-paristech.fr.
- **SecBus**: hw/sw for protecting memory buses. secbus.telecom-paristech.fr.
- **Rover** is an autonomous robotic system for embedding innovative payloads e.g. radars.

Scientific Production Overview: Table 12.1 represents the overall scientific production between 2013 and 2018. The detailed bibliography is listed in the dedicated accompanying document

Journals	Articles in Proceedings	Books and Book Chapters	Patents	Keynotes and Tutorials	Other Invited Talks	Habilitation thesis	Completed PhD
29	77	8	0	9	4	0	4

Table 12.1: Overall Scientific Production

12.2 Research activities

12.2.1 Overview

The LabSoC research activities focuses on the **design, analysis and proposition of new architecture for embedded systems** as depicted in Figure 12.1.

Topic #1. By **design**, we mean **the methods, models and verification techniques that could improve the development of complex (embedded) systems**, i.e. improve the development time, or make these systems more safe, secure and efficient. This includes the definition of models, with a focus on models that are used to perform the design space exploration of embedded systems, but also the formal verification techniques that are useful to check a system against safety, security and performance properties. **This is our main research topic with the involvement of all team members** and most Ph.D. students.

Topic #2. By **analysis**, we mean the (automated) **investigation of existing systems**. We mostly target the security analysis of embedded systems, i.e. defining new techniques that can automate the identification of vulnerabilities and malicious codes. L. Apvrille is involved in this research area.

Topic #3. By **definition of innovative embedded architectures**, we mean inventing new embedded architectures for improving existing systems with new features, e.g. security features and autonomous capabilities. R. , L. Apvrille, S. Coudert and T. Tanzi are involved in this research area.

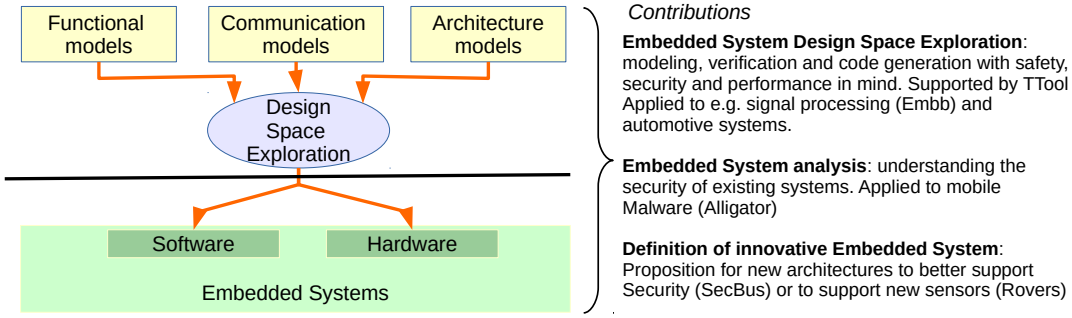

FIGURE 12.1: Overview of the LabSoC domain of expertise

Our contributions, based on five platforms (TTool, Alligator, Embb, SecBus, Rover) have first been defined internally before being applied during academic, collaborative projects (FUI Netcom, H2020 AQUAS) and industrial collaborations (Freescale, VEDECOM, Nokia, Engie).

When a contribution complies with several research topics, it has been integrated in the most obvious one. For instance, the definition of methods for designing safe and secure systems (topic 1) has led us to define new automotive architectures (topic 3).

12.2.2 Topic 1: Designing Embedded Systems

Modern embedded systems are intrinsically complex and heterogeneous. They are typically composed of a large variety of both software and hardware components described with different characteristics and use diverse means of co mmunication. At the same time, these systems should also comply to a wide spectrum of dependable/robustness requirements. The ambition of the LabSoC is to deal with the design of embedded systems, at various stages, by using correct-by-construction approaches and formal methods. System design activity refers to modeling, programming, formal verification and analysis activities, with a focus on the design space exploration stage.

Safe & secure modeling and verification with SysML-Sec

The SysML-Sec environment created by LabSoC is a Model Driven Approach that considers security (and safety and performance) since the very first methodological stages [553]. SysML-Sec enhances the OMG SysML language with views in which security is explicit: the notion of security requirements, the addition of formal fault trees, the possibility to perform security-aware HW-SW partitioning [544] and the design of security mechanisms (e.g. security protocols) [546]. SysML-Sec modeling aspects are totally supported by the free and open-source toolkit named **TTool**, mostly developed by our research. TTool was originally designed for safety and performance matters. An important aspect of SysML-Sec is the fact that most diagrams are formally defined for both safety and security proofs [532]. During these last years, a lot of efforts have been put on the model-to-formal-code transformation in order to be able to rely on the existing security prover ProVerif. In particular, we have proved the soundness of our the main transformation. Also, different safety&security aspects can be handled at different abstraction levels [543] (best paper award). SysML-Sec has been evaluated for different systems ranging from small devices to larger systems (industrial systems, automotive systems, Public Safety Networks [537]). It has been started in the scope of a FP7 European project (EVITA) and continued with grants from Sophia@UCN Labex and VEDECOM. We are also partner in the H2020 AQUAS project that deals with the joint assurance of safety/security/performance in the design of embedded system. Last but not least, we have obtained grants from the "C3S chaire" of Telecom ParisTech, as well as a second grant from VEDECOM. Over the period, SysML-Sec led to the publication of 3 book chapters (e.g. [538]), one magazine article and 11 conference papers, with the involvement of 3 Ph.D. students. It is currently supported with VEDECOM and H2020 grants.

Formal specification and verification

If many formal methods and verification techniques have been defined, they are rather used only for (small) sub-parts of complex systems because of the combinatory explosion issue. Our work aims at raising the abstraction level upon applying formal methods, at focusing only on relevant features of existing models, and at providing theories, methodologies, and tools that are scalable. To do so, we first study how to efficiently define new correct-by-construction techniques with refinement-based techniques. Thus, our new approach vertically links the design stages along with usual development cycles. This leads us to formally define founded refinement rules for communication [539] that ensure the complete consistency of the final design. Component-based approaches combined with correctness-by-construction is another promising research avenue we investigated. To support modular and compositional design of correct-by-construction software, we developed new variants of symbolic behavioral semantics [530], allowing to construct compositionally finite representations of the behavior of systems with explicit handling of data or other aspects. Still to ensure correct interoperation of components, a semantics-preserving composition of hardware components has been proposed [541].

Combining different formalisms (e.g., B, model-checking, business expertise, risk analysis [535]) is another efficient formal verification technique we developed to address complex systems where one specific formalism is well adapted to one given sub part of the system. The combination is studied in the scope of a collaboration with Engie for railway systems with safety and performance requirements.

Additionally to safety proofs we now cover security (resistance to attacks) aspects from both theoretical and practical viewpoints. In particular, in the scope of program certification, a new specific formalism has been proposed to express security best practices. The proposed formalization is based on a logical language that intends to be used directly by programmers in order to easily conduct formal verifications on the conformance of programs with security guidelines [540].

Hardware / software architectures for Digital Signal Processing

DSP intensive applications, like the physical layer of wireless communications, are frequently implemented as a mixture of dedicated hardware accelerators, DSP processors and General Purpose Processors (GPP). Our open source **Embb** research project is a hardware architecture proposal for wireless communications. It consists in a library of flexible DSP units, each dedicated to a given class of data processing (vector processing, channel decoding, interleaving...) assembled around an interconnection network and controlled by a GPP.

Programming Embb or any similar commercial baseband processor is challenging because of Non-Uniform Memory Access (NUMA) nature, heterogeneity, hard real time constraints... The actual programming complexity is even worse: like most recent commercial solutions, Embb is dedicated to the Software-Defined Radio (SDR) where all computation, storage and communication resources are shared among several applications. To tackle this specific programming problem we proposed a UML-based very high level modeling strategy associated with code generation of the embedded control software [529]. This strategy is implemented in the TTool framework and now further developed in the scope of the NOKIA grant. Currently, 3 Ph.D. students are involved in this project. Over the period, Embb contributed to the publication of one magazine article and 6 conference papers, with the involvement of 3 Ph.D. students. It has been supported by the NETCOM (FUI) and SPECTRA (CELTIC) projects.

12.2.3 Topic 2: Embedded systems analysis

Our research on embedded systems analysis intends to define new investigation techniques for understanding the security of embedded devices. Apart from the participation to security challenges (also known as "CTF") in conferences (e.g. Hack.lu) for which we have obtained prices (e.g. at SSTIC), we have defined techniques to automatically identified unknown mobile malware applications.

Automated identification of malware applications

To discover unknown mobile malware - called "0-day" -, the SherlockDroid framework [549] was designed with Fortinet. SherlockDroid crawls mobile applications from market places, and then extracts code-level features, and finally classifies unknown applications with our toolkit **Alligator**. Alligator is a classification tool that efficiently and automatically combines several classification algorithms. In a learning stage, Alligator determines the "best" combination between many classification algorithms (meta-classifier). It is then used to categorize unknown applications between suspicious and non suspicious. To demonstrate the efficiency of our approach, we have used sets of applications with 500k applications. We were able to identify 31 unknown Android malware, which constitutes a record with automated techniques (DroidRanger has the second place with 2 unknown malware) [534]. If Alligator has been firstly designed for malware application (e.g. rate of false positive / negative), alligator has also broken classification records for publicly available sets of images, e.g. in biometrics [551], in collaboration with the biometrics team of Eurecom. Results have been published in 1 journal paper [534], 4 conferences (including [549] and [551]), and presented in several hacking conferences. Also, all (good) Android anti-viruses should now filter the 31 identified malware. Last but not least, alligator is a free and open-source toolkit available at alligator.telecom-paristech.fr. A Post-doctoral student was involved in this topic.

12.2.4 Topic 3: New Architectures for Embedded Systems

The LabSoC defines new architectures of embedded systems in order to better support security (e.g., the SecBus project) and to offer autonomous functions with e.g. drones, rovers,

also on automotive systems as demonstrated by the current project with VEDECOM.

Security of microprocessor memories

The physical communication link that connects a microprocessor (CPU) to its external working memory (RAM), and the memory itself, are critical components on the security point of view. By spying at them attackers can retrieve sensitive data (passwords, secret keys...) and by tampering with them, they can alter the behaviour of the system (bypass of access control...) [547]. Our open source **SecBus** research project, settles with the SSH team of LTCI, aims at protecting computer systems against such attacks, with an acceptable overhead in terms of performance and cost [552] The project benefited from a partnership with STMicroelectronics and from the TRESCCA FP7 European project. A complete hardware and software solution has been demonstrated on System-on-Chip (SoC) prototyping platforms. The solution consists in a Hardware Security Module (HSM) embedded in the same integrated circuit as the CPU. The HSM applies software-defined security policies to all memory accesses, allowing real-time encryption/decryption and integrity checking/update [550]. The performance evaluation show that a fully protected (confidentiality and integrity) GNU/Linux operating system is indeed feasible and perfectly usable. While some of the SecBus features have been recently integrated in Intel microprocessors (SGX architecture), most are still ahead of time (flexibility, integrity...).

To increase the confidence in SecBus, we have relied on the B formal method to avoid implementation errors, and to prove that algorithms actually ensure detection of attacks. If B has been defined with safety in mind and for top-down approaches, we have successfully applied it for security - with reasonable proof efforts - and for a pre-existing system.Over the period, SecBus led to the publication of 4 conference papers, with the involvement of 2 Ph.D. students. It has been supported by the TRESCCA (FP7) project.

Autonomous systems for data Collection: from signal to information

Autonomous measurement systems for monitoring environmental data operating in total autonomy has been proposed a long time ago, yet measurement technologies have strongly improved with e.g. constant monitoring and not simple snapshots. Moreover, the use of (wireless) connection technologies now facilitates the real-time acquisition and fusion of different measurements from distributed acquisition systems [536]. However these systems require the deployment of fixed infrastructure to operate (e.g. fixed sensors, cables, etc.).

The development of autonomous vehicles with modern sensors (LIDAR, Radar, GPR, video, etc.) [542] [545] offers better ways to acquire information of different types and in different environments, while limiting both human intervention and complex infrastructure.

For instance, as shown in [548], environments with (partially) destroyed infrastructure because of accidents or disasters, can still be efficiently monitored. Captured information can be used in two ways: on the one hand, to understand and model the environment for a successful completion of the mission, and on the other hand to reuse this modeling in a broader framework to support decision-making process for rescue teams deployed to handle a disaster [531], [528], [533].

Finally, our goal is to provide an open autonomous platform to validate autonomous data collection systems.

12.2.5 Scientific Highlights:

- Responsibilities in scientific society. T. Tanzi is member of Standing Publications Committee of URSI and president of URSI French F commission.

- Organization of Workshops and Conferences:
  - CARDIS'2016, eSAME (since 2005), EUSIPCO'2015, Ph0wn'17/18
  - French URSI'17/18, ISPRS TC III'2018, Gi4DM'2018, URSI AT-RASC'2018
- PC chair of workshok: French URSI'2017 and Gi4DM'2018 (T. Tanzi)
- Free and Open-Source Software: Alligator, TTool, Embb
- Awards
  - Best paper award, Modelsward'2017: L. Li, L. Apvrille
  - Most Original Solution award, SSTIC'2015 sec. competition: L. Apvrille, F. Lugou
- Significant Contracts with Industrials, Chairs
  - 2017, Nokia Bell labs, Programming techniques for future mobile communication infrastructures: L. Apvrille, R. Pacalet, M. Bertolino, E. Gharbi, B. Dauphin
  - 2015, VEDECOM: Safe and secure automotive architectures for autonomous vehicles: L. Apvrille, R. Ameur Boulifa (Two Ph.D. grants)
  - 2017, Chair C3S: Connected Car Cyber Security: L. Apvrille
- Publicly funded projects
  - Netcom FUI project (2014-2018): R. Pacalet, L. Apvrille, A. Canuel
  - Labex UCN@Sophia (2014-2019), Ph.D scholarships of F Lugou, H. Zhao
  - H2020 AQUAS project (2017-2020): L. Apvrille, R. Pacalet, D. Blouin, M. Zoor
- Other results
  - Identification of more than 30 unknown Android malware: Ludovic Apvrille, full list: alligator.telecom-paristech.fr/external_hallofshame.html

12.3 SWOT analysis

Strength	**Weakness**
Research contracts totally support our research strategy. The lab is built upon complementary skills in electronics, computer science, formal techniques and risk engineering, both on theoretical and practical aspects. Local, national and international collaborations both with academic and industrial partners	Mismatch between the high number of contracts and the quite small size of the team.
Opportunities	**Threats**
Close proximity with the Sophia-Antipolis ecosystem, as demonstrated by contracts and publications with local institutes e.g. FUI Netcom, EURECOM, INRIA, CNRS, Labex, ... Many of our Ph.D. students come from the EURECOM cursus	Difficulties to maintain all activities with academic and industrial partners of the lab after the coming retirement of one researcher Ph.D. financing mostly depends on contracts (end of Labex). End of the Labex UCN@Sophia in two years (current, two Ph.D. students are financed by the Labex), with no possibility to participate to the local IDEX (legal issue).

12.4 Scientific project for the the next five years

The main objective of the LabSoC team is to **develop models and methods to (better) formally verify and (automatically) program safe and secure embedded systems**. This project contains two sub objectives.

12.4.1 Project 1: Towards new formal verification techniques

Our first sub objective is to propose **new approaches for verifying complex embedded systems that can handle safety/security/performance**. Indeed, complex embedded systems have to face many constraints: interaction with their environment and critical decisions. Thus, the use of formal methods becomes necessary in order to increase the confidence we can have in these systems. We intend to define new theoretical models that shall able to address both the software and hardware aspects, in contrary to existing techniques that do not support SW and HW explicitly. Typical research paths that we intend to investigate is **the automated combination of verification techniques**.

12.4.2 Project 2: Programming automation

Our second sub objective is to **define and implement methods and tools for the automated code generation for complex embedded systems**. TTool already partly addresses this problematics. As demonstrated by many contracts, TTool is an important framework to attract new partnerships with academic and industrial partners. Nonetheless, several aspects such as the management of safety (e.g., handling of degraded modes, of redundancy techniques), the fine analysis between safety-security-performance have barely been investigated. For automated code generation, our proposal is a 2-step approach: (i) a system-level design and validation stage, and (ii) a compilation stage from high-level models to executable code with automated scheduling and memory placement.

Our two sub projects need concrete investigations fields to confront our propositions with concrete up-to-date systems, either for publications or partnerships. The FUI Netcom, H2020 AQUAS project and Nokia project are very good short-term examples. For instance, the ongoing work on software and hardware implementations for 5G networks (with Nokia Bell Labs, development of *TTool* and *embb*) is an interesting domain for both theoretical and more practical work (e.g. tools). Autonomous systems also constitute a domain of experimentation: automotive systems, drone systems, rover systems are used in the scope of academic and industrial partnerships (e.g., H2020 AQUAS, VEDECOM, Engie).

12.5 Scientific production (selection)

Articles in Journals

[528] M. Chandra and T. J. Tanzi. Drone-borne gpr design: Propagation issues. *Comptes Rendus Physique*, 19(1-2):72–84, March 2018.

[529] A. Enrici, L. Apvrille, and R. Pacalet. A model-driven engineering methodology to design parallel and distributed embedded systems. *ACM Transactions on Design Automation of Electronic Systems*, 22(2):34:1–34:25, March 2017.

[530] R. Ameur-Boulifa, L. Henrio, O. Kulnkhina, E. Madelaine, and A. Savu. Behavioural semantics for asynchronous components. *Journal of Logical and Algebraic Methods in Programming*, January 2017.

[531] L. Apvrille, T. J. Tanzi, Y. Roudier, and J.-L. Dugelay. Drone humanitaire : état de l'art et réflexions. *Revue Française de Photogrammétrie et de Télédétection*, (213-214):63–71, January 2017.

[532] F. Lugou, L. Apvrille, and A. Francillon. Toward a methodology for unified verification of hardware/software co-designs. *Journal of Cryptographic Engineering*, pages 1–12, November 2016.

[533] T. J. Tanzi, M. Chandra, J. Isnard, D. Camara, O. Sebastien, and F. Harivello. Towards drone-borne disaster management: Future application scenarios. *isprs-annals*, III(8):181–189, June 2016.

[534] A. Apvrille and L. Apvrille. Sherlockdroid: a research assistant to spot unknown malware in android marketplaces. *Journal of Computer Virology and Hacking Techniques*, 11(39):1–11, July 2015.

Book Chapters

[535] S. Coudert and T. J. Tanzi. . formal methods for safe design of autonomous systems dedicated to risk management in book: Information technology in disaster risk reduction. In *Information Technology in Disaster Risk Reduction*, pages 61–76. IFIP, 2017.

[536] T. J. Tanzi and J. Isnard. Public safety network: an overview. In *Public Safety Networks Volume 1: Overview and Challenges*, chapter 1, pages 1–20. ISTE Press - Elsevier, London (UK), 2015.

[537] L. Apvrille and L. W. Li. *Wireless Public Safety Networks 3*, chapter Safe and Secure Support for Public Safety Networks, pages 185–210. elsevier, 2017.

[538] L. Apvrille and Y. Roudier. *Model-Driven Engineering and Software Development*, chapter Designing Safe and Secure Embedded and Cyber-Physical Systems with SysML-Sec, pages 293–308. Springer International Publishing, Switzerland, 2016.

[539] H. Mokrani, R. Ameur-Boulifa, and E. Encrenaz-Tiphene. *Languages, Design Methods, and Tools for Electronic System Design*, chapter Assisting Refinement in System-on-Chip Design, pages 21–42. Springer International Publishing, 2014.

Articles in Conference Proceedings

[540] Z. Zhioua, Y. Roudier, and R. Ameur-Boulifa. Formal specification of security guidelines for program certification. In *The 11th Theoretical Aspects of Software Engineering Conference (TASE 2017)*, Nice, France, September 2017.

[541] S. Chabane, R. Ameur-Boulifa, and M. Mezghiche. Rethinking of i/o-automata composition. In *Forum on specification & Design Languages (FDL 2017)*, Verona, Italy, September 2017.

[542] T. J. Tanzi and M. Chandra. Propagation modelling towards the design of drone-borne gpr for humanitarian applications. In *in XXXII General Assembly of the International Union of Radio Science*, Montréal, Canada, August 2017. URSI.

[543] D. Genius, L. W. Li, and L. Apvrille. Model-driven performance evaluation and formal verification for multi-level embedded system design. In *5th International Conference on Model-Driven Engineering and Software Development (Modelsward)*, Porto, Portugal, February 2017.

[544] L. W. Li, F. Lugou, and L. Apvrille. Security-aware modeling and analysis for hw/sw partitioning. In *5th International Conference on Model-Driven Engineering and Software Development (Modelsward)*, Porto, Portugal, February 2017.

[545] M. Chandra and T. J. Tanzi. Propagation issues relevant to the design of a drone-borne gpr (ground penetrating radars). In *Kleinheubacher Tagung 2016 (KHB-2016).*, Miltenberg, Germany, September 2016.

[546] F. Lugou, L. W. Li, L. Apvrille, and R. Ameur-Boulifa. Sysml models and model transformation for security. In *Conferénce on Model-Driven Engineering and Software Development (Modelsward'2016)*, Rome, Italy, February 2016.

[547] L. W. Li, G. Duc, and R. Pacalet. Hardware-assisted memory tracing on new socs embedding fpga fabrics. In *Annual Computer Security Applications Conference - ACSAC 2015*, Los Angeles, USA, December 2015.

[548] T. J. Tanzi, Y. Roudier, and L. Apvrille. Towards a new architecture for autonomous data collection. In *ISPRS Geospatial Week 2015, GeoUAV track*, La grande Motte, France, October 2015.

[549] L. Apvrille and A. Apvrille. Identifying unknown android malware with feature extractions and classification techniques. In *The 14th IEEE International Conference on Trust, Security and Privacy in Computing and Communications (IEEE TrustCom-15)*, Helsinki, Finland, August 2015. IEEE.

[550] S. Ouaarab, G. Duc, and R. Pacalet. Performance optimizations of integrity checking based on merkle trees. In *Hardware and Architectural Support for Security and Privacy (HASP)*, Portland, OR, USA, June 2015.

[551] N. Kose, J.-L. Dugelay, and L. Apvrille. Facial makeup detection technique based on texture and shape analysis. In *11th IEEE Conference on Automatic Face and Gesture RecognitionFG'2015*, Ljubljana, Slovenia, May 2015.

[552] J. Brunel, R. Pacalet, G. Duc, and S. Ouaarab. Secbus, a software/hardware architecture for securing external memories. In *International Workshop on Trusted Platforms for Mobile and Cloud Computing*, Oxford, UK, April 2014.

[553] L. Apvrille and Y. Roudier. Sysml-sec: A sysml environment for the design and development of secure embedded systems. In *APCOSEC 2013*, Yokohama, Japan, August 2013.

Chapter 13

RFM^2

Radio-Frequencies, Millimeter and Micro Waves

13.1 Presentation of the team

Team leader: Xavier Begaud (FP, team leader between 2013 and July 2017) and Jean-Christophe Cousin (AP, team leader since July 2017)

Faculty between 2013 and 2018: Xavier Begaud (FP), Eric Bergeault (FP), Jean-Christophe Cousin (AP), Bernard Huyart (FP til 2018 Feb.), Anne Claire Lepage (AP), Alain Sibille (FP), Christophe Roblin (AP), Joe Wiart (SRS Head of Chair C2M since 2015)

Permanent Research Engineer: Antoine Khy (RE)

PostDocs and non permanent Research Engineers: Rehan Hashmat (Post Doc 2013), Francesco Mani (Post Doc 2013), Stefan Varault (Post Doc 2013-2014), Yenny Constanza Pinto Ballesteros (Post Doc 2013-2015 & Non permanent Research Engineer 2016), José Enriquez Gonzalez (Post Doc 2015), Tarek Bdour (Post Doc 2016), Taghrid Mazloum (Post Doc 2016-2017), Tomas Bernabeu Jimenez (Post Doc 2017-), Maurício Henrique Bezerra Cardoso (Post Doc 2017-), Yuanyuan Huang (Post Doc 2017-), Zicheng Liu (Post Doc 2017-), Olivier Rance (Post Doc 2017-).

PhD Students: Lila Mouffok (2009-2013), Lana Damaj (2009-2013), Christopher Djoma (2010-2013), Zeinab Mhanna (2010-2014), Yunfei Wei (2010-2014), Xin Zeng (2011-2014), Mark Donny Clemente Arenas (2011-2014), Thanh Nga Maï (2011-2014), José Enriquez Gonzalez (2011-2014), Rupesh Kumar (2011-2014), Abdou Kaissoine (2012-2015), Issam Maaz (2012-2015), Anis Krayni (2012-2016), Taghrid Mazloum (2012-2016), Yuanyuan Huang (2013-2016), Soufien Kammoun (2013-2016), Mohammad Abdi Abyaneh (2013-2016), Chetan Joshi (2013-2016), Taguhi Chalumyan (2014-2017), Jinxin Du (2015-2018). Cheikh Abdou Ladh Diakhate (2016-), Thi Dao Pham (2016-), Nour Awarkeh (2016-), Soumaya Azzi (2016-), Amirreza Chobineh (2016-), Juan Carlos Bucheli Garcia (2017-), Badre Youssef (2017-), Bader Fetouri (2017-).

Platforms: The team has developped and/or exploits the following platforms:

- Non linear characterization of millimeter wave components
- Microwave and millimeter waves anechoic chambers
- StarLab for near field measurements

Scientific Production Overview: Table 13.1 represents the overall scientific production between 2013 and 2018. The detailed bibliography is listed in the dedicated accompanying document.

Journal	Articles in Proceedings	Books and Book Chapters	Patents	Keynotes & Others Invited Talks	Others Articles	Habilitation thesis	Completed PhD
60	121	3	2	6	13	1	20

Table 13.1: Overall Scientific Production

13.2 Research activities

13.2.1 Overview

The aim of our team is to connect humans or machines with wireless systems, either mobile or embedded, with sensing mechanism to adapt to their environment applications. It is then necessary to provide optimal connectivity with respect to cost, energy efficiency, performance, flexibility with any type of environment. It is also important to reduce exposure below the legal limits. The field of competences of the RFM² (Radio Frequency and Microwaves) team has extended during these last five years. This evolution results from two decisions: the investment in the millimeter waves domain and the treat on of the C2M (Characterization, Modeling and Control of Exposures) Chair. The perimeter of the RFM² (Radio Frequency, Microwaves and Millimeter waves) team covers now the design of components and subsystems for radio links involved in 5G, IoT, satellites, localization, reliable and secured massive communications ... The performance of these components and systems are highlighted by the innovative characterization methods in microwaves and millimeter wave domains. The modeling is the third skill to formalize both the behavior of components and subsystems and to determine the interaction between waves and humans. In the previous evaluation, two research axes have been selected. The first one was «wideband wireless, antenna, circuits, metamaterials» and the second one was «design and joint modeling of RF subsystems, antenna & channel». The following parts summarize the results and some contributions have been added to take into account the evolution of the team during this period.

13.2.2 Wireless and wide band, Antenna, Metamaterials, Circuits

Antenna design and Metamaterials:

The development of modern communications brings multiple challenges on antenna design, primarily due to the introduction of massive MIMO and beam forming techniques, to new millimeter bands opening, or to the IoT onset. To face these rising challenges, the RFM² team has continued its long-standing research on metamaterial antennas and absorbers. By addressing wideband or ultra-wideband structures that overcome the inherent narrow band feature of metamaterials, promising developments well suited to communication applications have been derived during the report period, as shown below.

Firstly, we used metamaterials to control the radiation pattern of conventional antennas. In particular, we proposed non-uniform metasurfaces which enable frequency stable radiation pattern in the whole operating frequency band [566] [580] [577]. Hence a non-uniform Artificial Magnetic Conductor (AMC) placed close to a compact wideband antenna enabled to turn an omnidirectional radiation pattern into a directive and stable one over a 73% frequency band. Moreover, thanks to an innovative approach based on the analysis of the phase of the surface current on the reflector, an alternative hybrid AMC was also designed as reflector of a wideband dipole antenna with an increase of the broadside gain over 46% of the bandwidth [564]. The propagation of electromagnetic waves can also be controlled thanks to the powerful Transformation Optics (TO) design method. By placing TO based flat superstrates above a classical antenna, we demonstrated how to drastically change the initial radiation pattern (PhDs of M. Clemente, 2014 and C. Joshi, 2016), transforming for instance the radiation pattern of a patch antenna into an antipodal one

[576]. However, the superstrate often requires exotic values of permeability and/or permittivity that can be reached by metamaterials only. By introducing new degrees of freedom, we showed how to obtain an easy to prototype all-dielectric superstrate which could be fabricated using 3D printing [563].

Secondly, we explored complex high-performance multi-layer structure based on metasurface. An analytical model was derived taking into account the multi-layer structure. This model is accurate not only for normal incidence but also for oblique incidence. To the authors' knowledge, it is the most complete analytical model for this type of structure [597]. Moreover, it is a general model which is easily reusable and adaptable to any multi-layer structure. Based on this technique, a dual polarized wideband and large scanning antenna was demonstrated [559] by adding a metasurface, specific dielectric layers and an anisotropic substrate to a self-complementary connected array antenna.

Thirdly, in the last period, the RFM² team has developed metamaterials based absorbers to face the increasing demand for non-reflective surface, either for defense or civil applications. Metamaterial absorbers represent a technological breakthrough as it allows reducing drastically the device thickness. Absorbers can be realized by High Impedance Surface (HIS) associated with a resistive material. In order to improve the absorber design, we have reused some parts of the analytical model developed for the multilayer antenna and adapted it to absorbers. Thus, we designed a thin ultra-wideband wide angle absorber able to operate on a 4.7:1 bandwidth at normal incidence and with preserved wideband properties up to an incidence angle of 60° [590]. This work is currently being adapted to naval materials and constraints.

In parallel, we focused on lightweight and wide angle absorbers for space applications [588]. We proposed and patented the concept of multi-sector absorbers. It consists in designing a proper absorber at a proper position when the angle of arrival is known and thus to reduce multipath noise on the satellite structure and many other applications [606]. Finally, we also analysed the impact of metamaterials (AMC and EBG) on mobile phones to reduce the exposure [565] in the framework of the Lexnet project (EU FP7 Lexnet).

As previously mentioned, the scope of the team changed with the arrival of studies and measurement facilities in the millimeter wave domain. The results relative to the characterization of circuits are given in a later paragraph. Regarding the antennas part, the design work initiated within the Q-band was extended to higher frequencies around 94 GHz. Initially, we designed for the TWEETHER program [593] (H2020) the horns and directive antennas (and also filters). These devices have been validated by laboratory measurements and in our anechoic chamber now operational up to 110 GHz. These first good results allowed us to contribute to another program concerning a scanner for the detection of hidden objects on passengers, operating between 92 and 96 GHz (FUI Scanvision). In this study, we are in charge of the design and measurement of a leaky wave antenna.

Circuits design and characterization:

The RFM² team has continued to work with LNE on the development of new and accurate techniques in fundamental metrology for microwave and millimeter wave characterization. There is an important need for integrated differential circuits characterization widely used in high speed applications. These circuits must be characterized by means of mixed-mode Scattering parameters (S-parameters) providing a full insight into the signal propagation in differential-mode, common-mode and cross-mode terms. From the viewpoint of electrical metrology, it is also necessary to establish the traceability to the International System of Units (SI). We have realized integrated Multimode TRL (Thru Reflect Line) calibration kits using CPW (CoPlanar wave) lines on quartz and GaAs substrates for on-wafer mixed-mode S-parameter measurements from 1 GHz up to 60 GHz. The feasibility and the validation of the method have been demonstrated for different integrated elements showing good agreement between simulated and measured results [591]. The improvement of the accuracy for traceability achievement is still under investigation.

The power amplifier is one of the most critical circuits responsible for the major fraction of

the communications system's power consumption and distortion. The design procedure requires a trade-off between output power, efficiency and spectral regrowth. Many millimeter-wave characterization systems, dedicated to PA optimization, have been realized but most of these techniques use only CW test signals. For accurate measurements, the transistor should be measured in its real conditions of use, i.e, when operating with realistic wideband communications signals. We have developed an original source-pull/load-pull system [603] that provides characterization using complex modulated signals with a symbol rate greater than 500 MS/s in the 40-60 GHz frequency range. Actually, we measure wide gap GaN power transistors for III-V Lab in order to estimate the potentiality of specific structures for power amplification at very high frequencies. It should be also noticed that we have published with XLIM (University of Limoges) characterization of traps effects involved in AlGaN/GaN HEMTs (also called kink effect) that directly affects the performances of microwave devices under pulse modulated signals. These characterizations are intended to develop and improve new non-linear models of GaN HEMTs taking into account the dynamics of traps for modulated signals.

Optimization of the circuits or antennas has been summarized before but it's also possible to minimize the consumption of systems by using carrier aggregation. The LTE Advanced standard enables data rates up to 1.3 Gb/s by mixing MIMO techniques and carrier aggregation. This method will be also used in the 5G standard. The team works in the field of carrier aggregation on the modulation and demodulation of frequency aggregated signals. For the demodulation side, our know-how is the mixing of RF signals occupying n frequency bands with n LO signals [575] [568]. This allows to use a single RF receive chain [605] with a low sampling frequency DAC. The goal is to obtain an integrated system with a size and a consumption suited for IoT applications, sensors and/or broadband mobile networks. The method to generate n LO signals is based on the computation of the suited shaping of baseband I-Q signals [599]. The obtained I-Q signals are converted by a DAC and modulate a single carrier OL signal [598]. This method is also used to generate directly an OFDM modulated RF signal involving 3 noncontiguous frequency band [557]. (PhDs of A. Kaissoine, 2015 and M. Abdi Abyaneh, 2016)

13.2.3 Channel Model and Antenna Surrogate Model, Indoor localization

Channel and antenna model:

The team has made the development of statistical approaches for channel and antennas an original scientific axis for more than ten years, including joint antenna/channel model [560]. We currently work on surrogate models of antennas in uncertain conditions, either extrinsic – due to close environment effects (human body, supports, close scatterers) [570]– or intrinsic such as natural deformations (flexible substrates, integration into clothing). Surrogates can be built to test new physical/link layer schemes and even be part of abstraction models for higher layers (MAC, traffic). These approaches are all the more useful today as the complexity and variety of emerging networks (NW) standards and usages is increasing (cell densification, cognitive radio, IoT...) [579] and as constraints imposed to devices are more demanding (multiband/very wide bands, multi-antennas...) [584]. Increased complexity requires a finer assessment of systems performance, e.g. through the evaluation of KPIs (Key Performance Indicators), such as power consumption, data rates, latencies, Electromagnetic Field exposure (EMF), etc. In the last years, these approaches were applied by the team to small terminals/small cells base stations or access points [581], which are operating in highly variable conditions, for various needs: EMF exposure (EU FP7 Lexnet project, PhD of A. Krayni, 2016), statistical model of RFID backscattering channel and tag antennas (EU FP7 Select project, collaboration with Univ. of Bologna, PhD of Z. Mhanna, 2014, and F. Guidi, 2013) [582] [578], indoor on-body propagation channel (PhDs of Y. Wei, 2014 and of B. Youssef, start 10/2017), cognitive radio (ReCoSS project, PhD of X. Zen, 2014), physical/channel based communication secrecy (Phylaws project, PhD of T. Mazloum, 2016) [571] [558], statistical surrogate model of deformable antennas (PhD of J. Du, 2018) [554] [561]. Since 2015, advanced

statistical techniques based on the polynomial chaos expansion and adaptive experimental designs have been used to develop surrogate models of deformable antennas, notably applied to textile antennas.

The RFM² team works also on channel model by relaying technology dedicated for the high data rate wireless communication systems. Typically, their performances are studied by system simulations including a reliable propagation channel model. Thus, it aims to improve the existing channel models dedicated to the access link and to study the impacts of the propagation environment on the performance of the relaying technique. We proved that some parameters, such as the relay antenna height, need to be well investigated [595] [601]. With a measurement campaign at 2.1 GHz in an urban environment, Path Loss models for the access link in line of sight and non-line of sight have been established as a function of the relay antenna height. The team has performed also the analysis of the relaying technology in terms of capacity and coverage. It shows that it is possible to enhance the capacity up to 40% with the relay antenna height (PhD of I Maaz, 2016). In the 5G context, the study of the behavior of mmWave channels is led for both urban outdoor and O2I (Outdoor to indoor) environments for the 3, 10, 17 and 60 GHz frequency bands. The channel parameters such as building penetration losses and the delay spread were evaluated (PhD of C Diakhate, start 02/2016) [592] [589]. With the help of the knowledge gathered in the design of circuits, subsystems and the behavior of the indoor radio channel, it's also possible to imagine new systems and architectures. In continuation of previous work, the team choose to develop original concepts dedicated to indoor localization.

Indoor Localization:

Nowadays, applications for IoT or human tracking require an accurate localization system. Many solutions exist for outdoor situation with GPS for example. For indoor localization, the accuracy decreases strongly because of multipaths phenomena. The RFM² team works on indoor localization by studying two complementary solutions for dedicated applications. In the first one, we develop a 3D UWB localization system [602]. A base station allows to localize tags by measuring the range and the azimuth and elevation angles with regard to a dedicated UWB localization base station. This base station is made of four UWB radars and the tags to localize are transceivers. With this solution, no synchronization is needed and, even if a line of sight situation is necessary, the backscattering and multipaths effects due to the indoor propagation environment are strongly reduced by using jointly dedicated antennas [585] [604] and different frequency bandwidths for the uplink (PhDs of R. Kumar, 2014) and the downlink [600]. The second method focuses on a self localization by smartphones or tablets and exploits the inertial sensors embedded in handsets. It is a complementary solution to assist RF systems on no covered area. The signals from inertial sensors are used by pedestrian dead reckoning (PDR) to determine the path done since a known position provided by a RF system [596]. In PDR case, a calibration provides data that is used to estimate the walking orientation and the number of steps (PhD of S. Kammoun, 2016).

13.2.4 Transverse work

Certain research activities are transverse to topic1 and topic2 and can not be satisfactorily included in either, especially in the context of collaborative projects with industrial partners or research centers. For instance the development of a UWB radar for helping blind people or for contactless breath monitoring of multiple persons [594] is taking place at CEA-LETI (PhD of Tien Tu Vo, started in 2015). This work inherits from the simultaneous understanding and modeling of the UWB indoor radio channel together with the design of multiple UWB antenna systems and direction of arrival estimation [587] and it targets the implementation of a complete smart multi-antenna impulse receiver internally based on code division multiplexing/demultiplexing.

Another PhD work (Juan Bucheli, started in 2017) in collaboration with Huawei-France intends to investigate simplified multi-antenna systems based on reactive beam forming (ESPAR architecture) for 5G base stations with reduced complexity or for improving coverage through smart multi-antenna relaying [586]. This work benefits from the long term experience of the team

in ESPAR antennas and radio channels and covers both the architecture of antenna systems and the associated algorithms operating at the physical layer level, for their optimal exploitation.

13.2.5 Chair "Characterization, Model and Control of Exposures" (C2M) of the Telecom Institute

The increasing use of wireless communication system using electromagnetic fields has been accompanied by a scientific and societal debate on the possible health impacts of exposure to radio frequency waves [583]. To provide technical expertise in the field of telecommunications, Telecom ParisTech, in partnership with Telecom Bretagne, decided in November 2015 to create the chair "Characterization, Modeling and Control of Exposures" (C2M) of the "Institut Mines Telecom" which contributes to the characterization, analysis and the model of exposures to electromagnetic waves induced by telecommunication systems and networks as well as the study of the perception of the risk linked to this exposure [555]. These studies are part of a multidisciplinary framework that is both technological (numerical computation, statistics, antennae, network architecture), sociological and philosophical. The skills of the Chair are internationally recognized: J Wiart has indeed been appointed as, on the one hand, Chairman of the EU standardization CENELEC TC106X and on the other hand as the chairman of the steering committee of "l'Observatoire des ondes de Paris". The works of the chair are :

Numerical and experimental Dosimetry: These research actions are follow up of the works carried out before 2015 by the Joe Wiart's team .The present works are dealing with hybridization of FDTD simulation with nearfield measurement based on spherical mode decomposition. These approaches have been used in the GREENCOM FUI project as well as in the CREST ANSES project. Present works are also analyzing the methods and equipments that can be designed and used to assess the real power emitted by mobile phone [562]. These works have been carried out within the MOBIKIDS EU project and in the DEVIN ANSES project

Stochastic and surrogate model of the exposure: This is a key research axis of the C2M Chair. The Development of statistical approaches and surrogate modeling for exposure assessment has been initiated in 2005 and is nowadays an important research axis to manage the increasing complexity of networks and usages. The team has worked on the use of polynomial chaos expansions for the global Exposure assessment induced by handset (PhD of A. Krayni, 2016) [556] [567] .The team has also worked on a new surrogate modeling technique combining Kriging and polynomial chaos expansions [572] and its application to uncertainty analysis in computational dosimetry (Phd of P Kersaudy 2016). The present work are dedicated to the surrogate modeling of stochastic function using the Karhunen Loeve decomposition. These works are contributing to the EU LEXNET project and in the ANSES AMPERE and Coriolis projects

New technologies and architecture Influence on RF exposure: The team research is following up the work carried out in EU project LEXNET that has been coordinated by J Wiart. LEXNET has introduced a new metric to evaluate electromagnetic exposure induced by wireless cellular networks. This metric takes into account the exposure induced by base station antennas as well as exposure induced by wireless devices to evaluate the average global exposure of the population in a specific geographical area (Phd of Y Huang 2017) [573].The present research objective is to build a surrogate model to assess such global objective and to analyze the sensibility of human 3G-induced EMF exposure to different influencing factors, such as, mobile usage data, emitted and received powers respectively by personal devices and from base stations [574] [569].To do so, statistical methods are used to estimate the propagation in indoor environments where there are a lack of information. These Works are carried out within the AMPERE ANSES project

Standardization of assessment methods: The team research is dealing with the uncertainty management in SAR measurement using vector probe array. These Works are carried out within the VECTOR SAR H2020 EMPIR project.The team activity is also to provide its skills to standardization bodies such as IEC or CENELEC.

13.2.6 Scientific Highlights:

- Administrative activities
  - Prof. Alain Sibille is the director of Doctoral Education of Telecom Paristech. He is also the director of the cluster 2 :"Réseaux, Information, Communications" of the Doctoral School: "Sciences et technologies de l'information et de la communication (STIC)" (UPSay university).
- Organization of Workshops and Conferences
  - EuCAP 2017
  - GDR Ondes 2014 and 2015
  - EuMW 2015
  - "Journées scientifiques d'URSI-France" 2013 to 2018
  - "Journées annuelles EMF days" 2013 to 2018
  - JNM 2013
- Technical Program Chair of Workshops and Conferences
  - EuCAP 2017
  - GDR Ondes 2017
  - UMEMA 2016
  - EuMW 2013 to 2018
  - ICUWB 2014
  - PIMRC 2013
  - JNM 2013, 2015 and 2017
- Standardization Committee
  - Chairman of the TC 106x of CENELEC (European Committee for Electrotechnical Standardization)
  - Chairman of the steering committee of "Observatoire des Ondes de Paris"
  - Member of the scientific committee of "Laboratoire National de Métrologie"
- Associate editors of journals
  - AWPL 2017
  - VT-Magazine 2015
  - Comptes Rendus Physique 2015
  - Annals of Telecommunications (since Feb. 2014)
  - REE-2014
  - Radio Science 2013
  - The Journal of Communications and Networks
- Awards
  - Palmes académiques 2018: Anne Claire Lepage
  - Anis Krayni: "Science et Vie Junior" Vulgarization Award JNM 2015
- Significant Contracts with Industrials, Chairs
  - 2015 : Chair C2M on Characterization, Modeling and Mastering of EMF Exposures from Telecom Paritech and Orange

- Significant sources of fundings
  - European fundings: SPECTRA (-2014), LEXNET (-2016), PHYLAWS (-2016), GERoNIMO (2015-2018), TWEETHER (2015-2018), VECTOR SAR-EMPIR (2017-2020)
  - ANR fundings: ACTe (-2016), SAFAS (2013-2015), SAFASNAV (2016-2020)
  - Others national fundings: RECOSS (-2014), MIMICRA (-2014), SCANVISION (2015-2018), ANSES DEVIN (2015-2017), OPTIMISME (2016-2019), AMPERE (2016-2021), ECLAIR (2016-2020), ANSES ELFES (2016-2020)
  - IDEX UPSay fundings: Nanodesign ANTENNE (2014-2016), ClassMet (2017-2018)

13.3 SWOT analysis

13.3.1 Strength

- The team concentrates 7 researchers on radio front ends with complementary skills that cover circuits and antenna designs, MMIC and antennas characterization, wave propagation and wave human Interactions model up to 110 GHz.
- The team has got a unique characterization platforms pool operating up to millimeter waves that attracts collaborations with industrial or academic institutions at both NewUni, the Université Paris-Saclay and beyond.
- The research addresses long term needs such as national security, public health, wireless communications which are independent from short term technical inflations and hypes.
- The team work has a sound scientific production, a significant numbers of bilateral contracts and benefits from research funding programs at national and European levels.

13.3.2 Weakness

- Difficulties in attracting Telecom ParisTech students into PhD studies in the microwave domain is enhanced by the competition with data related topics (Big data, artificial intelligence, ...)
- The Electrical Engineering domain is only weakly present in the novel NewUni consortium
- The retirement of a researcher not currently replaced.

13.3.3 Opportunities

- The single non linear characterization platform dedicated to components and systems benefits from the GaN growing market, with rising collaboration with the III-V lab (including Nokia-Thales-CEA).
- The "Paris Saclay Plateau" offers a unique scientific environment where the skills of the team in antennas and metamaterials design or characterization, and propagation modeling is well recognized.
- To consolidate academic and industrial interactions with the C2M Chair on the Human and wave interactions.
- Currently, the technology orientations for the 5G standard are not yet fully established. This is a timely period for innovation and breakthrough research, especially in the millimeter wave regime.

13.3.4 Threats

- With the demand on Big Data or Machine Learning for Data Mining activities, the students' disaffection for research activities on hardware topics is real, and getting excellent PhD students becomes a growing issue.
- The creation of Université Paris-Saclay, then "NewUni", is a time consuming task that diverts energy and thoughts and requires reconsidering the balance between competing interests. A stable and global organization will be not fully operating but on a reduced part of the coming HCERES period.
- The economy of the telecommunication sector continues to be rapidly changing, with a shift of the industrial players in the hardware domain outside France and Europe

13.4 Scientific project for the the next five years

The optimization of technologies and networks for telecommunications requires a perfect knowledge of the systems or subsystems and requires multi-domain skills. The ability of RFM^2 to work, simultaneously, in the antenna-circuit co-design and integration and also in the channel-antenna co-design is essential to meet the needs of diverse and complex architectures. Then the main goals of the RFM^2 team are the optimization of the telecommunication systems by :

- Pushing the RF technologies to the limit with physics and technology innovations: from low cost/ low speed to high performance / broadband for men, objects and connected machines.
- Pushing the optimization of "5G and beyond" technologies by improving indoor localization system, developing novel methodologies and behavioral models for antennas and propagation by taking into account the nearby environment and analyzing the human and waves interactions.

13.4.1 Antennas & circuits design, co-design and integration up to millimeter waves

Metamaterials are now entering a phase of maturity with extraordinary characteristics but still operating in a resonant mode. To increase the potential of these materials, the team draws on its long experience in the field of antennas and broadband circuits to increase the usable frequency bands and thus targets broadband applications. With the frequency rise, this allows to reduce the size of the devices but both the difficulty of the design and the realization of the devices are increased. For example, all interconnections must be minimized to reduce losses. To optimize the new components and in particular their efficiency, the team has a pool of characterization platforms for microwave and millimeter wave components (< 110 GHz) (antennas, circuits and non-linear components). Thus the GaN-type large gap devices have a high potential for a power amplification but operate at relatively low frequencies. In that way, an informal Industrial collaboration with III-V Lab has started and it will focus on the characterization of components around 40 GHz, to optimize technological processes and then extract and validate non-linear electrical models essential to the circuit design. The objective is then to extend this work around 60 GHz and to make measurements in the presence of broadband modulated signals to get as close as possible to the real operating conditions.

13.4.2 Stochastic behavioral models for antennas and propagation for '5G and beyond" systems, Localization and human/waves interactions

With the development of the "5G and beyond" telecommunications systems and of the IoT, it becomes necessary to characterize the behavior of far and near propagation environments in order to optimize the quality of communications while reducing the consumption of systems. On this

point, the objectives of the RFM² team will focus on the development of antennas stochastic surrogate models in fluctuating conditions: deformable antennas (flexible substrates, integrated in textiles, etc.) and "enclosed" antennas (influence of the near environment, near scatters, etc.). With the operating frequency increasing, the modeling also becomes essential but complex in order to predict the response of the environment while maintaining a reasonable computing time. For this purpose, a second research axis is to develop statistical models to reduce the number of simulations in order to evaluate the environment influence on the radio systems functionality, measured by indicators (as "KPI") at different steps (radio link, traffic, exposure, etc.). Here the goal is to substitute these new models to the analytical model including heavy simulations (FDTD, FEM, or ray tracing). Such a model is not related to the processing of a large amount of data, as the "big data", but to the availability of a minimum of simulations corresponding to the "hypo data". This approach applies in particular to the interactions between a communicating object and the environment (antenna and environment including the human body as well as multipath propagation with a remote node).

The localization research activity of the RFM² team is oriented on the known problem of the indoor localization in the context of connected humans. The team is developing an UWB localization system. In addition to the orientation or the search for connected objects, localization can enable communication systems to optimize their consumption by focusing the signal transmissions in expected directions.

With the increasing number of communicating objects, the human/waves interactions are a more and more than relevant issue in order to estimate the consequences of waves on humans exposed to a congested electromagnetic environment. The C2M chair has recognized expertise in the measurement and model development of these interactions and participate to several national and international research programs.

13.5 Scientific production (selection)

Articles in Journals

[554] J. Du and C. Roblin. Stochastic surrogate models of deformable antennas based on vector spherical harmonics and polynomial chaos expansions: Application to textile antennas. *IEEE Transactions on Antennas and Propagation*, June 2018.

[555] E. Chiaramello, M. Parazzini, S. Fiocchi, P. Ravazzani, and J. Wiart. Assessment of fetal exposure to 4g lte tablet in realistic scenarios: Effect of position, gestational age and frequency. *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology*, August 2017.

[556] A. Krayni, A. Hadjem, G. Vermeeren, A. Sibille, C. Roblin, W. Joseph, L. Martens, and J. Wiart. Modeling and characterization of the uplink and downlink exposure in wireless networks. *International Journal of Antennas and Propagation*, pages 1–15, June 2017.

[557] M. Abdi.Abyaneh, B. Huyart, and J.C. Cousin. Carrier aggregation of three ofdm signals using a single oscillator and I/Q modulator. *IEEE Transactions on Microwave Theory and Techniques*, PP (99):1–9, March 2017.

[558] Ch. L. Kameni Ngassa, R. Molière, F. Delaveau, A. Sibille, and N. Shapira. Secret key generation scheme from wifi and lte reference signals. *Analog Integrated Circuits and Signal Processing*, March 2017.

[559] S. Varault, M. Soiron, A. Barka, A. C. Lepage, and X. Begaud. Rcs reduction with a dual polarized self complementary connected array antenna. *IEEE Transactions on Antennas and Propagation*, 65 (2):567–575, February 2017.

[560] A. Sibille and P.-S. Kildal. Guest editorial awpl special cluster on "impact of user-related randomness on antennas and channels". *IEEE Antennas and Wireless Propagation Letters*, 16, 2017.

[561] J. Du and C. Roblin. Statistical modeling of disturbed antennas based on the polynomial chaos expansion. *IEEE Antennas and Wireless Propagation Letters*, PP(99), September 2016.

[562] S. Dahdouh, N. Varsier, M. Nunez Ochoa, J. Wiart, A. Peyman, and I. Bloch. Infants and young children modeling method for numerical dosimetry studies: application to plane wave exposure. *Physics in Medicine and Biology*, 61(4):1500–1514, 2016.

[563] Ch. Joshi, A. C. Lepage, and X. Begaud. A dielectric-only superstrate inspired from transforma-

tion optics for complete reorientation of electromagnetic waves in azimuthal plane. *EPJ Applied Metamaterials*, June 2016.

[564] Ch. Joshi, A. C. Lepage, J. Sarrazin, and X. Begaud. Enhanced broadside gain of an ultra wide band diamond dipole antenna using a hybrid reflector. *IEEE Transactions on Antennas and Propagation*, 64(7):3269–3274, May 2016.

[565] Y. Pinto and X. Begaud. Mobile phone model with metamaterials to reduce the exposure. *Applied Physics A*, 122(4), April 2016.

[566] S. N. Burokur, A. C. Lepage, S. Varault, X. Begaud, G.-P. Piau, and A. De Lustrac. Low-profile metamaterial-based l-band antennas. *Applied Physics A*, 122(4), April 2016.

[567] A. Krayni, A. Hadjem, A. Sibille, C. Roblin, and J. Wiart. A novel methodology to evaluate uplink exposure by personal devices in wireless networks. *IEEE Transactions on Electromagnetic Compatibility*, 58(3):896–906, March 2016.

[568] A. Kaissoine and B. Huyart. Non contiguous tri-band receiver for carrier aggregation rf system. *Horizon Research Publishing-Universal Journal of Communications and Network*, 4:15–27, February 2016.

[569] I. Liorni, M. Parazzini, N. Varsier, A. Hadjem, P. Ravazzani, and J. Wiart. Exposure assessment of one-year-old child to 3g tablet in uplink mode and to 3g femtocell in downlink mode using polynomial chaos decomposition. *Physics in medicine and biology*, 61(8):3237, 2016.

[570] C. Roblin. A statistical assessment of ambient electromagnetic field using body-worn multiaxial sensors. *Comptes Rendus de l'Académie des Sciences - Physique*, 16(9):802–818, November 2015.

[571] T. Mazloum and A. Sibille. Analysis of secret key randomness exploiting the radio channel variability. *International Journal of Antennas and Propagation*, page 13, September 2015.

[572] P. Kersaudy, B. Sudret, N. Varsier, O. Picon, and J. Wiart. A new surrogate modeling technique combining kriging and polynomial chaos expansions–application to uncertainty analysis in computational dosimetry. *Journal of Computational Physics*, 286:103–117, September 2015.

[573] N. Varsier, D. Plets, Y. Corre, G. Vermeeren, W. Joseph, S. Aerts, L. Martens, and J. Wiart. A novel method to assess human population exposure induced by a wireless cellular network. *Bioelectromagnetics*, 36(6):451–463, September 2015.

[574] P. Gajsek, P. Ravazzani, J. Wiart, J. Grellier, Th. Samaras, and G. Thuróczy. Electromagnetic field exposure assessment in europe radiofrequency fields (10 mhz-6 ghz). *Journal of exposure science and environmental epidemiology*, 25(1):37, September 2015.

[575] A. Kaissoine and B. Huyart. New three phase demodulator circuit operating in a wide frequency range. *Microwave and Optical Technology Letters*, August 2015.

[576] M. Clemente, A. C. Lepage, and X. Begaud. Antipodal radiation pattern of a patch antenna combined with superstrate using transformation electromagnetics. *Applied Physics A*, 117(2):699–703, November 2014.

[577] L. Damaj, A. C. Lepage, and X. Begaud. Compact wideband antenna above a wideband non-uniform artificial magnetic conductor. *Applied Physics A*, 117(2):705–711, November 2014.

[578] F. Guidi, A. Sibille, C. Roblin, V. Casadei, and D. Dardari. Analysis of uwb tag backscattering and its impact on the detection coverage. *IEEE Transactions on Antennas and Propagation*, 62(8): 4292–4303, June 2014.

[579] X. Zeng, F. Mani, and A. Sibille. On the impact of antenna disturbances by urban furniture on deterministic propagation simulations. *IEEE Transactions on Antennas and Propagation*, May 2014.

[580] Ch. Djoma, M. Jousset, A. C. Lepage, S. Mallegol, C. Renard, and X. Begaud. Maximal bandwidth of an archimedean spiral antenna above a reflector. *IEEE Antennas and Wireless Propagation Letters*, January 2014.

[581] N. Decarli, A. Guerra, A. Conti, R. D'Errico, A. Sibille, and D. Dardari. Non-regenerative relaying for network localization. *IEEE Transactions on Wireless Communications*, 1:174–185, January 2014.

[582] F. Guidi, A. Sibille, and C. Roblin. Interaction of uwb tag backscattering with close metallic reflectors. *IEEE Antennas and Wireless Propagation Letters*, 13:245–248, January 2014.

Books

[583] J. Wiart. *Radio-Frequency Human Exposure Assessment: From Deterministic to Stochastic Methods*. willey, 2016. ISBN 9781848218567.

Book Chapters

[584] A. Sibille, F. Delaveau, Ch. L. Kameni Ngassa, R. Molière, T. Mazloum, A. Kotelba, J. Suomalainen, S. Boumard, and N. Shapira. *Trusted Communications with Physical Layer Security for 5G and Beyond*, chapter Application cases of secret key generation in communication nodes and terminals. IET, 2017.

[585] R. Kumar, J. C. Cousin, and B. Huyart. *Wideband, Multiband, and Smart Reconfigurable Antennas for Modern Wireless Communications*, chapter Antenna System & Architecture- Circular Polarized UWB Antennas for Indoor Positioning Application: Introduction, Radio Waves in Indoor Environment, Two-Dimensional Planar Circular Polarized Antenna, page 23. IGI Global- Research Essentials Collection, 2015.

Articles in Conference Proceedings

[586] J. Bucheli Garcia, A. Sibille, and M. Kamoun. Digital vs. analog coherent combining on rl-espar antennas. In *IEEE Wireless Communications and Networking Conference*, Barcelona, Spain, April 2018. IEEE.

[587] T. T. Vo, L. Ouvry, A. Sibille, and S. Bories. Mutual coupling modeling and calibration in antenna arrays for aoa estimation. In *AT-RASC*, Gran Canaria, Spain, May 2018. IEEE.

[588] A. C. Lepage, Y. Pinto, O. Rance, X. Begaud, and N. Capet. Lightweight and wide-angle metamaterial absorbing material concept. In *EuCAP 2018*, London, United Kingdom, April 2018.

[589] Ch. Diakhate, J.-M. Conrat, J. C. Cousin, and A. Sibille. Antenna aperture impact on channel delay spread in an urban outdoor scenario at 17 and 60 ghz. In *EuCAP2018*, Londres (UK), April 2018.

[590] X. Begaud, S. Varault, A. C. Lepage, M. Soiron, and A. Barka. Design of a thin ultra wideband metamaterial absorber. In *International Conference on Electromagnetics in Advanced Applications (ICEAA 2017)*, Verona, Italy, September 2017.

[591] PH. Thi-Dao, D. Allal, F. Ziadé, and E. Bergeault. Conception d'étalons coplanaires couplées pour la méthode d'étalonnage multimode trl. In *JNM2017*, St Malo, France, May 2017.

[592] Ch. Diakhate, J.-M. Conrat, J. C. Cousin, and A. Sibille. Millimeter-wave outdoor-to-indoor channel measurements at 3, 10, 17 and 60 ghz. In *EuCAP 2017*, Paris,France, March 2017.

[593] J. Enriquez, X. Begaud, B. Huyart, Q. T. Le, R. Zimmermann, and F. Magne. Millimeter wave antennas for backhaul networks. In *EuCAP 2017*, Paris, France, March 2017.

[594] T. T. Vo, L. Ouvry, and A. Sibille. Time domain complex radar cross section of human body for breath-activity monitoring. In *EuCAP 2017*, Paris, France, March 2017. IEEE.

[595] I. Maaz, J.-M. Conrat, and J. C. Cousin. Channel model validation for the relay-mobile link in microcell environment. In *IEEE VTC 2015*, Boston, USA, September 2015.

[596] S. Kammoun, J.-B. Pothin, and J. C. Cousin. An efficient fuzzy logic step detection algorithm for unconstrained smartphones. In *PIRMC 2015*, Hong Kong, Chine, September 2015.

[597] S. Varault, M. Soiron, A. Barka, A. C. Lepage, and X. Begaud. Analytical model and performances at large scanning angles of an ultra-wideband self-complementary connected array antenna. In *META'15, the 6th International Conference on Metamaterials, Photonic Crystals and Plasmonics*, New York, USA, August 2015.

[598] M. Abdi.Abyaneh, B. Huyart, and J. C. Cousin. Qpsk-ofdm carrier aggregation using a single transmission chain. In *IEEE MTT-S 2015*, Phoenix, Etats Unis, June 2015.

[599] M. Abdi.Abyaneh, A. Kaissoine, B. Huyart, and J. C. Cousin. Multiple rf continuous-wave generation using a single signal generator for carrier aggregation in lte-advanced. In *EuMW 2014*, Rome Italie, October 2014.

[600] R. Kumar, J. C. Cousin, and B. Huyart. Performance of indoor localization system in presence of scatter for strong multipath condition. In *IEEE ICUWB 2014*, Paris, France, September 2014.

[601] I. Maaz, J.-M. Conrat, and J. C. Cousin. Path loss models in nlos conditions for relay mobile channels. In *IEEE VTC 2014 - fall*, Vancouver, Canada, September 2014.

[602] R. Kumar, J. C. Cousin, and B. Huyart. Indoor localization system for 2d measurement in european uwb band with one reference position. In *IEEE MTT-S 2014*, Tampa Bay, Floride, June 2014.

[603] R. Mohellebi, E. Bergeault, B. Huyart, and A. Khy. Système de mesure ″source-pull/load-pull″ dans la bande de fréquence 40 ghz - 60 ghz en présence de signaux modulés large bande. In *JNM 2013*, Paris,France, May 2013.

[604] R. Kumar, B. Huyart, J. C. Cousin, and K. Mabrouk. Dual-circular polarized dumbbell-shaped crossed-dipole planar antenna for uwb application. In *EuCAP 2013*, Goteborg, Suède, April 2013.

[605] A. Kaissoine, B. Huyart, and K. Mabrouk. Demodulation of aggregated rf signal in three frequencies bands with a unique rx chain. In *EuMW 2013*, Nuremberg, Allemagne, February 2013.

Patents

[606] N. Capet, Y. Pinto, A. C. Lepage, J. Sarrazin, and X. Begaud. Dispositif et procédé d'absorption multi-secteurs. (WO2015136121), September 2015.

Chapter 14

SSH

Secure and Safe Hardware

14.0.1 Presentation of the Team

Team leader: Jean-Luc Danger (FP)

Faculty between 2013 and 2018: Sumanta Chaudhury (AP since April 2014), Jean-Luc Danger (FP), Guillaume Duc (AP), Tarik Graba (AP), Philippe Hoogvoorst (JRS til June 2015), Ulrich Kühne (AP since Sept. 2016), Philippe Matherat(JRS til Sept. 2015), Yves Mathieu (FP), Lirida Naviner (FP), Alexis Polti (AP), Laurent Sauvage (AP)

Invited Professors: Hervé Chabanne (MORPHO then IDEMIA), Sylvain Guilley (Ministery of Defense then Secure-IC)

Sabbatical Professors: Ming Tang (2015-2016, Wuhan University), Noriyuki Miura (2014, Kobe University), Nafumi Homma (2016-2017, Tohoku University)

Permanent Research Engineers: Abdelmalek Si-Merabet (RE since Dec.2014)

PostDocs and non-permanent Researchers: Emna Amouri(2013, Y. Mathieu), Shivam Bhasin (2013-2014, J-L Danger), Paulo-Francisco Butzen (2014-2015, L. Naviner), Hao Caï (2013-2017, L. Naviner), Marcia Costa (2013-2014, L. Naviner), Maxime lecomte (2017, L. Sauvage), Florent Lozac'h (2013, J-L Danger), Maha Naceur (2016-, U. Kühne), Zakaria Najm (2013-2014, J-L Danger), Isaac Pessoa (2016, L. Naviner), Florian Praden (2013-2015, J-L Danger), Mariem Slimani (2013-2016, L. Naviner), Michaël Timbert (2014, J-L Danger)

PhD Students: Ting An (2011-2014, L. Naviner), Arwa Ben Dhia (2011-2014, L. Naviner), Molka Ben Romdhane (2011-2014, J-L Danger, T. Graba), Fabio Batagin (2016-, L. Naviner), Cyril Bottoni (2012-2015, L. Naviner), Nicolas Bruneau (2014-2017, S. Guilley), Sébastien Carré (2017-, J-L Danger, S. Guilley), Eloi de Cherisey (2015-, O. Rioul, S. Guilley), Taoufik Chouta (2010-2015, J-L. Danger, T. Graba), Benjamin Coeffic (2013-2018, L. Naviner), Elaine Crespo Marques (2016- L. Naviner), Nicolas Debande (2011-2014, J-L Danger, H. Chabanne), Margaux Dugardin (2015-2017 J-L Danger-S. Guilley), Annelie Heuser (2014-2016, O. Rioul, S. Guilley), Natalja Jovanovic (2012-2016, L. Naviner), Khaled Karray (2015-, J-L Danger, S. Guilley), Natalija Jovanovic (2012-2015, L. Naviner), Kaikai Liu (2011-2014, L. Naviner), Nilson Maciel (2017-, L. Naviner), Damien Marion (2014- , S. Guilley), Cédric Murdica (-2014, P. Hoogvorst), Samuel Nascimento (2011-2013, L. Naviner), Xuan-Thuy Ngo (2013-2016, J-L Danger, S. Guilley), Salaheddine Ouaarab (2014-2016, G. Duc), Samuel Pagliarini (2010-2013, L. Naviner) Xavier Pons-Masbernat (2012-2015, L. Naviner), Pabo Rauzy (2012-2014, S. Guilley), Sébastien Sarrazin (2011-2015, L. Naviner), Alexander Schaub (2017-, O. Rioul, S. Guilley), Sofiane Takarabt (2017-, Y. Mathieu), Sébastien Thomas (2009-2013, J-L Danger, G. Duc), Mariem Slimani (2009-2013, P. Matherat), Michaël

Timbert (2016- , J-L Danger), You Wang (2014-2017, L. Naviner), Xuecan Yang (2017-, S. Chaudhury, L. Naviner, L. Likforman).

Platforms: The team develops and exploits the following platforms:

- Trust Analysis Platform (TAP)
- Digital Circuit Safety Analysis

Scientific Production Overview: Table 14.1 represents the overall scientific production between 2013 and 2018. The detailed bibliography is listed in the dedicated accompanying document.

Journals	Articles in Proceedings	Books and Book Chapters	Patents	Keynotes and Tutorials	Other Invited Talks	Habilitation thesis	Completed PhD
54	182	11	15	5	14	0	38

Table 14.1: Overall Scientific Production

14.1 Research activities

14.1.1 Overview

The SSH team conducts research on architectures and methods to design “efficient” embedded systems and digital electronic circuits to meet the requirements emerging from the IoT, 5G, autonomous car, smart building, etc. In addition to traditionnal properties of low-cost, high performance level and low power, the SSH team concentrates on **Security** and **Safety** constraints to propose robust architectures. These properties become vital to tackle the numerous threats linked to the rising number of applications requiring a high level of trust and autonomy in hostile environments. The SSH research is at the crossroad of industrial requirements and new digital technologies with strong collaborations with the international communities . It focuses on two main themes:

- **Architectures and analysis tools for security**.
- **Architectures and analysis tools for safety and reliability**.

The study of architecture does make sense if associated with solid validation methods. This is why many studies are related to the security/safety analysis which can take many forms : abstract (formal), simulation and real circuit as FPGAs and custom ASIC fabricated in new CMOS technologies.

14.1.2 Topic 1: Architectures and analysis tools for Security

Secure architectures have been studied in order to provide embedded systems resistant to any kinds of attacks exploiting physical weaknesses or software vulnerabilities. The main objective is to propose Hardware or Low-level software to enhance the level of security against a large range of attack. To achieve this goal, attacks have to be perfectly understood and formalized. On this basis, the protections have to be verified. The validation can be carried out by three actions: simulation, formal proof and analysis on real silicon. Prototyping devices on real silicon is a crucial point as it allows to validate the protection and contributes to understand the mechanism in a "whitebox" approach. Moreover the use of last semiconductor technologies inform us about the trends in term of intrinsic physical properties and security.

- One of the most famous attack on Hardware is Side-Channel Analysis (SCA), which exploits some information leakage on intermediate physical variables which are linked to secret information, as for instance a cryptographic key.

  One countermeasure relies on "masking". It combines the sensitive variables with random variables. Different new masking schemes have been studied and validated. The "leakage squeezing" [631, 630] creates a digital mask that fuzzes the leaked information. A proof has been formalized concerning the "high-order" masking schemes exploiting the use of many masks [610, 614]. The quality of the countermeasure relies on the knowledge of an adequate leakage model. We developped an optimal tool, called "distinguisher", to discriminate the good cryptographic key guess from the bad. An important result, obtained jointly with the digital communication team, is the closed form expression of the optimal distinguisher [658]. The theory has been extended to High order masked protections [611], template attacks which are based on a profiling step, collision and stochastic attacks [613]. The masking protection can also be implemented and formalized by using error correcting codes. More specifically a class of codes, called "Orthogonal Direct Sum Masking", has been studied with MORPHO in the frame of the ISA common Lab [659]. One interesting result is the scalability of the security level which is directly linked to the codes parameters.

  Another type of protection consists in using the Dual Rail with Precharge Logic (DPL) which provides a constant leakage during computation by means of a true and false networks. The challenge in this protection is to design a well-balanced network between the True and False channels. Methods have been developped in programmable circuits (FPGA) [629], and in ASIC specially designed to implement an FPGA with balanced DPL networks [657].

- The Fault Injection Attacks (FIA) with Electromagnetic (EM) Injection is a powerful attack coming from its non-intrusivity property and its spatio-temporal flexibility. Many studies have been done to assess the real impact of such EM injection. The SPACE project with japanese laboratories (Tohoku, Kobe, UEC) provided a framework to design a test chip and better understand the EM fault injection attacks [634]. A specific focus has been done on software implementation which is particularly sensitive to fault injection attacks by EM injection [664]. The attack on the cache lines on ARM processors allows for instance an adversary to recover secret informations [651]. Protections against these attacks have been proposed. They mainly rely on novel detection techniques [644].

- Another pernicious threat is the Hardware Trojan Horses (HTH) which can be maliciously added by the design house or the circuit manufacturer. The SSH research was to develop either static or run-time methods to detect HTH. The study on detection by optical methods, i.e. a comparison between the reference layout to a modified one by HTH, showed that it is difficult to insert a HTH if the occupancy rate of an ASIC circuit is important [620]. The detection by side channel, consisting in observing the EM field, has been carried out on FPGAs [620]. This method has the advantage to be non intrusive and it has been proven that it is little sensitive to the technological mismatch. Detection methods at run-time, i.e. when the HTH is triggered, have been devised by inserting HDL assertion code in the circuit model [649]. Prevention methods have been studied by taking advantage of logic encoding [650]. The use of codes allow to obtain formal security parameters which quantify the difficulty for the HTH to be triggered and the number of nets it can modify without impact.

- A number of studies about the Physically Unclonable Function (PUF) primitive have been performed in SSH. The PUF function must provide a fingerprint of a digital circuit, but has to meet mandatory properties such as unicity, robustness against physical attacks and reliability [674]. The impact of aging has been carried out on a Loop PUF architecture proposed by SSH and on custom ASIC circuits. It showed that aging has more impact on sequential elements, and that a pure combinatorial PUF is less sensitive to aging [641]. The PUF entropy needs a proper formalism if it is to generate a cryptographic key. The entropy of the Loop PUF has been demonstrated when the challenges come from a set of Hadamard Codes [643].

- In order to prevent reverse engineering, a shielding on top of the circuit is generally designed. We proved that the current passive shielding techniques are not robust enough, especially if the adversary use Focus Ion Beam (FIB) instruments which allow to cut and reconstruct the shield wires. We introduced the active shielding which detects if the shield has been modified [616]. In this study we also demonstrated that the use of 3D technologies is an asset for shielding. To be very efficient the shielding has to be done at both sides of the device. This is especially important with recent packages where the silicon cores are "Flip-chip". We introduced the concept of back-side shielding which allows to mix-up the shield at the lower metal layer and in combination with the transistor cells [675].
- The attacks on implementations of asymmetric cryptography has been largely covered. An exhaustive study of all the physical attacks and their countermeasures has been done during the PhD of C. Murdica who proposed attacks enhancement, like the Big mac Attack based on pattern recognition [622]. One important weakness exploited by side-channel analysis come from the non constant time computation, especially in the finite field operations necessary in asymmetric cryptography. This vulnerability gave rise to works exploiting this time difference [642] and efficient countermeasures were proposed.
- A topic rised by the SSH group is to know if cyber attacks (hence Software) could be thwarted by Hardware. Several robust protections in customized processors have been proposed and validated [623]. For instance the HCODE protection is to check the integrity of the execution flow, as the attack tries to jump to its malevolent code. It also checks the integrity of a sequence of instructions, or basic Blocks. This strategic topic has been developped in the frame of a DGA RAPID project.

14.1.3 Topic 2: Architectures and analysis tools for reliability and defect tolerance

The reliability of integrated circuits (IC) based on deep submicron technologies (DSM), is becoming increasingly dependent on the interaction of such IC with environmental radiation. Indeed, energetic particles can produce Single Event Upsets (SEUs) and soft errors with significant impact on the error rate of digital IC. By the way, defectless manufacturing of nanoscale IC is becoming ever more expensive. In addition, with CMOS downscaling to tens of nanometers, aging problems have emerged as a major challenge in electronics because lifetime is strongly sensitive to process parameter variations as well as to temperature and supply voltage level changes.

Within the scope of reliability the SSH team addressed defects, ageing, variability and single event transients. Basic blocks, reconfigurable architectures and micro-processors were targeted in this work, which covered both assessment and improvement aspects and produced methods and tools suitable for different abstraction levels.

- Research on efficient solutions for evaluating Single Event Transient (SET) effects lead to a method that deals with bitflips/faults in combinational and sequential circuits [633], some approaches for simplified fault-propagation analysis [669], and the proposal of practical metrics [640]. We proposed a cross-layer investigation of aging effects in $\Sigma\Delta$ converters [626] and studied statistical variability-aware method for circuit performance analysis [665]. We also proposed an analytical method for defect tolerance assessment [627]. A joint work with CEA-LIST addressed the problem of delay degradation and concurrent delay fault detection [670]. A strategy for Flip Flop selection for in-situ slack-time detection has also been proposed [660].
- A collaborative project with LIP6 and TIMA laboratories focused on the design of a defect tolerant mesh FPGA. It included analysis and improvement of fault tolerance strategies [667, 632, 628]. The impact of cluster size on testability has also been investigated [666]. In collaboration with the ITA (Brazil), we evaluated the impact of logic blocks configuration on FPGA's Soft Error Rate estimation (SER) [645]. Then we used FPGA self-produced transients to emulate SETs, and proposed a probability aware fault-injection approach for SER estimation [639]. An ongoing project addresses ageing effects on ARTIX7 XILINX FPGA [612].

- As part of a partnership with ST Microelectronics, an extensive work on microprocessor reliability analysis was conducted. This work consisted in the development and the integration of a fault-tolerance assessment approach suitable for System-On-Chip processors and consistent with ISO-26262. We analyzed heavy-ions impact [661] and the frequency and voltage effects on SER of a 65nm SPARC-V8 [654]. Then, we proposed a layout-aware fault-injection approach for SER prediction [655]. The proposed FI approach has been used to guide [647] and/or to analyse the hardening impact [656]. The validity of the SER predictions has been obtained through comparisons with experimental results [646].

Low power is one of the most challenging topics in electronics, given the growth of the nomad IC market (sensor networks, connected objects, etc.). Nevertheless, the solutions for low-power generally worsen reliability issues, and this motivated our work on subthreshold operation as well as on emerging devices such as non-volatile memories (NVM). These works have enabled cooperations with different partners such as CEA-LETI, Universidad de la Republica (Uruguay), and Beihang University (China).

- We studied the effect of intrinsic noise in subthreshold nanoscale CMOS and searched for a minimum operating voltage [617]. Then, we proposed a model [607] and an asymmetrical length biasing [608, 638] for energy minimization. We also proposed a process-variation-resilient methodology of circuit design by using asymmetrical forward body bias in 28nm FDSOI [618].
- We developed compact models for Magnetic Tunnel Junction (MTJ) [624] that embed temperature fluctuation and dielectric breakdown. The models have been developped as open source and used by many other international institutes [671]. This enabled analysis [619, 615, 637] and development [625, 621, 609] of several structures for mixed CMOS/MTJ circuits such as flip-flops, majority voter. We also proposed solutions suitable for stochastic and approximate computation. Some work on OxRAM NV-FF has also been done [648].
- Within the context of a collaboration with Airbus, the problem of power consumption has also been addressed in a higher abstraction level. We studied different solutions to improve the energy consumption of PMR (Professional Mobile Radio) terminals. We analyzed the uplink energy efficiency in LTE systems [668] and proposed algorithms for battery-aware discovery [663] and vertical handover decision [662]. Furthermore, we studied D2D broadcast communications [653] and proposed an energy efficient D2D LTE structure [652]. This work has resulted in two patent registrations [672, 673] and a book chapter [635].

14.1.4 Scientific Highlights:

- Organization of Workshops and Conferences:
  - Workshop on Security Proofs for Embedded Systems (PROOFS): 2013 to 2018
  - Workshop on Constructive Side-Channel Analysis and Secure Design (COSADE): 2013,2014,2017
  - Cyberphysical Security Education Workshop (CPSED): 2017
- Steering Committee members of conferences
  - Workshop on Security Proofs for Embedded Systems (PROOFS)
  - Workshop on Constructive Side-Channel Analysis and Secure Design (COSADE)
- PC chair of workshops
  - Symposium on Foundations & Practice of Security (FPS): 2013
  - Conference on Security, Privacy, and Applied Cryptography Engineering (SPACE): 2013 and 2017
  - Workshop on Security Proofs for Embedded Systems (PROOFS): 2014
  - Workshop on Information Security Applications (WISA): 2016

  - Conference on Reconfigurable Computing and FPGAs (RECONFIG): 2016
  - Workshop on Constructive Side-Channel Analysis and Secure Design (COSADE): 2017

- Associate editors of journals
  - Journal of Cryptographic Engineering "JCEN"
  - IEEE Transactions on Information Forensics and Security "T-IFS"

- Awards
  - 2014
    * Best poster award: European Symposium on Reliability of Electron Devices, Failure Physics and Analysis (ESREF'14)
    * Palmes académiques: Hervé Chabanne, Jean-Luc Danger
    * Best Student paper award: Hardware Oriented Security and Trust (HOST'14)
    * Best Student paper award: Applied Cryptography and Network Security (ACNS'14)
    * FIEEC Award for founding the spin-off Secure-IC (45 employees in 2018)
  - 2015
    * Best paper: SOI-3D-Subthreshold Conference (S3S'15)
  - 2016
    * Best Télécom Paristech PhD: Annelie Heuser (2016)
    * Best Hardware Demonstration: Hardware Oriented Security and Trust (HOST'16)
  - 2017
    * Palmes académiques: Alexis Polti (2017)
  - 2018
    * Chinese Government Award for Outstanding Self-financed Phd Students Abroad: You Wang

- Significant Contracts with Industrials, Chairs
  - 2015: Security analysis of connected car with PSA
  - 2017: Chair on "Connected Car Cyber Security" (C3S) with the INFRES/S3 reserach group from Télécom ParisTech, Renault, Nokia , Thalès, Wavestone

- Common Lab with Industrial/Universities
  - Common Lab with MORPHO "Identity and Security Alliance".
  - Memorandum of Understanding to prepare common research lab with:
    * Tohoku University,
    * Nara Institute of Science and Technology,
    * Kobe University,
    * University of ElectroCommunications

14.2 SWOT analysis

14.2.1 Strength

- The team has expertise to address the cybersecurity and safety requirements at the embedded system level, encompassing the knowledge of most hardware and software weaknesses and strengths. This capacity to fathom the security and safety of new technologies comes from both the digital design expertise in ASICs and FPGAs, and the efficient tools to assess the robustness level.
- The design of custom circuits in new technologies allows the SSH researcher to better understand physical phenomemon and evaluate the protections. Our circuits can be considered as white boxes which can become grey or black according to the level of analysis effort.
- The analysis platforms are powerful tools to carry out tests on real silicon and understand the weakness of the implementation. The expertise on the acquisition stage, including the probing features and digital signal processing techniques provide accurate assessment results.
- The close collaboration with other research groups working in complementary domains, as the Digital Communications, is mutually valuable to apply mathematical tools to practical use cases. This allows to take advantage of the information theory to enhance the analysis, or use formal methods to validate the quality of the architecture in terms of security/safety property.

14.2.2 Weakness

- The research activity requires a plurality of competences: nanotechnology, digital design, formal proof, information theory, artificial intelligence, cryptography... that needs a constant technological survey and/or collaboration with other teams. The weakness is in the difficulty to take up the challenge of keeping the link with the latest developments.
- The participation in emerging topics requires strong links with industrials and collaboration with recognized academics. This involves specific management in time and human resources which is highly consuming.
- The administrative burden and environment changes have slowed down the research work. The future must bring more stability to concentrate on high quality research and education, project management, research of new collaboration and funding.

14.2.3 Opportunities

- New applications relying on distributed architectures , as IoT, autonomous car, smart city, blockchains, postquantum cryptography... are particularly demanding for trusted and robust architectures.
- The team is involved in new collaborative projects closely linked with the future products: C3S Chair about the autonomous car, Common lab with EdF about the smart cities...
- The move to Saclay could bring new collaboration with complementary research teams, as the LIX and SAMOVAR.

14.2.4 Threats

- The continuous change of the industrial landscape is not in favour of long term collaborations.
- The efforts to design circuits in the latest semiconductor technologies are increasing.

14.3 Scientific project for the the next five years

14.3.1 Connected Car

With the S3 research team, SSH is involved in the chair C3S about the security of connected cars. The research topics addressed by the team are risk assessment, agile and lightweight cryptography, identity management and intrusion detection. This chair is a real opportunity to collaborate with industrials and sustain our competences in embedded systems to create trusted mobile environment

14.3.2 Circuit design in new technologies

The close collaboration with japanese labs on the validation of physical security in IoT will continue. This will allow to test architectures which are greatly technology dependent such as the randomness generation, and to assess the real leakage or fault sensitivity in emerging technologies. On the other hand, within our collaboration with the Southeast University and the Beihang University/Spintronics Interdisciplinary Center in China we will continue the exploration of MRAM design focusing on reliability issues (ageing, variability, ionization, etc.). This will also include IoT related processors and ultra-low power memories.

14.3.3 New Processors

Many security features will be embedded in future processors to face physical attacks coming from the microarchitecture, and cyber attacks on the software. The attacks on the cache timing are specially powerful, as recently demonstrated with Spectre and Meltdown threats. The team will continue intensively its research about robust processors against side-channel and cyber attacks. This work will tackle both the finding of new vulnerabilities and the study of low intrusive protections.

14.3.4 Vulnerability to faults

It remains many unexplained behaviors regarding the impact of fault injection attack. Similarly, much remains to be accomplished for fault tolerance to Single Event Effects (SEE) in complex System on Chip (SoC). The fault types are numerous, some of them could even be perpetrated remotely, becoming cyber attacks on software applications. The better understanding of disturbances and fault models is mandatory to propose efficient countermeasures. The study will focus on electromagnetic and laser fault injections on software implementation, and faults in non volatile memory.

14.3.5 Machine Learning

This powerful technology requires intensive computation which impairs the power consumption. The team will address the complexity of implementation in order to achieve low power by using Machine Learning (ML) techniques. The ML algorithms will also be used to enhance security properties. For instance the intrusion detection can take advantage of ML to detect abnormal behaviors. Power consumption aspects will be targeted through approximate/stochastic computing/storage with emerging nano-electronic devices, especially hybrid CMOS/MTJ.

14.4 Scientific production (selection)

Articles in Journals

[607] F. Veirano, L. Alves de Barros Naviner, and F. Silveira. Optimal asymmetrical back plane biasing for energy efficient digital circuits in 28 nm utbb fd-soi. *Integration, the VLSI Journal*, December 2017.

[608] F. Veirano, L. Alves de Barros Naviner, and F. Silveira. Optimum nmos/pmos imbalance for energy efficient digital circuits. *IEEE Transactions on Circuits and Systems I: Regular Papers*, December 2017.

[609] H. Cai, Y. Wang, L. Alves de Barros Naviner, and W. Zhao. Robust ultra-low power non-volatile logic-in-memory circuits in fd-soi technology. *IEEE Transactions on Circuits and Systems I: Regular Papers*, December 2017.

[610] M. Tang, Z. Qiu, Z. Guo, Y. Mu, X. Huang, and J.-L. Danger. A generic table recomputation-based higher-order masking. *T-CAD*, December 2017.

[611] N. Bruneau, S. Guilley, A. Heuser, D. Marion, and O. Rioul. Optimal side-channel attacks for multivariate leakages and multiple models. *Journal of Cryptographic Engineering*, 7(4):331–341, November 2017.

[612] M. Slimani, K. Benkalaia, and L. Alves de Barros Naviner. Analysis of ageing effects on artix7 xilinx fpga. *Microelectronics Reliability Journal*, October 2017.

[613] N. Bruneau, C. Carlet, S. Guilley, A. Heuser, E. Prouff, and O. Rioul. Stochastic collision attack. *IEEE Transactions on Information Forensics & Security*, 12(9):2090–2104, September 2017.

[614] M. Tang, Z. Gou, A. Heuser, Y. Ren, J. Li, and J.-L. Danger. Pfd - a flexible higher-order masking scheme. *IEEE transactions on CAD*, 36, August 2017.

[615] Y. Wang, H. Cai, L. Alves de Barros Naviner, and W. Zhao. A non-monte-carlo methodology for variability analysis of magnetic tunnel junction-based circuits. *IEEE Transactions on Magnetics*, 53 (3):1–6, March 2017.

[616] X.-Th. Ngo, J.-L. Danger, S. Guilley, T. Graba, Y. Mathieu, Z. Najm, and S. Bhasin. Cryptographically secure shield for security ips protection. *IEEE Transaction on Computers*, 66(2), February 2017.

[617] F. Veirano, F. Silveira, and L. Alves de Barros Naviner. Minimum operating voltage due to intrinsic noise in subthreshold digital logic in nanoscale cmos. *Journal of Low Power Electronics*, 12:74–81, December 2016.

[618] Y. Wang, H. Cai, L. A. B. Naviner, W. Zhao, Y. Zhang, J.-O. Klein, X. Zhao, and M. Slimani. A process-variation-resilient methodology of circuit design by using asymmetrical forward body bias in 28 nm fdsoi. *Microelectronics Reliability*, September 2016.

[619] H. Cai, Y. Wang, L. Alves de Barros Naviner, and W. Zhao. Breakdown analysis of magnetic flip-flop with 28nm utbb fdsoi technology. *IEEE Transactions on Device and Materials Reliability*, 16 (3):376–383, September 2016.

[620] X.-Th. Ngo, Z. Najm, S. Bhasin, S. Guilley, and J.-L. Danger. Method taking into account process dispersion to detect hardware trojan horse by side-channel analysis. *JCEN*, September 2016.

[621] H. Cai, Y. Wang, L. Alves de Barros Naviner, and W. Zhao. Low power magnetic flip-flop optimization with fdsoi technology boost. *IEEE Transactions on Magnetics*, 52(8):1–7, August 2016.

[622] J.-L. Danger, S. Guilley, Ph. Hoogvorst, C. Murdica, and D. Naccache. Improving the big mac attack on elliptic curve cryptography. *LNCS : The new codebreakers*, 9100:374–386, May 2016.

[623] J.-L. Danger, S. Guilley, Th. Porteboeuf, F. Praden, and M. Timbert. Hardware-enforced protection against buffer overflow using masked program counter. *LNCS: the new codebreakers*, (9100):439–454, May 2016.

[624] Y. Wang, H. Cai, L. A. B. Naviner, Y. Zhang, X. Zhao, E. Y. Deng, J.-O. Klein, and W. Zhao. Compact model of dielectric breakdown in spin transfer torque magnetic tunnel junction. *IEEE Transactions on Electron Devices*, 63(4):1762–1767, April 2016.

[625] H. Cai, Y. Wang, W. Zhao, and L. Alves de Barros Naviner. Multiplexing sense amplifier based magnetic flip flop in 28nm fdsoi technology. *IEEE Transaction on Nanotechnology*, 14(4), October 2015.

[626] H. Cai, Y. Wang, K. Liu, L. Alves de Barros Naviner, H. Petit, and J.-F. Naviner. Cross-layer investigation of continuous-time sigma–delta modulator under aging effects. *Microelectronics Reliability*, (3):645, October 2015.

[627] M. Slimani, A. Ben Dhia, and L. Alves de Barros Naviner. A novel analytical method for defect tolerance assessment. *Microelectronics Reliability Journal*, 55:1285–1289, October 2015.

[628] A. Ben Dhia, M. Slimani, H. Cai, and L. Alves de Barros Naviner. A dual-rail compact defect-tolerant multiplexer. *Microelectronics Reliability Journal*, 55:662–670, March 2015.
[629] W. He, S. Bhasin, A. Otero, T. Graba, E. De la Torre, and J.-L. Danger. Sophisticated security verification on routing repaired balanced cell-based dual-rail logic against side channel analysis. *IET Information Security*, January 2015.
[630] C. Carlet, J.-L. Danger, S. Guilley, and H. Maghrebi. Leakage squeezing: Optimal implementation and security evaluation. *Journal of Mathematical Cryptology*, September 2014.
[631] H. Maghrebi, C. Carlet, J.-L. Danger, S. Guilley, and E. Prouff. Achieving side-channel high-order correlation immunity with leakage squeezing. *JCEN*, February 2014.
[632] A. Ben Dhia, S. Nascimento Pagliarini, L. Alves de Barros Naviner, H. Mehrez, and Ph. Matherat. A defect-tolerant area-efficient multiplexer for basic blocks in sram-based fpgas. *Microelectronics Reliability*, page 1189–1193, July 2013.
[633] S. Nascimento Pagliarini, A. Ben Dhia, L. Alves de Barros Naviner, and J. F. Naviner. Snap: a novel hybrid method for circuit reliability assessment under multiple faults. *Microelectronics Reliability*, page 1230–1234, July 2013.
[634] Y.-I. Hayashi, N. Homma, T. Mizuki, H. Shimada, T. Aoki, H. Sone, L. Sauvage, and J.-L. Danger. Efficient evaluation of em radiation associated with information leakage from cryptographic devices. *IEEE Transactions on Electromagnetic Compatibility*, 55(3):555–563, June 2013.

Books

Book Chapters

[635] X. Pons Masbernart, E. Georgeaux, Ch. Gruet, F. Montaigne, and L. Alves de Barros Naviner. *Wireless Public Safety Networks: Overview and Challenges*, chapter From DMO to D2D, pages 9–126. ISTE Press & Elsivier, London, United Kingdom, 2015.
[809] J. Le Feuvre and Y. Mathieu. *Emerging Technologies for 3D Video*, chapter 23 : Graphics Composition for Multiview Displays. Wiley, 2013.

Articles in Conference Proceedings

[637] H. Cai, Y. Wang, L. Alves de Barros Naviner, J. Yang, W. Kang, and W. Zhao. Enabling resilient voltage-controlled meram using write assist techniques. In *Proceedings of IEEE International Symposium on Circuits and Systems (ISCAS)*, Florence, Italy, May 2018.
[638] F. Veirano, F. Silveira, and L. A. B. Naviner. Optimum nmos/pmos imbalance for energy efficient digital circuits. In *Proceedings of IEEE International Symposium on Circuits and Systems (ISCAS)*, Florence, Italy, May 2018.
[639] F. B. Armelin, L. Alves de Barros Naviner, and R. d'Amore. Probability aware fault-injection approach for ser estimation. In *Proceedings of IEEE Latin American Test Symposium (LATS)*, São Paulo, SP, Brazil, March 2018.
[640] A. Stempkovskiy, D. Telpukhov, R. Solovyev, E. Balaka, and L. Alves de Barros Naviner. Practical metrics for evaluation of fault-tolerant logic design. In *IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering*, pages 569–573, Saint Petersbourgh, Russia, February 2017.
[641] N. Karimi, J.-L. Danger, F. Lozac'h, and S. Guilley. Predictive aging of reliability of two delay pufs. In *SPACE*, Hyderabad, December 2016.
[642] M. Dugardin, J.-L. Danger, S. Guilley, Z. Najm, and O. Rioul. Correlated extra-reductions defeat blinded regular exponentiation. In *Cryptographic Hardware and Embedded Systems (CHES 2016)*, Santa Barbara, USA, August 2016.
[643] O. Rioul, P. Solé, S. Guilley, and J.-L. Danger. On the entropy of physically unclonable functions. In *2016 IEEE International Symposium on Information Theory (ISIT'16)*, Barcelona, Spain, July 2016.
[644] N. Miura, Z. Najm, W. He, S. Bhasin, X.-Th. Ngo, M. Nakata, and J.-L. Danger. Pll to the rescue: a novel em fault countermeasure. In *DAC*, Austin, USA, June 2016.
[645] F. B. Armelin, L. A. d. B. Naviner, R. d'Amore, and I. A. Azevedo. Impact evaluation of logic blocks configuration on fpga's soft error rate estimation. In *2016 IEEE International Conference on Electronics, Circuits and Systems (ICECS)*, pages 277–280, December 2016.
[646] B. Coeffic, V. Malherbe, J.-M. Daveau, G. Gasiot, L. A. B. Naviner, J.-L. Autran, and Ph. Roche. A layout-based fault injection methodology for ser prediction: Implementation and correlation with

65nm heavy ion experimental results. In *Proceedings of IEEE Nuclear and Space Radiation Effects Conference (NSREC)*, New Orleans, USA, July 2016.

[647] B. Coeffic, J.-M. Daveau, G. Gasiot, A.E. Pricco, S. Parini, T. Scholastique, L. A. B. Naviner, and Ph. Roche. Radiation hardening improvement of a serdes under heavy ions up to 60 mev.cm2/mg by layout-aware fault injection. In *Proceedings of IEEE Workshop on Silicon Errors in Logic - System Effects (SELSE)*, Austin, Texas, USA, March 2016.

[648] N. Jovanovic, E. Vianello, O. Thomas, B. Nikolic, and L. A. B. Naviner. Design insights for reliable energy efficient oxram-based flip-flop in 28nm fd-soi. In *Proceedings of IEEE SOI-3D-Subthreshold Microelectronics Technology Unified Conference (S3S)*, Sonoma Valley, CA, USA, October 2015.

[649] X.-Th. Ngo, J.-L. Danger, S. Guilley, Z. Najm, and O. Emery. Hardware property checker for run-time hardware trojan detection. In *ECCTD*, Trondheim, August 2015.

[650] X.-Th. Ngo, S. Bhasin, J.-L. Danger, S. Guilley, and Z. Najm. Linear complementary dual code improvement to strengthen encoded circuit against hardware trojan horses. In *HOST*, Mc Lean, virginie, May 2015.

[651] L. Rivière, Z. Najm, P. Rauzy, J.-L. Danger, J. Bringer, and L. Sauvage. High precision fault attacks on the instruction cache of armv7-m architectures. In *HOST*, Mc lean, Virginie, May 2015.

[652] Xavier Pons Masbernart, Christophe Gruet, Eric Georgeaux, and Lirida Naviner. An energy efficient d2d lte structure for mpr based on FlashLinQ. In *Proceeding of International Symposium on Wireless Communication Systems (ISWCS)*, Brussels, Belgium, August 2015.

[653] Xavier Pons Masbernart, Christophe Gruet, Eric Georgeaux, and Lirida Naviner. D2D broadcast communications for 4G PMR networks. In *Proceedings of IFIF International Conference on New Technologies, Mobility and Security (NTMS)*, Paris, France, July 2015.

[654] C. Bottoni, B. Coeffic, J.-M. Daveau, G. Gasiot, F. Abouzeid, S. Clerc, L. A. d. B. Naviner, and Ph. Roche. Frequency and voltage effects on ser on a 65nm sparc-v8 microprocessor under radiation test. In *Proceedings of IEEE International Reliability Physics Symposium (IRPS)*, Monterrey, CA, USA, April 2015.

[655] C. Bottoni, B. Coeffic, J.-M. Daveau, G. Gasiot, L. A. d. B. Naviner, and Ph. Roche. A layout-aware approach to fault injection for improving failure mode prediction. In *Proceedings of Workshop on Silicon Errors in Logic - System Effects (SELSE)*, Austin, USA, March 2015.

[656] C. Bottoni, B. Coeffic, J.-M. Daveau, L. A. d. B. Naviner, and Ph. Roche. Partial triplication of a sparc-v8 microprocessor using fault injection. In *Proceedings of IEEE Latin American Symposium on Circuits and Systems (LASCAS)*, Montevideo, Uruguay, February 2015.

[657] E. Amouri, S. Bhasin, Y. Mathieu, T. Graba, J.-L. Danger, and H. Mehrez. Balancing wddl dual-rail logic in a tree-based fpga to enhance physical security. In *FPL*, Munich, Germany, September 2014.

[658] A. Heuser, O. Rioul, and S. Guilley. Good is not good enough: Deriving optimal distinguishers from communication theory. In *16th Workshop on Cryptographic Hardware and Embedded Systems (CHES 2014)*, volume LNCS 8731, pages 55–74, Busan, Korea, September 2014. Springer LNCS.

[659] J. Bringer, C. Carlet, H. Chabanne, S. Guilley, and H. Maghrebi. Orthogonal direct sum masking - a smartcard friendly computation paradigm in a code, with builtin protection against side-channel and fault attacks. In *WISTP*, Heraklion, July 2014.

[660] S. Sarrazin, S. Evain, I. Miro Panades, A. Valentian, L. Alves de Barros Naviner, and V. Gherman. Flip-flop selection for in-situ slack-time monito- ring based on the activation probability of timing-critical paths. In *IEEE International On-line Test Symposium*, July 2014.

[661] C. Bottoni, J.-M. Daveau, G. Gasiot, L. Alves de Barros Naviner, and Ph. Roche. Heavy ions test result on a 65nm sparc-v8 radiation-hard microprocessor. In *IEEE International Reliability Physics Symposium*, Waikoloa, Hawai, USA, June 2014.

[662] Xavier Pons Masbernart, A Mesodiakaki, Christophe Gruet, Lirida Naviner, F. Adelantado, L. Alonso, and C. Verikoukis. An energy efficient vertical handover decision algorithm. In *Proceedings of IEEE International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD)*, pages 1145–1150, Austin USA, December 2014.

[663] Xavier Pons Masbernart, S. Althunibat, G Kibalya, Christophe Gruet, Lirida Naviner, and Fabrizio Granelli. Battery-aware network discovery algorithm for mobile terminals within heterogeneous networks. In *Proceedings of IEEE International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD)*, Athens, Greece, December 2014.

[664] L. Rivière, M.-L. Potet, Th.-H. Le, J. Bringer, H. Chabanne, and M. Puys. Combining high-level and low-level approaches to evaluate software implementations robustness against multiple fault injection attacks. In *Foundations and Practice of Security - 7th International Symposium, FPS 2014, Montreal, QC, Canada, November 3-5, 2014. Revised Selected Papers*, pages 92–111, 2014.

[665] H. Cai, K. Liu, and L. Alves de Barros Naviner. A study of statistical variability-aware methods. In *IEEE International Symposium on Radio Frequency Integration Technology (RFIT)*, Hefei, Chine, August 2014.

[666] S. U. Rehman, A. Blanchardon, A. Ben Dhia, M. Benabdenbi, R. Chotin-Avot, L. A. B. Naviner, E. Amouri, H. M. Mehrez, and Z. Marrakchi. Impact of cluster size on routability, testability and robustness of a cluster in a mesh fpga. In *Proceedings of IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, Tampa, FL, USA, July 2014.

[667] A. Ben Dhia, L. Alves de Barros Naviner, and Ph. Matherat. Evaluating clb designs under multiple sets in sram-based fpgas. In *IEEE Symp. Defect and Fault Tolerance (DFT)*, pages 112–117, New-York City, United States, October 2013.

[668] X. Pons Masbernart, R. Palacios, Ch. Gruet, L. Alves de Barros Naviner, H. Marques, F. Granelli, and J. Rodriguez Guisantes. Uplink energy efficiency in {LTE} systems. In *IEEE International Workshop on Computer Aided Modeling and Design of Communication Links and Networks*, Berlin, Germany, September 2013.

[669] S. Nascimento Pagliarini, T. Ban, L. Alves de Barros Naviner, and J.-F. Naviner. Reliability assessment of combinational logic using first-order-only fanout reconvergence analysis. In *Midwest Symposium on Circuits and Systems (MWSCAS)*, Columbus, OH., August 2013.

[670] S. Sarrazin, S. Evain, L. Alves de Barros Naviner, Y. Bonhomme, and V. Gherman. Scan design with shadow flip-flops for low performance overhead and concurrent delay fault detection. In *Design, Automation, and Test in Europe (DATE)*, Grenoble, France, March 2013.

Patents

[671] Y. Wang, Y. Zhang, W. Zhao, Y. Lakys, D. Ravelosona, J.-O. Klein, L. Alves de Barros Naviner, and H. Cai. Compact model of dielectric breakdown in spin transfer torque magnetic tunnel junction 6.0, 2018.

[672] Christophe Gruet, Eric Georgeaux, Hervé Gromat, Xavier Pons Masbernat, and Lirida Naviner. Procede permettant d'etablir une strategie d'economie d'energie de batterie de terminaux mobiles, June 26 . WO Patent App. PCT/EP2013/003,489.

[673] Xavier Pons Masbernart, Christophe Gruet, Eric Georgeaux, and Lirida Naviner. Battery share algorithm to reduce the energy during scanning procedures, 2016.

[674] S. Guilley and J.-L. Danger. Device and method for testing a physically unclonable function. (EP20160305419 20160408), April 2016.

[675] S. Guilley, J.-L. Danger, and Th. Porteboeuf. System and method for protecting integrated circuit (ic) device. (EP20150307161 20151229), December 2015.

Part III

Detailed activities: Image, Data and Signal

Chapter 15

IMAGES

Image Modeling, Analysis, GEometry & Synthesis

15.1 Presentation of the team

Team leader Isabelle Bloch (until 9/14), Florence Tupin (since 9/14)

Faculty A. Almansa (DR2 CNRS, HDR, until 12/16), I. Bloch (FP), T. Boubekeur (FP), H. Brettel (CR1 CNRS, until 06/15), M. Campedel (until 12/14), J. Delon (CR1 until 08/13), P. Gori (AP, since 01/17), Y. Gousseau (FP), S. Ladjal (AP), H. Maître (emeritus), P. Memari (CR1 CNRS, until 11/16), J.-M. Nicolas (FP), M. Roux (AP), H. Sahbi (CR1 CNRS, HDR, until 12/16), Y. Tendero (AP, since 12/14), J.-M. Thiery (AP, since 09/16), J. Tierny (CR1 CNRS, until 7/14), F. Tupin (FP).

In 2018: 5 FP, 5 AP, 1 emeritus

Faculty on leave: E. Angelini (AP, HDR), C. Campedel (AP)

Faculty who left: 6 research scientists (1 DR2 and 5 CR1 CNRS)

Faculty who was hired: 3 associate professors

Average equivalent full time: 7 persons.year

Associated researchers C. Adamsbaum (since 2013), H. Sun (until 12/16)

PhD students *Defended:* Jing Huang (09/09-02/13), Matthias Holländer (01/10-03/13), Mauricio Delbraccio (01/10-03/13), Nicolas Bourdis (02/10-05/13), Noura Faraj (12/09-06/13), Kristyn Falkenstern (01/10-07/13), Yuan Yang (10/10-07/13), Avid Roman-Gonzales (10/09-10/13), Yoann Le Montagner (09/10-11/13), Jean-Baptiste Poisson (10/10-12/13). Guillaume Quin (10/10-01/14), Thierry Guillemot (10/10-02/14), Catherine Herold (12/10-02/14), Alasdair Newson (01/11-03/14), Baptiste Mazin (09/10-03/14), Ujjwal Verma (10/10-03/14), Vo Dinh-Phong (10/10-03/14), Cecilia Aguerrebere (04/11-05/14), Flora Dellinger (10/10-07/14), Yann Traonmilin (07/11-07/14), Nausikaa Geeraert (09/11-10/14), Wang Beibei (07/11-11/14). Leila Schemali (01/11-01/15), Xin Su (10/11-03/15), Guillaume Tartavel (10/11-04/15), Mariem Gargouri (10/11-06/15), Stéphane Calderon (12/11-06/15), Paolo Irrera (07/12-06/15), Romane Gauriau (06/12-06/15), Ling Wang (01/12-09/15), Antoine Deblonde (02/12-09/15), Henrique Morimitsu (09/11-10/15), Teun Baar (10/12-10/15). Chahira Miloudi (09/12-01/16), Emilie Guy (10/12-01/16), Baptiste Morel (12/12-06/16), Sonia Tabti (10/12-06/16), Loïca Avanthey (10/12-10/16), Yifan Yang (10/13-10/16), Flora Weissgerber (10/13-11/16). Malik Boughida (10/13-03,17), Guillaume Terrasse (01/14-03/17), Gang Liu (01/14-04/17), Ana-Maria Vintescu (05/14-06/17), Hélène Legrand (10/13-10/17), Sylvain Lobry (10/14-11/17), Timothée Evain (07/14-12/17). Hélène Urien (10/14-01/18), Paul Riot (10/14-02/18), Christian Felipe Ocampo Blandon (09/14-04/18), Quentin Oliveau (02/15-04/18), Clara Barbanson (01/15-05/18).

Current (dates for the beginning of the PhD): Hadrien Bertrand (11/15), Marcela Carvalho (10/16), Vincent Couteaux (05/18), Rodrigo Daudt (10/17), Gordana Draskovic (10/16), Nicolas Gonthier (10/17), Antoine Houdard (10/15), Adrien Kaiser (10/15), Gilles Laurent (10/14), Ivan Laurin (10/17), Thuc Trinh Le (10/15), Thibault Lescoat (10/16), Chenguang Liu (10/16), Victor Lucquin (10/16), William Meiniel (10/14), Corentin Mercier (10/17), Cécile Muller (11/16), Antoine Pirovano (3/18), Clément Rambour (10/15), Aymeric Reshef (10/14), Sylvain Rousseau (10/16), Ruben Sanchez de la Rosa (06/16), Jérémie Schertzer (10/17), Davis Schwartz (10/15), Iyèd Trimèche (10/17), Alessio Virzi (11/15), Zhao Weiying (12/15), Xiaoyi Yang (01/16), Xiangli Yang (12/17).

PostDocs, Research Engineers Rémy Abergel (10/16-12/17), Abdalbassir Abou-El-Ailah (01/10-12/12), Ricardo de Aldama (03/13-02/14 and 04/15-09/15), Yara Bachalany (02/14-11/14), Samy Blusseau (3/17-2/18), Malik Boughida (04/17-10/17), Norbert Bus (12/15-02/17), Stéphane Calderon (06/15-09/16), Sonia Dahdouh (10/11-01/15), Noura Faraj (06/13-01/14), Mingyuan Jiu (07/14-12/15), Marthe Lagarrigue-Charbonnier (10/14-02/15), Thibaud Lambert (02/18-), Hélène Legrand (08/17-), Yann Leprince (3/15-2/16), Nicolas Lermé (02/14-09/14), Christophe Lino (10/17-), Alasdair Newson (01/17-06/18), Edoardo Provenzi (04/13-03/14), Giovanni Sileno (05/16-07/18), J.-M. Thiery (01/13-01/14), Yifan Yang (11/16-01/17).

Sabbatical Professors Ramon Pino Pérez (11/14, 11/17, 04/18-07/18), Anca Ralescu (1 month per year), Yongchao Xu (9/14-9/17, 2 days a week).

Platforms: The team exploits the following platforms:

- FabLab (with DIVA)
- Digicospe (with DIVA)
- Multi-modal acquisition lab (with S2A)

Scientific Production Overview: Table 15.1 represents the scientific production between 2013 and 2018. More details are given in Section 15.5.

Journals	Articles in Proceedings	Books and Book Chapters	Patents	Keynotes and Tutorials	Other Invited Talks	Defended PhD Theses
131	228	21	2	7	33	39

Table 15.1: Overall Scientific Production

15.2 Research activities

15.2.1 Overview

The core expertise of the IMAGES team[1] is the modeling of images, tri-dimensional and numerical objects, with the development of mathematical models, ranging from the physical acquisition to the high-level interpretation, and artificial intelligence models (spatial reasoning, knowledge representation). The team has also a strong expertise in computer graphics for geometric modeling, image synthesis, virtual reality and 3D interactive systems. The team deals with applications in medical imaging, remote sensing imaging, computational photography and creative industries. The main contributions of the team are described next, and are organized into mathematical methods and artificial intelligence (Section 15.2.2), computer graphics (Section 15.2.3), and applications with a societal impact (Section 15.2.4).

[1]The team was previously named TII (for Image Processing and Understanding) and changed its name in January 2017 to better take into account the evolution of its research topics.

The scientific animation of the team is done at different levels. A general team seminar is organized every two months with an invited researcher; it covers a wide range of subjects. At a more specific level, working seminars are organized on different topics: computer graphics, medical imaging and artificial intelligence, remote sensing imaging, deep learning. They involve a sub-part of the team and have variable temporal frequencies. PhD candidates have a bi-monthly seminar. The team staff has a weekly meeting to discuss scientific, administrative and educational issues.

To welcome new PhD candidates, an "IMAGES Welcome day" seminar is organized every year in November providing practical information. It is also an opportunity for the first year PhD candidates to describe their subject and for the second year students to present a poster.

The team is deeply involved in the monthly organization of "The Mathematics of Imaging" Parisian seminar.

Details on these seminars are available at https://images.telecom-paristech.fr/seminars.html.

15.2.2 Mathematical methods and artificial intelligence

Faculty: all.

This section presents our contributions in the field of mathematical modeling for image analysis and understanding. Modeling concerns both data and knowledge about the domain or the data, and is based on various fields of mathematics and computer sciences (statistics, variational approaches, machine learning, algebraic and symbolic artificial intelligence approaches...).

Acquisition aware image restoration and enhancement The following methods developed for multi-resolution and noise filtering rely on a rigorous modeling of the image acquisition principles. A new framework for the decomposition of complex multi-channel data from coherent imagery has been proposed, allowing for the use of Gaussian denoisers to Wishart distributed data [694]. An automatic selection of the best set of parameters (window size, patch size, pre-filtering strength), by aggregation strategy driven by variance / bias measurement [722] thanks to noise modeling, has provided state of the art results for coherent image denoising. HDR performances have been improved using patch-based single shot HDR and patch-based exposure fusion [737]. An innovative method for automatic white balance through projections on the Planckian locus [719] has been presented, and the robustness of sparse reconstruction towards outliers in the context of multi-image super-resolution has been improved [716].

More precisely, the fusion of multiple images to obtain a higher quality image is an important approach in image restoration, especially when the physical support of images becomes so potent, cheap and ubiquitous. In such a setting, the common assumption is that the same scene is acquired many times. But actually it is seldom true that the scene does not change between acquisitions. The theory of compressed sensing allows us, under sparsity hypotheses, to reconstruct exactly a signal by means of convex optimization. We investigated the scenario of realistic multi-image restoration by handling the minor changes in the scene as outliers, in order to determine whether the sparsity hypothesis leads to an exact reconstruction also in the presence of outliers. We showed in [716] that the structure of the outliers and signal jumps (using the popular total variation as the "L1-norm") must conform to certain conditions in order to achieve robustness to outliers. We also studied the choice of the regularization parameter in this setting.

In [704] we provided a fine modeling and analysis of the so-called flutter-shutter cameras, which reduce motion blur. This study yielded the development of the first methodological, mathematical and numerical framework in order to optimize flutter-shutter cameras. This innovative work was highlighted in SIAMS News, a wide audience publication by SIAM.

Stochastic image modeling A recurrent activity within our group is the mathematical modeling of natural images and texture. This axis has been investigated along different modalities. First, we have demonstrated the usefulness of different statistical constraints (sparsity, local dependency, Fourier spectrum, CNN features) for the purpose of both texture synthesis [721, 757] and texture-aware image restoration [710]. In the same direction, a simple explanation for the

second order statistical structure of color images has been provided in [695]. Going beyond the second order property of natural images, our team has also proposed two contributions for the stochastic modeling of image patches. We have introduced geometric and radiometric invariance properties for the Gaussian mixture modeling of patches. In [689], and still in the framework of a Gaussian modeling of patches, we have introduced a hyperprior-based approach for the restoration of images, with specific applications to denoising, interpolation and single-image HDR imaging. Some of the mathematical models we have developed have also been explored for the synthesis of abstract images [712, 752].

Another activity is the development of statistical methods for low level detection tasks. In [741], the generic *a contrario* framework has been extended to enable the grouping of non-independent events. This generalization has proven useful for part-based object detection and line segment detection in SAR images (see also Section 15.2.4). Another methodological contribution to *a contrario* methods was the introduction of a locally adaptive detection method for the purpose of default detection in old movies [736]. Still in the same framework, methods for the matching of images through local features have been developed for SAR images [720] and color natural images. Another contribution models convergent structures in an *a contrario* method with applications in mammography [738].

The non-local patch paradigm was also exploited for image and video inpainting, combining geometry and texture [728, 751]. This work was awarded the Google best student paper, CVMP 2013, for A. Newson, and led to an international patent [767].

Machine learning and deep learning The contributions of the IMAGES team in machine learning are varied, and a recent turn has been taken to investigate deep learning methods. In particular, we developed original methods to explore the huge space of parameters, based on random search and Gaussian processes combined with Hyperband, in collaboration with Philips [755]. To face the problems of reduced training sets, as is often the case in medical imaging, our recent focus is on transfer learning [747] (collaborations with Philips, Epita and Huazhong University of Science and Technology). Relying on pre-trained networks (e.g. VGG) on sometimes completely different images, we discard the fully connected layers, and add specialized convolutional layers at the end of each of the five convolutional stages in VGG network. A linear combination of these specialized layers (i.e. fine to coarse feature maps) results in the final segmentation. Additionally, 3D information is taken into account.

In computer graphics, methodologies based on machine learning have also been developed. In particular *SimSelect* [733], a smart 3D interaction system, has been designed to automatically recognize regions of a 3D surface which are similar to the one currently selected, in real time. In rendering, a new local learning mechanism based on a specialized Bayesian model [685] has been developed to denoise Monte Carlo rendering solutions. In virtual reality, the *LazyNav* system [760] was proposed to easily navigate in a virtual environment, using body shape recognition to control the camera.

Noting the growing use of machine learning and deep neural networks for mimicking the human perceptual faculties, we examined one of the possible ultimate frontiers of this domain: the automatic assessment of beauty in images. More specifically, we draw a comparison between the tracks used today by computer scientists with those which have been cleared in the past literature: philosophical (aesthetics, experimental psychology, psycho-sociology), biologic (the so-called neuro-aesthetics), artistic and photographic, through handbooks and textbooks. We propose some paths to make digital methods more efficient [766].

The domain of deep learning is evolving very rapidly, and the team has decided to increase its research efforts in this direction, as detailed in Section 15.4.

Discrete mathematics, algebraic and structural models, and artificial intelligence Our contributions in this domain are at the cross-road of lattice based formalisms for structured knowledge representation and information processing, with an original and strong anchoring in both mathematical morphology and symbolic artificial intelligence. Based on common algebraic features

of mathematical morphology and of logics, we proposed and developed the so-called morpho-logics, in different settings. Our initial work in propositional logics was extended in two directions: exploiting morphological operations on propositional formulas to design concrete operators answering classical questions in artificial intelligence, such as revision, fusion, abduction, and extending these ideas to different logics, such as description logics, or more generally satisfaction systems and stratified institutions, encompassing large families of logics [680]. In this general setting, revision was defined based on the notions of relaxation and dilation, and abduction on the notions of cutting, retraction and erosion [676]. This work was exploited for spatial reasoning based on a knowledge base. For instance, interpreting an image can be formalized as an abduction process, where the "best" interpretation has to be inferred from the observations (the image) and a knowledge base (expressed in description logics and using formal concept analysis) [732]. To account for the structural information, we proposed to define mathematical morphology on hypergraphs, leading in particular to similarity measures between hypergraphs that are robust to some small transformations [743, 718]. Graph-based representations of image information were also used for multi-object tracking in videos, where the graph structure leads to more robustness with respect to occlusions and ambiguities for instance [692]. The knowledge representation, both in logics and using graphs, can be further enhanced by spatial relations, which are best modeled using fuzzy sets [727]. Our recent work in this domain includes the extension of constraint satisfaction problems to deal with complex fuzzy relations, for image understanding applications [744, 705], and the comparison between distributions (for instance representing spatial relations) using mathematical morphology and optimal transport [703]. Based on the links we established between fuzzy sets, mathematical morphology, rough sets, F-transforms, hypergraphs and formal concept analysis [711, 754], we are currently investigating applications to mathematical musical representations [749]. Applications in medical imaging are detailed in Section 15.2.4.

Collaborations: Univ. Paris Dauphine (Lamsade), Centrale-Supelec (MICS), IRCAM-STMS, Univ. Merida (Math. Dept.), LRDE-Epita, Huazhong University of Science and Technology (HUST), UCLA (Math. Dept.), Rice university (dept. of Electrical and Computer Eng.), Amazon Lab. 126, Duke university (dept. of Electrical and Computer Eng.), Northwestern university (dept. of Electrical Eng. and Computer Science), ENS Paris-Saclay (CMLA), Lyon-1 (Institut Camille Jordan), Paris Descartes (MAP5), DxO, Technnicolor, Philips.

15.2.3 Computer graphics

Faculty: I. Bloch (FP), T. Boubekeur (FP), P. Gori (AP, since 01/17), P. Memari (CR1 CNRS, until 11/16), J.-M. Thiery (AP, since 09/16), J. Tierny (CR1 CNRS, until 7/14).

The computer graphics activities of IMAGES mainly take place in the fields of modeling and rendering, with occasional contributions to computer vision. One structuring concept in these activities is the notion of efficient approximations, which helps breaking complexity order when it comes to graphics simulation (e.g., shape deformation, light transport).

Shape Modeling A large part of the computer graphics activities are centered on discrete 3D surface representations such as point clouds and meshes. Several methods have been developed to approximate efficiently such typically dense data sets, with in particular (i) the *sphere-mesh* representation [739], which helps approximating complex 3D shapes with a handful of numbers and has been further developed to tackle animated 3D data [702]; (ii) morphological frameworks to process and analyze detailed 3D shapes at large scale, including the *point morphology* framework [731] for point-based mathematical morphology and *bounding proxies* [688] for mesh-based conservative approximations; (iii) statistical modeling approaches to both enrich interactive modeling tools with live shape recognition primitives [733] and improve automatic processing chains with self-similarity aware reconstruction and filtering [764]; (iv) real time geometry processing methods, based on new parallel scalable operators designed to run efficiently on GPU and reducing by several orders of magnitude the time needed to process large 3D data sets [759] (patent pending); (v) volume meshers, with a new fast, scalable and feature-preserving volume remesher [696] which was published

in the Computer and Graphics journal and presented at the Shape Modeling International 2016 conference, where it received the best paper award.

Geometrical and topological analysis With the aim of processing and visualizing complex data, the team contributed to works on least squares affine transitions for global parameterization, conformal factor persistence for fast hierarchical cone extraction [690], weighted triangulations for geometry [734], topological analysis and visualization based on the analysis of critical points on 3D uncertain scalar fields [894] (implemented in the TTK software: https://topology-toolkit.github.io/).

Rendering The computer graphics activities also target image synthesis applications, with several contributions related to the efficient simulation of global illumination, including a collection of works for the *many-lights* rendering approach, in particular regarding *point-based global illumination* framework [713] which makes possible scalable rendering and non-diffuse lighting effects for this framework, as well as light cuts for the real time rendering of global illumination on large dynamic CAD models [699] (patent pending). Physically-based rendering has also been addressed in the context of Monte Carlo simulations, with in particular a new efficient guiding strategy [687] based on a product-space hierarchy for importance sampling, as well as a new generic Monte Carlo rendering denoiser [685], now used in production at Ubisoft and integrated to several major renders thanks to its open source distribution.

Vision, virtual reality and 3D printing results The team has developed a collaboration with Osaka University, Japan to study how interactive 3D navigation could be achieved in mid-air for virtual reality applications. One of the key challenges was to let users navigate a virtual world, while still being able to use freely their hands, head and eyes. This collaboration led to the *LazyNav* system [760], which tracks subtle body motions to translate them into camera paths and was evaluated in a complete user study. This work was published at the IEEE 3DUI 2015 and received the best paper award. An extension of this work was then published in the IEEE TVCG journal, with in particular an adaptation to head-mounted displays (HMD) such as the Oculus Rift or the HTC Vive. Regarding 3D printing, the team has developed a collaboration with TU Berlin, Germany, to create new geometry processing operators designed to enhance the visual perception of 3D shapes when printed at different scales. The main contribution of this work [684] boils down to a new form of unsharp masking filter for 3D geometry, which scales to large data sets as it does not involve any global optimization. This work was published in the Computer and Graphics journal and presented at the Shape Modeling International 2017 conference, where it received the best paper award. Regarding 3D computer vision, the team has developed a collaboration with CNR Pisa, Italy, during which the team hosted Italian students for several months, to develop new point-based methods for captured 3D content. In particular, a new change detection algorithm has been proposed to address the problem of large "re-scans" performed over previously digitalized areas.

Collaborations : academic collaborations: LIX, TU Berlin, TU Vienna, CNR Pisa, TU Delft and Osaka University; industrial partnerships: Allegorithmic, Ubisoft and Dassault Systèmes.

15.2.4 Image applications and society

Faculty: all.

Remote sensing and SAR imagery

The team is leading research activities at different levels for the improvement and exploitation of remote sensing data, specially SAR images. This part is in connection with Section 15.2.2.

Concerning the acquisition system and the modeling of SAR image synthesis, different works have been led. A new model has been developed exploiting the complex spectrum and target

extraction to reduce the side-lobe effects and the between pixel correlation, thus improving further processing [679]. A method to combine a high resolution single polarization image with a polarimetric data of lower resolution through complex spectrum exploitation has been proposed [756]. It received the best student paper award of EUSAR conference. Concerning moving targets, an approach for ground moving trajectory reconstruction with single-channel circular SAR data is presented in [715].

At the level of data modeling and speckle reduction, we have carried on our modeling work on Mellin framework by developing the following topics: the use of Meijer distribution as a generic law for SAR data [729]; the study of the mimicking potential of Fisher and Generalized Gamma distributions [682]; the generalization of the wavelet operators to deal with multiplicative noise [698]. To reduce speckle, efficient patch-based approaches have been developed along the past years. In [722] a general framework is presented, able to process complex vectorial SAR data from a wide range of SAR images (interferometric, polarimetric, and combination) and to select automatically the best local parameters. This paper has been awarded the best paper award of IEEE TGRS. In [678] we proposed to combine patch-based methods with TV (Total Variation) regularization to take benefit from both models (see also Section 15.2.2 and [748]) and applied it to elevation reconstruction with multi-channel interferometric data. Recently, a decomposition framework of complex SAR data called MuLOG has been proposed to take benefit from the advances in Gaussian noise reduction [694] and opening the way to new speckle reduction methods.

At a higher level of information extraction, Markovian models (such as triplet Markov fields [740]) have been defined for segmentation and elevation retrieval, with graph-cuts as optimization tools [742]. Markov random fields have also been exploited for water surface extraction in the context of the future SWOT mission, or for road network detection combining optic and SAR sensors [697]. By introducing contextual information in the context of SAR tomography, elevation information inside the resolution cells has been recovered. The popular SIFT control points, widespread in computer vision, have been adapted to the statistical specificities of SAR data with “SAR-SIFT" key-points and descriptors [720].

The main applications in remote sensing benefiting from the previously described methods are the followings: multi-temporal data processing and analysis, urban area monitoring, and the SWOT mission. First, we have worked in the past years on SAR time series. Methods for time series decomposition as a mixture of background and bright targets (possibly changing in time) have been proposed [700]. An adaptation of patch-based approaches for multi-temporal despeckling is presented in [735], followed by change detection and analysis [717]. A visualization tool for change detection in SAR time series has been recently proposed [750] (best paper award of the CFPT conference). We also worked with optical range images on change detection and the use of expert systems to analyze time series [714]. Secondly, we are focusing on 3D building monitoring in urban areas using interferometry, polarimetry and tomography [686]. Besides, the team is also involved since 2016 as an ADT (*Algorithm Definition Team*) member of the coming SWOT (*Surface Water and Ocean Topography*) mission for water surface and hydrological networks survey.

Other applications deal with Ground Penetrating SAR [683] in the framework of the FUI project G4M, object classification (e.g. ships from remote sensing data) using machine learning approaches [691] and 3D reconstruction focused on shallow water seabed [701].

A book on remote sensing imagery has been co-editored [746].

Collaborations: Télécom Saint-Etienne (laboratoire Hubert-Curien), IMB, Universities: Rennes I (IETR), Savoie Mont-Blanc (LISTIC), SupCom Tunis (Tunisia), Parthenope University (Italy), ONERA, CNES, CEA.

Medical imaging

The paradigm underlying all our contributions in medical imaging is the modeling of available knowledge and information, which is then used for image understanding. The knowledge to be modeled includes acquisition characteristics (geometry, statistical signal or noise properties),

anatomy, shape and appearance, spatial relations, pathology characteristics. This leads to mathematical models, that are then exploited in segmentation, recognition and higher level understanding. For instance, X-ray acquisitions were modeled in the case of low-dose imaging and for dose estimation [707], for dual acquisitions in brain C-arm CBCT (Cone beam computed tomography) [693], or for new tomosynthesis methods. Shape and appearance models were developed, together with spatial relations, for vessels in high resolution CT [708], abdominal multi-organ localization and segmentation [724], teeth segmentation and recognition in CBCT, and retina vessels in optical coherence tomography and adaptive optics [706, 726] with clinical applications [725]. The developed methods strongly rely on the theoretical developments described in Section 15.2.2, and were applied on different imaging modalities and for different types of anatomical structures and pathologies, with two main directions: brain and pediatric imaging. Our most recent works in these directions include the localization and segmentation of brain lesions in MRI (Magnetic Resonance Imaging), guided by PET (Positon Emission Tomography) images (from combined PET-MRI acquisitions) using max-trees and deformable models, the segmentation of neonatal brain images (normal structures and white matter hyperintensities) using mathematical morphology, spatial relations and deep-learning [681], denoising of biological images, and new applications in image-guided surgery of the pelvis for pediatric patients, for which we developed segmentation and 3D modeling methods, again relying on computational models of the anatomy. A new topic recently emerged in the team on brain tractography with contributions in: 1) the analysis of structural connectivity using diffeomorphisms [677], 2) a reproducible and anatomically relevant segmentation of tractograms based on fuzzy spatial relations modeling their qualitative anatomical definitions, 3) the definition and comparison of appropriate distances suited for the analysis of tractograms [753].

Conversely, images can also be used to build realistic anatomical models. This work originates from the need to base simulations of wave propagation (typically to study the influence of electromagnetic waves on biological tissues) on realistic models. Within several ANR and ANSES national and international projects, we developed original voxelized and meshed 3D models of adult and children brains, fetus and pregnant women, whole body children, from MRI and ultrasound 3D images, and associated deformation models to simulate different positions and sizes [723, 709]. Models are publicly available for research purposes at http://femonum.telecom-paristech.fr/.

Collaborations: RHU (Lariboisière and XV-XX hospital, ISEP), IMABRAIN (Sainte-Anne), IMAG2 (Necker), academic (at international level: Trento, Sao Paulo, HUST...; at national level: LRDE-Epita, Aramis team, ISEP, LIX...), medical (several CHU in Paris, joint teams, C. Adamsbaum (Bicêtre hospital) associated researcher, PhD and master theses of medical doctors) and industrial collaborations (Philips, General Electric, KeenEyes...).

Computational photography

An in-depth study of the modern photographic camera under various aspects: optical, electronic, digital ... led to a comprehensive handbook, the first one published on this topic [745]. Several applications described in Section 15.2.2 are related to computational photography.

Creative Industries

The computer graphics activities of IMAGES presented in Section 15.2.3 have strong ties to video game, computer-aided design (CAD) and VFX/Animated Picture industries. First, an Industrial Research Chair has been co-conducted during five years, funded by Dassault Systèmes, PSA, Ubisoft and Orange, with the aim to determine how imaginary worlds can be modeled, fed and used to develop innovative concepts in various industries. One key challenge occurring in this project relates to the ability to convey the mental model of a 3D scene to a computer, interactively and intuitively. Secondly, a long term collaboration with Ubisoft Motion Picture has exploited the research results coming from the group for actual movie and TV series productions. Last, a joint research laboratory with Allegorithmic has been created to invent the future technologies of 3D digital content creation (3D DCC) for games, design and VFX.

15.2.5 Scientific Highlights:

- Organization of Workshops and Conferences
  - Workshop on computational photography at IPAM (UCLA campus, Los Angeles) 2015 (Y. Tendero).
  - Workshop on co-conception: *Co-conception of hybrid systems: when acquisition devices and numeric processing meet* in partnership with GdR ISIS, MIA and MaDICS (Télécom-ParisTech): Oct. 2017 (with GdR MIA and MaDICS), Jun. 2016 (with GdR MIA), Oct. 2014. (A. Almana, Y. Tendero).
  - Co-animation of a GdR ISIS action on remote sensing (until 2015): organization of annual meetings (F. Tupin).
- Associate editors of journals
  - Fuzzy Sets and Systems, Medical Image Analysis, Computer Vision and Image Understanding (I. Bloch).
  - Image Processing On Line (A. Almansa, Y. Gousseau, Y. Tendero).
  - IEEE Transactions on Geoscience and Remote sensing (until 2016), Journal of Spatial Science (since 2016) (F. Tupin).
  - Computer Graphics Forum (T. Boubekeur).
- Editorial or program committees
  - ISMM, LFA, ISBI 2015, 2017, DGCI, Area chair of IFSA 2017 and IJCAI-ECAI 2018 (I. Bloch).
  - RFIAP 2018, RFIA 2016, GRETSI 2017, 2015, 2013 (F. Tupin).
  - SIGGRAPH 2013, 2014, 2016, SIGGRAPH Asia 2017, 2018, EUROGRAPHICS 2013, 2015, 2016, 2018, EGSR 2013, 2014, 2015, 2017, 2018, SGP 2013, 2014, 2015, 2016, 2017, 2018, Shape Modeling International2015, 2016, 2018, Graphics Interface 2016, High Performance Graphics 2017, I3D 2018 (T. Boubekeur).
- Tutorials in international conferences
  - FLSC 2015, IJCAI 2016, ICPRAM 2017 (I. Bloch).
  - IGARSS 2015, IGARSS 2017 (F. Tupin).
- Keynotes
  - Junction 2017 (Helsinki, Finland) (T. Boubekeur).
  - 13^{th} IEEE ICSP 2016, (Chengdu, Chine), SPIE MIPPR 2015 (Enshi, Chine) (H. Maître).
  - Multitemp 2015 (Annecy), 3^{rd} China High Resolution Earth Observation Conference 2016, (Shanghaï, Chine) (F. Tupin).
  - Mathematical Modeling of Complex Systems (MMCS) 2016, Spatial Accuracy 2016 (I. Bloch).
- Awards
  - IEEE Transactions on Geoscience and Remote sensing best paper award 2016 [722].
  - 1^{st} *Prix de thèse* from Fondation Mines-Télécom (S. Lobry, 2018).
  - 2^{nd} *Prix de thèse* from Télécom ParisTech (F. Weissgerber, 2017).
  - 2^{nd} *Prix de thèse* from Télécom ParisTech (E. Guy, 2016).
  - SFGBM best thesis innovation award (P. Irrera, 2015).
  - EUSAR best student paper award 2016 (F. Weissgerber [756]).
  - Shape Modeling International 2017 Best Paper Award [684].
  - Shape Modeling International 2016 Best Paper Award [696].
  - Google best student paper, CVMP 2013 (A. Newson) [765].
  - Second Place Winner of the Wolfgang Straßer Award 2015 (best paper at ACM SIGGRAPH High Performance Graphics) [759].
  - IEEE 3DUI 2015 Best Paper Award [760].
  - IEEE ICIP 2014 Top 10% Paper Award [761].
  - SFP 2014 best poster award [763].
  - ICPR 2014 Best Scientific Paper Award [762].
  - IEEE IPTA 2016 best poster award [758].
  - SIAM IS conference best poster award 2018 (A. Houdard).
  - CFPT best paper award 2018 [750].

- Fundings
  - EU: Harvest4D (FET 2013-2016), Reverie (IP 2011-2015), 3DLife (NoE, 2009-2013).
  - ANR: LOGIMA (2012-2016), DESCRIBE (2013-2016), MIRIAM (2014-2018), ALYS (ANR-ASTRID, 2015-2019), ReVeal (2013-2016), TRT-cSVD (2017-2022), FETUS (2011-2014), ANSES ACTe (2013-2016), STAP (2017-2021), AllegoRI (ANR-LabCom, 2017-2020), iSpace-Time (2010-2014).
  - CNES projects, Cifre grants with industries, FSN project funded by BPI (with Ubisoft, CNRS, UPEM and CEA).
  - IMT Health Program (2018).
  - Labex DIGITEO and DIGICOSME, Lidex-PIM project within the IDEX Paris-Saclay.
- Significant Contracts with Industrials, Chairs
  - Chair *Modélisations des imaginaires* (Dassault Systèmes, PSA, Ubisoft, Orange).
  - Technology transfer with Allegorithmic.
  - FUI : G4M...
  - Long term collaborations with the industry in the field of medical imaging (Philips, General Electric...).
  - Long term collaborations with CNES in the field of remote sensing and SAR imaging.
- Common Lab with Industrial/Universities
  - Joint research laboratory with Allegorithmic
- Sofware
  - **AOV**: segmentation and analysis of adaptive optics images of retina vessels, with ISEP and XV-XX: software deposit to APP number IDDN.FR.001.300006.000.S.P.2014.000.21000 at the date of 07/15/2014 (used by several hospitals).
  - **SegmentCC**: corpus callosum segmentation in pediatric brain MRI (used by CHU Bicêtre).
  - **NeoBrainSeg**: Softwares for cerebral structures and hyper-intensities segmentation in MRI images of neonates, with EPITA, HUST and CHU Bicêtre (https://www.lrde.epita.fr/wiki/NeoBrainSeg).
  - **DeformR**, an interactive shape deformation plateform design for fast prototype, written in C++ and OpenGL and transferred to an industrial within an exclusive licence contract.
  - **BCD**, an open source denoising library for Monte Carlo Rendering [685], currently integrated in production pipelines (Ubisoft Motion Picture) and large open source framework such as AppleSeed and LUX Render (C++/CUDA).
  - **SimSelect**, an open source interactive application for selection [733] and segmentation on 3D shapes (C++/OpenGL/GLSL).
  - **DHC**, an open source code for Monte Carlo importance sampling in rendering (C++).
  - **SQEM**, a standalone open source implementation of our Spherical Quadric Error Metric [739] for shape approximation (C++).
- Evaluation and scientific committees
  - Members of scientific councils and boards: INRIA, IRCAM, EPITA and LISTIC (Annecy) (I. Bloch), RTRA *Aéronautique et Espace* Toulouse (H. Maître), IGN and Engineering UFR of Paris Sorbonne (F. Tupin), several labex.
  - Members or chairs of national or international selection committees (universities, INRIA).
  - Members of evaluation board of national or international projects: HCERES, ANR, ERC starting grant, national agencies (Italy, Belgium, Austria, Canada, Swiss, Sweden...).
  - Member of #FranceIA group and contribution to Villani's report (I. Bloch).
  - Member of IEEE Special Interest Group (SIG) on Computational Imaging (CI) (Y. Tendero).
- Vulgarization
  - Contributions to IMT research blog, Earthzine magazine (2016), REE journal (2015), Doc-Sciences journal (2013), *La Main à la Pâte*, conferences at *Collège de France*,
  - Presentations for *Maths en Jeans* (2016, 2017).
- Out-going sabbatical and long visit in other labs
  - Sao Paulo (Brazil) and Merida (Venezuela) (I. Bloch).
- Contribution to higher level and research education

- Masters in computer science: joint accreditation with Sorbonne University (chair of the IMA program), with Université Paris-Saclay (coordination tasks, courses and student supervision).
- Master in mathematics: joint accreditation with Université Paris-Saclay (MVA) (coordination tasks, courses and student supervision).
- Masters in Engineering: joint accredidations with Université Paris-Saclay (ATSI), and Paris-Descartes (Bio-Medical Engineering) (coordination tasks, courses and student supervision).
- The team is in charge of the image processing course of the 4th year students of the SJTU-ParisTech Elite Institute of Technology at Shanghaï Jiaotong University.
- Board of doctoral schools: EDITE, ED-STIC.

15.3 SWOT analysis

15.3.1 Strength

- A specificity of the team is the mastery of the *whole chain of image and data processing*, ranging from the acquisition step to information extraction and higher level understanding.
- A strength of the team is the room devoted to *methodological developments based on applied mathematics and computer science*, with a strong focus on modeling aspects.
- The team has the distinctive characteristic of *covering many aspects of AI*: recent machine learning methods, as well as symbolic artificial intelligence.
- The team also benefits from the *strong interactions between all research topics* (for instance computer graphics and image processing and analysis activities), which are promoted in our research and are beneficial for all topics.
- The expertise of the team relies on *in-depth knowledge of privileged application fields* (medical imaging, remote sensing imaging, computational photography, creative industries), with strong and long-term collaborations with academic and state or industrial partners. The team is also open to new collaborations according to the evolution of its research directions and evolution of the domain.

15.3.2 Weakness / To be improved

- Gathering all softwares developed by the staff, the PhD candidates, and during the various projects we have, is still a point we are working on. This work is already done for each research theme separately, and our ongoing effort is to make each topic benefit from developments carried out in other projects. To this aim, we have now a gitlab, and we encourage all members of the team to contribute to it. This is important for software heritage.
- Whenever it is possible, we will also increase our effort towards reproducible research, by distributing the codes to the scientific community. Again, this has already been done for several codes we developed, and will be further encouraged and enhanced in the future.

15.3.3 Opportunities

Our research in AI will benefit from our collaborations on learning with academic and industrial partners, as well as the French national program in AI following #FranceIA and C. Villani's report. The very recent recruitment of a new assistant professor will reinforce our research in this domain.

In medical imaging, an important evolution of the regional context is the launching of new structures involving important labs such as ICM (Pitié-Salpétrière university hospital) and Neurospin in Saclay, and emerging pluri-disciplinary teams to which we are contributing (IMABRAIN in Sainte-Anne Hospital, with applications in MRI brain imaging, IMAG2 in Necker Enfants Malades Hospital, with applications in image-guided pediatric surgery, Kremlin-Bicêtre Hospital, with applications on premature brain MRI, RHU TRT-cSVD with XV-XX and Lariboisière hospitals, a large project on small vessel diseases). Moreover, our collaboration with AP-HP through

the IMT digital health program should allow the LTCI to welcome medical doctors for research stays in the lab. These evolutions should anchor our actual collaborations and bring out new research topics.

15.3.4 Threats

The recent evolutions of Paris-Saclay, which are still on-going, are a cause of concern, since they can be antagonist with other key evolutions (like for instance in medical imaging with the intra-muros Paris initiatives).

In remote sensing and SAR imaging, the planned leave of a professor retiring will potentially weaken this research topic, specially on the physical aspects of the SAR acquisition system and our collaborations in the defense domain.

The new structures in medical imaging make the sustainability of developed methods and tools even more necessary, in order to support translational research and transfer to medical end-users. At this point, we do not have the necessary resources to achieve these tasks.

15.4 Scientific project for the the next five years

The scientific project of the IMAGES team for the next years aims at:

1. **Strengthening our research in machine learning**: develop research activities in different fields of artificial intelligence and increase the part dedicated to machine learning.
2. **Developing the research in computer graphics**: new methods for 3D representations, animation, and real time synthesis.
3. **Making the applicative domains evolve** to account for the development of new sensors, new data, and to the evolution of the societal context.

For the first objective, a new researcher was recently hired, specifically to develop research on deep learning for images, hence strengthening our expertise in this field. Our research agenda includes: the reduction of CNN sensitivity to the learning images, transfer learning, the cooperation between learning and restoration algorithms, the integration of knowledge (anatomical, structural...) in CNN, interpretability of CNN (understanding the underlying models, post-hoc explanation of the obtained predictions...) towards explainable AI.

In strong interactions with the second topic, we propose to investigate how interactive design tools can be used for modeling and editing a neural network, how the classical pre-visualization in image synthesis can be developed for neural networks in order to visualize their behavior and internal mechanisms, how approximation algorithms developed in computer graphics can be extended to process networks components in a spatial or statistical way in order to achieve optimization, simplification, refining, parameterizing, etc.

On the symbolic side of AI, new researches will be carried out to model complex spatial relations in Riemannian geometry (to handle curved structures, defined on manifolds) and to compare them, using mathematical morphology and optimal transport in such Riemannian spaces. The association between mathematical morphology and logics will be investigated in the more general setting of stratified institutions, with applications to reasoning on information with different levels of relevance or of priority, to spatial reasoning (for instance in medical imaging and computational anatomy), and to musical representations.

In computer graphics, the team proposes to develop new approaches for 3D shape representation, adapted to emerging applications: real time 3D sensors (partial, uncertain, massive point sets, which can be updated several times per second), AI (shape analysis and high level representations), digital manufacturing (surface-volume interactions, perception), optimization and assisted design of volumetric structures, with applications to simulation.

Intuitive animation methods will be developed: (i) analysis and frequency transfer of movement for the efficient synthesis of realistic movements, taking into account the geometry of the

animation structure (skeleton) and of the animated shape (mass/volume, stiffness properties); (ii) animation/edition of fluid simulations, based on the analysis and extraction of editable structures such as vortex (rotational), current (gradient), source/sink (divergence); (iii) high level design and constrained optimization of heat fields for the efficient and physically plausible artistic realization of turbulences and mirages.

We also propose to develop new approaches for real time image synthesis and light field synthesis. Our proposal is to decorrelate, asynchronously, the simulation loop of the light transport in the 3D space (using a light field model) from the high speed and high resolution imaging system required for future applications ($\geq$8k, $\geq$140Hz, $\geq$1-screen).

In medical imaging, an important evolution of our research is to move from low level processing and analysis to high-level understanding and interpretation. This will be an expected important enrichment of our work in segmentation and recognition of normal and pathological structures. One of our research lines will be *multi-modal computational functional anatomy*. We will develop new geometrical and computational models, as well as appropriate deformation methods, to analyze organizational, morphological and functional alterations of anatomical structures (e.g. brain) due to pathologies. This will extend our recent works in computational anatomy by combining anatomical and functional information obtained from multiple modalities such as MRI, d-MRI, PET and f-MRI. The application to brain tumors will be carried out within the IMABRAIN team at Sainte-Anne hospital. The case of pediatric and neo-born patients for several brain pathologies will be investigated within the STAP project, with Bicêtre hospital and Sao Paulo university hospital. Another direction will be the creation of a software for the automatic, reproducible and anatomically relevant segmentation of white matter tracts. In this context, we will expand the preliminary results obtained within the DigiCosme project Neural MetaTracts. Such methods will also be developed for the pelvic nerves in pediatric MRI, for image-guided surgery, within the IMAG2 team at Necker Hospital. The aim is to build an individual 3D model of the patient before the surgery (virtual patient). We also plan to investigate the domain of radiomics (for brain, lungs, liver), as well as the fusion of imaging data with other information (clinical, biological...), also contributing to the virtual patient paradigm. The theoretical and methodological aspects, with a strong anchoring in mathematical and computational modeling, have close links with topics developed in themes 1 and 2.

In remote sensing and SAR imaging, the team has two major objectives both in connection to the new spatial missions (SWOT and BIOMASS in 2021, and the future bistatic SAR sensors): first to develop methods to process and analyze very long temporal series (denoising, change detection, tomographic reconstruction ...), then to combine heterogeneous signals (ascending / descending modes, polarimetric / non-polarimetric, multi frequency, optical / SAR ...). Our recently developed statistical methods but also the methods developed in theme 1 should contribute to reach these goals, supported by freely available data and open datasets to which we intend to contribute. As long as applications are concerned, our developments focus on Global Environment Survey (hydrology with our implication in the ADT -Algorithm Definition Team- of SWOT mission and forests supervision with BIOMASS), and urban areas monitoring (with temporal series from SENTINEL-1 and TerraSAR-X).

In computational photography, our objective is to work on co-conception by studying different specifications of the acquisition sensor / lecture mode of the CMOS sensor, spatial and temporal resolutions, automatic control of the contrast or compression rate, for instance to elaborate the best processing methodology depending on the application. Another research topic is the study of the compressed sensing sensors (for instance 1 pixel camera). They could be very useful to overcome some sensor limitations, like for instance infra-red LWIR cameras with expensive and "noisy" (non-uniform) sensors.

15.5 Scientific production (selection)

Articles in Journals

[676] M. Aiguier, J. Atif, I. Bloch, and R. Pino Pérez. Explanatory relations in arbitrary logics based on satisfaction systems, cutting and retraction. *International Journal of Approximate Reasoning*, 102: 1–20, 2018.

[677] P. Gori, O. Colliot, L. M. Kacem, Y. Worbe, A. Routier, C. Poupon, A. Hartmann, N. Ayache, and S. Durrleman. Double diffeomorphism: combining morphometry and structural connectivity analysis. *IEEE Transactions on Medical Imaging*, 2018.

[678] G. Ferraioli, Ch.-A. Deledalle, L. Denis, and F. Tupin. PARISAR: Patch-based estimation and regularized inversion for multi-baseline SAR interferometry. *IEEE Transactions on Geoscience and Remote Sensing*, 56(3):1626–1636, March 2018.

[679] R. Abergel, L. Denis, S. Ladjal, and F. Tupin. Sidelobes Suppression and Strong Targets Extraction in Single Look Complex SAR Images with Several Applications. *IEEE Journal of Selected Topics in Applied Observation and Remote Sensing*, 11(3):759–776, March 2018.

[680] M. Aiguier, J. Atif, I. Bloch, and C. Hudelot. Belief revision, minimal change and relaxation: A general framework based on satisfaction systems, and applications to description logics. *Artificial Intelligence*, 256:160–180, 2018.

[681] Y. Xu, B. Morel, S. Dahdouh, E. Puybareau, A. Virzi, H. Urien, Th. Géraud, C. Adamsbaum, and I. Bloch. The challenge of cerebral magnetic resonance imaging in neonates: A new method using mathematical morphology for the segmentation of structures including diffuse excessive high signal intensities. *Medical Image Analysis*, 48:75–94, 2018.

[682] H. Sportouche, J.-M. Nicolas, and F. Tupin. Mimic Capacity Of Fisher And Generalized Gamma Distributions For High Resolution SAR Image Statistical Modeling. *IEEE Journal of Selected Topics in Applied Earth Observation and Remote Sensing*, 10(12):5724–5735, December 2017.

[683] G. Terrasse, J.-M. Nicolas, E. Trouvé, and E. Drouet. Application of the curvelet transform for clutter and noise removal in GPR data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 10(10):4280–4294, December 2017.

[684] Ph. Herholz, S. Koch, T. Boubekeur, and M. Alexa. Unsharp masking geometry improves 3d prints. *Computer & Graphics (Proc. Shape Modeling International 2017)*, 66:135–142, September 2017.

[685] M. Boughida and T. Boubekeur. Bayesian collaborative denoising for Monte Carlo rendering. *Computer Graphics Forum (Proc. EGSR 2017)*, 36(4):137–153, September 2017.

[686] F. Weissgerber, E. Colin Koeninger, J.-M. Nicolas, and N. Trouvé. 3D monitoring of buildings using TerraSAR-X InSAR, DInSAR and PolSAR capacities. *Remote Sensing*, 9(10):1010, September 2017.

[687] N. Bus and T. Boubekeur. Double hierarchies for directional importance sampling in Monte Carlo rendering. *Journal of Computer Graphics Techniques*, 6(3):35–37, August 2017.

[688] S. Calderon and T. Boubekeur. Bounding proxies for shape approximation. *ACM Transactions on Graphics (Proc. SIGGRAPH 2017)*, 36(5):57.1–57.13, July 2017.

[689] C. Aguerrebere, A. Almansa, J. Delon, Y. Gousseau, and P. Musé. A Bayesian hyperprior approach for joint image denoising and interpolation, with an application to HDR imaging. *IEEE Transactions on Computational Imaging*, 3(4):633–646, May 2017.

[690] A.-M. Vintescu, F. Dupont, G. Lavoue, P. Memari, and J. Tierny. Least squares affine transitions for global parameterization. *Journal of WSCG*, 25(1), May 2017.

[691] Q. Oliveau and H. Sahbi. Learning attribute representations for remote sensing ship category classification. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 10 (6):2830–2840, March 2017.

[692] H. Morimitsu, I. Bloch, and R. M. Cesar. Exploring structure for long-term tracking of multiple objects in sports videos. *Computer Vision and Image Understanding*, 159:89–104, 2017.

[693] A. Reshef, C. Riddell, Y. Trousset, S. Ladjal, and I. Bloch. Dual-rotation C-arm cone-beam computed tomography to increase low-contrast detection. *Medical Physics*, 44(9):164–173, 2017.

[694] Ch.-A. Deledalle, L. Denis, S. Tabti, and F. Tupin. MuLoG, or How to apply Gaussian denoisers to multi-channel SAR speckle reduction? *IEEE Transactions on Image Processing*, 26(9):4389–4403, 2017.

[695] E. Provenzi, J. Delon, Y. Gousseau, and B. Mazin. On the second order spatiochromatic structure of natural images. *Vision Research*, 120:124–144, September 2016.

[696] N. Faraj, J.-M. Thiery, and T. Boubekeur. Multi-material adaptive volume remesher. *Computer and Graphics Journal*, 58(C):150–106, August 2016.

[697] T. Perciano, F. Tupin, R. Hirata, and R. M. Cesar. A Two-level Markov Random Field for Road

Network Extraction and its Application with Optical, SAR and Multitemporal Data. *International Journal of Remote Sensing*, 37(16), July 2016.

[698] A. Atto, E. Trouvé, J. M. Nicolas, and Th. T. Lê. Wavelet operators and multiplicative observation models - application to change-enhanced regularization of sar image time series. *IEEE Transactions on Geoscience and Remote Sensing*, 54(11):6606–6624, July 2016.

[699] G. Laurent, C. Delalandre, G. De La Rivière, and T. Boubekeur. Forward light cuts: A scalable approach to real-time global illumination. *Computer Graphics Forum (Proc. EGSR 2016)*, 35(4): 79–88, July 2016.

[700] S. Lobry, L. Denis, and F. Tupin. Multi-temporal SAR image decomposition into strong scatterers, background, and speckle. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 9(8):3419–3429, June 2016.

[701] L. Avanthey, L. Beaudoin, A. Gademer, and M. Roux. Tools to perform local dense 3D reconstruction of shallow water seabed. *Sensors*, 16(5), May 2016.

[702] J.-M. Thiery, E. Eisemann, and T. Boubekeur. Animated mesh approximation with sphere-meshes. *ACM Transactions on Graphics*, 35(3):30:1–30:13, May 2016.

[703] I. Bloch and J. Atif. Defining and computing Hausdorff distances between distributions on the real line and on the circle: link between optimal transport and morphological dilations. *Mathematical Morphology: Theory and Applications*, 1(1):79–99, March 2016.

[704] Y. Tendero and S. Osher. On a mathematical theory of coded exposure. *Research in the Mathematical Sciences (RMSS)*, 3(1):1–39, March 2016.

[705] M.-C. Vanegas, I. Bloch, and J. Inglada. Fuzzy constraint satisfaction problem for model-based image interpretation. *Fuzzy Sets and Systems*, 286:1–29, 2016.

[706] N. Lermé, F. Rossant, I. Bloch, M. Paques, E. Koch, and J. Benesty. A fully automatic method for segmenting retinal artery walls in adaptive optics images. *Pattern Recognition Letters*, 72:72–81, 2016.

[707] P. Irrera, I. Bloch, and M. Delplanque. A flexible patch based approach for combined denoising and contrast enhancement of digital X-ray images. *Medical Image Analysis*, 28:33–45, 2016.

[708] D. Lesage, E. D. Angelini, G. Funka-Lea, and I. Bloch. Adaptive particle filtering for coronary artery segmentation from 3D CT angiograms. *Computer Vision and Image Understanding*, 151: 29–46, 2016.

[709] S. Dahdouh, N. Varsier, M. Nunez Ochoa, J. Wiart, A. Peyman, and I. Bloch. Infants and young children modeling method for numerical dosimetry studies: application to plane wave exposure. *Physics in Medicine and Biology*, 61(4):1500–1514, 2016.

[710] G. Tartavel, Y. Gousseau, and G. Peyré. Wasserstein loss for image synthesis and restoration. *SIAM Journal on Imaging Sciences*, 9(4):1726–1755, 2016.

[711] J. Atif, I. Bloch, and C. Hudelot. Some relationships between fuzzy sets, mathematical morphology, rough sets, F-transforms, and formal concept analysis. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, 24(S2):1–32, 2016.

[712] L. D. Alvarez-Corrales, Y. Gousseau, J.-M. Morel, and A. Salgado. Exploring the space of abstract textures by principles and random sampling. *Journal of Mathematical Imaging and Vision*, 53(3): 332–345, September 2015.

[713] B. Wang, X. Meng, and T. Boubekeur. Wavelet point-based global illumination. *Computer Graphics Forum*, 34(4):143–154, July 2015.

[714] S. Réjichi, F. Chaabane, and F. Tupin. Expert Knowledge-Based Method for Satellite Image Time Series Analysis and Interpretation. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 8(5):2138–2150, June 2015.

[715] J.-B. Poisson, H. Oriot, and F. Tupin. Ground Moving Target Trajectory Reconstruction in Single-Channel Circular SAR. *IEEE Transactions on Geoscience and Remote Sensing*, April 2015.

[716] Y. Traonmilin, S. Ladjal, and A. Almansa. Robust multi-image processing with optimal sparse regularization. *Journal of Mathematical Imaging and Vision*, 51(3):413–429, March 2015.

[717] X. Su, Ch.-A. Deledalle, F. Tupin, and H. Sun. NORCAMA: Change analysis in SAR time series by likelihood ratio change matrix clustering. *ISPRS Journal of Photogrammetry and Remote Sensing*, 101:247–261, March 2015.

[718] I. Bloch, A. Bretto, and A. Leborgne. Robust similarity between hypergraphs based on valuations and mathematical morphology operators. *Discrete Applied Mathematics*, 183:2–19, February 2015.

[719] B. Mazin, J. Delon, and Y. Gousseau. Estimation of illuminants from projections on the Planckian locus. *IEEE Trans. Image Processing*, 24(6):1944–1954, February 2015.

[720] F. Dellinger, J. Delon, Y. Gousseau, J. Michel, and F. Tupin. SAR-SIFT: a SIFT-like algorithm for

SAR images. *IEEE Transactions on Geoscience and Remote Sensing*, January 2015.

[721] G. Tartavel, Y. Gousseau, and G. Peyré. Variational texture synthesis with sparsity and spectrum constraints. *JMIV*, 52(1):124–144, January 2015.

[722] Ch.-A. Deledalle, L. Denis, F. Tupin, A. Reigber, and M. Jäger. NL-SAR: a unified Non-Local framework for resolution-preserving (Pol)(In)SAR denoising. *IEEE Transactions on Geoscience and Remote Sensing*, 53(4):2021–2038, 2015.

[723] S. Dahdouh, E. D. Angelini, G. Grangé, and I. Bloch. Segmentation of embryonic and fetal 3D ultrasound images based on pixel intensity distributions and shape priors. *Medical Image Analysis*, 24:255–268, 2015.

[724] R. Gauriau, R. Cuingnet, D. Lesage, and I. Bloch. Multi-organ localization with cascaded global-to-local regression and shape prior. *Medical Image Analysis*, 23:70–83, 2015.

[725] M. Paques, A. Brolly, J. Benesty, N. Lermé, E. Koch, F. Rossant, I. Bloch, and J.-F. Girmens. Venous nicking without arteriovenous contact: The role of the arteriolar microenvironment in arteriovenous nickings. *JAMA Ophtalmology*, 2015.

[726] F. Rossant, I. Bloch, I. Ghorbel, and M. Paques. Parallel double snakes. Application to the segmentation of retinal layers in 2D-OCT for pathological subjects. *Pattern Recognition*, 48:3857–3870, 2015.

[727] I. Bloch. Fuzzy sets for image processing and understanding. *Fuzzy Sets and Systems*, 281:280–291, 2015.

[728] A. Newson, A. Almansa, M. Fradet, Y. Gousseau, and P. Perez. Video inpainting of complex scenes. *SIAM Journal on Imaging Sciences*, 7(4):1993–2019, October 2014.

[729] G. Quin, B. Pinel-Puysegur, J. M. Nicolas, and Ph. Loreaux. MIMOSA: An Automatic Change Detection Method for SAR Time Series. *IEEE Transactions on geoscience and Remote Sensing*, 52 (9):5349–5363, September 2014.

[894] D. Guenther, J. Salmon, and J. Tierny. Mandatory critical points of 2D uncertain scalar fields. *Computer Graphics Forum*, 33(3):31–40, August 2014.

[731] S. Calderon and T. Boubekeur. Point morphology. *ACM Transactions on Graphics (Proc. SIGGRAPH 2014)*, 33(4):Art. 45, August 2014.

[732] J. Atif, C. Hudelot, and I. Bloch. Explanatory reasoning for image understanding using formal concept analysis and description logics. *IEEE Transactions on Systems, Man and Cybernetics: Systems*, 44(5):552–570, May 2014.

[733] E. Guy, J.-M. Thiery, and T. Boubekeur. Simselect: similarity-based selection for 3d surfaces. *Computer Graphics Forum (Proc. EUROGRAPHICS 2014)*, 33(2):165–173, May 2014.

[734] F. de Goes, P. Memari, P. Mullen, and M. Desbrun. Weighted triangulations for geometry processing. *ACM Transactions on Graphics (TOG)*, 33(3):28, March 2014.

[735] X. Su, Ch.-A. Deledalle, F. Tupin, and H. Sun. Two-Step Multitemporal Nonlocal Means for Synthetic Aperture Radar Images. *IEEE Transactions on Geoscience and Remote Sensing*, March 2014.

[736] A. Newson, A. Almansa, Y. Gousseau, and P. Perez. Robust automatic line scratch detection in films. *IEEE Trans. Image Processing*, 23(23):1240–1254, February 2014.

[737] C. Aguerrebere, J. Delon, Y. Gousseau, and P. Musé. Best algorithms for HDR image generation. a study of performance bounds. *SIAM Imaging Sciences*, 7(1):1–34, January 2014.

[738] G. Palma, I. Bloch, and S. Muller. Detection of masses and architectural distortions in digital breast tomosynthesis images using fuzzy and a contrario approaches. *Pattern Recognition*, 47:2467–2480, 2014.

[739] J.-M. Thiery, E. Guy, and T. Boubekeur. Sphere-meshes: Shape approximation using spherical quadric error metrics. *ACM Transactions on Graphics (Proc. SIGGRAPH Asia 2013)*, 32(6):Art. 178, December 2013.

[740] D. Benboudjema and F. Tupin. Markovian modelling and Fisher distribution for unsupervised segmentation of radar images. *International Journal of Remote Sensing*, June 2013.

[741] A. Myaskouvskey, Y. Gousseau, and M. Lindenbaum. Beyond independence: An extension of the a contrario decision procedure. *International Journal of Computer Vision*, 101(1):22–44, January 2013.

[742] A. Shabou, J. Darbon, and F. Tupin. Multilabel partition moves for MRF optimization. *Image and Vision Computing*, 31:14–30, January 2013.

[743] I. Bloch and A. Bretto. Mathematical morphology on hypergraphs, application to similarity and positive kernel. *Computer Vision and Image Understanding*, 117:342–354, 2013.

[744] O. Nempont, J. Atif, and I. Bloch. A constraint propagation approach to structural model based

image segmentation and recognition. *Information Sciences*, 246:1–27, 2013.

Books

[745] H. Maître. *From Photon to Pixel: The Digital Camera Handbook*. Wiley-ISTE, London, Royaume-Unis, 1 edition, 2015.

[746] F. Tupin, J. Inglada, and J. M. Nicolas. *Remote Sensing Imagery*. ISTE - Wiley, 2014.

Book Chapters and articles in collections

[747] Y. Xu, Th. Géraud, E. Puybareau, I. Bloch, and J. Chazalon. White matter hyperintensities segmentation in a few seconds using fully convolutional network and transfer learning. In *BrainLes*, pages 501–514. Springer, LNCS 10670, 2018.

[748] Ch.-A. Deledalle, L. Denis, G. Ferraioli, and F. Tupin. *Mathematical Models for Remote Sensing Image Processing*, chapter Mathematical models for very high resolution SAR data and their applications. Springer, 2017.

Articles in Conference Proceedings

[749] C. Agon, M. Andreatta, J. Atif, I. Bloch, and P. Mascarade Relano. Musical descriptions based on formal concept analysis and mathematical morphology. In *23rd International Conference on Conceptual Structures (ICCS)*, volume LNAI 10872, pages 105–119, Edinburgh, UK, June 2018.

[750] E. Colin Koeninger, J.-M. Nicolas, B. Pinel-Puysségur, J. M. Lagrange, and F. Janez. Visualisation des changements sur séries temporelles radar : méthode REACTIV évaluée à l'échelle mondiale sous google earth engine. In *CFPT 2018*, Marne la Vallée, June 2018.

[751] Th. T. Le, A. Almansa, Y. Gousseau, and S. Masnou. Motion-consistent video inpainting. In *ICIP*, September 2017.

[752] N. Faraj, G.-S. Xia, J. Delon, and Y. Gousseau. A generic framework for the structured abstraction of images. In *Proceedings of the Symposium on Non-Photorealistic Animation and Rendering. ACM*, August 2017.

[753] E. Olivetti, G. Bertò, P. Gori, N. Sharmin, and P. Avesani. Comparison of distances for supervised segmentation of white matter tractography. In *Pattern Recognition in Neuroimaging (PRNI)*, Toronto, Canada, June 2017.

[754] I. Bloch. Morphological links between formal concepts and hypergraphs. In *International Symposium on Mathematical Morphology (ISMM 2017)*, volume LNCS 10225, pages 16–27, Fontainebleau, France, March 2017.

[755] H. Bertrand, M. Perrot, R. Ardon, and I. Bloch. Classification of MRI data using deep learning and Gaussian process-based model selection. In *IEEE International Symposium on Biomedical Imaging*, pages 745–748, Melbourne, Australia, 2017.

[756] F. Weissgerber. Resolution enhancement of polarimetric images using a high resolution mono-channel image. In *EUSAR 2016: 11th European Conference on Synthetic Aperture Radar*, Hamburg, June 2016.

[757] G. Liu, Y. Gousseau, and G.-S. Xia. Texture synthesis through convolutional neural networks and spectrum constraints. In *ICPR*, 2016.

[758] M. Lagarrigue, F. Rossant, I. Bloch, M.-H. Errera, and M. Paques. Segmentation of retinal vessels in adaptive optics images for assessment of vasculitis. In *International Conference on Image Processing Theory, Tools and Applications (IPTA)*, Oulu, Finland, 2016.

[759] H. Legrand and T. Boubekeur. Morton integrals for high speed geometry simplification. In *ACM SIGGRAPH/EUROGRAPHICS High Performance Graphics 2015*, pages 105–112, Los Angeles, USA, August 2015.

[760] E. Guy, P. Punpongsanon, T. Boubekeur, D. Iwai, and K. Sato. LazyNav: 3D ground navigation with non-critical body parts. In *IEEE Symposium on 3D User Interfaces*, pages XX–XX, Arles, France, April 2015.

[761] T. Boubekeur. Shellcam: Interactive geometry-aware virtual camera control. In *IEEE International Conference on Image Processing (ICIP)*, pages 4003–4007, Paris, France, October 2014.

[762] N. Lermé, F. Rossant, I. Bloch, M. Paques, and E. Koch. Segmentation of retinal arteries in adaptive optics images. In *International Conference on Pattern Recognition (ICPR)*, pages 574–578, Stockholm, Sweden, August 2014.

[763] B. Morel, S. Kemel, S. Dahdouh, C. Adamsbaum, and I. Bloch. Etude de la reproductibilité des interprétations d'irm cérébrales néonatales. In *Congrès des Sociétés de Pédiatrie*, Lyon, France, July 2014.

[764] Th. Guillemot, A. Almansa, and T. Boubekeur. Covariance trees for 2D and 3D processing. In *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, pages 556–563, Colombus, USA, June 2014.

[765] A. Newson, A. Almansa, M. Fradet, Y. Gousseau, and P. Perez. Towards fast generic video inpainting. In *(CVMP '13) Proceedings of the 10th European Conference on Visual Media Production*, London, UK, 2013.

Invited Talks

[766] H. Maître. Automatic appreciation of aesthetics in photography: Where are we going? In *Image Processing for Art Investigation (IP4AI)*, Ghent, Belgique, June 2018.

Patents

[767] A. Newson, A. Almansa, M. Fradet, Y. Gousseau, and P. Perez. Method for inpainting a target area in a target video. (European Patent Application EP 2 899 689 A1), July 2015.

[768] J. M. Nicolas, L. Kopp, F. Mosca, C. Cohen Bacrie, and Ch. Fraschini. Imaging device with image acquisition rate optimization. (20140024943), February 2014.

Chapter 16

MM

Multimedia

16.1 Presentation of the team

Team leader: Béatrice PESQUET-POPESCU (P, until December 2015), Marco CAGNAZZO (AP, since December 2015)

Faculty: Marco CAGNAZZO (AP), Gérard CHOLLET (Emeritous SRS, – 12/2016), Chloé CLAVEL (AP, 02/2013 – 12/2016), Cyril CONCOLATO (AP, – 08/2017), Frédéric DUFAUX (SRS, – 09/2016), Jean-Claude DUFOURD (FP, 04/2015 –), Attilio FIANDROTTI (AP, 04/2018 –), Jean LE FEUVRE (AP), Laurence LIKFORMAN SULEM (AP, – 12/2016), Jean-Claude MOISSINAC (AP), Catherine PELACHAUD (SRS, – 09/2016), Béatrice PESQUET-POPESCU (FP, – 01/2018), Marc SIGELLE (AP, – 11/2015), Giuseppe VALENZISE (JRS, – 10/2016).

Invited Professors: Michel KIEFFER (FP, Univ. ParisSud and L2S).

Sabbatical Professors: Tulay ADALI (09/2014 – 12/2014), Anup BASU (06/2015 – 08/2015), Philip DE LEON II (02/2016 – 05/2016), Anna ESPOSITO (08/2013 – 09/2013, 09/2014 – 10/2014, 09/2015, 09/2016), Marco FRATARCANGELI (03/2014 – 06/2014), Jonathan GRATCH (07/2016 – 07/2016), Ergina KAVALLIERATU (10/2015 – 02/2016), Benoit MACQ (09/2014 – 08/2015), Stacey MARSELLA (08/2013 – 09/2013).

Permanent Research Engineers: Aurélien DAVID (01/2017 –).

PostDocs, non-permanent Research Engineers: Angelo CAFARO (10/2014 – 08/2015), Sabrina CAMPANO (07/2013 – 05/2015), Francesca DE SIMONE (11/2012 – 12/2014), Nicolas DEROUINEAU (09/2016 – 05/2018), Yu DING (10/2014 – 03/2015), Brice DONVAL (12/2015 – 10/2016), Jean-Claude DUFOURD (04/2009 – 01/2014), Wei FAN (09/2015 – 08/2016), Jacques FELDMAR (08/2012 – 01/2013), Aniello FIENGO (12/2016 – 03/2017), Raffaele GAETANO (11/2010 – 05/2013), Matthieu GOLSENNE (01/2015 – 12/2015), Jérome GORIN (01/2013 – 11/2013), Claudio GRECO (07/2012 – 08/2013), Mahdi GUEFFAZ (09/2013 – 08/2014), Marie-Laure GUÉNOT (09/2015 – 12/2015), Jing HUANG (09/2014 – 03/2015), Vedad HULUSIC (09/2015 – 12/2017), Ahmed JELIJLI (03/2016 – 10/2017), Alpert KOZ (10/2011 – 07/2013), Samuel LERAH (01/2016 – 06/2016), Elie Gabriel MORA (03/2014 – 12/2014), Viet Than Trung NGUYEN (01/2012 – 06/2016), Radoslaw NIEWIADOMSKI (01/2009 – 04/2013), Ali OKER (02/2016 – 12/2016), Cagri OZCINAR (06/2015 – 05/2016), David PANOU (09/2015 – 12/2015), Giovanni PETRAZZUOII (02/2013 – 01/2015), André-Marie PEZ (11/08 – 09/2014), Pierre PHILIPPE (01/2011 – 03/2015), Emmanouil POTETSIANAKIS (11/2013 – 11/2015), Ken PREPIN (12/2013 – 03/2014), Andrei Jacob PURICA (07/2017 –), Brian RAVENET (02/2017 – 12/2017), Jean-Philippe RUIJS (06/2016 – 12/2017), Stephan SCHLOGL (11/2012 –

10/2013), Ahmed Rida SEKKAT (03/2016 – 12/2018), Araf SHAFIEI (10/2012 – 07/2013), Giovanni TROTTA (01/2015 – 12/2015), Giovanna VARNI (07/2015 – 07/2016).

Current PhD Students Anas EL RHAMMAD (10/2016), Theodoros Alexandros KARAGKIOULES (02/2017), Caroline LANGLET (11/2013 [1]), Iulia MITRICA (11/2016), Pavel NIKITIN (01/2017), Irina POLTAVCHENKO (01/2015 [1]), Emmanouil POTETSIANAKIS (12/2015), Kevin SANLAVILLE (11/2013 [1]), Hiba YOUSEF (06/2018), Shuo ZHENG (10/2015).

Defended PhDs theses Nassima BOUZAKARIA (12/2012 – 07/2017), Benoit BOYDJADIS (02/2014 – 02/2018), Marco CALEMME (12/2012 – 09/2016), Giovanni CHIERCHIA (10/2011 – 04/2015), Mathieu CHOLLET (11/2011 – 04/2015), Marc DECOMBAS (10/2010 – 07/2014), Yu DING (10/2010 – 09/2014), Antoine DRICOT (10/2013 – 03/2017), Aniello FIENGO (12/2012 – 11/2016), Nesrine FOURATI (11/2014 – 09/2016), Nadine GLAS (01/2013 – 09/2016), Vincent GROS (03/2012 – 09/2016), Jing HUANG (09/2009 – 02/2013), Sylwia-Julia HYNIEWSKA (11/08 – 03/2013), Thomas JANSSOONE (10/2014 – 12/2017), Maxim KARPUSHIN (10/2013 – 11/2016), Houssemeddine KHEMIRI (04/2010 – 09/2013), Paul LAUGA (10/2011 – 12/2015), Quoc-Anh LE (09/2009 – 06/2013), Irina MASLOWSKI (01/2015 – 01/2018), Marwa MEDDEB (02/2013 – 02/2016), Hamlet MEDINA (11/2010 – 11/2013), Pierrick MILHORAT (02/2012 – 12/2014), Elie Gabriel MORA (10/2011 – 02/2014), Irina Delia NEMOIAUNU (11/2009 – 06/2013), Florian PECUNE (11/2012 – 09/2016), Giovanni PETRAZZUOLI (11/2009 – 01/2013), Andrei Jacob PURICA (06/2014 – 06/2017), Aakanshka RANA (04/2015 – 03/2018), Brian RAVENET (03/2012 – 12/2015), Bertha-Helena RODRIGUEZ (01/2009 – 02/2013), Mira SARKIS (04/2013 – 10/2017), Arash SHAFIEI (08/2013 – 09/2013), Yafei XING (01/2012 – 01/2015), Emin ZERMAN (02/2015 – 01/2018).

Scientific Production Overview: Table 16.1 represents the overall scientific production between 2013 and 2018. The detailed bibliography is listed in the dedicated accompanying document. The number of **equivalent full-time researchers** in the considered period is **6.08**. Moreover, during the evaluation period, 35 PhD theses and 2 HDR (M. Cagnazzo and C. Concolato) have been defended within the MM team. In addition to the "classical" scientific publications listed in this table, the team has a strong activity in the MPEG standardization committees, with more than 170 contributions. Finally, the members of the MM team were editors of more than 80 standards and official MPEG documents.

Journals	Articles in Proceedings	Books and Book Chapters	Patents	Keynotes and Tutorials	Other Invited Talks	Habilitation thesis	Completed PhD
61	252	27	28	11	11	2	35

Table 16.1: Overall Scientific Production

16.2 Research activities

16.2.1 Overview

The Multimedia team's research concerns all the life cycle of multimedia documents and signals: acquisition, coding, transmission, transport, interactivity. More specifically, our activity can be divided into three main areas: compression and transmission of images and videos; interactive services delivery and orchestration; multimodal content and interactions.

As for the first research area, the team has an intense activity in **image and video compression**, in particular for the purpose of effective and reliable transmission. In the 2013-2108 period,

[1] Since January 2017 in the S2A team

the research has focused on the compression and transmission of emerging, immersive formats, such as for example multiview video, high-dynamic-range video, digital holography. Moreover, we had an intense activity in the field of robust video transmission, with a consistent set of contributions in the domains of distributed video coding, network coding and linear video coding. Along with these activities, the team kept working on more traditional yet still very relevant problems such as rate-distortion optimization, transcoding, super-resolution.

The increasing diffusion of immersive visual formats requires new solutions not only for compression, but also for the transmission architectures: to this end, our team has recorded an intense activity in interactive and adaptive **multimedia streaming**. Moreover, we have preformed a considerable amount of work on multimedia **orchestration**, which can be considered as the natural extension of the group activity on interactive services, since it concerns the case of multiple sources using multiple networks to deliver the stream to multiple screens.

Within the Multimedia team, research also targets various multimodal contents. Several subtopics can be enumerated in this area. A first one consists in developing hidden Markov models and recurrent neural network-based architectures to the problem of **handwriting recognition**. The Markov models have also been used for modeling wireless networks, while neural networks have also been employed for speech recognition. Another important field of activity is the one of **multimodal socio-emotional interaction**, where we have been working on different aspects of human-agent interactions.

It is worth noting that the Multimedia team has undergone a significant reorganization in the last years, due to the departure of CNRS researchers (4 people), retired and on-leave staffs (4 people) and the change of team (2 people). The current size of the team is therefore 5 people, working on the areas of multimedia compression (Sect. 16.2.2), and interactive services delivery and orchestration (Sect. 16.2.3). The equivalent full-time research staff is 6.08 in average in the evaluation period, and 2.5 at the end of it.

The gross revenue of the team during the evaluation period is slightly more than 1.1M€ per year, achieved through almost 70 contracts, projects and subventions.

16.2.2 Compression and transmission of visual data

Faculty : Marco Cagnazzo, Attilio Fiandrotti (from Apr. 2018), Béatrice Pesquet-Popescu (until Jan. 2018), Frédéric Dufaux (until Oct. 2016), Giuseppe Valenzise (until Nov. 2016).
Average equivalent full-time research staff: 2.18.

Video compression: Rate-distortion optimization, rate control, semantic coding. One of the main research areas of the Multimedia team is video compression, which consists in looking for reduced-size representations of a video signal, submitted to several and often conflicting constraints, such as preserving a given quality, being robust with respect to losses, complying to delay and complexity requirements. One of the most powerful tools in this context is the rate-distortion model [802, 786], which allows to express the relation between quality and rate in an analytic form. In turns, this makes possible to find optimal solutions of the rate-distortion [775] and rate control problems [793], in particular when coupled with convex optimization methods [797]. This approach based on rate-distortion modeling and convex optimization allows also to deal with related problems such as video super-resolution [811] and image recovery [792]. We also worked on other subjects close to the video compression area, namely semantic video coding [789], joint coding and encryption of video [776], and video transcoding [772].

Immersive video: multiview formats, integral imaging, view synthesis, hologram compression, high-dynamic-range video, quality, features. Besides the "traditional" video compression activity, the team has focused on the emerging immersive formats such as 3D video (multiview, multiview+depth, integral imaging) [807], high-dynamic-range (HDR) video [805], and holograms [806]. We highlight that [807, 805, 806] are books published by the team members during the evaluation period. As for 3D video, we have worked on several aspects, ranging from improved tools for coding [796, 785, 794, 782], transmitting [795, 787] and subjective quality evaluation [788],

while for digital holography, our focus was essentially on compression [798, 790, 812, 769]. As for the HDR format, our contributions were mainly about tone mapping [818], coding and quality evaluation [770, 771, 774, 799]. Quality evaluation on generic visual formats is a strong research area for our team [778]. Finally, the new immersive formats allow to better deal with classical problems of computer vision. Among them, the Multimedia team has proposed new and effective keypoint detection algorithms based on the depth information [779].

Network coding, distributed video coding, linear video coding. The Multimedia team has also worked at the problem of compressed representations for effective video transmission. At the beginning of the period, we had an intense activity on Distributed Video Coding (DVC), which is a coding paradigm that departs from traditional approaches and potentially allows low-complexity encoders and enhanced error robustness. Our contributions in this area are related to effective DVC for immersive formats [794] and effective motion representation [803].

Another area at the crossing of coding and transmission is network coding (NC). In NC the intermediate nodes of a network do not simply forward received packets, but are allowed to process them before retransmission. In particular, in Linear Network Coding (LNC), they forward linear combinations of received packets. In this framework, it is possible to achieve increased robustness of packet transmission, which is particularly beneficial for video transmission applications. Our contributions are mostly related to the application on immersive formats [787], but we also considered some more theoretical problems [795]. Finally, we recently started a research activity in the area of Linear Video Coding (LVC). LVC is a special case of cross-layer channel-source coding for video, where all the non-linear parts of traditional video compression and transmission systems are dropped. This is particularly suitable for video broadcast over non-reliable channels, because in this case LVC automatically adapts to the channel quality of each user. This recent framework is gathering much attention from researchers, and our contributions are related to power allocation [819, 813] and dimensionality reduction [828].

Most relevant projects: CR IDF **Austral** (387k€), Bilateral **Sentinel2** (160k€), Digitéo **VIEW** (109k€), ANR **Suricate** (180k€), Eureka Eurostar **TofuTV** (100k€), ANR **Nevex** (200k€), IDF **PleinPhar** (390k€).

16.2.3 Interactive Services Delivery and Orchestration

Faculty: Jean Le Feuvre, Cyril Concolato (until August 2017), Jean-Claude Moissinac, Jean-Claude Dufourd.
Average equivalent full-time research staff: 1.70.

The other main research area of the Multimedia team is media transport and real-time architectures, which consists in optimizing delivery of multimedia content for consumption on a variety of environments: device capabilities, network capacity, service types (2D video, 360 video, *etc.*), user preferences. The team has focused on several aspects of multimedia delivery: efficient delivery over HTTP infrastructures ("Over The Top" OTT delivery), efficient delivery for very large videos (panoramas, 360 video at resolution 8k and more) and multi-path delivery over hybrid networks infrastructures (typically, mix of broadcast and broadband).

For OTT delivery, we have demonstrated in [832] [825] that low-latency delivery of HTTP streaming content such as MPEG-DASH was achievable over existing network infrastructures with very few additional cost. This work was introduced in the MPEG-DASH (MPEG Dynamic Adaptive Streaming over HTTP) standard and its follow-up CMAF profile, which has been used by HLS, SmoothStreaming and MPEG-DASH providers. We have also optimized MPEG-DASH startup latency [826], and the result of this work has been integrated in MPEG-DASH broadcast profiles. We have finally demonstrated MPEG-DASH transmission of media and associated timed meta-data [816] [827] [830], now part of an on-going standard activity at MPEG.

As for large resolution video distribution, we have shown [773] [823] [822] the possibility of mixing several parts of different video bitstreams encoded with the motion-constrained tiling

mechanisms provided by H.265/HEVC (High Efficiency Video Coding, the most recent MPEG standard), allowing spatial adaptation of the content for various use cases while using a single decoder at the receiving end. We have demonstrated that this approach is suited for scenarios such as 360 video, where the quality should be enhanced for the viewer region-of-interest (ROI), and that it enables reducing storage and compression costs by avoiding encoding and/or delivering each possible viewpoints. Our work was integrated in the ISO Base Media File format of MPEG and is used as a base for the upcoming OMAF standard for 360 video. This work has also been integrated in the HEIF (High Efficiency Image Format) image format, a flexible image format designed for storage of still images, burst sequences, HDR multi-exposition, animated images. The HEIF was developed at MPEG based on works from Apple, Nokia, Telecom ParisTech, Canon and Sony, and is now deployed on various devices (iOS, OSX, Android, Windows and many open source tools exist for Linux).

For multi-path hybrid delivery, we have shown the possibility to reach frame-accurate synchronization on distribution networks mixing both broadband and broadcast links, and have demonstrated this using scalable services (HD to 4K) and 3D services (mono to stereo). The work has been standardized as extensions to MPEG-2 Transport Stream, and is used by DVB (Digital Video Broadcast) for their Companion Screen and Services (DVB-CSS) standard.

Finally, the team has been actively upgrading its open-source platform GPAC (http://gpac.io) implementing all its research results, and has contracted two private licenses on GPAC and initiated the creation of the company MotionSpell in order to industrialize and support GPAC (http://gpac-licencing.com). This activity also integrates other work of the team on "Ultra HD Phase 2" services, including High-Dynamic-Range / High-Frame-Rate / 4K playback and on next-generation 3G broadcast (eMBMS), and complements the other dissemination activities of the team [784, 810, 808, 809, 835].

Most relevant projects: Eureka CELTIC **H2B2VS** (60k€), E.U. **KIC EIT ICT Labs** (137k€), D.G.E. **AUSTRAL** (387k€), D.G.E. **M44G** (129k€), D.G.E. **M44GEvo** (136k€), D.G.E. **OptiSat2** (138€), D.G.E. **4Ever** (206k€), D.G.E. **4Ever-2** (302k€), D.G.E. **AdicTV** (157k€), D.G.E. **Live360TV** (180k€), D.G.E. **ConvergenceTV** (203k€)

16.2.4 Multimodal Content and Interaction

Faculty: Chloé Clavel (until december 2016), Laurence Likforman (until december 2016), Catherine Pelachaud (until december 2016), Gérard Chollet (until december 2016), Marc Sigelle (until december 2015).
Average equivalent full-time research staff: 2.19.

Written interactions We have been working on handwriting recognition systems. Handwritten shapes are highly variable and language resources (dictionary and language modeling) are necessary to direct recognition. Stochastic and deep learning approaches have been proposed for modeling character shapes. We started from HMMs systems and then shifted to recurrent neural networks (RNNs), exploiting the so-called Bidirectional Long Short Term Memory (BLSTM) RNN architecture, but still using hand-designed features. We have applied the BLSTM architecture to the recognition of handwritten mails (Rimes database) in [902]. In [901], we exploit the very large and freely available Wikipedia corpus in order to obtain dynamic dictionaries on the fly. This allows our systems to recognize out-of-vocabulary words. In contrast with preprocessing approaches, we have also exploited hidden factors in handwriting, such as vertical scale and stroke width, to improve handwriting recognition through modelling [920]. This approach was included in both HMM and RNN-based recognition systems.

We started a deep learning activity in [956] inspired by Spatial Transformer Networks (STNs). The approach, referred to as Tied Spatial Transformer Networks (TSTNs), consists of training a system which combines a localization CNN and a classification CNN whose weights are shared. The localization CNN is used for predicting an affine transform for the input image, which is then processed according to the predicted parameters and passed through the classification CNN. We have conducted initial experiments on the cluttered MNIST dataset of noisy digits, comparing

the TSTN and STN with identical configurations of trainable parameters, but untied, as well as the classification CNN only, applied to the unprocessed images. In all these cases, we obtain better results using the TSTN. We conjecture that the TSTN provides a regularization effect, as compared to untied STNs. Further experiments seem to support this hypothesis.

We participated in several international challenges, including the NIST OpenHart 2013 competition on the recognition of Arabic handwritten texts.

Multimodal socio-emotional interaction We have been working on different aspects of human-agent interactions : the generation of agent's socio-emotional behavior (embodied conversational agents and robots), the development of interaction strategies and the detection of user's socio-emotional behavior. Both reasoning and machine learning models have been built to improve the naturalness and the fluidity of human-agent interaction. New models based on random forests [781], conditional random fields and hidden markov models [833] have been built for the generation of agent's gestures and facial expressions corresponding to a socio-emotional behavior. Knowledge-based approaches have been used for the detection of the user's sentiment and opinion during their interaction with the agent [903]. Formal logic has also been used for the modelling of the social relation between the agent and the user [820].

Two other fields of activity shall be mentioned here. The first is related to the transfer of image processing-related methodologies (such as Markov Random Fields, Bayesian networks, Graph Cuts in relationships with Statistical Physics) to the modeling and stochastic optimization of **wireless networks** [800, 777] The second is related to **speech processing and recognition** [804, 817] and biometry [834]. These activities were conducted by now-retired researchers.

Most relevant projects: PIA **AVATAR A1-1** (280k€), E.C. **TARDIS** (271k€), D.G.E. **Play Serious** (249k€), OSEO **ARHOME** (246k€), D.G.E. **EMMA** (239k€), ANR **IMMEMO** (181€), ITESOFT **Reconnaissance de mots cursifs** (180k€), E.C. **COMPANIONABLE**, (150k€), ANR **SURFONHERTZ** (148k€), ANR **VASSIST** (137k€), D.G.E. **MaClasse3.0** (129k€) **Intelligence emotionnelle** (121k€), ANR **ORIGAMI2** (107k€), D.G.E **ANIPEV 1** (106k€), Chaire **MODIM** (86k€).

16.2.5 Scientific Highlights:

- Organization of Workshops and Conferences
  - The MM team was involved in the organization of the **2014 IEEE International Conference on Image Processing** (IEEE ICIP 2014). The general co-chair (B. Pesquet-Popescu), the vice-general chair (F. Dufaux), the Award co-chair, the Electronic Media chair, and the Local Arrangement chair were member of the Multimedia team. The 2014 edition was the 21st in the series, and with more than 1700 attendees it has set a participation record in the history of IEEE ICIP.
  - The MM team was also involved in the organization of the Media Synchronization and Hybrid Delivery workshop (2014). The workshop took place during the 110th MPEG meeting and gathered more than 200 attendees.
  - B. Pesquet-Popescu et F. Dufaux organized the symposium on Perception Inspired Multimedia Signal Processing Techniques at IEEE GlobalSIP 2014.
  - C. Pelachaud has (co-)chaired the conferences "ACM International conference on Multimodal Interaction ICMI, November 2016, Tokyo"; "ACM Siggraph conference, Motion in Games MIG'15"; "International Conference on Affective Computing and Intelligent Interaction, ACII 2013"; and "13th International Conference on Intelligent Virtual Agents - IVA 2013".
- Contribution to Scientific Societies
  - M. Cagnazzo: IEEE Signal Processing Society: Image, Video, Multidimensional Signal Processing (IVMSP) Technical Committee (Jan. 2018-Jan. 2021)

  - M. Cagnazzo: Board (*Conseil d'Administration*) of the Research Group in Signal and Image Processing (*Groupe de Recherche en Traitement du Signal et de l'Image, GRETSI*)
  - F. Dufaux: IEEE Signal Processing Society: Image, Video, Multidimensional Signal Processing (IVMSP) Technical Committee (2013-2018)
  - F. Dufaux: IEEE Signal Processing Society: Multimedia Signal Processing (MMSP) Technical Committee (2012-2017)
  - F. Dufaux: EURASIP Special Area Team on Visual Information Processing (SAT-VIP) (2015-present)
  - C. Pelachaud: member of executive committee of Humaine association
  - C. Pelachaud: member of conference Board of ICMI

- Editor-in-Chief of journals
  - F. Dufaux, Elsevier Signal Processing Image Communications (2010-present)

- Associate editors of journals
  - M. Cagnazzo: IEEE Transactions on Circuits and Systems for Video Technology, IEEE Signal Processing Letters, Elsevier Signal Processing, Elsevier Signal Processing Image Communications
  - C. Pelachaud: International Journal of Human Computer Studies, ACM Transactions on Interactive Intelligent Systems, IEEE Transactions on Affective Computing
  - B. Pesquet-Popescu: IEEE Transactions on Image Processing, IEEE Transactions on Multimedia, IEEE Transactions on Circuits and Systems for Video Technology, Elsevier Image Communication
  - G. Valenzise: IEEE Transactions on Circuits and Systems for Video Technology, Elsevier Signal Processing Image Communications

- Books
  - **Frederic Dufaux**, **Beatrice Pesquet-Popescu**, **Marco Cagnazzo**. Emerging Technologies for 3D Video: Creation, Coding, Transmission and Rendering. Wiley, 2013
  - Yafei Xing, Mounir Kaaniche, **Beatrice Pesquet-Popescu**, **Frederic Dufaux**. Digital Holographic Data Representation and Compression. Academic Press, 2015
  - **Frederic Dufaux**, Patrick Le Callet, Rafal Mantiuk, Marta Mrak. High Dynamic Range Video: from Acquisition to Display and Applications. Academic Press, 2016
  - **L. Likforman-Sulem** and E. H. Barney Smith, Reconnaissance des Formes, Théorie et Pratique sous matlab, Collection Technosup, Éditions Ellipses, 2013.

- Awards
  - **Personal awards**
    - IEEE Fellowship, B. Pesquet-Popescu
    - EURASIP Fellowship, B. Pesquet-Popescu
    - IEEE Fellowship, F. Dufaux
    - Doctor *Honoris Causa* (Université de Genève), C. Pelachaud
    - ACM – SIGAI Autonomous Agents Research Award, C. Pelachaud
  - **Project awards**
    - Awards: Prix international des Trophées 2014 Images et Réseaux (OptiSaT2)
    - Prix "Loading the Future 2015" Images et Réseaux (4Ever project)
    - NAB Technology Innovation Award 2016 (4Ever2 project)
    - Celtic+ Excellence Award in Multimedia (H2B2VS)

  - ∗ NAB Technology Innovation Award 2018 (ConvergenceTV)
  - **Thesis awards**
    - ∗ Fondation Telecom Thesis Award 2014 (Olivier Morillot)
    - ∗ Fondation Telecom Thesis Award 2017 (Maxim Karpushin)
    - ∗ 1st Prix at Thesis Pitch Competition for Nokia Bell Labs Student Day (A. Dricot, 2016).
  - **Paper awards**
    - ∗ Best Paper Award at the International Conference IVA'14 [831]
    - ∗ Best Paper Award at the International Conference IVA'15 [829]
    - ∗ Best Paper Award at the International Conference on 3D Imaging [824].
    - ∗ NOSSDAV'17 Best Paper Award [814]
    - ∗ Best student paper award at SPIE Photonics Europe 2018 [812]
    - ∗ Applied Optics Editor's Pick [769]

- Significant Contracts with Industrials, Chairs and Projects
  - Chair MODIM (C. Pelachaud)
  - Project **Data et Musée**, 410k€, Project **Plein Phare**, 390k€, Project **Austral**, 387k€, 3 European Commission Projects: **MPAT**, 275k€; **TARDIS**, 271k€; **COMPANIONABLE**, 150k€; Other European projects: 2 Eureka projects

- Industrial Impact
  - GPAC platform: 8000+ visitors/month, 30000+ page views, 2000+ downloads/month
  - Two private licenses on GPAC software
  - Creation of MotionSpell, company in charge of industrialization and support of GPAC (http://gpac-licencing.com)
  - Collaboration with the IRT "BCom" (M. Cagnazzo and B. Pesquet-Popescu, 15% of research time)
  - 33 patents, among which: "Method, device, and computer program for encapsulating scalable partitioned timed media data" [837] and "Method of handling packet losses in transmissions based on dash standard and flute protocol" [836].
  - Standardization: more than 170 contributions to MPEG

- Contribution to Masters
  - Master Multimedia Networking (UPSay): Responsability and teaching in 5 modules.

16.3 SWOT analysis

In sight of the new organization of the Multimedia team, the SWOT analysis is only provided for the research topics of **Compression and transmission of visual data** and **Interactive Services Delivery and Orchestration** As for **Multimodal socio-emotional interaction**, the researchers working on this topic have now moved to S2A team, where the related SWOT analysis can be found.

16.3.1 Strength

- **Compression and transmission of visual data** The team has a long and successful record of publications in this area. During the years, it has built a network of collaborations with many top-level scientific partners, both in France (CentraleSupélec, Inria Rennes, Univ. Nice, Polytech'Nantes, Univ. Valenciennes) and abroad (University of Southern California, EPFL, National Institute of Informatics - Tokyo, Vrije University Bruxelles, University of Padoua,

University of Naples, University of Rome, ...). Likewise, we have several industrial partners, with long-term or recent collaborations: Orange Labs, Huawei, Zodiac. This network of excellent partners is a strong premise for setting up ambitious collaborative projects, at European and national level. It also assure a regular flow of "CIFRE" PhD grants.

The growing activity in this area has resulted in a new associate professor position in Immersive Video (A. Fiandrotti). This constitutes an excellent opportunity to feed the growth of the team's research activities in this area and to overcome the difficulties related to the departure of CNRS members of the team.

- **Interactive Services Delivery and Orchestration** The team has a strong expertise in multimedia delivery with a worldwide visibility, with a wide collaboration network of universities (INSA Rennes, Telecom SudParis, University of Klagenfurt, EPFL, VTT Finland, RWTH Aachen University...) and industrial partners (Canon, Orange, Ateme, TDF, Enensys, Expway, Netflix, Samsung...). This network allows the team to take its place in many research collaborations. Second to that, the visibility of its GPAC platform identifies the team as a well-known expert and valuable partner for reseach and prototyping activities, thereby naturally increasing its collaboration network, ensuring a regular flow of projects and "CIFRE" PhD grants.

16.3.2 Weakness

- **Compression and transmission of visual data**. The departure of the CNRS members (F. Dufaux and G. Valenzise) along with the leave of B. Pesquet-Popescu has an impact on the size of the team. This is partially mitigated on one hand by the fact that the team keeps collaborating with the former CNRS members; and on the other by the recruitement of a new associate professor in 2018 (A. Fiandrotti).
- **Interactive Services Delivery and Orchestration** The departure of C. Concolato also has an impact on the activity, both in terms of research and teaching. Hiring a similar profile will be necessary to maintain the strength of the team at its current level.

16.3.3 Opportunities

- **Compression and transmission of visual data**.

  The interest of the major economic players in the area of immersive video (Facebook, Google just to mention two among the largest) leads to an increased visibility of the original results in the field and could attract new funding for our group. Immersive formats are also at the heart of the issues addressed in the IRT B-Com, to which our group is associated. Collaborations in this context take place, through a project that allowed the financing of two PhD theses as well as the possibility of benefiting from the expensive equipment and facilities made available to us and maintained by B-Com.

  More in general, we expect an increasing interest in video coding in the next few years, both from the industrial and academic worlds. This is due to 1) the emergence of the new, immersive formats, that need suitable compression methods and 2) the development of new compression standards (from MPEG and from industrial partnerships such as the Open Media Alliance).

- **Interactive Services Delivery and Orchestration** The deployment of ATSC-3.0 in the US opens the road for strategic shifting of traditionnal broadcast, potentially replacing historical MPEG-2 Transport Stream in the DVB world in the next decade. We are already partnering with industrials in the sector (TeamCast, Enensys) and foresee a growing activity on this topic in the years to come.

  The growing interest of major actors (Facebook, Google, Apple, Samsung, Qualcomm) in 3DoF and 6DoF entertainment and the national and EU research programs associated to this is a strong opportunity for the team, given its large background on the topic (BIFS/LASeR/VRML). We already participate in the upcoming MPEG-I standardization effort on immersive media and foresee collaborations on the topic in the year to come.

Finally, the complexity of interactive services keeps increasing with the diversity of sources, networks and devices, opening new research topics in media orchestration such as multi-screen applications and migration or UGC-based interactive presentations, for which the team has a strong expertise through its work in MPEG (BIFS, LASeR) and W3C (SVG, HTML5).

16.3.4 Threats

- **Compression and transmission of visual data**. An important part of the research in this field is likely to migrate towards the big industrial groups, with a stronger and stronger attraction for the students towards these companies, to the detriment of the PhD tracks and academic careers. Another risk is related to the increased need for expensive computing resources related to the new immersive formats.
- **Interactive Services Delivery and Orchestration**. The risks are multiple: firstly, the possibility of seeing a major part of the research in this field undergone within large industrial groups, with few or no feedback to the academic community, decreasing the attractiveness for this academic path hence our number of students; secondly, the media industry, especially the broadcast one, is known for its strong inertia towards the new formats, and although the demand for new technologies is very strong, their commercial deployment is far from assured which may impact the amount of private/national/EU funding.

16.4 Scientific project for the next five years

In sight of the new structure of the team, some research topics will be discontinued (retirement or departure of the researchers): this is the case of the Multimodal Content and Interaction area.

Compression and transmission of visual data

Today, we are witnessing the rise of new **immersive video formats**, such as 360 video, augmented reality, (super-)multi-view and digital holography. Also, more traditional formats are evolving into more realistic and immersive forms, such as *high dynamic range* (HDR), ultra-HD (8K, 12K, and beyond), *high frame rate* (HFR). These immersive formats are a very active research topics and receive a keen interest from the industrial world: among the major industrial groups that have invested in this area we can mention Facebook, Google / Youtube, Huawei. Even now classic platforms like Netflix and Amazon will no longer be deprived of immersive formats. In parallel, standardization is continuing and new video coding standards suitable for immersivity are expected for 2019/2020 (H.266, MPEG-I).

Mastering this field is therefore a strategic goal of the team, in particular two persons (M. Cagnazzo and A. Fiandrotti) will focus their research on it. The team will also try to recruit further permanent staff in order to strengthen its workforce. The area of immersive video represents the evolution of one of the team's iconic research axes, that is, **video coding**. Building on experience and international notoriety, we intend to continue to conceive effective and innovative methods of visual information representation. To this end, we will also take advantage from historical partnerships and collaborations (e.g., L2S, Univ. Paris-Sud, Inria Rennes, INSA Rennes, Polytech'Nantes, UNSA, Univ. Valencienne, Orange, Ateme, Vitec, EPFL, IIT, Universities of Naples and Padua, Polytechnical shools of Milan and Turin, ...).

Moreover, as in many fields related to image and video processing, compression can take advantage from the modelling power of neural networks (NN). We intend to strengthen our skills and knowledge in this field, in order to be able to profitably use NN's in compression. To this end, the latest recruitment will help us. Moreover, the team has just launched a study group named "Machine Learning for Compression" `https://mlcompr.wp.imt.fr/` which in a few weeks has gathered the interest of several researchers from LTCI but also other labs (both academic and industrial) in the Parisian area (Paris 5, Paris 13, Supélec, Orange, Vedecom, Vitec) and beyond (Univ. Poitiers, Univ. Valencienne, Insa Rennes, RWTH Aachen).

Finally, building on the existing skills and knowledge, and on those that we are developing, we intend to meet the new challenges associated with immersive formats: to ensure a high level qual-

ity of experience while reducing the coding rate; to obtain the best compromise between storage, transmission and interactivity requirements; to guarantee an excellent robustness against channel losses.

Interactive Services Delivery and Orchestration

This last point makes a natural link with the second strategic objective of the team, which concerns formats transmission. The diffusion of new multimedia formats (ultra HD, HFR, immersive video) does not only require innovations in terms of coding, but also poses new challenges for broadcast architectures: efficiency and robustness of the transmission, migration with the IP broadband world for content customization or redistribution in broadband network (home network, WiFi hot-spot, micro-cells), fine synchronization of broadcast networks and broadband to allow a better optimization of mass media delivery according to the terminal park. Recent standards such as MPEG-DASH or MMT (MPEG Media Transport), in which the group has been heavily involved, are the first steps towards a re-architecture of MPEG-2 Transport Stream-based broadcast networks. New advances (eg: Linear Video Coding, ATSC ROUTE) show the extent of the issues still to be covered; we will also tackle the mass delivery of interactive content over upcoming IP protocols such as HTTP/2 and QUIC. The period 2018-2022 is likely to define broadcast technologies for the next 20 years, and here again domain control will enable new and effective methods to be proposed and contribute to standardization and associated patents.

The orchestration is a natural extension of the group's activities on interactive services. Until recently, interactive services were rendered on a single device and were processing information coming from a single source, which most of the time is a camera. This configuration is related to as linear media. However, modenr interactive services encompass a multitude of sources with varying characteristics and associated meta-data and targets multiple concurrent screens, using a multitude of networks. In this context, known as "triple multitude", the team, based on its expertise in interactive services, has the objective of proposing innovative solutions in the domains of User Generated Content, multi-screen applications (DVB-CSS, MPEG MORE) and immersive rendering (MPEG-I), evaluating both the efficiency and the quality of user experience of the proposals.

16.5 Scientific production (selection)

Articles in Journals

[769] A. El Rhammad, P. Gioia, A. Gilles, M. Cagnazzo, and B. Pesquet-Popescu. Color digital hologram compression based on matching pursuit. *Applied Optics*, 13, May 2018.

[770] Y. Liu, N. Sidaty, W. Hamidouche, O. Déforges, G. Valenzise, and E. Zerman. An adaptive quantizer for high dynamic range content: Application to video coding. *IEEE Transactions on Circuits and Systems for Video Technology*, 2018.

[771] E. Zerman, G. Valenzise, and F. Dufaux. An extensive performance evaluation of full-reference hdr image quality metrics. *Quality and User Experience*, 2(1), April 2017.

[772] E. G. Mora, M. Cagnazzo, and F. Dufaux. Avc to hevc transcoder based on quadtree limitation. *Springer Multimedia Tools and Applications*, 76(6):8991–9015, March 2017.

[773] C. Concolato, J. Le Feuvre, F. Denoual, F. Mazé, E. Nassor, N. Ouedraogo, and J. Taquet. Adaptive streaming of hevc tiled videos using mpeg-dash. *IEEE Transactions on Circuits and Systems for Video Technology*, March 2017.

[774] V. Hulusic, K. Debattista, G. Valenzise, and F. Dufaux. A model of perceived dynamic range for hdr images. *Signal Processing: Image Communication*, 51:26–39, February 2017.

[775] A. Fiengo, G. Chierchia, M. Cagnazzo, and B. Pesquet-Popescu. Rate allocation in predictive video coding using a convex optimization framework. *IEEE Transactions on Image Processing*, 26(1), January 2017.

[776] B. Boyadjis, C. Bergeron, B. Pesquet-Popescu, and F. Dufaux. Extended selective encryption of H.264/AVC (CABAC) and HEVC encoded video streams. *IEEE Trans. on Circ. Syst. for Video Tech.*, November 2016.

[777] M. Minelli, M. Ma, M. Coupechoux, J.-M. Kélif, M. Sigelle, and Ph. Godlewski. Uplink energy-

delay trade-off under optimized relay placement in cellular networks. *IEEE Transactions on Mobile Computing*, 15(9):2376–2387, September 2016.

[778] N.K. Kottayil, I. Cheng, F. Dufaux, and A. Basu. A color intensity invariant low level feature optimization framework for image quality assessment. *Signal, Image and Video Processing*, 10(6): 1169–1176, September 2016.

[779] M. Karpushin, G. Valenzise, and F. Dufaux. Keypoint detection in RGBD images based on an anisotropic scale space. *IEEE Transactions on Multimedia*, 18(9):1762–1771, September 2016.

[903] C. Langlet and Ch. Clavel. Grounding the detection of the user's likes and dislikes on the topic structure of human-agent interactions. *Knowledge-Based Systems*, 106:116–124, August 2016.

[781] N. Fourati and C. Pelachaud. Perception of emotions and body movement in the emilya database. *IEEE Transactions on Affective Computing*, July 2016.

[782] Th. Maugey, G. Petrazzuoli, P. Frossard, M. Cagnazzo, and B. Pesquet-Popescu. Reference view selection in DIBR-based multiview coding. *IEEE Transactions on Image Processing*, 25(4):1808–1819, April 2016.

[904] Ch. Clavel and Z. Callejas. Sentiment analysis: from opinion mining to human-agent interaction. *Affective Computing, IEEE Transactions on*, 7(1):74–93, March 2016.

[784] O. van Deventer, H. Stokking, M. Hammond, J. Le Feuvre, and P. Cesar. Standards for multi-stream and multi-device media synchronization. *IEEE Communications Magazine – Communications Standards Supplement*, pages 16–21, March 2016.

[785] A. Purica, E. G. Mora, B. Pesquet-Popescu, M. Cagnazzo, and B. Ionescu. Multiview plus depth video coding with temporal prediction view synthesis. *Transactions on Circuits and Systems for Video Technology Experience*, 26(2):360–374, February 2016.

[786] S. Li, C. Zhu, Y. Gao, Y. Zhou, F. Dufaux, and M.-T. Sun. Lagrangian multiplier adaptation for rate-distortion optimization with inter-frame dependency. *IEEE Trans. on Circ. Syst. for Video Tech.*, 26(1):117–129, January 2016.

[787] C. Greco, I. D. Nemoianu, M. Cagnazzo, and B. Pesquet-Popescu. Rate-distortion optimized multiview streaming in wireless environment using network coding. *EURASIP Journal of Advances on Signal Processing*, 2016, January 2016.

[788] A. Dricot, J. Jung, M. Cagnazzo, B. Pesquet-Popescu, F. Dufaux, P. T. Kovács, and V. K. Adhikarla. Subjective evaluation of super multi-view compressed contents on high-end light-field 3D displays. *Signal Processing: Image Communication*, 39(B):369–385, November 2015.

[789] M. Décombas, Y. Fellah, F. Dufaux, B. Pesquet-Popescu, F. Capman, and E. Renan. Seam carving modeling for semantic video coding in security applications. *APSIPA Trans. on Signal and Information Processing*, 4:1, August 2015.

[790] Y. Xing, M. Kaaniche, B. Pesquet-Popescu, and F. Dufaux. Adaptive non separable vector lifting scheme for digital holographic data compression. *Applied Optics*, 54(1):A98–A109, January 2015.

[901] C. Oprean, L. Likforman-Sulem, A. Popescu-Belis, and Ch. Mokbel. Handwritten word recognition using web resources and recurrent neural networks. *IJDAR*, January 2015.

[792] G. Chierchia, N. Pustelnik, B. Pesquet-Popescu, and J.-Ch. Pesquet. A non-local structure tensor based approach for multicomponent image recovery problems. *IEEE Transaction on Image Processing*, 23(12):5531–5544, December 2014.

[793] M. Meddeb, M. Cagnazzo, and B. Pesquet-Popescu. Region-of-interest-based rate control scheme for high-efficiency video coding. *APSIPA Transactions on Signal and Information Processing*, 3(16): 18, December 2014.

[794] G. Petrazzuoli, Th. Maugey, M. Cagnazzo, and B. Pesquet-Popescu. Depth-based multiview distributed video coding. *IEEE Transactions on Multimedia*, 16(7), November 2014.

[795] C. Greco, I. D. Nemoianu, M. Cagnazzo, and B. Pesquet-Popescu. On a hashing-based enhancement of source separation algorithms over finite fields for network coding perspectives. *IEEE Transactions on Multimedia*, 16(7), November 2014.

[796] E. G. Mora, J. Jung, M. Cagnazzo, and B. Pesquet-Popescu. Initialization, limitation and predictive coding of the depth and texture quadtree in 3d-hevc video coding. *IEEE Transactions on Circuits and Systems for Video Technology*, 24(9):1554–1565, September 2014.

[797] G. Chierchia, N. Pustelnik, J.-Ch. Pesquet, and B. Pesquet-Popescu. Epigraphical projection and proximal tools for solving constrained convex optimization problems. *Signal, Image and Video Processing*, July 2014.

[798] Y. Xing, M. Kaaniche, B. Pesquet-Popescu, and F. Dufaux. Vector lifting scheme for phase-shifting holographic data compression. *Optical Engineering*, 53(11):112312, May 2014.

[799] A. Koz and F. Dufaux. Methods for improving the tone mapping for backward compatible high

dynamic range image and video compression. *Elsevier Signal Processing: Image Communication*, 29(2), February 2014.

[800] M. Minelli, M. Ma, M. Coupechoux, J.-M. Kélif, M. Sigelle, and Ph. Godlewski. Optimal relay placement in cellular networks. *IEEE Transactions on Wireless Communications*, 13(2):998–1009, February 2014.

[902] O. Morillot, L. Likforman-Sulem, and E. Grosicki. New baseline correction algorithm for text-line recognition with bidirectional recurrent neural networks. *Journal of Electronic Imaging*, 22(2), July 2013.

[802] M. Kaaniche, A. Fraysse, B. Pesquet-Popescu, and J.-C. Pesquet. A bit allocation method for sparse source coding. *IEEE Trans.on Image Processing*, February 2013.

[803] A.-B. Abou-Elailah, F. Dufaux, J. Farah, M. Cagnazzo, and B. Pesquet-Popescu. Fusion of global and local motion estimation for distributed video coding. *IEEE Trans. on Circ. Syst. for Video Tech.*, 23(1):158–172, January 2013.

[804] H. Khemiri, D. Petrovska-Delacrétaz, and G. Chollet. Automatic detection of known advertisements in radio broadcast with data-driven ALISP transcriptions. *Multimedia Tools and Applications*, 62 (1):35–49, January 2013.

Books

[805] F. Dufaux, P. Le Callet, R. Mantiuk, and M. Mrak. *High Dynamic Range Video - From Acquisition, to Display and Applications*. Academic Press, 2016.

[806] Y. Xing, M. Kaaniche, B. Pesquet-Popescu, and F. Dufaux. *Digital Holographic Data Representation and Compression*. Academic Press, 2015.

[807] F. Dufaux, B. Pesquet-Popescu, and M. Cagnazzo. *Emerging Technologies for 3D Video*. Wiley, 2013.

Book Chapters

[808] J. Le Feuvre and C. Concolato. *MediaSync - Handbook on Multimedia Synchronization*, chapter 18: Synchronization in MPEG-4 Systems. Springer, 2017.

[809] J. Le Feuvre and Y. Mathieu. *Emerging Technologies for 3D Video*, chapter 23 : Graphics Composition for Multiview Displays. Wiley, 2013.

[810] C. Greco, I. D. Nemoianu, M. Cagnazzo, J. Le Feuvre, F. Dufaux, and B. Pesquet-Popescu. *Academic Press Library in Signal Processing Volume 5: Image and Video Compression and Multimedia*, chapter Multimedia Streaming, pages 1–80. Elsevier, 2013.

Articles in Conference Proceedings

[811] B. Boyadjis, A. Purica, B. Pesquet-Popescu, and F. Dufaux. Video enhancement with convex optimization methods. In *ICASSP*, April 2018.

[812] A. El Rhammad, P. Gioia, A. Gilles, M. Cagnazzo, and B. Pesquet-Popescu. View-dependent compression of computer-generated hologram based on matching pursuit. In *SPIE Photonics Europe 2018 - Optics, Photonics and Digital Technologies for Imaging Applications*, Strasbourg, France, April 2018.

[813] S. Zheng, M. Kieffer, and M. Cagnazzo. Precoding matrix desing in linear video coding. In *IEEE International Conference on Acoustics, Speech and Signal Processing*, Calgary, Canada, April 2018.

[814] Th. Karagkioules, C. Concolato, D. Tsilimantos, and S. Valentin. A comparative case study of http adaptive streaming algorithms in mobile networks. In *NOSSDAV'17*, Taipei, Taiwan, June 2017.

[920] E. Chammas, Ch. Mokbel, and L. Likforman-Sulem. Stroke width exploitation to improve automatic recognition of arabic handwritten texts. In *ASAR 2017*, Nancy, September 2017.

[816] C. Concolato, J. Le Feuvre, and E. Potetsianakis. Extended video streams for spatiotemporal navigation. In *The Graphical Web*, Exeter, UK, November 2016.

[817] A. Khosravani, C. Glackin, N. Dugan, G. Chollet, and N. Cannings. The intelligent voice 2016 speaker recognition system. In *NIST-SRE-Workshop*, San Diego, December 2016.

[818] A. Rana, G. Valenzise, and F. Dufaux. An evaluation of hdr image matching under extreme illumination changes. In *The International Conference on Visual Communications and Image Processing (VCIP)*, Chengdu, China, November 2016.

[819] Shuo Zheng, Marc Antonini, Marco Cagnazzo, Lorenzo Guerrieri, Michel Kieffer, Irina Delia Nemoianu, Roger Samy, and Bo Zhang. Softcast with per-carrier power-constrained channel. In *IEEE International Conference on Image Processing*, Phoenix, Arizona USA, September 2016.
[820] F. Pecune, A. Cafaro, M. Ochs, and C. Pelachaud. Evaluating social attitudes of a virtual tutor. In *Intelligent Virtual Agents*, Los Angeles, Etats-Unis, September 2016.
[956] B. Cirstea and L. Likforman-Sulem. Tied spatial transformer networks for digit recognition. In *ICFHR*, Shenzen, Chine, August 2016.
[822] O. Niamut, E. Thomas, D. Mico, C. Concolato, F. Denoual, and S. Y. Lim. Mpeg dash srd - spatial relationship description. In *ACM MMSys*, Klagenfurt, Austria, May 2016.
[823] J. Le Feuvre and C. Concolato. Tiled-based adaptive streaming using mpeg-dash. In *ACM MMSys*, Klagenfurt, Austria, May 2016.
[824] A. Purica, M. Cagnazzo, B. Pesquet-Popescu, F. Dufaux, and B. Ionescu. A distortion evaluation framework in 3d video view synthesis. In *The International Conference on 3D Imaging*, Liege, Belgium, December 2015.
[825] J. Le Feuvre, C. Concolato, N. Bouzakaria, and V. T. Nguyen. Mpeg-dash for low latency and hybrid streaming services. In *ACM MM*, Brisbane, Australia, October 2015.
[826] N. Bouzakaria, C. Concolato, and J. Le Feuvre. Fast dash bootstrap. In *MMSP*, Xiamen, China, October 2015.
[827] C. Concolato and E. Potetsianakis. Packaging web graphics and media for easier internet delivery. In *The Graphical Web*, Pittsburg, USA, September 2015.
[828] M. Cagnazzo and M. Kieffer. Shannon-kotelnikov mappings for softcast-based joint source-channel video coding. In *IEEE International Conference on Image Processing*.
[829] B. Ravenet, A. Cafaro, B. Biancardi, M. Ochs, and C. Pelachaud. Conversational behavior reflecting interpersonal attitudes in small group interactions. In *Intelligent Virtual Agents*, volume 9238, pages 375–388, Delft, The Netherlands, August 2015. Brinkman, Willem-Paul and Broekens, Joost and Heylen, Dirk.
[830] C. Concolato, J. Le Feuvre, and E. Potetsianakis. Synchronized delivery of 3D scenes with audio and video. In *Proceedings of the Twentieth International ACM Conference on 3D Web Technologies*.
[831] Y. Xu, C. Pelachaud, and S. Marsella. Compound gesture generation: A model based on ideational units. In *International Conference on Intelligent Virtual Agents*, volume 8637, pages 477–491, August 2014.
[832] N. Bouzakaria, C. Concolato, and J. Le Feuvre. Overhead and performance of low latency live streaming using mpeg-dash. In *IISA QoE for Over-The-Top Multimedia Services*, pages 92–97, Chania, Greece, July 2014.
[833] Y. Ding, M. Radenen, T. Artières, and C. Pelachaud. Speech-driven eyebrow motion synthesis with contextual markovian models. In *ICASSP*, pages 3756–3760, Canada, May 2013.

Invited Talks

[834] G. Chollet, A. Jimenez, D. Petrovska-Delacrétaz, and B. Raj. Privacy preserving biometric identity verification. In *COST IC1206 Training School*, Las Palmas, February 2017.
[835] C. Concolato. Mp4box.js, a gpac development. In *FOSDEM*, Brussels, Belgium, January 2016.

Patents

[836] C. Thienot and J. Le Feuvre. Method of handling packet losses in transmissions based on dash standard and flute protocol. 2018.
[837] F. Denoual, F. Mazé, J. Le Feuvre, and C. Concolato. Method, device, and computer program for encapsulating partitioned timed media data using sub-track feature. 2016.

Chapter 17

S^2A

Signal, Statistics and Machine-Learning

17.1 Presentation of the Team

Team leader: Stephan Clémençon

Faculty Roland Badeau (AP) - Pascal Bianchi (AP, -12/15; FP, 01/16-) - Gérard Blanchet (Emeritius) - Olivier Cappé (DR CNRS, -12/16) - Jean-François Cardoso (DR CNRS, -12/16) - Maurice Charbit (Emeritius) - Chloé Clavel (AP) - Stephan Clémençon (FP) - Florence d'Alché (FP, 10/14-) - Bertrand David (AP, -12/15; FP, -01/16) - Slim Essid (AP, -12/16; FP, 01/17-) - Olivier Fercoq (AP, 02/15-) - Gersende Fort (DR CNRS, -12/16) - Robert M. Gower (AP, 09/17-) - Alexandre Gramfort (AP, 03/17; IP, 04/17-) - Yves Grenier (FP, -03/18; Emeritius, 04/18-) - Laurence Likforman-Sulem (AP) - Eric Moulines (FP, -08/15) - François Portier (AP, 03/16-) - Gaël Richard (FP) - François Roueff (FP) - Anne Sabourin (AP, 10/13-) - Joseph Salmon (AP) - Umut Simsekli (AP, 07/16-) - Giovanna Varni (AP, 09/17-)

PhD students P. Ablin (09/16-), M. Achab (09/16-), S. Amar (09/17-), A. Ataya (-11/13), H. Bai (-02/16), V. Barrière (10/15-), B. Baylin (10/15-07/16), Y. Bekhti (01/15-03/18), A. Belhomme (10/14-12/17), V. Bisot (10/14-03/18), H. Braham (01/13-12/15), S. Chambon (09/15-), E. Chammas (11/13-11/17), E. Chautru (-06/13), J.A. Chevalier (10/17-), M. Chiapino (12/14-06/18), G. Ciolek (09/16-), B. Cirstea (10/14-), I. Colin (11/13-11/16), A.C. Conneau (-06/16), F. Dardard (11/13-09/15), A. Dematteo (-10/14), M. Djerrab (10/15-), T. Dupré La Tour (10/15-), S. Durand (10/13-05/17), A. Durmus (09/14-12/16), P. Elancheliyan (10/15-01/17), K. Elgui (05/17-), S. Fenet (-09/13), C. Filmont (03/15-09/15), R. Foucard (-12/13), C. Fox (-05/13), B. Fuentes (-03/13), A. Garcia (09/16-), E. Gentet (09/17-), N. Goix (09/13-11/16), S. Henriet (12/16-), K.J. Hong (09/16-), O. Iacoboaiea (-10/15), P. Ilhe (10/13-09/16), H. Jalalzai (10/17-), M. Jas (03/15-), X. Jaureguiberry (06/15-), Y. Kahn (-02/15), E. Kaufmann (-10/14), A. Korba (10/15-), M. Jala (-12/13), R. Laby (01/14-05/17), J. Lafond (11/13-12/16), A. Lambert (10/17-), P. Laforgue (10/16-), C. Laroche (03/14-05-17), S. Leglaive (10/14-12/17), N. Lopèz-Zuleta (-07/14), P. Magron (10/13-12/16), M. Massias (09/16-), A. Masurelle (-10/15), G. Morrall-Adell (-01/15), O. Morillot (-01/14), T. Nabil (01/15-01/18), E. Ndiaye (10/15-), T.H. Nguyen (09/17-), T. Nguyen (05/13-11/16), A. Nouvellet (02/13-02/16), C. Oprean (-01/15), G. Papa (10/14-01/18), S. Parekh (01/16-), F. Rigaud (-12/13), S. Robbiano (-06/13), A. Salim, A. Sanchez-Perez (-09/15), A. Schreck (-07/14), N. Seichepine (-09/15), E. Sibony (-06/16), T. Sim (03/13-03/16), C. Taleb (09/17-), A. Thomas (05/14-10/17), K. Tor (09/17), N.G. Tran (-04/15), C. Vernade (10/14-10/17), R. Vogel (06/17-), F. Weber (02/14-06/17) T. Wohlfarth (-12/13), R. Zhang (-09/14), B. Zheng (-11/13).

Post-docs and Engineers F. Asgari (09/17-), M. Bacak (10/14-07/15), D. Basaran (10/16-11/17), A. Bellet (10/14-10/15), M. Ben Jannet (11/17-12/18), A. Ben Youssef (09/16-08/17), E. Benaroya (12/16-10/17), A. Benichoux (02/15-07/15), R. Blouet (10/16-10/17), I. Colin (12/16), C. Damon (05/12-10/13), C. Dhanjal (12/12-11/14), A. Drémeaux (09/11-09/13), T. Dupré La

Tour (04/1509/15), S. Fenet (10/14-12/17), O. Fercoq (08/14-01/15), T. Fillon (01/1-03/13), P. Gaillard (10/16-12/16), T. Guillemot (01/16-12/17), J. Lafond (09/13-11/13), Y. Leprince (03/15-12/15), B. Palaniappan (01/17-10/17), T. Vinh-Luu (05/17-), M. Maazaoui (06/12-11/14), R. Manhaes Monnerat (07/14-12/14), D. Mauro (01/13-01/14), J. Montoya (04/15-03/16), R. Mourya (05/16-03/17), K. Nathwani (06/15-05/16), A. Nouvellet (04/16-10/16), G. Papa (10/17-), A.L. Poite (11/15-07/16), R. Porchetto (01/17-12/17), R. Rajagopalan (10/15-08/17), F. Rigaud (01/14-07/14), B. Ravenet (02/17-12/17), M. Sangnier (03/15-02/16), J.B. Schiratti (10/16-10/17), R. Serizel (10/14-10/15), U. Simsekli (09/15-06/16), D. Sullivan (07/14-12/14), M. Tagorti (01/16-10/16), A. Thomas (05/17-10/17), L. Wei (06/14-05/15), C. Wolley (03/15-06/16),

Associated Professors P. Bertail (02/16-), A. Gramfort (10/16-), Ons Jelassi (02/16-), E. Moulines (IP, 09/15-)

Scientific Production Overview

Journals	Proceedings	Book Chapters	Patents	Invited Talks
156	264	9	9	48

Be it for prediction or interpretation purposes, the statistical analysis of data collected by means of modern technologies raises a wide variety of methodological issues, related to their great complexity (e.g. high-dimensional, structured, heterogeneous/multiscale, massive, incomplete/censored data, data streams, audio signals, text, weak signals and rare events), in order to design more "intelligent" machines/devices (artificial intelligence).

An abundance of new applications such as health monitoring of complex infrastructures, recommending systems, chatbots, machine-listening and opinion-mining, together with the availability of massive data samples (Big Data) and technological constraints inherent to information acquisition and access (e.g. sensor networks, IoT, distributed file systems) and to computation (e.g. infrastructures for massively parallelized/distributed computation, on-line processing) has put pressure on the scientific community to development new methods and algorithms. The development of these new methods rests on techniques from various domains such as probabilistic modeling, statistical learning, simulation, optimization or signal processing. Rallying expertise in these fields, more complementary today than ever, the team S^2A has been committed to develop algorithms and concepts for modern data analysis. The S^2A team is the result of joining the former teams STA (Statistics and Applications), AAO (Audio Signal Processing) and some researchers from the team MM (Multimedia) together, acknowledging in particular the ubiquity of machine-learning approaches in all domains involving data processing. The team has structured itself around four intertwined topics, according to which its research activities are subsequently described.

- Probabilistic modeling and mathematical statistics
- Machine-Learning and optimization
- Audio data analysis and signal processing
- Social computing

As evidenced by its publication activity, the S^2A team is dedicated to produce sound methodological research in the four domains listed above, in response to some of the challenges raised by the nature and format of modern data and to the high societal expectations for the development of efficient, reliable and ethical data-based artificial intelligence solutions. The members of the S^2A team are actively teaching, in particular at the master level in the fields of probability and statistics, machine-learning, signal processing at Telecom ParisTech (M2 Data Science) and in other Grandes Ecoles (Ecole Polytechnique, ENPC ParisTech, ENSAE ParisTech) and universities (Master 'MVA' at ENS Paris Saclay, Master 'M2MO' at Paris 7, Master 'Statistics' at Paris Orsay, Master ATIAM with Sorbonne Université and IRCAM). F. Roueff is assistant director of the doctoral school 'Mathematics-Hadamard' of Université Paris-Saclay. In addition to the academic collaborations, the team has forged links with many companies/institutions (e.g. BNP, Idemia, Deezer, Air Liquide, ANSSI, BNF, Airbus) through joint responses to European/ANR

project calls, bilateral contracts and CIFRE PhD theses and also developed long term partnerships through the industrial chair 'Machine Learning for Big Data' (Safran, BNP, PSA, Valeo, Criteo) in particular. The team enjoys a high national and international recognition, with members in editorial boards of top ranked journals, in program committees of major conferences (e.g. ICASSP, ICML, NIPS) and in executive boards of research funding programs such as the Labex Digicosme of Université Paris-Saclay. Members of the team are regularly invited to give talks and keynote lectures (e.g. [957, 958, 959, 960, 961, 963, 962]) and have (co-)organized various conferences (e.g. IEEE DSAA '15) and workshops (e.g. WIAMIS 2013) and are participating in the organization of regular seminars in the Parisian environment (e.g. statistical machine learning in Paris "SMILE", sémaire parisien de statistique). Members of the group have been distinguished by several awards during the period (see the S^2A team highlights section). The team is also involved in technology transfer and development, through the licensing of patents (e.g. the TreeRank patents with the company IT4PME) and spin-off projects (e.g Y. Grenier and S. Essid received pre-maturation grants from the SATT Paris-Saclay, in 2014 and 2017, respectively, for a novel audio indexing method and a novel machine listening system, the latter having subsequently received a maturation grant aiming at setting up a Telecom ParisTech spin-off company).

17.2 Research Activities

17.2.1 Probabilistic Modeling and Statistics

Contributors: Stephan Clémençon, Olivier Cappé, Gersende Fort, Eric Moulines, François Portier, François Roueff, Umut Simsekli, Anne Sabourin

Extremes, Rare Events

Certain members of the team contribute actively to the fields of extreme values and long range dependence analysis. In many applications related to risk management, understanding the structure of tail events is a major concern. In particular, multivariate extreme value analysis aims at characterizing the distribution of a multivariate quantity of interest conditionally to its norm being asymptotically large. Long range dependence is a distinct but related property of stochastic processes: A stochastic process is long range dependent when its time (or space) correlations are heavy tailed. Concerning multivariate extremes, scaling up existing statistical methodology to a high dimensional context is an emerging field of research. We investigated clustering of high dimensional extreme events, in the application context of food risk (*cf* E. Chautru's PhD thesis with the French governmental agency dealing with sanitary safety in food, the environment and at work). Tail index estimation was studied in a multivariate context [882]. Taking advantage of sharp concentration inequalities in extreme regions we obtained finite sample guarantees on estimators of the tail dependence function, a functional summary of the dependence structure of extremes [952]. We proposed a dimension reduction device specialized to tail regions, accompanied by a finite sample control of the approximation error [948, 870]. Specializing to the case where the dependence structure is corrupted by noise we proposed an exploratory analysis algorithm aiming at recovering the maximal groups of features with the potential of being simultaneously large [951]. We proposed an application to anomaly detection *via* Minimum volume set estimation in tail regions [925]. In the context of multi-armed bandits, we investigated the case where the goal is to minimize the maximum reward, as opposed to the average reward [917]. From a probabilistic perspective, we proposed a generalization of the continuous theory for max stable processes to upper semi-continuous processes [869], which are encountered in applied spatial statistics when modeling processes with strong local variations (*e.g.* rainstorms). Anne Sabourin and Stephan Clémençon gave invited talks to the bi-annual international Extreme Value Analysis conferences (Ann Arbor, 2015, Delft 2017). We studied the limit behavior of some empirical processes involving distributions with heavy tails in [889]. It is well known that in this case the limiting behavior is α-stable with $\alpha < 2$, thus non-Gaussian. Other interesting unusual limit behaviors appear in

limit theorems involving long range dependence. We participated to a series of work dedicated to the wavelet analysis of long range dependent subordinated Gaussian processes where Rosenblatt (chaos or order 2) limiting distributions appear, or even distributions in higher chaos, see [898, 899, 883]. More recently, we got interested in the case of multivariate long range dependent processes, and proposed to perform an efficient time-scale analysis based on *analytic* wavelets, see [918].

Time Series, Markov Chains and Dependent Data

In many real world applications, the data at hand is inherently dependent, across space or time, sometimes across both dimensions. This dependence must be exploited in order to derive predictors or to perform meaningful analysis, in space, time or frequency. We already mentioned the specific problems raised by the presence of long range dependence in the data in Section 17.2.1. Here we present works involving more standards models, such as geometrically ergodic Markov chains or more general state space models. The main challenge when such models are involved is related to the potentially high dimensions of the data, or the fact that the information of interest is not directly observed, making the numerical procedures more difficult to handle. Our research activity in this topic includes methodological and theoretical aspects as well as applications. Methodological contributions in statistical include signal processing for system identification with applications to the modeling of the thermal behavior of a building [939], anomaly detection [896], or statistical inverse problems for exploiting γ-spectroscopy measurements, [891]. A large part of the theoretical results developed in the team in mathematical statistics for dependent data are concerned with the class of partially observed Markov chains [879] or point processes [881], which embeds standard models such as hidden Markov models or observation driven models. Such an expertise is very useful for studying Monte Carlo methods or more general stochastic algorithms (see Section 17.2.1), as well as prediction algorithms, for instance for locally stationary time series [890]. In recent years, we have also been interested in web log data mining using Markov chains and Markov processes for modeling web sessions. We initiated a collaboration with the Biblilab, a joint laboratory of the SES department at Télécom-ParisTech and the BNF (Bibliothèque Nationale de France).

Monte Carlo and Advanced Simulation Methods

The team is highly involved in the study of advanced simulation methods which are indisputably useful for statistical inference (e.g., Bayesian statistics and latent variable models) or complex model simulation (e.g., pricing of financial derivatives). The results obtained by the group take place within a big data context in which the scalability and the computation time of the algorithms stand as one of the leading aspects. Online simulation methods are necessary to handle Big Data as they allow to drastically reduce the computing time by uploading the new information with a small additional cost. The group has been particularly active on this field of research establishing new convergence rates for such online algorithms [886, 863]. Another important feature with Big Data is the sparsity of the underlying model which occurs when only a small group of variables is relevant to the analysis. Variables selection in a Bayesian framework is investigated in [877]. In a context where the objective function cannot be computed exactly, [871] studied MCMC strategies within a proximal optimization approach with a penalty term. Extension of Langevin Monte Carlo is studied in [924] in which a subsampling is used to reduce the computation time. Designing and studying adaptive strategies is one of the most challenging issues in Monte-Carlo as it largely improves the accuracy of nonadaptive methods. In [888], the group has been working on some adaptive version of the Metropolis-Hasting algorithm. Some sample-adaptive strategies are studied in [907] where new concentration inequalities are obtained. Those inequalities consist of an explicit error bound depending directly on the sample size. In addition, the group effort has been focused on establishing new convergence rates for Markov chains [895, 878]. Simulation methods such as re-sampling schemes allow to make accurate inference when the data is complexe. These methods are shown to be valid and applied within the Cox semiparametric model [847] well

known for its success in treating clinical data. Re-sampling schemes for dependent data has been studied in [900, 897].

17.2.2 Machine Learning and Optimization

Contributors: Pascal Bianchi, Chloé Clavel, Stephan Clémençon, Florence d'Alché-Buc, Slim Essid, Olivier Fercoq, Gersende Fort, Robert M. Gower, Alexandre Gramfort, Laurence Likforman-Sulem, Eric Moulines, Joseph Salmon, Anne Sabourin, Gaël Richard.

The team develops research activities in Machine Learning with both a solid theoretical grounding and a strong motivation to solve practical issues discussed with the companies with whom the group collaborates (see Machine Learning for Big Data Chair: `http://machinelearningforbigdata.telecom-paristech.fr/fr/`). A common focus of interest for several researchers in the group concerns the design of novel methods to solve newly defined tasks that go beyond classification and regression such as learning to rank, structured output prediction, outlier detection, quantile regression and link prediction. The omnipresence of social networks and internet data calls for the improvement of recommendation systems that are also addressed in the group. Optimization, as a key to learning, is another main topic of interest for the group. We are committed to prove theoretical properties of optimization algorithms that we design. Our interests range from saddle-points problems for which we develop primal-dual algorithms, improvement of stochastic gradient descent algorithm and distributed optimization algorithms. The know-how we develop in convex optimization also directly impacts some of the issues of Machine Learning such as feature selection in high dimensional spaces. It is the availability of very large databases that has renewed the interest in deep learning and large scale learning methods.

Beyond Classification and Regression

Ranking. Recommendation systems and search engines are becoming ubiquitous in modern technological tools. Operating continuously on still more content, use of such tools generate or take as input more and more massive data. The design of machine-learning algorithms, tailored for these data, is crucial in order to optimize the performance of such systems (*e.g.* rank documents by degree of relevance for a specific request in information retrieval, propose a sorted list of items/products to a prospect she/he is most liable to buy in e-commerce). The scientific challenge relies on the nature of the data feeding or being produced by such algorithms: input or/and output information generally consists of (partial) rankings/orderings, expressing *preferences*. Because the number of rankings explodes with the number of instances, traditional methods in machine-learning and statistics become quickly intractable and the approaches proposed these last few years to deal with preference data can be hardly implemented in large-scale settings. Whatever the type of task considered (supervised, unsupervised), machine-learning algorithms generally rest upon the computation of statistical quantities such as averages or medians, summarizing/representing efficiently the data or the performance of a predictive rule candidate applied to the data. However, summarizing ranking variability is far from straightforward and extending simple concepts such as the average or median in the context of preference data raises a certain number of deep mathematical and computational problems. In statistical signal and image processing, novel harmonic analysis tools such as wavelet bases and their extensions have recently revitalized structured data analysis and lead to sparse representations and efficient algorithms for a wide variety of statistical tasks: estimation, prediction, de-noising, compression, *etc.* Following in the footsteps of advances in computational harmonic analysis and its applications to high-dimensional data analysis, new concepts and algorithms to handle preference data and use them to solve statistical learning problems, motivated by the applications aforementioned (efficient/sparse representation of rankings, ranking aggregation, prediction of rankings) have been developed in a series of papers, see e.g. [953, 926, 908].

Structured Output Prediction. New challenges in computer vision, machine listening, natural language processing and bioinformatics often calls for Structured Output Prediction (SOP). The

main bottleneck of these methods are the computational cost of training, the test phase and the difficulty of the supervision task. To solve these issues, we have developed a general and flexible two-step approach based on the resolution of an easy-to-solve surrogate problem and the computation of a pre-image. We first derive a family of methods called Input Output Kernel Regression for which the surrogate problem relies on the kernel trick in the output space and penalized regression in Reproducing Kernel Hilbert Spaces of vector-valued functions [851]. Such a method considerably reduces the training time, allowing for real applications such as metabolite identification from mass spectra [853]. However the pre-image problem still remains a bottleneck. We then defined and studied new output embeddings that lead to closed-form solutions and have a very good performance on few-shot learning problems [842]. Another line of work focuses on the development of matrix factorisation techniques for temporally structured data, especially in multi-view learning settings. In particular, we have developed new majorisation-minimisation algorithms for i) smooth nonnegative matrix factorisation (NMF), including piece-wise constant NMF [942] (using total-variation like regularisation); and ii) *soft* co-factorisation [947] of two or more data views (e.g. audio and visual views) which encourages the activations corresponding to each view to be close (cf. Section 17.2.3). Also worth mentioning is our contribution to NMF-based feature learning within a semi-Markovian conditional random field framework [864].

Anomaly Detection and Quantile Regression

Motivated by a great range of applications such as the design of search engines in information retrieval, credit-risk screening in finance or supervised anomaly detection in signal processing, the problem of learning how to rank data with ordinal labels has been the subject of a great deal of attention in machine-learning these last few years and many practical ranking algorithms, supported by sound theoretical results extending the probabilistic theory of pattern recognition, are now documented in the literature. However, in many applications, which can be referred to as unsupervised anomaly/novelty detection and comprise the monitoring of complex systems such as the functioning of aircraft engines, system management in data centers, network intrusion surveillance or fraud detection, it is desirable as well to rank multivariate data, so that top ranked observations should be ideally the likeliest "outliers", in absence of any output variable indicating the degree of "abnormality". Various concepts, theoretical results and applications related to anomaly ranking/scoring have been developed by the team in a series of articles, see e.g. [954, 905, 846]. Quantile regression that provides a better picture of the conditional output distribution is of special interest in critical domains such as biomedical applications, default diagnosis and climate prediction where the user needs more details than a mean regression. The team has developed a generic method to learn a single function for many-quantile regression task in a consistent way by relying on multi-task learning with appropriate matrix-valued kernels [950].

Numerical optimization

Stochastic algorithms. When statistical learning on large data sets is at stake, the use of stochastic methods is frequently required. The abundance of data often makes it impossible to use deterministic (so-called "batch") methods and requires updating the iterates in an "online" mode, where the data is processed as and when it arrives. The case of adaptive parameter estimation is also part of this framework. The work of [871] establishes exact bounds on the rate of convergence of stochastic gradient type algorithms and variants. An other contribution is the development of a generic framework for developing new stochastic approximation algorithms and establishing their convergence. By introducing the concept of random monotone operator, we have proposed a stochastic version of the famous proximal point algorithm, which allows us to find the zero of a montone operator, and from which many popular optimization algorithms are derived [876, 880]. The methodology has been extended to other algorithms: Forward-Backward, Douglas-Rachford and several primal-dual methods, Passty's algorithm. The analysis is at the crossroads of Markov chains, convex analysis, and dynamic systems. Some specific applications have been investigated, such as regularization problems on graphs for instance. Other works focus on adaptive sampling

for empirical risk minimization.

Random Coordinate Descent. Random coordinate descent (RCD), popularized by Nesterov in 2010, is a key optimization algorithm that explores the separability over the domain, often present in large scale machine learning problems, to efficiently find an approximate solution. So far, the principle of RCD was mainly applied to primal methods, hence excluding a broad part of optimization algorithms. Our main contribution was to prove that RCD applies to a much more generic class of algorithms, namely fixed point algorithms involving a non-expansive operator [955, 872]. Many generic numerical optimization methods derive from such fixed points algorithms. As a consequence, we introduced new RCD version of such algorithms. Later, we developped a specific RCD version of the popular Vũ-Condat algorithm. The method allows non-separable non-smooth functions and longer step-sizes than previously proposed ones, which makes the algorithm fast and widely applicable. We showed the convergence of the algorithm as well as its speed of convergence, despite technical difficulties due to the generality of the method.

New Primal-dual methods. We studied smoothing techniques for saddle point problems with unbounded domains. By smoothing the duality gap, we obtained algorithms that naturally have a state of the art performance [868]. We developed many extensions like line search, coordinate descent or conditional gradient variants.

Feature selection by screening rules. Feature selection is an important matter in machine learning. Sparsity-promoting optimization problems such as LASSO are a way to achieve this goal. Screening methods provide simple criteria to obtain some information on the support of the sparse solution *beforehand*, that is, before solving the programming problem. This allows to reduce the dimension of the problem to be solved. Safe screening is based on properties of the dual problem and convex analysis in order to guarantee that some variables are zero at the optimum [854]. Combined with active set methods and coordinate descent, we could obtain state-of-the-art algorithms for the resolution of sparse regression problems. We also worked on the application of these acceleration techniques to the case where the structure of the observation noise is more complex, with potential impact for neuro-imaging data [934]. Methods based on the l1-regularization are known to induce a bias to the model. We worked on algorithmic advances for the computation of statistical estimator using a de-biasing step, as well as minimax results for the automatic setting of the regularization parameter [848].

Distributed optimization. Distributed optimization plays an important role in statistical learning, when data is stored in a distributed fashion, and in signal processing (sensor networks). We consider a network of agents with local computing capabilities, and inter-agent communications. The objective is to minimize a sum of functions, each individual function being (partially) observed of an agent, but unknown to others. Our contribution was to develop and analyze distributed optimization algorithms, under the assumption of imperfect communications and asynchronous protocols. By asynchronous, we mean that we consider a context where agents do not have any common clock that would organize communications externally. Initially, we focused on diffusion-adaptation methods: at each iteration, each agent locally adapts the value of its local estimate by a (stochastic) gradient step, then combines the result with the received estimates of his neighbors. The challenge was multiple: characterize convergence rates, build asynchronous methods, highlight the influence of the communication protocol on performance, include the presence of noise, imperfect propagation channels, and variations in network topology. In a second step, we looked at the use of primal-dual approaches. It is known since the works of Schizas (2008) that the ADMM (Alternating Distributed Method of Multipliers) method makes it possible to construct distributed optimization algorithms on a graph, with certain advantages over the diffusion-adaptation methods mentioned above. We studied the convergence speed of this type of algorithm according to the topology of the network [875]. New distributed algorithms of primal-dual kind have been proposed [874]. We also introduced "on-line" variants of distributed optimization methods, in the case where the objective functions are not fixed, but replaced by a series of random functions, observed over time.

Large Scale learning

The availability of massive datasets call for learning methods with low computational complexity. While the Empirical Risk Minimization theory is now consolidated, putting this approach in practice generally leads to significant computational difficulties in large-scale settings. In many concrete cases, the mere computation of the risk involves a summation over an extremely high number of tuples and runs out of time or memory on most machines. In a series of papers, we developed theoretical results and practical algorithms based on survey/sampling theory, addressing this challenging problems, see e.g. [873, 885, 887, 949]. We also developed a method based on a generalization of random Fourier Features to scale up operator-valued kernel methods devoted to vector-valued prediction [933] and time-series modeling.

Recommendation systems and graph inference

One main issue of recommendation systems is to complete a user-item matrix from a sample of observed entries. Matrix completion in the case of discrete and finite entries was addressed in [884] with a derivation of bounds for the Kullback-Leibler divergence between the true and estimated distributions.
Network inference is key to the understanding of interactions at work in a dynamical system. We proposed a novel method for inferring a graph of interactions between state variables of a dynamical system from a finite number of observations, based on the Jacobian of a nonparametric model. The approach boils down to kernel learning under non smooth constraints using a proximal gradient descent algorithm [852].

Machine Reading

The main activity of the handwriting analysis and document recognition team consists in developing Recurrent Neural Network-based architectures (RNNs), and apply them to the recognition of handwritten documents. A powerful CRNN architecture (Convolutional Recurrent Neural Network) was developed in [841], mixing convolutional layers with stacked BLSTM layers. We applied it to the recognition of Latin or Arabic scripts, and obtained state-of-the-art results (2nd place at the READ 2017 challenge, E. Chammas, L. Likforman).

17.2.3 Audio data analysis and signal processing (ADASP)

Contributors: Roland Badeau, Jean-François Cardoso, Gaël Richard, Umut Simsekli, Slim Essid, Alexandre Gramfort, Yves Grenier, Bertrand David, Chloé Clavel

The members of the team involved in the ADASP research topic (Audio Data Analysis and Signal Processing, formerly known as the AAO group) develop temporal data analysis methods primarily targeting audio data. These developments rely on signal processing and machine learning techniques, focusing on: data decomposition and representation learning methods, especially sparse representation learning; as well as parametric modelling methods. Such methods are used essentially to address two types of tasks: *source separation* and *human activity-related scene and content analysis*, notably using classification methods; with applications in: machine listening; music information retrieval (MIR); heterogeneous, multiview or multimodal data analysis, especially multimedia content analysis; physiological signal analysis, especially M/EEG data; audio signal transformation (denoising, enhancement, dereverberation, spatialisation); and musical acoustics. In the following we briefly expose prominent contributions in the ADASP domain through a selection of tasks and applications which best reflect this line of research.

Source separation

Source separation is a traditional research theme of LTCI which has received a continuous and growing interest in this period, in particular for speech and music applications, but also for EEG

data analysis or astronomy. As far as audio signals are concerned, our work has gradually moved to the more difficult, but also more realistic, problems of speech/audio source separation in noisy and reverberant spaces. In practice, the source separation problem is usually underdetermined (the number of sensors is lower than the number of sources), the sources are not punctual, and because of reverberation, the mixture is both non-instantaneous and diffuse (signals come from all directions of space). Accurate models of both the source signals [840, 915] and the acoustic mixture [855], in either blind or (semi)-supervised scenarios, were developed and evaluated in real life cases. In particular, statistical and deterministic structured models (for example based on NMF) were developed for representing general audio sources [857] or specific sources such as drums using additional constraints or apriori knowledge [838]. Concurrently, radically new time-domain approaches exploiting heavy-tail Student-t distributions were proposed to model the mixing process which permits to significantly overperform classic approaches [839], in particular in remixing applications. Also worth mentioning is our effort towards multiview and multimodal source separation using co-factorisation methods which were successfully applied to multichannel [893] and audio-visual recordings [927, 913]. Dedicated models were also developed for other source separation applications, including advanced ICA models in astronomy [892] based on physical modeling of the cosmic microwave background, probabilistic semi non-negative models for Non-Invasive Load Monitoring (NILM) applications, subspace-based models for engine predictive maintenance.

Machine listening and sound transformation

The team has developed a substantial research work in various areas of machine listening, including general audio indexing [865], speaker diarization and identification [947, 938], acoustic scene and event classification [849, 928, 921], speech or audio enhancement [857, 850], and audio source localisation [941]. While most dereverberation methods focus on how to estimate the magnitude of an anechoic signal in the time-frequency domain, we have proposed a method which also takes the phase into account. By applying a harmonic model to the anechoic signal, we derive a formulation to compute the amplitude and phase of each harmonic. These parameters are then estimated by our method in presence of reverberation. They then serve to reconstruct an estimate of the anechoic signal that reveals a strong level of dereverberation [914]. Within the Romeo2 project [941], we developped a method for the localization of audio sources that was based on the joint use of a microphone array in the head of the humanoïd and an artificial vision algorithm to enhance the precision of the audio localization (otherwise limited by the size of the microphone array with respect to the wavelength of the useful frequency band). As far as audio classification is concerned, in particular environmental scene and event classification, efforts were dedicated to learning appropriate representations, using nonnegative matrix factorisation and deep learning, which led to efficient solutions [849, 928]. Notably our group ranked third in the international DCASE 2016 challenge on audio scene classification. Further developments consider the use of NMF to train deep neural networks for these tasks. Sound classification using deep learning systems usually rely on the network to learn meaningful representations from spectrograms or hand-crafted features. Instead, we introduce a NMF-based feature learning stage before training the networks, which proves particularly efficient, especially for multi-source acoustic environments such as sound scenes. This allows us, with simple architectures, to reach performance which is competitive with more complex systems such as convolutional networks. The proposed systems outperform neural networks trained on time-frequency representations on two acoustic scene classification datasets as well as the best systems from the 2016 DCASE challenge [921]. Further, significant efforts have also been dedicated to sound transformation and rendering which can in some cases be directly associated with source separation. In other cases, we focused on the design of efficient parametric methods for artificial reverberation, bridging the gap between Feedback Delay Network perceptual approches and physically based acoustic Radiance Transfer Methods (RTM) [859]. Another line of research was dedicated to apply voice transformation concepts to optimize speech intelligibility of vocal messages in adverse conditions (such as in car environments) [850].

Music Information Retrieval

Music Information Retrieval has been an important line of research for the S^2A team for more than 15 years. The topics of major interest include audio identification (or audio fingerprinting), music transcription and music-to-score alignment. Our research essentially consists of devising novel signal models or machine learning techniques dedicated for the problem at hand. For example different learning strategies were followed to obtain optimal and discriminative features for music-to-score alignment based on Conditional Random Fields modelling [864]. In music transcription, most efforts were spent on the problems of melody extraction [861**?**], multipitch estimation [866] and rhythm analysis. We have been, in particular, interested in the specific problem of beat and downbeat estimation and tracking [940], which has direct applications in music repurposing or recommendation. Our State-of-the-art approach [856] consists in fusing an ensemble of convolutional neural networks, each dedicated to a typical musical dimension: harmony, melody, rhythm and bass content. Other contributions target content-based audio identification, where the goal is to retrieve the metadata (title, author, album...) of an unknown audio excerpt from the analysis of the audio signal. The most efficient techniques to solve this problem are fingerprinting techniques. Thus, we have developed a new system that is not only robust to the standard distortions (pitch-shifting, equalization...) but is also able to handle important variations that occur when a title is re-recorded (different musicians or recording conditions). This patented method allows not only the identification of an excerpt but also the detection of similarity [945]. A project to set up a spin-off company on this topic is currently pursued.

Brain Data Analysis

The team has developed a significant research activity on modeling and processing neural time series, primarily electroencephalograpy (EEG) and magnetoencephalography (MEG) which are multivariate signals used for clinical neuroscience (sleep, epilepsy) and cognitive neuroscience. On the clinical side the team has recently proposed a state-of-the-art neural network architecture for scoring sleep stages using multimodal polysomnography data (PhD S. Chambon CIFRE with Rythm.co company). On epilepsy, a collaboration with the Brain and Spine Institute and the Bioserenity company has led to a new predictive system improving the detection of epileptic seizures from intracranial EEG [910]. Besides supervised learning tasks for clinical applications, a series of papers was dedicated to the MEG/EEG source imaging problem which is a challenging inverse problem. Contributions were based on time-frequency representations [867] and fast solvers [858] when working with sparsity promoting regularizers, as well as model selection techniques [922]. The strength of this line of research is to fully exploit the spatiotemporal properties of M/EEG signals to disambiguate complex configurations of neural generators. Another work has been on using statistical machine learning to automate certain processing tasks and parameter selections. Work has been done to improve the estimation of M/EEG data covariance [860] and to automate the correction of artifacts [932]. This latter work, validated on more than 200 recordings is particularly relevant in a period where M/EEG datasets can reach hundreds of subjects, and for which data analysis time may become prohibitive when tasks are not enough automated. Another fruitful line of research was on the modeling of electrophysiology signals that exhibit a rich diversity in morphology, with non-linear effects. Jas et al. proposed to learn the morphology of transient neural events with convolutional sparse coding [911]. The contribution is both on the modeling and optimization sides with a state-of-the-art alternate optimization scheme exploiting quasi-Newton methods. To capture, inter-frequency interactions, a non-linear auto-regressive model was also explored. It was showed to be a well adapted model to capture and quantify so-called nested oscillations and cross-frequency coupling (CFC) [931, 843]. Finally, in terms of dissemination, the MNE software was consolidated by the team during the period [862] (almost 300 citations). MNE is now one of the leading opensource software to process MEG and EEG data. It is particularly strong for source imaging, and machine learning tasks now commonly used to test cognitive hypothesis using such data. MNE exploits for this the scikit-learn software that was further developped and maintained by members of the team during the evaluation period

(paper published before the period has now more than 10,000 citations).

Multimodal data analysis

The team has also developed research on multimodal data analysis, that is research aimed at automatically extracting information from data that involves two or more modalities. This is essentially approached as a *multi-view learning* problem where the *data views* are possibly of different physical natures (typically visual views vs audio views in audio-visual data analysis scenarios). Beyond the development of ad-hoc systems for specific use-cases (e.g. dance performance analysis [943, 946] within the EU FP7 3DLife and REVERIE projects), much effort has been dedicated to *matrix co-factorisation* techniques and their applications. Data from different modalities usually live in feature spaces of completely different topology and dimensionality (think of audio as opposed to images of a video), preventing the possibility of "naturally" representing them by the same tensor. In this case, one may resort to co-factorisation techniques, *i.e.* techniques performing two (or more) factorisations in parallel, which are linked in a particular way. Because of the different nature of the modalities, this link has usually to be characterized through dependencies between the expansion coefficients, a.k.a activations, in cross-modal correspondence, and unlikely through dependencies between dictionary elements of different modalities. Our *soft* co-factorisation model [893] encourages the activations corresponding to each modality to be close while allowing for possible local discrepancies across the modalities (this happens for example, in video analysis scenarios, when there is a mismatch between the audio and the images information, say because of a visual occlusion). It has been found successful for various applications, including multimodal speaker diarization [947] and multimodal music audio source separation [930, 916].

17.2.4 Social computing

Contributors: Chloé Clavel, Florence d'Alché Buc, Slim Essid, Laurence Likforman, Giovanna Varni, Nicolas Rollet (I3, SES), Christian Licoppe (I3, SES)

The Social Computing topic aims to gather research around computational models for the analysis of social interactions whether for web analysis or social robotics. Previous activities of this topic were carried out in the MM team (Research activity multimodal content and interaction) until december 2016. The peculiarity of this theme is its multidisciplinarity: computational models are established in close collaboration with research fields such as psychology, sociology, and linguistics. They are based on methods from various fields in signal processing (*e.g* speech signal processing for the recognition of emotions), in machine learning (*e.g.* use of Conditional Random Fields for the detection of opinions in texts), in computer science (ex: the automatic processing of the natural language for the detection of opinions, the integration of the socio-emotional component in the human-machine interactions).

Emotion recognition in handwriting and EEG

We work on the detection of negative emotions from on-line handwriting and drawing. A publicly available database called EMOTHAW [845] has been built from 129 participants whose emotional states, namely anxiety, depression and stress, are assessed by the Depression Anxiety Stress Scales (DASS) questionnaire. We have developed an analysis of the handwriting, using a machine-learning approach (random forests), from measurements related to timing and ductus. Following this work, we have also started a new work for the detection of Parkinson disease (PD) through handwriting [919]. The team has also developed research towards automatic emotion recognition from electroencephalographic (EEG) recordings, partly as part of the EU FP7 VERVE project, and partly as part of its involvement in the SMART labex SeNSE project. Compared to other modalities which have been considered in previous work on emotion recognition, EEG has the advantage of capturing information related to internal emotional states not necessarily resulting in any observable external manifestations. Our work first consisted in assembling a new dataset

for this task, using audiovisual elicitation [929], which has been made publicly available. Further efforts were dedicated to the study and the development of appropriate features for this task, using either feature engineering [944] or feature learning techniques [929]. Also of note is the study inter-subject correlation using EEG recordings of subjects undergoing audiovisual emotional stimuli with a view to driving a multi-task learning approach to this problem, where similar subjects are processed jointly.

Human-agent interaction : from social signal perception to generation

Regarding social signal processing and emotion recognition (multimodal analysis - text, audio, video, social and emotional signals) in human-agent interactions [904], HCRF (Hidden Conditional Random Fields) and LSTM (Long-Short-Term Memory) have been studied for the detection of user's opinions in human-agent interactions [909]. We also develop weakly supervised machine learning models for the prediction of user engagement breakdown in human-robot interaction [912]. New multimodal interaction models have been proposed using both cross-recurrence analysis [844] and sequence pattern mining [923] in order to study socio-emotional behavior during human-agent interaction. Regarding the generation of agent's socio-emotional behaviors, we have been working on the generation of agent's co-speech gestures and their alignment to the verbal content [906].

17.3 SWOT analysis

Opportunity. Machine-learning, probabilistic modelling and signal processing are not new fields of research. Statistical data analysis has a very long history and its development has been stimulated by various new application domains and the ever growing availability of data (e.g. social sciences, agronomy, industrial quality control, econometrics, insurance, epidemiology, environmental sciences, ... etc). However, the digital information boom, that goes hand in hand with the recent technological advances in data collection and management (e.g. web, IoT, mass spectrometry, distributed platforms), offers new perspectives in many areas of human activity (e.g. transportation, energy, health, commerce, insurance), and confront these domains with major scientific challenges for exploiting these data, bringing about many new major scientific challenges for exploiting these data, which in turn calls for more interdisciplinarity. The field that is now referred to as Data Science has precisely emerged in response to the complexity of modern data, to meet the need of increased automation and computational efficiency, with the goal to design more and more "intelligent" systems, able to interact with their environment in a reliable fashion. Among these data, social data are ever more present and raise new scientific challenges in terms of both machine learning methods, social signal processing, and natural language processing.
Strength. To ensure that research in Data Science has a high impact, theory and practice must walk hand in hand. In particular, to ensure a practical aim, partnerships with industry and services through the development of chairs, joint labs, bilateral contracts, ... etc, are vital. The guiding hand of practical applications through such partnerships together with fundamental methodological research is what guarantees a lasting impact and value creation. In this regard, the size and span of activities of the team from theory to applications are clear strengths and allow the team to have both impact and visibility in its community and beyond.
Weakness. Beyond the recent joining of forces guaranteeing the presence of more complementary skills to tackle challenges in machine-learning and data-science and the recruitment of the young associate professors O. Fercoq (optimization), U. Simsekli (machine-learning and signal processing), François Portier (statistics), R. M. Gower (machine-learning and optimization) and G. Varni (social computing) and of senior researchers F. D'Alché-Buc (machine-learning), G. Peeters (deep learning for audio signal processing) as full professor, the team has indeed witnessed a significant turn-over with the departures of historical members (O. Cappé, G. Fort, J.F. Cardoso, E. Moulines, A. Gramfort). If the size of the team may represent some risk, the *pivotal* organisation of the team around open "scientific topics" (Machine learning, Audio data and Signal Processing,...) with their own scientific activities and seminars permits on the one hand to mitigate the

risk of dispersion and on the other hand to facilitate collaboration within S^2A and more generally within LTCI.

Threat. Also, whereas the socio-economic expectations are very high in this domain, in order to avoid harmful dispersal one must be careful to distinguish between what falls under development tasks (in this regard, our role essentially consists in training skillful graduates), what comes within the competency of expertise and what comes under research, which should be based in the long run on well-balanced academic and industrial partnerships.

17.4 Scientific project for the next five years

The era of big data and generalized artificial intelligence (AI) has opened. It uses technological bricks to automatically store and process in a short time a massive quantity of data of various sorts and formats. The infatuation with machine learning is spreading to nearly all fields (science, transportation, energy, medicine, security, banking, insurance, commerce, etc.) as the Internet of things (IoT) and the widespread use of technology for analytics (e.g., mass spectrometry or the cloud) make more data available with an ever finer granularity. Expectations are high. AI is supposed to allow for the development of personalized medicine that will adapt a treatment to the patient's genetic traits. It is to be used to design systems of predictive maintenance for complex infrastructures, such as electricity grids. It will help make aircrafts with systems for the early detection of "weak" signals that announce breakdowns, and will thus serve to plan the replacement of components before their probable failure. The vehicles using AI will be safer and fully autonomous, and be in service for longer. There is no denying the opportunities, and we can rightfully hope for operational applications with big data as the input. However AI will keep its promises only if certain issues are addressed. Before becoming THE solution, machine learning raises several exciting problems, in particular for applied mathematicians. A major problem in mathematics is to find a sparse, adaptative representation of information and work out algorithms for quickly calculating it. This is the key to efficient data processing. A representation will be all the more operational insofar as it eliminates "noise" and symmetries, highlights "patterns" and augments the predictive capacity of the algorithms of statistical learning that uses the thus formatted data as input. In several cases, the many layers of deep neural networks produce representations that make it easier to adjust the rules of prediction to the right degree of generalization. As biometrics is deployed on smartphones, the operation of embedded predictive models should not compromise the autonomy of the systems where they are embedded and should take account of the constraints of (nearly) real time operations. This raises questions about compressing information and the rules for processing it. The IoT is coming. Smart sensors (for applications such as predictive maintenance in transportation systems) connected in a network will be able to come up with the best strategy for sharing information and distributing the tasks of calculation as a function of the data collected and of the tasks to be performed. Several scientific questions crop up. In some cases, the level of "delegation" to be granted to "smart systems" will heavily depend on how research in methodology will answer questions of ethics (the processing of personal data while respecting privacy) and reliability. This brings us back to the development of statistical learning techniques that hold up even if part of the data has been "contaminated" (for example due to biases in measurements or the deliberate intention to impair the operation of the automated system). Not only must they hold up under such circumstances, but they must also yield decisions that end users (human beings) can interpret. Relying on a renewed configuration, one may highlight a few examples of crucial methodological issues that will be tackled by the team in the near future. In collaboration with some of its historical industrial partners (Safran, Valeo, Idemia, Airbus Defence and Space), the team is implementing a new Chair "AI and Data Science for Digitized Industry and Services" for the next five years, widening considerably the scientific perimeter of the original chair 'Machine-Learning for Big Data' (http://machinelearningforbigdata.telecom-paristech.fr/fr/) with four scientific axes: 1) Building predictive analytics on time series and data streams, 2) Exploiting Large Scale, Heterogeneous, Partially Labeled Data, 3) Machine Learning for trusted and robust decision, 4) Learning through interactions with environment. The potential of social computing

topic and human-agent interaction also offers opportunities to build industry collaboration and generating new challenges: i) structured output learning for accurate user's opinion prediction, ii) ranking prediction for user's preferences modeling, iii) semi-supervised and transfer learning (a crucial challenge for social computing as massive consensual opinion annotations are difficult to obtain); iv) reinforcement learning for the development of socio-emotional interaction strategies with robots.

17.5 Scientific production (selection)

Articles in Journals

[838] C. Laroche, M. Kowalski, H. Papadopoulos, and G. Richard. Hybrid projective nonnegative matrix factorization with drum dictionaries for harmonic/percussive source separation. *ACM/IEEE Transacations on Audio, Speech and Language Processing*, June 2018.

[839] S. Leglaive, R. Badeau, and G. Richard. Student's t source and mixing models for multichannel audio source separation. *IEEE Transactions on Audio, Speech and Language Processing*, 26(5):1–15, May 2018.

[840] P. Magron, R. Badeau, and B. David. Model-based stft phase recovery for audio source separation. *IEEE Transactions on Audio, Speech and Language Processing*, 26(6):1095–1105, February 2018.

[841] E. Granell, E. Chammas, L. Likforman-Sulem, C.-D. Martínez-Hinarejos, Ch. Mokbel, and B. Cirstea. Transcription of spanish historical handwritten documents with deep neural networks. *Journal of Imaging*, 4(1):22, January 2018.

[842] M. Djerrab, A. Garcia Rojas, M. Sangnier, and F. d'Alché-Buc. Output fisher embedding regression. *Machine learning Journal*, 108, April 2018.

[843] T. Dupré la Tour, L. Tallot, L. Grabot, V. Doyère, V. Van Wassenhove, Y. Grenier, and A. Gramfort. Non-linear auto-regressive models for crossfrequency coupling in neural time series. *PLOS Computational Biology*, December 2017.

[844] G. Varni, I. Hupont, Ch. Clavel, and M. Chetouani. Computational study of primitive emotional contagion in dyadic interactions. *IEEE Transactions on Affective Computing*, November 2017.

[845] L. Likforman-Sulem, A. Esposito, M. Faundez-Zanuy, S. Clémençon, and G. Cordasco. Emothaw: A novel database for emotional state recognition from handwriting and drawing. *IEEE THMS*, September 2017.

[846] S. Clémençon and A. Thomas. Mass volume curves and anomaly ranking. *Electronic Journal of Statistics*, July 2017.

[847] F. Portier, A. El Ghouch, I. Van Keilegom, and others. Efficiency and bootstrap in the promotion time cure model. *Bernoulli*, 23(4B):3437–3468, July 2017.

[848] D. Chételat, J. Lederer, and J. Salmon. Optimal two-step prediction in regression. *Electron. J. Statist.*, 11(1):2519–2546, July 2017.

[849] V. Bisot, R. Serizel, S. Essid, and G. Richard. Feature learning with matrix factorization applied to acoustic scene classification. *IEEE/ACM Transactions on Audio, Speech, and Language Processing*, 25(6):1216–1229, June 2017.

[850] K. Nathwani, G. Richard, D. Bertrand, P. Prablanc, and V. Roussarie. Speech intelligibility improvement in car noise environment by voice transformation. *Speech Communication*, (91):17–27, May 2017.

[851] C. Brouard, M. Szafranski, and F. d'Alché-Buc. Input output kernel regression: Supervised and semi-supervised structured output prediction with operator-valued kernels. *Journal of Machine Learning Research*, 17(176):1–48, October 2016.

[852] N. Lim, F. d'Alché-Buc, C. Auliac, and G. Michailidis. Operator-valued kernel-based vector autoregressive models for network inference. *Machine Learning Journal*, 99(3):489–513, June 2015.

[853] M. Heinonen, O. Guipaud, F. Milliat, V. Buard, B. Micheau, M. Benderitter, F. Zehraoui, and F. d'Alché-Buc. Detecting time periods of differential gene expression using gaussian processes: an application to endothelial cells exposed to radiotherapy dose fraction. *Bioinformatics*, 31(5): 728–735, April 2015.

[854] E. Ndiaye, O. Fercoq, A. Gramfort, and J. Salmon. Gap safe screening rules for sparsity enforcing penalties. *J. Mach. Learn. Res.*, 18(128):1–33, November 2017.

[855] S. Leglaive, R. Badeau, and G. Richard. Multichannel audio source separation with probabilistic

reverberation priors. *IEEE Transactions on Audio, Speech and Language Processing*, 24(12):2453–2465, December 2016.

[856] S. Durand, J. P. Bello, B. David, and G. Richard. Robust downbeat tracking using an ensemble of convolutional networks. *IEEE/ACM Transactions on Audio, Speech, and Language Processing*, November 2016.

[857] X. Jaureguiberry, E. Vincent, and G. Richard. Fusion methods for speech enhancement and audio source separation. *IEEE/ACM Transactions on Audio, Speech and Language Processing*, 24(7), July 2016.

[858] D. Strohmeier, Y. Bekhti, J. Haueisen, and A. Gramfort. The iterative reweighted mixed-norm estimate for spatio-temporal meg/eeg source reconstruction. *IEEE Trans. Medical Imaging*, April 2016.

[859] H. Bai, L. Daudet, and G. Richard. Late reverberation synthesis: From radiance transfer to feedback delay networks. *IEEE/ACM Transactions on Audio, Speech, and Language Processing*, 23(12):2260–2271, December 2015.

[860] D. Engemann and A. Gramfort. Automated model selection in covariance estimation and spatial whitening of meg and eeg signals. *Neuroimage*, 108:328–342, March 2015.

[861] J. Salomon, E. Gomez, D. Ellis, and G. Richard. Melody extraction from polyphonic music signals: Approaches, applications and challenges. *IEEE Signal Processing magazine*, 31(2):118–134, March 2014.

[862] A. Gramfort, M. Luessi, E. Larson, D. Engemann, D. Strohmeier, Ch. Brodbeck, L. Parkkonen, and M. Hamalainen. Mne software for processing meg and eeg data. *Neuroimage*, 86:446–460, February 2014.

[863] A. Schreck, G. Fort, E. Moulines, and M. Vihola. Convergence of markovian stochastic approximation with discontinuous dynamics. *SIAM Journal on Control and Optimization (SICON)*, 2014.

[864] C. Joder, S. Essid, and G. Richard. Learning optimal features for polyphonic audio-to-score alignment. *IEEE Transactions on Audio Speech and Language Processing*, 21(10):2118–2128, October 2013.

[865] G. Richard, S. Sundaram, and S. Narayanan. An overview on perceptually motivated audio indexing and classification. *Proceedings of the IEEE*, September 2013.

[866] B. Fuentes, R. Badeau, and G. Richard. Harmonic adaptive latent component analysis of audio and application to music transcription. *IEEE Transactions on Audio, Speech and Language Processing*, 21(9):1854–1866, September 2013.

[867] A. Gramfort. Time-frequency mixed-norm estimates: Sparse m/eeg imaging with non-stationary source activations. *Neuroimage*, 70(15):410–422, April 2013.

[868] Q. Tran-Dinh, O. Fercoq, and V. Cevher. A smooth primal-dual optimization framework for nonsmooth composite minimization. *SIAM Journal on Optimization*, 28(1):96–134, 2018.

[869] A. Sabourin and J. Segers. Marginal standardization of upper semicontinuous processes. with application to max-stable processes. *Journal of applied probability*, September 2017.

[870] S. Clémençon, N. Goix, and A. Sabourin. Sparse representation of multivariate extremes with applications to anomaly detection. *Journal of Multivariate Analysis*, July 2017.

[871] Y. Atchadé, G. Fort, and E. Moulines. On stochastic proximal gradient algorithms. *Journal of Machine Learning Resaerch*, January 2017.

[872] P. Bianchi, W. Hachem, and F. Iutzeler. A coordinate descent primal-dual algorithm and application to distributed asynchronous optimization. *IEEE Transactions on Automatic Control*, 61(10):2947–2957, October 2016.

[873] S. Clémençon, E. Chautru, and P. Bertail. Empirical processes in survey sampling with (conditional) poisson designs. *Journal of Scandinavian Statistics*, July 2016.

[874] W. Benameur, P. Bianchi, and J. Jakubowicz. Robust distributed consensus using total variation. *IEEE Transaction on Automatic Control*, 61(6):1550–1564, June 2016.

[875] F. Iutzeler, P. Bianchi, Ph. Ciblat, and W. Hachem. Explicit convergence rate of a distributed alternating direction method of multipliers. *IEEE Transactions on Automatic Control*, 61(4):892 – 904, April 2016.

[876] P. Bianchi. Ergodic convergence of a stochastic proximal point algorithm. *SIAM Journal on Optimization*, 26(4):2235–2260, April 2016.

[877] A. Schreck, G. Fort, S. Le Corff, and E. Moulines. A shrinkage-thresholding metropolis adjusted langevin algorithm for bayesian variable selection. *IEEE J. of Selected Topics in Signal Processing*, 10(2):366–375, March 2016.

[878] A. Durmus, G. Fort, and E. Moulines. Subgeometric rates of convergence in wasserstein distance for

markov chains. *Annales de l'Institut Henri Poincaré, Probabilités et Statistiques*, 52(4):1799–1822, 2016.

[879] R. Douc, F. Roueff, and T. Sim. The maximizing set of the asymptotic normalized log-likelihood for partially observed markov chains. *Annals of Applied Probability*, 26(4):2357–2383, 2016.

[880] P. Bianchi and W. Hachem. Dynamical behavior of a stochastic forward-backward algorithm using random monotone operators. *Journal on Optimization Theory and Applications*, 171:90–120, 2016.

[881] F. Roueff, R. von Sachs, and L. Sansonnet. Locally stationary hawkes processes. *Stochastic Processes and their Applications*, 126(6):1710–1743, 2016.

[882] S. Clémençon and A. Dematteo. On tail index estimation based on multivariate data. *Journal of Nonparametric Statistics*, November 2015.

[883] M. Clausel, F. Roueff, and M. S. Taqqu. Large scale reduction principle and application to hypothesis testing. *Electron. J. Statist.*, 9(2):153–203, October 2015.

[884] O. Klopp, J. Lafond, E. Moulines, and J. Salmon. Adaptative multinomial matrix completion. *Electronic Journal of Statistics*, April 2015.

[885] S. Clémençon, P. Bertail, and E. Chautru. On survey sampling and empirical risk minimization. *Statistics*, January 2015.

[886] G. Fort. Central limit theorems for stochastic approximation with controlled markov chain dynamics. *ESAIM PS*, 19:60–80, January 2015.

[887] S. Clémençon, A. Bellet, and I. Colin. Scaling-up empirical risk minimization: Optimization of incomplete u-statistics. *Journal of Machine Learning Research*, January 2015.

[888] R. Bardenet, O. Cappé, G. Fort, and B. Kegl. Adaptive mcmc with online relabeling. *Bernoulli*, 21 (3):1304–1340, 2015.

[889] F. Roueff and Ph. Soulier. Convergence to stable laws in the space d. *Journal of Applied Probability*, 52(1):1–17, 2015.

[890] Ch. Giraud, F. Roueff, and A. Sánchez Pérez. Aggregation of predictors for non stationary sub-linearprocesses and online adaptive forecasting of time varyingautoregressive processes. *The Annals of Statistics*, 43(6):2412–2450, 2015.

[891] P. Ilhe, E. Moulines, F. Roueff, and A. Souloumiac. Nonparametric estimation of mark's distribution of an exponential shot-noise. *Electronical Journal of Statistics*, 9(2):3098–3123, 2015.

[892] The Planck collaboration and J.-F. Cardoso. Planck 2013 results. xvi. cosmological parameters. *Astronomy and Astrophysics*, 571, November 2014.

[893] N. Seichepine, S. Essid, C. Févotte, and O. Cappé. Soft nonnegative matrix co-factorization. *IEEE Transactions on Signal Processing*, 62(22):5940–5949, September 2014.

[894] D. Guenther, J. Salmon, and J. Tierny. Mandatory critical points of 2d uncertain scalar fields. *Computer Graphics Forum*, 33(3):31–40, August 2014.

[895] Ch. Andrieu, G. Fort, and M. Vihola. Quantitative convergence rates for sub-geometric markov chains. *Advances in Applied Probability*, June 2014.

[896] A. Nouvellet, M. Charbit, F. Roueff, and A. Le Pichon. Slowness estimation from noisy time delays observed on non-planar arrays. *Geophysical Journal International*, 198:1199–1207, May 2014.

[897] S. Clémençon, P. Bertail, and J. Tressou. Bootstrapping robust statistics for markovian data applications to regenerative r- and l-statistics. *Journal of Time Series Analysis*, February 2014.

[898] M. Clausel, F. Roueff, M. S. Taqqu, and C. Tudor. Asymptotic behavior of the quadratic variation of the sum of two {H}ermite processes of consecutive orders. *Stoch. Proc. App.*, 124(7):2517–2541, 2014.

[899] M. Clausel, F. Roueff, M. S. Taqqu, and C. Tudor. Wavelet estimation of the long memory parameter for {H}ermite polynomial of {G}aussian processes. *ESAIM P\&S*, 18:42–76, 2014.

[900] S. Clémençon, P. Bertail, and J. Tressou. Regenerative block-bootstrap confidence intervals for the tail and extremal indexes. *Electronic Journal of Statistics*, 7:1224–1248, July 2013.

[901] C. Oprean, L. Likforman-Sulem, A. Popescu-Belis, and Ch. Mokbel. Handwritten word recognition using web resources and recurrent neural networks. *IJDAR*, January 2015.

[902] O. Morillot, L. Likforman-Sulem, and E. Grosicki. New baseline correction algorithm for text-line recognition with bidirectional recurrent neural networks. *Journal of Electronic Imaging*, 22(2), July 2013.

[903] C. Langlet and Ch. Clavel. Grounding the detection of the user's likes ´ and dislikes on the topic structure of human-agent interactions. *Knowledge-Based Systems*, 106:116–124, August 2016.

[904] Ch. Clavel and Z. Callejas. Sentiment analysis: from opinion mining to human-agent interaction. *Affective Computing, IEEE Transactions on*, 7(1):74–93, March 2016.

Book Chapters

[905] S. Clémençon, N. Baskiotis, and N. Vayatis. Anomaly scoring/ranking in a high dimensional space: the unsupervised treerank algorithm. In *Unsupervised Learning Algorithms*. Springer, 2015.

Articles in Conference Proceedings

[906] B. Ravenet, Ch. Clavel, and C. Pelachaud. Automatic nonverbal behavior generation from image schemas. In *International Conference on Autonomous Agents and Multiagent Systems*, Stockholm, Suède, July 2018.

[907] S. Clémençon and F. Portier. Beating monte-carlo integration: a nonparametric study of kernel smoothing methods. In *AISTATS*, Lanzarote, Espagne, April 2018.

[908] S. Clémençon, A. Korba, and E. Sibony. Ranking median regression: Learning to order through local consensus. In *Algorithmic Learning Theory*, Lanzarotte, Espagne, April 2018.

[909] V. Barriere, Ch. Clavel, and S. Essid. Attitude classification in adjacency pairs of a human-agent interaction with hidden conditional random fields. In *ICASSP*, April 2018.

[910] J.-B. Schiratti, J.-E. Le Douget, M. Le Van Quyen, S. Essid, and A. Gramfort. An ensemble learning approach to detect epileptic seizures from long intracranial eeg recordings. In *International Conference on Acoustics, Speech, and Signal Processing*, Calgary, Canada, April 2018.

[911] M. Jas, T. D. La Tour, U. Simsekli, and A. Gramfort. Learning the morphology of brain signals using alpha-stable convolutional sparse coding. In *Advances in Neural Information Processing Systems*, pages 1099–1108, December 2017.

[912] A. Ben Youssef, Ch. Clavel, S. Essid, M. Bilac, M. Chamoux, and A. Lim. Ue-hri: A new dataset for the study of user engagement in spontaneous human-robot interactions. In *ACM International Conference on Multimodal Interaction*, pages 464–472, Glasgow, Scotland, November 2017.

[913] S. Leglaive, R. Badeau, and G. Richard. Separating time-frequency sources from time-domain convolutive mixtures using non-negative matrix factorization. In *WASPAA*, New Paltz, New York, USA, October 2017. IEEE.

[914] A. Belhomme, R. Badeau, Y. Grenier, and E. Humbert. Amplitude and phase dereverberation of harmonic signals. In *WASPAA*, New Paltz, New York, USA, October 2017. IEEE.

[915] M. Fontaine, A. Liutkus, L. Girin, and R. Badeau. Explaining the parameterized wiener filter with alpha-stable processes. In *WASPAA*, New Paltz, New York, USA, October 2017. IEEE.

[916] S. Parekh, S. Essid, A. Ozerov, Q.-K.-N. Duong, P. Perez, and G. Richard. Guiding audio source separation by video object information. In *IEEE Workshop on Applications of Signal Processing to Audio and Acoustics (WASPAA)*, New Paltz, New York, U.S.A, October 2017.

[917] M. Achab, S. Clémençon, A. Garivier, A. Sabourin, and C. Vernade. Max k-armed bandits: On estremehunter and an alternative approach. In *ECML*, Skopje, Macédoine, September 2017.

[918] I. Gannaz, S. Achard, M. Clausel, and F. Roueff. Ondelettes analytiques, application à l'analyse des processus multivariés à longue mémoire. In *GRETSI*, Juan-Les-Pins, September 2017.

[919] C. Taleb, L. Likforman-Sulem, M. KHACHAB, and Ch. Mokbel. Feature selection for an improved parkinson's disease identification based on handwriting. In *ASAR 2017 Arabic Script Analysis and Recognition*, Nancy, September 2017.

[920] E. Chammas, Ch. Mokbel, and L. Likforman-Sulem. Stroke width exploitation to improve automatic recognition of arabic handwritten texts. In *ASAR 2017*, Nancy, September 2017.

[921] V. Bisot, R. Serizel, S. Essid, and G. Richard. Leveraging deep neural networks with nonnegative representations for improved environmental sound classification. In *IEEE International Workshop on Machine Learning for Signal Processing MLSP*, Tokyo, Japan, September 2017.

[922] Y. Bekhti, R. Badeau, and A. Gramfort. Hyperparameter estimation in maximum a posteriori regression using group sparsity with an application to brain imaging. In *EUSIPCO*, pages 256–260, Kos, Greece, August 2017.

[923] F. Landragin, G. Dubuisson Duplessis, and Ch. Clavel. Automatic measures to characterise verbal alignment in human-agent interaction. In *18th Annual Meeting of the Special Interest Group on Discourse and Dialogue (SIGDIAL)*, Saarbrücken, Germany, August 2017.

[924] U. Simsekli. Fractional langevin monte carlo: Exploring lévy driven stochastic differential equations for mcmc. In *International Conference on Machine Learning (ICML)*, August 2017.

[925] S. Clémençon, A. Gramfort, A. Sabourin, and A. Thomas. Empirical minimum volume set on the sphere: A canonical anomaly detection method. In *AISTATS*, Fort Lauderdale, USA, June 2017.

[926] S. Clémençon, A. Korba, and E. Sibony. A learning theory of ranking aggregation. In *AISTATS*, Fort Lauderdale (USA), June 2017.

[927] S. Leglaive, R. Badeau, and G. Richard. Multichannel audio source separation: variational inference of time-frequency sources from time-domain observations. In *42nd International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, New Orleans, USA, March 2017. IEEE.

[928] V. Bisot, S. Essid, and G. Richard. Overlapping sound event detection with supervised nonnegative matrix factorization. In *2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP),*, March 2017.

[929] A.-C. Conneau, A. Hajlaoui, M. Chetouani, and S. Essid. Emoeeg: a new multimodal dataset for dynamic eeg-based emotion recognition with audiovisual elicitation. In *The European Signal Processing Conference (EUSIPCO)*, Kos island, Greece, 2017.

[930] S. Parekh, S. Essid, A. Ozerov, Q.-K.-N. Duong, P. Perez, and G. Richard. Motion informed audio source separation. In *IEEE International Conference on Acoustics Speech and Signal Processing (ICASSP)*, New Orleans, USA, 2017.

[931] T. Dupré la Tour, Y. Grenier, and A. Gramfort. Parametric estimation of spectrum driven by an exogenous signal. In *ICASSP*, New Orleans, March 2017.

[932] M. Jas, D. Engemann, F. Raimondo, Y. Bekhti, and A. Gramfort. Automated rejection and repair of bad trials in meg/eeg. In *PRNI*, Trento, Italie, June 2016.

[933] R. Brault, M. Heinonen, and F. d'Alché-Buc. Random fourier features for operator-valued kernels. In *ACML*, volume 63, pages 110–125, Hamilton, New-Zealand, November 2016. JMLR Workshop and Conference Proceedings.

[934] M. Massias, A. Gramfort, O. Fercoq, and J. Salmon. Generalized concomitant multi-task lasso for sparse multimodal regression. In *AISTATS*, April 2018.

[935] N. Kourtellis, G. D. F. Morales, A. Bifet, and A. Murdopo. Vht: Vertical hoeffding tree. In *Big Data (Big Data), 2016 IEEE International Conference on*, pages 915–922, June 2016.

[936] J. P. Barddal, H. M. Gomes, F. Enembreck, B. Pfahringer, and A. Bifet. On dynamic feature weighting for feature drifting data streams. In *Joint European Conference on Machine Learning and Knowledge Discovery in Databases*, pages 129–144, June 2016.

[937] D. Marrón, J. Read, A. Bifet, T. Abdessalem, E. Ayguadé, and J. Herrero. Echo state hoeffding tree learning. In *Asian Conference on Machine Learning*, pages 382–397, June 2016.

[938] R. Serizel, S. Essid, and G. Richard. Group nonnegative matrix factorisation with speaker and session variability compensation for speaker identification. In *ICASSP*, pages 5470–5474, Shangai, Chine, March 2016.

[939] T. Nabil, F. Roueff, J.-M. Jicquel, and A. Girard. Identification of a thermal building model by learning the dynamics of the solar flux. In *Machine Learning for Signal Processing Workshop (MLSP)*, Tokyo, Japon, September 2017.

[940] Th. Fillon, C. Joder, S. Durand, and S. Essid. A conditional random field system for beat tracking. In *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Brisbane, Australia, April 2015.

[941] A. K. Pandey, R. Gelin, R. Alami, A. Buendia, M. Chetouani, L. Devillers, D. Filliat, Y. Grenier, A. Kheddar, F. Lerasle, M. Maazaoui, R. Meertens, and R. Viry. Romeo2 project: Humanoid robot assistant and companion for everyday life: I. situation assessment for social intelligence. In *International Workshop on Artificial Intelligence and Cognition*, Torino, Italy, November 2014.

[942] N. López, Y. Grenier, G. Richard, and I. Bourmeyster. Single channel reverberation suppression based on sparse linear prediction. In *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, Florence, Italy, May 2014. IEEE.

[943] A. Masurelle, S. Essid, and G. Richard. Gesture recognition using a nmf-based representation of motion-traces extracted from depth silhouettes. In *ICASSP*, Florence, Italy, May 2014.

[944] A.-C. Conneau and S. Essid. Assessment of new spectral features for eeg-based emotion recognition. In *International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, Florence, Italie, May 2014.

[945] S. Fenet, Y. Grenier, and G. Richard. An extended audio-fingerprint method with capabilities for similar music detection. In *ISMIR*, pages 569–574, Curitiba, Brazil, November 2013.

[946] A. Dremeau and S. Essid. Probabilistic dance performance alignment by fusion of multimodal features. In *IEEE Int'l Conf. on Acoustics, Speech and Signal Processing (ICASSP)*, Vancouver, Canada, May 2013.

[947] N. Seichepine, S. Essid, C. Févotte, and O. Cappé. Soft nonnegative matrix co-factorization with application to multimodal speaker diarization. In *ICASSP*, Vancouver, May 2013.

[948] N. Goix, A. Sabourin, and S. Clémençon. Sparse representation of multivariate extremes with applications to anomaly ranking. In *AISTATS 2016*, Cadiz, Espagne, December 2016.

[949] S. Clémençon, P. Bertail, and G. Papa. Learning from survey training samples: Rate bounds for horvitz-thompson risk minimizers. In *ACML*, Hamilton, New Zealand, December 2016.
[950] M. Sangnier, O. Fercoq, and F. d'Alché-Buc. Joint quantile regression in vector-valued rkhss. In *Neural Information Processing Systems (NIPS)*, Barcelone, Espagne, December 2016.
[951] M. Chiapino and A. Sabourin. Feature clustering for extreme events analysis, with application to extreme stream-flow data. In *ECML workshop "New Frontiers in Mining Complex Patterns"*, Riva del guarda, Italie, September 2016.
[952] S. Clémençon, N. Goix, and A. Sabourin. Learning the dependence structure of rare events: a non-asymptotic study. In *COLT 2015*, Paris, France, May 2015.
[953] S. Clémençon, E. Sibony, and J. Jakubowicz. Mra-based statistical learning from incomplete rankings. In *ICML*, Lille, France, April 2015.
[954] S. Clémençon and S. Robbiano. Anomaly ranking as supervised bipartite ranking. In *ICML 2014*, Pékin (Chine), June 2014.
[955] F. Iutzeler, P. Bianchi, Ph. Ciblat, and W. Hachem. Asynchronous distributed optimization using a randomized alternating direction method of multipliers. In *IEEE Conference on Decision and Control*, Florence (Italy), December 2013.
[956] B. Cirstea and L. Likforman-Sulem. Tied spatial transformer networks for digit recognition. In *ICFHR*, Shenzen, Chine, August 2016.

Invited Talks

[957] F. Roueff. Time frequency analysis of locally stationary hawkes processes. In *2018 IMS Annual Meeting on Probability and Statistics*, Vilnius, Lithuanie, July 2018.
[958] S. Clémençon. Machine-learning meets extreme value theory. In *Annual Conference of the German Statistical Society*, Rostock, Allemagne, September 2017.
[959] R. Brault and F. d'Alché-Buc. Random fourier features for operator-valued kernels. In *New Directions for Learning with Kernels and Gaussian Processes*, Dagstuhl, November 2016. Dagstuhl Seminar 16481.
[960] S. Essid. Audio and brain research at telecom paristech. In *Hearing Seminar of the Center for Computer Research in Music and Acoustics (CCRMA), Stanford University*, Stanford, USA, September 2016.
[961] G. Richard. Acoustic scene and events recognition: How similar is it to speech recognition and music genre recognition? In *International Workshop on Detection and Classification of Acoustic Scenes and Events*, Budapest, Hongrie, March 2016.
[962] A. Sabourin. Dimension reduction in multivariate extremes application to anomaly detection. In *Extreme Value Analysis*, Ann Arbor, USA, June 2015.
[963] L. Likforman-Sulem. Extracting style and emotions from handwriting. In *WIRN 2014*, Vietri-sulmare, Italy, March 2014.

Organization of Conferences, Workshops

- Co-organization of the 2016 IEEE DSAA conference,
- Organization of the 1st Paris-Saclay Junior Conf. on Data Science and Engineering in 2016,
- Co-organization of the 2017 NIPS Workshop: Learning on Distributions/Functions/Graphs/Groups,
- Co-organization of the conference *Heavy Tails and Long Range Dependence* in 2017,
- Area chair of NIPS 2014, 2015, 2016 and 2018 (senior), of ICML 2015 (F. d'Alché),
- General co-chairs of WIAMIS2013, WASPAA 2015 and ISMIR2018 (S. Essid, G. Richard),
- Program chair of the IEEE-ASAR 2017 (L. Likforman),
- Co-organization of the workshop *rare events, extremes and machine learning* in 2018,
- Co-organization of a special session in the LVA/ICA 2018 conference (U. Simsekli).

Strategic Partnerships and Grants

- ERC Starting Grant "Signal and learning for brain data (SLAB)" for A. Gramfort (2017-),

- 1 International ANR-Project (FBI-Matrix, U. Simsekli); 2 Marie-Curie International Training Networks (ITN) (Animatas, C. Clavel and MIP-Frontiers, G. Richard),
- Industrial chair ML4BGD with Safran, PSA, BNP, Criteo, Valeo (2013-2018, $\sim 2000K$ euros),
- Joint lab *Analytics Big Data* with Orange Labs (2015-2016),
- ANR JCJC MAOI (Multimodal Analysis of Opinion Analysis in Interactions, C. Clavel),
- PSPC Project (BPI): Expresso with Valeo (2018-21).

Awards and Prizes

- O. Cappé received the 2013 EADS prize of the French Academy of Sciences,
- J.F. Cardoso received the 2013 Doisteau-Bluzet prize of the French Academy of Sciences,
- G. Richard has been elevated to IEEE Fellow in 2017,
- S. Clémençon: IBM Faculty Research Award in 2014, Criteo Faculty Award in 2017,
- IEEE Senior Member Best paper ISMIR 2015 (S. Essid),
- 2nd prize at the ICDAR 2017 Competition(E. Chammas, L. Likforman),
- Ranked 3rd at DCASE 2016 international challenge (Victor Bisot),
- Best Poster Award in the International Workshop on Non-Intrusive Load Monitoring (Simon Henriet).

Responsabilities

- Labex DigiCosme: Deputy Head in 2016, Scientific Head since 2017 (F. D'Alché),
- Co-head of the Doctoral School Maths-Hadamard in Paris-Saclay since 2015 (F. Roueff),
- Co-head of the LTCI lab (2014-2017, O. Cappé),
- IEEE Technical committee on Audio and Acoustic Signal Processing (G. Richard),
- Member of the IAPR Conferences and Meetings Committee (2017-) (L. Likforman),
- Co-head of the Master Data-Science in Paris-Saclay since 2015 (F. D'alché),
- Head of the Specialized Master 'Big Data' (S. Clémençon).

Transfer

- Licensing of the TreeRank patents (IT4PME),
- 2 pre-maturation and 1 maturation project (SATT Paris Saclay),
- 6 patent applications in the ADASP domain.

Popularization of Science

- France Culture 'La méthode scientifique' (C. Vernade 09/21/17, C. Clavel 03/21/18),
- Scientific Committee of Terra Data exhibition (Cité des Sciences, 2017, S. Clémençon),
- Articles in Le Monde (p4-5) 'Les défis scientifiques du Big Data' (01/29/14),
- France Culture 'La recherche montre en main' (e.g. N. Goix, C. Vernade).

Editorial Activities

- Editor of a special issue 'Sound Scene and Event Analysis' of ACM/IEEE Trans. on Audio, Speech and Language Processing (G. Richard, 2017),
- Editor of a special issue 'Informed Acoustic Source Separation' of EURASIP (G. Richard, 2013),
- Editor of the special issue on Document Image Processing (2018, L. Likforman) Journal of Imaging,
- Editor of a special issue on Special Section on Affect and Interaction in Agent-based Systems and Social Media in ACM Transactions on Internet Technology (TOIT), (2018, C. Clavel),
- Associate Editor of IEEE Transactions on Acoustics, Speech and Language Processing (TASLP) (R. Badeau, since 2017),
- Associate Editor of EURASIP Journal on Audio, Speech, and Music Processing (JASMP) (R. Badeau, since 2012),
- Associate Editor of EURASIP Journal on Audio, Speech, and Music Processing (SIGPRO) (P. Bianchi, 2012 - 2017),
- Associate Editor of Statistics and Probability Letters (F. Roueff, since 2017).

Softwares and databases

- Software dialign (CECIL licence), for the computation of generic measures of verbal alignment in dyadic dialogue based on sequential pattern mining (C. Clavel),
- Databases SAFE corpus, UE-HRI, EMOTHAW, EMOEEG, ADVRASS,
- Scikit-learn algorithms Isolation forests and 1-class SVM (N. Goix, A. Thomas),
- Operalib (R. Brault).