Research Report 2009–2011

Laboratoire Traitement et Communication de l'Information
Télécom ParisTech & CNRS

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Contents

Chapter 1

General Survey of Research Activities

This report presents the activities of Télécom ParisTech in research between July 2009 and December 2011. A general outline of research is given in the first chapter along with consolidated figures giving resources allotted and the results obtained collectively. In the four following chapters are listed and analysed the scientific achievements of each of the research teams of the four departments of Télécom ParisTech. A separate document will develop what is projected in research over the next four years.

1.1 Background

Successor to the Ecole Supérieure de Télégraphie (EST), founded in 1878, Télécom ParisTech's names were, in order, the Ecole professionnelle supérieure des postes & télégraphes (EPSPT) and later on, the Ecole supérieure des postes & télégraphes (ESPT), the Ecole nationale supérieure des postes, télégraphes et téléphones (ENSPTT), Ecole nationale supérieure des télécommunications (ENST), Télécom Paris, and to emphasize its connection with ParisTech, of which it is a founding member since 1991, Télécom ParisTech, when ParisTech became a "PRES"[1] in 2008.

Télécom ParisTech has occupied its current site on rue Barrault in the 13th arrondissement of Paris since 1934. A unit of the school was set up within EURECOM in Sophia Antipolis in 2003. A number of its departments and services later migrated to two annexes on the rue Dareau (in the 14th arrondissement).

Under the authority of the Direction générale des telélécommunications (part of the Ministry of PTT), and later of France Télécom in 1991, ENST became part of the Groupe des Ecoles des Télécommunications (GET) in 1996, which had the status of an "établissement public administratif" (EPA), and which was placed under the minister responsible for telecommunications. The GET became Institut Télécom in 2008.

Up to 1968, ENST did not develope its own research labs, taking advantage of the Ministry's facilities. In 1968, C. Gueguen opened the first lab rue Barrault.

In 1982, the signal processing and digital communications teams made the first joint ERA (Equipe de Recherche Associée) with CNRS. It has become an URA (Unité de Recherche Associée) and then an UMR (Unité Mixte de Recherche) by progressively associating reserch teams in computer science, networking, applied physics for telecoms, image processing and, at last, management and social sciences. Today the UMR 5141 LTCI (see Section **??**) covers all the research activity of Télécom ParisTech.

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[1]PRES= "Pôle de Recherche et d'Enseignement Supérieur" is a regional cluster of institutes and universities for research in higher education

1.2 Administration and Organization

1.2.1 Télécom ParisTech As a Member of Institut Télécom

The Institut Télécom, which in addition to Télécom ParisTech, includes Télécom Bretagne and Télécom & Management SudParis, federates and coordinates its research activities in the separate schools within a "Comité Directeur de la Recherche" (= Research Management Committee). This body is under the authority of the Research Director of the Institut (Francis Jutand) and includes Télécom ParisTech's own Research Director and Director of Innovation and Development.

Part I

Communications and Electronics

Communications and Electronics Department (COMELEC)

The research led in the **" Communications and Electronics "** department is devoted to the physical layer of ICT (Information and Communication technology). A useful concept for depicting the department main research concern is that of "physical information", where the information content is actually reached through some physical properties and manipulated using physical laws such as Maxwell electromagnetic equations or Quantum Hamiltonians. The department covers both the field of communication and that of information processing (electronics). The department accounts for 36 permanent research staff and hosts about 90 non permanent researchers, including PhD students. The research activity is covered by four different teams. While fixed communications are dealt with by the **Optical communication group**, the **Electronics and RF systems team** concentrate on the transformation from analog to digital information and to its transmission through wireless means. The **Digital communications team** works on the digital coding of the information, and prepare for the future digital communication breakthrough in MIMO system, multi-hop communications or multi-users wireless communications. Processing information requires extremely sophisticated Silicon chips (processors, FPGAs, SOCs), the architecture of which is central to the **Complex Digital Electronics system team**. Transverse to all these activities, one may also find security as a main topic. The department research policy claims for a research effort that spreads from fundamental physics to applied results. One may for example note the use of quantum dots for optical clock recovery (see the optical communication team) or that of photonic crystal (also called metamaterial) for advanced antennas (Electronics and RF Systems team). The balance between exploratory research and market oriented results is well expressed by the 1:4 ratio between our private partners funding and our total research contract income (7 Meuros cumulated over the period). Because of an innovation minded research taking its roots in fundamental theories, the department was granted 29 patents while publishing over 550 papers in journals and conferences in the evaluation period. The department is also strongly involved in educating students for research. This is reflected by the 70 defended PhD thesis over the period. A budget of about 75 keuros is also spent yearly for master student internships in the department research groups, with a total of about 150 man.month of internship generated every year. Besides its contribution to the "ingenieur courses" of TELECOM ParisTech, the department researcher's participate to master courses with ParisVI, ParisXI, as well with the University of Nice. In terms of outreach, the department was strongly involved in a number of initiatives both at local, national and international levels. Among other actions, one may notice the Electronics and RF systems team involvement in the creation of the GIS Esys "Groupement pour l'Electronique des Systèmes" led by Supelec. The Complex Digital Electronics system team initiated the Sophia-Antipolis Formal Analysis group SAFA and recently animated its first workshop. The Electronics and RF systems team was also a recognized actor in the launching of the joint IEEE Newcas-TAISA conference. Of interest, a world open contest on electronics attacks was launched by the Complex Digital Electronics system team at the CHESS meeting. In order to help for a better European visibility, the department head created and chaired the IDEA League (Imperial College, Delft University, Eth Zurich, Aachen RWTH) ICT cluster. As an international impact indicator, the department teams are currently involved into two European STREPS, three

European NOE's, one Eureka program and lead a Carnot-Fraunhofer project.

Faculty [IT, CNRS]	[32.8, 4]
PhD students	65.5
Post-docs, engineers and sabbaticals	16.1
Defended PhD thesis	43
Defended HDR	black 3
Journal papers [published, in press]	[143, 18]
Papers in conference proceedings	410
Chapters and books	15
Patents and software	[13, 3]
Grants [public, private, european] (k€)	[2667, 876, 1207]

Chapter 2

Digital Communications

Team leader Philippe Ciblat (P).

Faculty

Jean-Claude Belfiore (P), Philippe Ciblat (P),
Walid Hachem (CR CNRS), Ghaya Rekaya-Ben Othman (MC),
Olivier Rioul (MC), Georges Rodriguez (MC),
Patrick Sole (CR CNRS), Aslan Tchamkerten (MC),
Michele Wigger (MC,12/09–).

PhD students

H. Laamari (11/01–10/09), A. Le Poupon (09/02–09/09), F. Robinet (10/04–09/09),
M. Sarkiss (12/04–08/10), Z. Zhao (10/05–09/10), C. Hucher (01/06–07/09),
R. Ouertani (01/06–11/09), M. Badr (09/06–03/10), E. Bouton (09/06–02/10),
R. Ayadi (10/06–08/09), L. Mroueh (10/06–01/10), A. Salah (10/06–07/10),
A. Bouzegzi (11/06–10/09), A. Le Duc (01/07–03/10), M. Nahas (09/07–12/10),
C. Abgrall (02/08–10/10), A. Osmane (10/08–), A. Charaf (11/08–),
M. Plainchault (11/08–), P. Delesques (09/09–), M. Sefidgaran (10/09–),
C. Mihoubi (11/09–), D. Serrano-velarde (11/09–), S. Marcille (01/10–),
S.H. Mirghasemi (03/10–), F. Iutzeler (10/10–), M.M. Azeem (01/11–),
R. Dela Cruz (01/11–07/11), L. Sok (01/11–), P. Pad (02/11–02/11),
J. Vinogradova (09/11–), S. Belhadjamor (10/11–), Y. Wu (10/11–).

Post-docs and engineers

L. Luzzi (10/07–05/10), F. Chapon (11/10–10/11), M.R. Palattella (07/11–10/11).

Sabbaticals

M. Burnashev (09/10–10/10), P. Saxena (12/10–12/10), M.C. Estela Zamora (03/11–04/11),
L. Budaghyan (04/11–10/11), C.C. Trinca (04/11–), S. Jitman (09/11–09/11),
D. Tuninetti (09/11–).

Faculty [IT, CNRS]	[6.8, 2]
PhD students	13
Post-docs, engineers and sabbaticals	1.8
Defended PhD thesis	11
Defended HDR	2
Journal papers [published, in press]	[38, 6]
Papers in conference proceedings	98
Chapters and books	1
Patents	6
Grants [public, private, european] (k€)	[322, 162, 163]

2.1 Objectives

For the last five years, the Digital Communication team has mainly been working on the physical layer of wireless networks. The most important results were in the context of single-user MIMO communication, cooperative communications (i.e., when a source and a destination are helped by additional nodes called relays), and finally multi-user cellular networks (when the communication is one-to-many or many-to-one). In such contexts, the team has focused on finding new:

- Coding techniques

- Resource allocation algorithms

- Estimation and synchronization methods

Nowadays, the most important topic is to design, analyze, and optimize many-to-many (wireless) communications where different flows of information are propagating through a common wireless network. Depending on the application, the network may be either centralized or ad hoc. The digital communications group has followed this important evolution by working on so-called Mobile Ad Hoc Networks (MANET). Our contributions cover different points of view: information theory, coding, resource allocation, distributed signal processing, and security (which is a major concern in such networks). Notice that the group has been enforced by hiring new Associate Professors in the area of Information Theory.

Even if our activities on wireless networking are central, we are also pursuing significant research activities on the (more traditional) physical layer of wireless or wired networks. Our main contributions here are new codes (asynchronous codes, etc) and improved cross-layer designs (hybrid ARQ which takes into account the network layer) for wireless networks, and new signal processing algorithms and codes for next generation fiber-optical systems. This last project is a collaboration with the Optical Telecommunications group. In our research we typically present solutions on the three important facets of signal processing, coding, and information theory.

The team has important international editorial activities: we take part in the technical committee of the flagship conferences and in the editorial board of IEEE Transactions on Information Theory and IEEE Transactions on Signal Processing. All our research activities are supported by national, European, or industrial funding.

Our group is also very active in teaching for the Engineering school as well as for various Masters programmes. In particular, jointly with the Université Pierre et Marie Curie, we are leading the "Master Recherche" called ESCO/STN.

2.2 Main Results

The main research results obtained during the period July 2009 - December 2011 are presented below.

2.2.1 Wireless Network Optimization

Faculty J.-C. Belfiore, P. Ciblat, W. Hachem, A. Tchamkerten, M. Wigger

Main events Philippe Ciblat has served as Associate Editor (resp. Area Editor) for IEEE Transactions on Signal Processing since 2008 (resp. 2010) as well as Track Chairman for the European flagship conference EUSIPCO'2001. Philippe Ciblat, Walid Hachem, and Michèle Wigger have been respectively invited professors at the International University of Rabat (Morrocco), the CTTC (Spain), and the Technion (Israel).

Projects ANR Chaire d'Excellence, "Futur & Ruptures" grants, DGA doctoral grant, Digiteo postdoctoral fellowship, ANR SESAME, Emergence Grant from the City of Paris, FP7 NoE NEWCOM++

Wireless network coding Wireless networks for high data rate transmissions are becoming more and more dominated by interference. Fundamental works in Information theory clearly shed a light by using lattices on this problem. But information theory states the fundamental limits but does not say anything about "how to achieve these fundamental limits". Thanks to our expertise concerning lattices for wireless communication, we obtained important results on lattice coding for interference channels. We are now able to propose new lattice coding schemes and analyze them. We are currently working on lattice network coding for which we were able to give a criterion of design for the lattice codes that are used. This work was a generalization of the so-called Compute-and-Forward protocol proposed by Nazer and Gastpar in 2009. In the same spirit, we started to work on the interference channel where we focus on the so-called lattice alignment for the interferers. This work had a big impact, theoretically and practically. We are developing some new tools to understand in a better way the behavior of lattices on such channels and relate it to the fundamental limits.

Fundamental Limits We studied the capacity of wireless networks where the transmitters or the receivers have some side-information, e.g., about other transmitters' messages or signals, or about the signals observed at some of the (other) receivers. Our contributions were twofold:

i) For the many-to-many interference network where the transmitters have side-information about the adjacent transmitters' messages (e.g., by prior communication over separate bluetooth links) and the receivers have side-information about the signals observed at adjacent receivers (e.g., by communication over a high-rate backhaul link) we studied the high-SNR behavior of the capacity. We mainly focused on Wyner's soft handoff model for cellular systems, for which we determined the degrees of freedom. Our result allowed us to establish a duality between the side-information at the transmitters and the side-information at the receivers in the sense that in terms of degrees of freedom they are equally valuable. We also determined the degrees of freedom when the transmitters only have partial knowledge of their adjacent transmitters' messages.

ii) For the one-to-two memoryless broadcast channels (BC) where the transmitter has feedback from both receivers (as is the case in most uplink-downlink scenarios) we studied the capacity region. This problem is unsolved for almost all memoryless BCs. In our works, we determined the capacity region of some BCs, and we proved that the capacity is increased even if the feedback is noisy. We also showed that for Gaussian broadcast channels in some cases the gain in capacity thanks to perfect feedback can be unbounded, and in most cases the high-SNR capacity is as if both receivers could perfectly cooperate. [3]

Motivated by practical communications systems, such as certain wireless sensor networks, the receiver of a communication system does not know perfectly the timing of information transmission and this leads to the so-called "asynchronous communication". This kind of communication has long been a neglected field in information theory. We have been investigating a new information theoretic model for asynchronous communication. Main results are the characterization of the minimum energy needed to transmit one bit of information asynchronously, and the proof of suboptimality of training in certain communication regimes. The second result says that the prevalent communication architecture where synchronization and information transmission are treated separately can be suboptimal; each transmitted bit should carry information while help the decoder locate the transmitted message [**? ?**].

Distributed computation In distributed computation/optimization/estimation communication is becoming a technological bottleneck. The problem arises both at the large and at the micro scales. Consider the task Google faces for search queries. After the query makes its way to a data center, the search task is handled to a number of servers working in cooperation. Yet, the minimum communication requirement to take advantage of multiple servers is not well understood. More traditionally in the field of wireless sensor netwokrs, resource allocation without a fusion center has to operate and can only be done in a distributive way. Similar problems occur for target location, etc.

We have focused on two types of computation: the maximum values of the sensor measurements and the average ones. Concerning the maximum computation, we have develop new algorithms well suitable for wireless communications. The main task has consisting in analyzing theoretically its performance [996]; Concerning the average computation, new powerful algorithms outperfoing exsintg ones have been introduced and analyzed also in depth. These computations are actually the first step of the distributed optimization issue which is a key point in the domain of the decentralized wireless networks. We also developed new algorithms for distributed estimation (one application could be the mobile location). These algorithms (basded mainly on the so-called stochastic approximation approach) have been deeply analyzed in terms of convergence, asymptotic properties (such as asymptotic normality, asymptotic covariance). Moreover, we are moving the analysis of such algorithms in a non-stationary environment.

Finally, to better understand some of the communications tradeoffs in distributed computing, we have been investigated function computation of separate sources of information. For this setting, we provided bounds on the minimum number of bits needed to be transmitted by each source so that the receiver can reliably compute the function. For certain functions and sources these bounds are tight. [**? ?**].

Detection theory for cognitive radio The random matrix theory has received a lot of attention in probaiblity, statictics and signal processing for communications. We have focused on the applications of this theory to the statistical estimation (direction of arrival, detection at the fusion center, Shannon capacity evaluation, etc). We have especially analyzed the extremal eigenvalues of large random matrices and the corresponding subspaces. [7]

2.2.2 Coding for single-user communication

Faculty J.-C. Belfiore, P. Ciblat, G. Rekaya-Ben Othman, P. Solé, A. Tchamkerten

Main events Jean-Claude Belfiore has served as Associate Editor for IEEE Transactions on Information Theory since 2010. Jean-Claude Belfiorer and Patrick Solé are the recipient of the Best Paper Award in *IEEE Information Theory Workshop* (ITW) in 2009. Patrick Solé and Jean-Claude Belfiore organized the International Conference SETA 2010 at the school site. This conference was supported partly by Digiteo and dealt with all aspects of sequences over finite alphabets. Ghaya Rekaya-Ben Othman has been invited professor at Indian Institute of Technolgy in Bangalore in 2010. Daniela Tuninetti (Ass. Professor at

Illinois Univ. at Chicago) is in sabbatical stay in the lab in 2011. Finally Ghaya Rekaya-Ben Othman has been selected to take place to the national event "1000 chercheurs parlent d'avenir".

Projects ANR ORIANA, CIFRE MITSUBISHI, CIFRES THALES, FP7 SMARTEN, "Futur & Ruptures" postdoctoral fellowship, Carnot Institute grant

Synchronization codes Our motivation was to study the performance of codes for joint coding and synchronization. A new class of codes intermediary between unrestricted binary codes and constant weight codes, namely bounded weight codes, and allied combinatorial functions, has been introduced. It turns out that the concept is also useful in list decoding, in bounding the list of candidate words at a given distance from the received word. In addition, but closely related, we worked on analytic number theory. We have especially connected the ideas of Alain Connes on a quantum mechanical approach to zeta functions with Jean-Louis Nicolas extremal view of arithmetic functions to derive an infinity of new criteria for Riemann Hypothesis.

Space time codes We still focused on the Space-Time codes design but in an original way. For the first time, codes over rings with non Hamming metrics are used to construct space time codes by a concatenation process similar to the so-called Construction A of lattices. We hope this work will attract the coding community attention to codes over *non commutative* rings an open territory in Coding Theory.

Cooperative communication The best known protocol for cooperative communication is the Dynamic Decode and Forward (DDF) protocol according to its Diversity-Multiplexing Tradeoff (DMT). We were interested on the practical implementation of this protocol for the relay channel with the assumption of relay unaware source. We have defined a new metric called Macro diversity (coming from long term SNRs) which represents the number of links necessary to achieve some QoS when all other links experience very low SNRs. We have proposed patching techniques in order to maximize the achievable micro and macro diversity. This technique consists of creation at the relays linear combinations of symbols already sent by the source and symbols going to be send by the source. The destination realize the same linear combinations (patching) of the received signals to build an equivalent transmission system. We have proposed different schemes using patching : patched Monostream, Patched Alamouti, Patched Golden Code and Patched Silver Code. [24]

To achieve the cooperative diversity, a synchronous communication is actually assumed. This a priori synchronization condition could be quite costly in terms of signaling and hard to handle in a relay networks. To relax this constraint, we have constructed $M \times M$ delay-tolerant codes based on cyclic division algebras of the $M \times M$ perfect codes. For $M = 2, 3, 4$ and 5, the new codes maintain the same properties (full rate, full diversity and non-vanishing determinants) as perfect codes in synchronous case. These codes are useful in a network without a direct link between the source and the destination. We have also proposed "bounded delay-tolerant STBC" which ensures optimal performances when the cooperative nodes are synchronous an a full diversity and optimal rates for a certain set of delay profiles that depends on the code length.

Hybrid ARQ schemes analysis In modern wireless networks, the physical layer is combined with Automatic ReQuest (ARQ) technique to improve the reliability of the whole system. Moreover the ARQ (or more generally, the Hybrid-ARQ (HARQ) which "belongs" to the MAC layer) can be greatly improved by taking into account the upper Network layer. Our first contribution has consisted in analysing deeply the theoretical performance (packet error rate, delay, jitter and efficiency) of any HARQ scheme at any layer for any channel model (the Gaussian one, the Rayleigh one, etc). We have also taken into account imperfect feedback conditions. We have also proposed new HARQ techniques more robust to imperfect feedback.

2.2.3 Optical communications

Faculty P. Ciblat, G. Rekaya-Ben Othman, O. Rioul

Projects FUI 100GFLEX, "Futur & Ruptures" Grants, ANR TCHATER, CIFRE MITSUBISHI

Due to the new applications (video streaming, cloud computing, etc), the amount of data in the optical core networks have strongly increased. To handle the saturation of the core network, advanced digital communications tools have to be applied to the optical communications field. Indeed, the information (passing through the optical fiber) now relies on the wave intensity but also on the wave phase. Therefore standard wireless digital communications can be now advocated for optical communications.

In this new paradigm, we have focused on various facets:

i) Usually adaptive approaches have been carried out to mitigate the inter-symbol interference (generated by the dispersion of the fiber and also the polarization mixing) and the carrier frequency offset. but as the channel is very slowly time-varying, we have proposed to counter-act these impairements by using block-wise methods. Thanks to simulations and experimental measurements, we have proven that this block-wise approach enables us to speed up significantly the convergence by the expense of moderate extra computational load, and thus is well adapted to burst mode transmission [272]. In addition, we have studied some near maximum a posteriori probability low-complexity phase estimators under phase uncertain channel for BPSK and QAM signals and prove their convergence, via a conditional gradient descent algorithm, towards the Bayesian Cramer-Rao lower bound for which we also found simple expressions depending on the modulation used and other assumption (off line / online, data aided / non data aided scenarios). This in particular explained anatically why such low-complexity estimators perform so well over a wide range of SNRs.

ii) In order to evaluate the ultimate performance of optical communications, we have also considered a information-theoretic point-of-view. We especially derive Shannon-like channel capacities when nonlinear impairments occur.

iii) The polarization multiplexed optical systems can be seen as multi-input multi-output (MIMO) systems, and so space-time coding techniques could be applied in this case. The implementation of such codes requires the use of OFDM systems. We have showed that the space-time coding can efficiently mitigate polarization dependent loss (PDL) impairments, and that their performance are very different from those obtained in wireless communication. The Silver Code performs better than the Golden code. This results was explained by an analysis of the error probability. We have also showed that the gain provided by Space-time coding is added to the gain provided by error correcting codes.

2.2.4 Security issues

Faculty J.-C. Belfiore, O. Rioul

Main events Jean-Claude Belfiore has been invited professor at NTU (Singapore).

Physical Layer Security Due the broadcast nature of the wireless channel, the security has also to be takein into acocunt by the physical layer (and not only but the cryptographic point of view). The most famous example is the so-called wiretap channel where one eavedrooper can listen to the message too. Our contribution dealt with the analysis of the nested lattice codes for the Gaussian wiretap channel as well as for the MIMO wiretap channel. The proposed closed-form expressions for the system performance were related to the theta series of the lattice (Gaussian case) and to some zeta function (which can be Epstein or Solomon) in the MIMO case. These results gave a design criterion for the lattice codes which have to be used. We are continuing with the proposition of practical lattice codes now.

Hidden channels for electronic devices   Side-channel analysis (SCA) aims at extracting cryptographic keys from a device by analyzing its leakage, knowing its input or output. The general formalisation of SCA models the leakage as well as the data that causes it (called the sensitive variable), from an information theoretic standpoint. The traditional approach consists in distinguishing the correct key from the bad key hypotheses by selecting the key guess that maximizes the mutual information between the leakage and the sensitive variable. Now, it is well known that this mutual information is equal to the Kullback- Leibler divergence between the leakage and the leakage conditioned by the sensitive variable. In this work, we have suggested another distinguisher consisting in the divergence between pairs of conditional leakage. Our goal were twofold: to compare it theoretically with the mutual information, and to study its efficiency for certain types of leakage (especially in the presence of countermeasures to SCA, like masking).

2.2.5   Tools for Information Theory and Statistics

Faculty   O. Rioul, A. Tchamkerten

Projects   ANR Chaire d'Excellence

About Fitt's law   Whether Fitts' law (a well-known model of human pointing movement in experimental psychology) is a logarithmic law or a power law has remained unclear so far. Papers have claimed that the power model they derived from their celebrated stochastic optimized-submovement theory encompasses the logarithmic model as a limiting case. We have shown that this claim is questionable mathematically. Our analysis revealed that these papers implie in fact a quasi-logarithmic (Shannon-like), rather than quasi-power model, the two models being not equivalent. Also, testing the prediction that throughput (TP) is conserved accross variations of speed/accuracy, we found it to be affected by the strategy, which pleads against a currently popular definition of TP which is incompatible with the Shannon equation. We also have shown that the statistical elaboration of the TP suffers from a problematic amount of random variability due to the inadvertent but multiple impact of Jensen's inequality.

About entropy power inequalities   While most useful information theoretic inequalities can be deduced from the basic properties of entropy or mutual information, up to now Shannon's entropy power inequality (EPI) is an exception: Existing information theoretic proofs of the EPI hinge on representations of differential entropy using either Fisher information or minimum mean-square error (MMSE), which are derived from de Bruijn's identity. I have derived a unified view of these proofs, showing that they share two essential ingredients: 1) a data processing argument applied to a covariance-preserving linear transformation; 2) an integration over a path of a continuous Gaussian perturbation. Using these ingredients, I developed a new and brief proof of the EPI through a mutual information inequality. The result has the advantage of being very simple in that it relies only on the basic properties of mutual information.

Theory of Optimal Stopping   Given sequential observations of a stochastic process, we consider the problem of estimating a stopping time defined with respect to an unobserved process which is correlated to the observation process. This problem, called the tracking stopping time (TST) problem, applies in a number of areas, including communications, monitoring, and forecasting. In spite of its simple formulation, the TST problem is hard as it also generalizes the well-known Bayesian change-point detection problem whose solutions have been reported only for specific (mostly asymptotic) settings. In spite of this apparent difficulty, we obtained interesting results for the natural settings where both the observed and unobserved processes are Gaussian random walks (possibly with drift), with the observed process being either a noisy version of the unobserved process, or a delayed version of the unobserved process. The stopping time to be estimated is some first-passage time of a given threshold. For this setting we characterized the best estimator with respect to arbitrary moment loss functions in the limit of large thresholds [**?**].

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Chapter 3

Electronics and RF systems (ELECRF)

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Bernard Huyart (P),	Anne Claire Lepage (MC),
Patrick Loumeau (P),	Jean-François Naviner (MC),
Van Tam Nguyen (MC),	Hervé Petit (MC),
Christophe Roblin(MC,09/10–),	Alain Sibille (P,09/10–)

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S. Kowlgi (11/08–10/11),	F. Ghanem (01/09–),	A. Maalej (01/09–),
M. Masoumi (09/09–09/09),	D. Pham (01/10–),	J. Enriquez Gonzalez (03/10–),
C. Djoma (07/10–),	H. Cai (09/10–),	F. Guidi (10/10–),
Z. Mhanna (10/10–),	M. Sacko (10/10–),	Y. Wei (10/10–),
M.A. Yousuf (10/10–10/11),	X. Zeng (02/11–),	A. Aghedu (07/11–07/11),
M.T. Nguyen (07/11–),	M. Clemente (09/11–),	O. Jamin (10/11–),
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A. Beydoun (02/08–08/09),	R. Planas (07/09–09/10),	K. Mabrouk (10/09–10/09),
S. Kaleem (04/10–04/10),	C. Ouffoue (11/10–),	J. Sarrazin (02/11–).

Sabbaticals

A. D'assuncao (10/09–10/09), J.P. Barbot (11/11–), F. Rangel De Souza (12/11–).

Faculty IT	10
PhD students	18.4
Post-docs, engineers and sabbaticals	4.1
Defended PhD thesis	7
Defended HDR	1
Journal papers [published, in press]	[23, 2]
Papers in conference proceedings	125
Chapters and books	9
Patents	3
Grants [public, private, european] (k€)	[674, 244, 498]

3.1 Objectives

Future "ambient intelligence" needs to have wireless RF systems, mobile or embedded, capable of configure themselves in networks according to the application. ELECRF addresses the primary bottlenecks for widespread use of ambient intelligence in our environment, which are related to: communications, energy sobriety, safety. The aim of our research is to innovate in developing new concepts at several levels: components (antenna), characterization and modeling (PA, radio channel), system architectures (cognitive radio) and communication schemes (modulation) for wireless communication systems.

The trend where terminals give their users ubiquitous access to a multitude of services drives the development of reconfigurable radios in deep-submicron CMOS. This calls for frequency-agile, multi-standard and multi-band terminals integrating the cellular standards GSM/EDGE, UMTS, LTE, LTE-Advanced and additional wireless communication standards for connectivity and positioning into more efficient radio architectures. Our research focuses on circuit designs, associated signal processing to correct errors, non-linearity and mismatch calibration, and system architecture for future wireless communication systems.

Our work on wireless communication systems technology concentrates on the so-called "RF front-end" which is one of the most sensitive parts of communicating objects. It involves improved modulation/demodulations schemes as well as the study of novel antenna technologies applied to several wireless communication standards from 450 MHz to 40 GHz. Another research topic is focused on wideband and low-profile antennas and arrays using artificial materials for the antenna's reflector.

Other relevant challenges are: to target the lowest possible power consumption by ultra-low power solutions for future generation ICs and optimized low voltage micro-architectures, to increase the efficiency of circuits that consume the most energy (such as PAs in the RF transmitters). In RF metrology, nonlinear power components operating in the Q band (33-50 GHz) have been characterized. The objective of this work is to enhance the performances of RF power amplifiers (PAs).

Electronics and RF Systems designers also have to face many challenges to handle nanoscale technology context (variability, new CMOS) for the AMS parts and benefit from dedicated technologies for the RF parts. In this context, our main research objectives are: to design reliable and robust mixed-signal circuits under an uncertain technological environment, to use design techniques portable to advanced technologies finding the best compromises between performance, cost and reliability.

Finally, there is a great benefit in considering radio channel aspects in conjunction with RF transceivers design. In this context, the sounding of RF propagation channels using relay be-

tween transmitter and receiver in a LTE communications scenario has been performed, in order to quantify the parameters of the propagation model. Research on antennas and radio channel modeling has also been conducted with a goal to model the radio channel by taking into account jointly the local propagation environment and the antennas. The method is based on a new statistical approach that includes both of these, and which has been applied to various use cases such as BAN networks, multiple antennas on terminals and UWB RFID tags. Parametric models of UWB antennas have in particular been developed, allowing a strong compression rate of the radiation data and lending themselves to statistical modeling of the antenna electromagnetic behavior.

3.2 Main Results

The main research results obtained during the period mid 2009 to end 2011 are presented below for the research areas of the "Electronics and RF systems" team.

3.2.1 From frequency-agile and reconfigurable transceiver to cognitive radio systems:

Faculty V.T.Nguyen, P.Loumeau, H. Fakhoury, P.Desgreys, H.Petit, J.F.Naviner

Main events Coordinator of the TEROPP project between 6 Carnot Institutes and 3 Fraunhofer institutes, 3 new European projects, leader of the task on multi-standard and multiband transceiver for cellular applications in ENIAC ARTEMOS project.

Projects FP7 SACRA, ENIAC ARTEMOS, CATRENE PANAMA, ANR-07-P2IC TEROPP, ANR-06-TCOM HyperSCAN.

Frequency-agile and reconfigurable receiver: The focus is on frequency agile high dynamic range digital friendly RF architectures suitable for nanoscale CMOS. The properties such as the RF carrier frequency, channel bandwidth, noise figure, linearity and selectivity characteristics can be adapted to the requirements of the communication standard. This work which is a close collaboration with ST-Ericsson, is a part from European ENIAC ARTEMOS project starting on April 2011 where we are the leader of the task on multi-standard and multiband transceiver for cellular applications.

High performances, reconfigurable ADCs: One of our main research topics for years is high performances, reconfigurable ADCs for various applications. It is one of the key building components of the receiver. Our main expertise is on innovative delta sigma modulator architecture and the design in advanced CMOS technology. We has proposed innovative architecture for high-pass delta sigma modulator [124, 125], reconfigurability with high-pass and low-pass [184], unity signal transfer function with global feedback loop [VTNISCAS2011] and high performance ADC designed in 65nm CMOS technology [166]. We have been also working on continuous-time modulator in order to improve the performance in terms of low power consumption and higher bandwidth. A very high performance ADC designed in 65 CMOS technology with 40MHz of bandwidth, 76dB of SNR, 88dB of SFDR and with less than 100 mW of power consumption using an innovative continuous-time modulator is recently sent to foundry. This work is a part of FP7 SACRA project and ENIAC ARTEMOS project. This ADC will be part of a demonstrator on cognitive radio systems in FP7 SACRA project.

The development of the software radio is still very much limited by the available resolution and speed of the ADC stage. Parallel ADCs seem to be the best suited way of increasing analog-to-digital conversion rates. After the study of time-interleaved (TI) Sigma Delta ADC with a four-channel [AB:ICASSP-10][Cha:Springer2011][AliCalib], we studying TI architecture employing Nyquist pipeline ADCs. The objective is to compensate the frequency response error between the different channels. This work is ongoing in a bilateral project with an industry. An alternative

solution for parallel architecture is to employ hybrid filter banks. The advantage of this approach compared to TI architecture is the robustness against channel mismatch at the cost of more complex analog and digital parts. An innovative solution has been proposed [174, 175] using time multiplexing and frequency multiplexing at the same time in order to retain the advantages of both architectures (TI and hybrid filter banks). This work is a part of ANR-07-P2IC TEROPP focusing on opportunistic and cognitive radio, but this approach can be used for other applications as well.

Non-uniform sampling: To deal with the suppression of RF anti-alias filtering, Non Uniform Sampling (NUS) based receiver architectures have been studied in a collaborative project with SUP'COM Tunis. We have demonstrated relaxed constraints on both RF filter and ADC dynamic power consumption using appropriate NUS architecture. The results have been published recently [**?**]

Disruptive technologies Disruptive technologies offer new ways to accomplish breakthroughs in cognitive and opportunistic radio. Based on superconductivity physics, the RSFQ (Rapid Single Flux Quantum) logic is a very low power consumption and ultra-fast electronic logic which is considered as the best alternative to CMOS in the ITRS for ultra high frequency applications. The team has proposed an RFSQ Analog to Digital architecture in a work conducted within the ANR Hyperscan project. The goal is a 2x8 bits and 500 MHz BW Sigma-Delta analog-to-digital converter (ADC or CAN) circuit with performance specifications to achieve space telecoms at 30 GHz carrier frequency. To verify the project feasibility, we have developed a model that implements superconductivity physics into the RFSQ ADC circuit simulation [**?**].

ADC design in the non linearity correction path of base station PA Power amplifiers (PA) are inherently non-linear and even more if we aim to reduce its power consumption, therefore they introduce unbearable distortions for new modes of communication. The digital predistortion (DPD) is a very effective linearization technique due to the increasing use of digital modulations and progress in digital signal processing. This technique requires digitizing at least five times the input PA signal bandwidth as the distorted output PA is spectrally made up of a high power signal band and of lower power adjacent signal bands resulting from intermodulation. To digitize this signal we need an Analog to Digital Converter (ADC). The design of one single ADC meeting the requirements of high dynamic range ($>$60 dB) and wide bandwidth ($>$75 MHz) would produce an oversized solution consuming much power than using several parallel converters with adapted specifications. We suggest using one primary A/D converter to convert the high power signal band (15 MHz) and two secondary converters for the adjacent bands (30 MHz each) with lower signal powers. The problem is that the secondary converters may be saturated by high power signal band so this band has to be attenuated. We propose to use the inherent signal shaping achieved in Delta Sigma modulators to do this attenuation. We have a patent pending for this innovative solution.

Cognitive Radio Systems: CRS is a disruptive technology targeting very high spectral efficiency. In CRS, cognition and intelligence are introduced in the terminal and cognitive network to take benefit of the high number of interacting devices to increase the spectral efficiency. Even interference is considered as an opportunity rather than a drawback by exploiting intelligently the degrees of freedom in CRS. CRS covers multidisciplinary areas attracting a large number of researches with many interesting obtained results. The challenges remain numerous, namely intelligence distribution and implementation, security, delay/protocol overhead, cross-layer design, flexible hardware design, etc. In this topic, we are working on high level concept of CRS [204], convincing use cases, RF receiver for spectrum sensing [174, 175**?**] and sensing algorithms talking into account the implementation constraints. We will study also cognitive radio resource management and smart spectrum management, all these taking into account the implementation constraints and perspectives. The work on CRS is part of ANR-07-P2IC TEROPP, FP7 SACRA project and ENIAC ARTEMOS project.

3.2.2 Nanoelectronics architectures and circuits

Faculty P.Desgreys, J.F.Naviner, H.Petit

Projects CATRENE RELY

Reliability of mixed-signal architectures and circuits: Works on reliability of analog or mixed-signal architectures were initiated in Oct. 2008 with a PhD thesis. Considering that many circuits are today Systems-on-Chip (SoC), that they include often various analog or mixed-signal sub-circuits and that the reliability level of a SoC results from both the reliability of each sub-parts and the connections/interactions between them, our main objectives are:

- to assess the reliability of basic functions considering the physical causes of failures (ageing effects or other causes),
- to assess the reliability of an architecture working at an abstracted behavioural level,
- to compare basic functions circuitries and architectures on both performance and reliability criteria,
- to define methods of architecture/circuit design that includes the reliability in the design criteria.

The present work is focusing on the reliability of A/D converters [114]. After studying the causes of degradation and failures in nanoscale integrated circuits with ageing [128], we are working on the prediction (early in the design process) of circuit lifetime facing process variability and devices aging (European project: RELY). This prediction will be based on physical models provided by physical design kits.

3.2.3 RF metrology

Faculty X.Begaud, E.Bergeault, J.C. Cousin, B.Huyart

Projects Bilateral project with LNE and Orange Labs, French ANR Smartvision (Système multi senseur de détection d´objets cachés)

Power probes and PAs: Our research in fundamental metrology with the LNE have yielded significant results on the RF power sensors (1-18 GHz) [? 140, 186, 139] and the probe measurements of MMIC components (Monolithic Microwave Integrated circuits) over a wide frequency band (few kHz-40 GHz) [? ? ?]. Our efforts have focused since 2009 on the design and implementation of a load & source Pull measurement setup in the Q-band. The nonlinearities of the components of the RF front-end (PAs) causes spectral Spreading over adjacent channels and distort the base band data. Numerical predistortion techniques have been used to fight the degradation of the RF signal [?]. The originality of our setup is that the excitation signals of the device under test have modulation bandwidths of gigabits/s [206].

Radio communications channel sounding: 2 sounders have been designed and realized for non stationary MIMO channel in the Wifi & UWB frequency bands. Our studies have been focused on the simultaneous determination of the angles of departure and arrival of transmitted and received signals [129] and the measurement of arrival time [? 161]. Comparisons between measurement and models were made from a 3D ray tracing [198]. Another aspect of channel sounding has been led with Orange Labs to estimate the contribution of relays in a multi link propagation channel modeling for the 4G systems. To this end, a multi link measurement campaign with relays has been carried out in realistic urban environments. These have allowed to assess the relaying aspects and to focus on the path loss models developed for the 4G systems [151], the shadow fading correlation [153, 152] and the impact of the relay antenna height [149]. A particular attention has been paid for the Base station-Relay Station link which had not been studied yet.

Smart vision project: An ANR project with Thales Service as the main leader has been developed since two years. This project has dealt with the realization of a smart corridor dedicated to an electronic body scanner to check people without a body search in airports for example. In this project, we have participated in the realization of the active body scanner based on a 77 GHz radar structure initially developed for the help drivers.

3.2.4 Wireless communication systems technology

Faculty X.Begaud, B. Huyart, A.C.Lepage

Main events Publication of the book "UWB antennas" (Wiley), co-edited by X. Begaud, GDR ONDES, CNRS (X.Begaud)

Projects European projects FP7 SACRA (Spectrum and Energy Efficiency through multi-band Cognitive Radio) and Celtic SPECTRA (Spectrum and energy efficiency in 4G and beyond communication systems), EDA project MIMiCRA (Metamaterial Inspired Microwave Conformal Radar Antenna), projects from the French Cluster SYSTEM@TIC PARIS-REGION : CONRAHD/OPTIMUM (CONnexion Radio sans fil Haut Débit) and PUMA (Produit Ultra haut débit sur bande millimétrique), bilateral projects with Thales Airborne Systems (2), Thales Air Systems (1), CNES, Innovation project "DEMODU" from Institut Telecom

MMIC design for RF "front-end": Our research activity has been focused on the design of demodulator dedicated to software defined radio applications. 2 three-phase demodulators using MMIC technology have been designed in the 1-24 GHz bandwidth [187] and Q band (33- 45 GHz) [**?**]. This demodulator architecture shows a better rejection of adjacent channels [127].

Metamaterial inspired wideband antennas: The RF team's research is devoted to the design of wideband antennas and arrays. We initially focused our work on UWB (UltraWideBand) applications [137**?** , 237, 232] and add today the design of novel artificial materials to reduce the size/thickness of wideband antennas [235]. One hand, the developed materials use periodic structures in order to exhibit the behaviour of an Artificial Magnetic Conductor (AMC) as well as that of an electromagnetic band-gap (EBG) structure [248, 247]. On the other hand, the extraordinary properties of Left Handed materials are exploited to develop miniaturized filters and directive antennas [**?** 146] and Leaky-wave antennas [222]. We are developing a new methodology that takes into account the interaction between the radiating element and its artificial ground plane [119, 172, 163**?**]. We are also considering refined characterizations of the artificial material itself, a necessary step for improving our control on the phenomena occurring in these metamaterials [**?** 157]. Finally, we are applying our artificial materials to the problem of reducing the coupling between elements in a wideband antennas array, with a focus on analytical models [247].

Antennas for cognitive radio: One of the main challenge of cognitive radio is to improve the efficiency of the system, ie. energy efficiency, spectrum efficiency and also reduction of the number of components. The following topics aim to propose solutions to these needs. In the framework of the European project SACRA, our research is focused on compact dual band dual polarized antennas for the terminal side dedicated to future systems using LTE and having also cognitive radio capabilities in the TVWS band (TeleVision White Space) [**?**]. Diversity performances studies are also performed for different environments. We are also studying co-design between antenna and filters: the objective of this topic is to develop an ultra wideband dual polarized antenna associated to a filter with non standard features in order to suppress any matching circuit. In the framework of the European project SPECTRA, we propose to design a compact wideband antenna associated with an automatic matching circuit. In fact, over a wide band, the input impedance of the antenna varies due to intrinsic properties, but also due to the environment.

3.2.5 Antennas and radio channel modelling

Faculty (from September 2009) C. Roblin, A. Sibille

Main events Publication of the book "MIMO: From Theory to Implementation" (Elsevier), co-edited by A. Sibille.

Projects European FP7 SELECT project on UWB RFID system, French FUI URC project on urban planning for radiocommunications, French ANR BANET on body area networks, French

FUI RECOSS project on high data rate communications for security services, European COST 2100 Action and COST IC 1004 Action on mobile networks.

Parametric models for ultra wide band antennas: The full characterisation of the radiation of UWB antennas requires a significant amount of data arising from either measurement or electromagnetic simulations. It is therefore desirable to use "data compression" methods to handle them more easily. A complete (parametric) modeling of both frequency and time domain far field antenna responses (for any direction of radiation) with extremely high order reduction ("ultra compression") has been developped. It is based on both the singularity expansion and the spherical mode expansion methods. Theoretical properties of the model parameters and relationships with global indicators of performance of UWB antennas have been derived. The modeling has been applied to full 3D measurements of omni-directionnal or moderately directive UWB antennas with a good accuracy and high data compression rates of more than 97 % (and up to more than 99.9 % for some cases). These models can be efficiently used in simulations of the physical or link layers, or in deterministic propagation simulators based on asymptotic methods (UTD/GTD "ray tracing", etc.).

Joint antennas and channels statistical modelling: Wireless networks need channel models in order to be able to test competing physical/link layer schemes and perform network level simulations. However there is an increasing complexity in the current and future communications standards, which are multiantennas, multifrequency and where the behaviour of terminals in a use context is highly variable. The group has initiated and developed since a few years a statistical approach of this behaviour [136], taking into account the variability of the terminals characteristics in their close environment. The method combines full antenna performance data to local propagation characteristics in order to arrive a an effective gain concept, seen as a stochastic quantity. It has been applied to the efficiency and effective gains of handsets in proximity to a user head and hand[AS:Eucap-1-10] [131] and to multiple antenna systems [214]. In body area networks, the influence of the human body on the behaviour of antennas is often of prime importance; the properties of the on-body propagation channel are very specific, and are notably sensitive to the subject movement for most scenarios. Both aspects, which are intricately related, have been studied with a statistical approach [**?** 214]. Joint space and frequency correlated path loss data have also been modelled through a simple semi-Kronecker approximation [135]. The latest works address the statistical analysis and modelling of UWB tag antennas employed in a backscattering based RFID system [218, 115, 116, 197].

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Chapter 4

Optical Telecommunications Group (GTO)

Team leader Didier Erasme (P).

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W. Akhtar (10/06–11/10),   A. Farhat (10/06–08/09),   M. Gharaei (10/06–09/10),
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H.T. Nguyen (11/10–),   E. Giacoumidis (11/11–).

Sabbaticals
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Associate Researchers
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Faculty IT	6
PhD students	13.75
Post-docs, engineers and sabbaticals	4.7
Defended PhD thesis	15
Journal papers [published, in press]	[65, 8]
Papers in conference proceedings	101
Chapters and books	3
Patents	1
Grants [public, private, european] (k€)	[654, 111, 157]

4.1 Objectives

The evolution of optical communication systems represents a particularly challenging guideline for research activities taking place in the Optical Communications group of Télécom ParisTech. In addition to the topics directly relevant to the upgrading of optical networking techniques, architectures, devices, components, etc., our field of activity expands both to subjects that use similar methods and technologies and to characterization systems for telecommunication devices.

Following a meditated focus on access network technical solutions (FTTx) bridging the "last mile" by means of optical support, the new evolution step in the field of optical communications is related to a merging with digital communications and fast digital electronics and affects all the levels of the optical network. Technical forecasts predict a constant increase of bit-rate demand for networks with a steady rising factor of 40 to 60% per year (according the Systematic Paris-region Telecom roadmap). This tendency is supported presently by video-related application associated with new terminal facilities. Presently, the three traditional fixed-network segments are all going through a strong evolution process:

- with the deployment of FTTH (Fibre-to-the-home), the optical access network has relied first developed on some rather traditional solutions while advanced optical technologies are still under strong competitive development (WDM PON, OCDMA, ...). New generation PON (NG-PON) investigating 10Gbit/s solutions are being normalized. A strong requirement on components able to fit the constraint of access network (technical specification, cost, consumption, foot-print) leads to some renewed question on sources and receivers;

- the metropolitan network has to cope with an enhanced connectivity and some constraints related to equipment cost which requires new technical solutions. New end-to-end network architecture are investigated;

- in the core network, traditional individual channel bit-rates enhancement up to 40 Gbit/s is progressively replaced through applications new paradigms making use of the somehow under-considered knowledge in digital communication that has been the key development tools of RF mobile communication. Multi-levels or multi-carriers modulations associated with digital signal processing thanks to high rate digital circuits, brings the spectral efficiency enhancement required.

In this wide panorama, the GTO group relies on its theoretical competence and its modelling and experimental know-how for developing new concepts and for participating in advanced collaborative research on optical systems.

A first research axis concerns the development of new optical signal processing techniques and functional analysis of new components for communication systems. This field covers several

related studies concerning light emission, light amplification, light transmission and new reception techniques. Although a number of applications lie in the field of telecommunication, the activity expands to other application areas such as energy, industrial process and defense.

The second research axis lies closer to the actual networks and transmission systems structures, approaching multiplexing techniques, high bit rate communication, new optical network architectural topics.

Finally, a specific research axis is related to quantum communications in particular to quantum key distribution for cryptography systems.

These research axes usually associate theoretical investigation and modelling activities, simulation using internal or commercial software and experimental activities. The latter rely on a rather well-equiped optical laboratory which includes a 4*10Gbit/s transmission platform, picosecond optical facilities allowing some 40Gbit/s experiments, very high sample rate arbitrary waveform generator associated to a real time oscilloscope and dedicated characterisation and sensor set-ups. The equipment for the assessment of coherent transmission systems and algorithm experimental testing, internally named "plateforme Penser 100Giga" has received a Region Ile-de-France SESAME-programme sponsorship.

The reporting period has been characterized by many national initiative interactions, (ANR, Cifre) and a strong activity on the European landscape. Through FP7-BONE and FP7-EURO-FOS Networks of Excellence our international activity has been pushed to a high level. In addition to project review papers involving many teams, we can count journal publications with laboratories representing many different countries (Denmark, Japan, USA, Germany, Mexico, China, Greece, Tunisia, China, Sweden).

4.2   Main Results

The main research results obtained during the period mid-2009 to 2011 are presented below for the research areas of the GTO team.

4.2.1   Optical functionalities and novel devices for communication systems and networks

Faculty G. Debarge, D. Erasme, R. Gabet, P. Gallion, Y. Jaouën, C. Ware, F. Grillot (CNRS-Photon)

Projects PôleSystem@tic-CARRIOCAS(10/06—09/09),ANR AROME (01/07—12/09), ANR L2CP, ANR MODULE (11/09-11/12), FUI TRILOB(09/09-09-12), FP7-EUROFOS (05/08—04/12), trilateral projet with EDF and LCPC, Bilateral project with ONERA and with CEA, 3 cifre Thesis, collaboration with Shanghaï Jiao Tong and Tondjï universities.

The widespread introduction of broadband at all levels of communication networks, the ubiquity of data exchange, the wired network infrastructure increasingly using the optical medium, and its being extended over the last mile all the way to the end-users, are changing the deal on signal processing functions implemented directly in the optical domain, giving them a foremost place in system design. These optical functionalities aim at keeping, as best can be done, the optical signal's integrity, avoiding optical-to-electrical conversions. The intrinsically high speed of the physical phenomena to be used allows them to take over processes, which were traditionally implemented in the electrical domain, and the development of devices adapted to these applications.

Clock recovery

After yielding record results during the previous reporting period, our clock recovery activity was rewarded by an invited paper in the Journal of Lightwave Technology [**?**]. It was built upon,

mostly through collaborations with international partners, especially in the framework of FP7-EUROFOS[1]. Bit rate was pushed up to 0.87 Tbit/s [355], including phase modulation.

Now that this level of performance and versatility has been shown, this activity is now reduced in priority in favor of network-oriented functionalities.

Integrated semiconductor optical sources and receivers

The recent evolution of the optical communication network led to a large demand for new low-cost and high-performance components. Following a proposal and some initial results obtained at the end of the CARRIOCAS project [344], the concept of "dual modulation", consisting in modulating simultaneous the laser and the modulator of an EML source leads to the proposal of the new ANR project MODULE[2], which we are leading. Condition for optimum modulation procedure for access—type distance range up to over 140km and rates up to 20Gbit/s. Single sideband modulation dedicated to radio-over-fibre and OFDM transmission have been demonstrated also [363, 325]. Simulation software has been used to confirm and explore transmission effect in dispersive fibres with dual-modulation. We also participated in the design of new "colourless" (wavelength-independent) devices for WDM-PONs and RoF applications, notably through a Cifre Thesis with Alcatel-Lucent III-V Lab, which more than doubled the state of the art for systems based on RSOAs (Reflective Semiconductor Optical Amplifiers) both in distance (100 km over standard fibre) and (separately) in bit rate (10 Gbps without any electronic processing). [251, 293, 371]. Additionally, another project FUI-TRILOB[3] studies the integration of ELM with a SOA in order to enhanced the budget of downstream access transmission in PONs. We have recently demonstrated the effect of chirp compression induced by the SOA, which allows the transmission distance to be augmented strongly [341, 342]. The group has been involved in other devices development through 2 more Cifre theses with III-V lab (on 100G receivers and reflective SOA modules for access networks). The former resulted in the development of state-of-the-art integrated very-high rate SOA-PIN receivers [369]. Modelling of semiconductor lasers have been push forward; Some new understanding on chirping effect and reduction in various configuration, especially in the case of feedback has been accessed [263],[324].

Optical Code-division access coders-decoders

For OCDMA implementation (see next chapter), the most commonly used optical component is fiber Bragg grating (FBG). Part of the ANR-SUPERCODE[4] project was focused on FBGs both for direct-sequence codes (DS-OCDMA) and spectral phase encoding (SPE-OCDMA).

The FBG-based coding method has the disadvantage that each FBG-based component can only generate one code word while as much as 64 may be required. We have proposed to realize the coding devices by using the Hadamard transform on a 2 dimensional multimode interference couplers (2DMMIC). The approach demonstrates the possibility to achieve the higher order Hadamard transform using simple 2D structures and provides a possible solution for all optical CDMA systems. It is worth mentioning that although the discussion is based on the MMI structure, the method of extension of 1D structure to 2D can be generalized for other devices, such as the LPFGs based Hadamard transform devices. The simulation results match the theoretical prediction precisely. [275]. In addition, we have analyzed the optical switch based on the MMI couplers and proposed the operation principles for this device based on an analytical transfer matrix theory. The device can be controlled by proportionally adjusting the inter-stage variable phase

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[1]FP7-EUROFOS (: Institute of Communication & Computer Systems/ National Technical University of Athens (leader), Heinrich-Hertz Institute, University of Essex, Universitat Politecnica de Catalunya, ACREO AB, Technical University of Eindhoven, Research and Educational Laboratory in Information Technology, Chalmers University of Technology, University of Karlsruhe, Politechnico di Torino, University College Cork, Scuola Superiore Sant'Anna, Universidad Politecnica de Valencia, Interuniversitair Micro-Elektronica Centrum IMEC, Instituto de Telecomunicaoes, Technical University of Denmark

[2]Partners: GIE Alcatel-Thalès III-V lab, CNRS-LPN, IRCOM, Orange labs

[3]Partners: 3S-Photobics (leader), GIE Alcatel-Thalès III-V lab, Egide, ESPCI, Orange labs

[4]Partners: Institut Carnot de Bourgogne (leader), CNRS PhLAM, XLIM

shifter array. An 8*8 MMI coupler based switch is analyzed in detail, which demonstrates the feasibility of the proposed operation principles he theoretical prediction is verified by the numerical simulations. Fabrication error tolerance analysis is provided afterwards. The design principles presented here can be used for the design of the integrated MMI coupler based switches with either thermal-optical or electro-optical index tuning. [276]

Distributed Raman amplification

The distributed amplification based on the Raman effect, appears as an alternative or an additional technique to the doped fiber amplifier (EDFA) widely used in today optical communications systems. It offers the benefits of low noise due to gain distribution over large span and of the potentiality of pump polarization attraction. However noise transfer from the pump noise to the signal, the pump polarization fluctuations and the double Rayleigh scattering (DRB) strongly impact the noise figure and the single pump configuration is bandwidth limited.

Raman amplifiers (RAs) with time-division-multiplexed (TDM) pumps have been analyzed using a computational cost-effective Fourier series approach. It gives deeper insight into the pump modulation induced noise (PMIN) in TDM pumped RAs. Moreover, the approach allows the analytical analysis of the TDM pumped RAs with multiple pumps. By optimizing the pumping order of the multiple pumps, more than 3-dB reduction of the PMIN can be achieved. For short fibres, by properly choosing the modulation frequency, more than 3-dB reduction of the PMIN can be realized. [277]

We have analyzed the Raman amplifiers (RAs) with time division multiplexed (TDM) pumps via analytical approaches for the forward and backward propagating configurations. The gain and the optimal analytical formulas of the pump power configuration have been derived, by using the least mean square (LMS) method. Explicit analytically formulas have been derived for double Rayleigh scattering (DRB) and ASE noises as well as the impact of the pump modulation. They provide a performing tool for the design, the analysis and the optimization of multi pump amplification. [274]

Brillouin-based optical sensors

Given its low required power threshold, the Brillouin effect in optical fibre is one of the most promising nonlinear effect to design new all-optical processing or optical sensors. A self-referenced technique for measuring the Brillouin gain in an optical fibre has been recently proposed, and the importance of acousto-optic effective area in place of optical effective area on the Brillouin efficiency has been confirmed for the first time [**?**]. The analysis of optical and acoustic properties of optical fibers is required for accurate Brillouin gain spectrum (BGS) determination. Under collaboration with EDF, a 2 D FEM model has been proposed for BGS calculation in acoustic guiding and anti-guiding singlemode optical fibres [352, 351]. The intrinsic residual draw-induced stresses during the cooling from fusion to temperature to room temperature can impact significantly optical and acoustic mechanical properties, and should be taken into account in the calculation of BGS. Different fibres all coming from a same perform but with different conditions have been realized by Draka. The predicted theoretical BGS show very good agreement with corresponding measurement [353]. The following step in the EDF collaboration should be the analysis of Brillouin frequency shift dependence with strain and temperature and finally propose a fibre design specially devoted to optical sensing.

High-power fiber lasers

The technology of rare-earth doped optical fibres - Ytterbium (Yb3+) for amplification at 1µm and Erbium/Ytterbium (Er3+/Yb3+) at 1.55µm - represents a strong contender for applications requiring high optical power. Our contribution is carried out mainly through collaborations with external laboratories (ONERA, CEA) and Keopsys Company. With ONERA we have participated in the

design of LMA fibre amplifiers, in the analysis of Brillouin spectrum of doped fibres in connection with doping, and more recently the combination of coherent fibre amplifiers in continuous regime [284, 278] and pulsed regime respectively [264, 330, 331, 286]. Spectral broadening is required on high power lasers to avoid Brillouin scattering in high power laser chains such as Laser Mégajoule. The collaboration with CEA concerns the spectral broadening properties on FM-AM conversion induced by non-sinusoidal phase modulation in comparison to the sinusoidal phase modulation case [259, 258, 343]. Taking into account recent developments in Thulium and Holmium fibres technology, more than 100W output powers with very good beam quality have been achieved at 2µm and are an alternative to actual laser solutions. In collaboration with Keopsys Company and ONERA, we develop currently advanced architectures of pulsed fibre Thulium laser for LIDAR or remote sensing.

Optical Low Coherence reflectometry

The optical low-coherence reflectometer (OLCR) developed in our laboratory has been upgraded over the years and has proven to be a unique investigation tool for the study and the characterization of new photonic components[**?**]. Through collaboration with component makers, we have been able to measure some otherwise inaccessible parameters in optical wavelength mux-demux, speciality optical fibers, fiber Bragg gratings, semiconductor devices, including semiconductor optical amplifiers... Our state-of-the-art phase-sensitive OLCR spatially resolves internal reflections of the device under test, and allows measurement of different polynomial terms of dispersion, birefringence, loss / gain material coefficient, phase/amplitude coupling coefficients. It has attracted many national and international collaborations, industrial and academic. The latest results concern the study of photonic bandgap semiconductor waveguides under the ANR-L2CP[5] project [290, 291, 295, 354, 273, 256**?** **?**] in collaboration with Thalès R&T and specialty fibers characterization [**?** 281, 282] for which the OLCR provides incomparable elements of analysis.

4.2.2 Optical network evolutions

Faculty D. Erasme, P. Gallion, C. Gosset, Y. Jaouën, C. Ware.

Projects ANR-SUPERCODE (11/06—11/09), ANR ECOFRAME (-12/09), ANR-TCHATER (10/07—12/10), ANR OCELOT(DATE), FUI 100G-Flex(DATE), FP7-BONE (1/08—12/10), FP7-EUROFOS (05/08—04/12), research project Orange labs, 3 Cifre PhD.

    Fast development of bandwidth consuming services like high-definition/on-demand television, network gaming, cloud computing, makes stringent the need to further network capacity. The objective to provide broadband to a maximum of users ("broadband-for-all") has been leading research and development in the field of fibre-to-the-home (FTTH) technology for the deployment of high bit-rate access networks. Deployment of FTTH, on one hand, of Cloud-computing on the other, will significantly impact the capacity requirement carried by metro and core transport networks in a medium-term future. The fibre capacity must also be maximized through the deployment of new techniques such as new multi-level modulation formats eventually combined with coherent detection, new techniques for multiplexing and routing (packet switching). Finally, a strong driver concerning the design of the physical layer or optical networks today is energy consumption.

Optical access (PON) and code-division multiple access

Today, passive optical network (PON) have been largely accepted as a robust technique for the last mile bottleneck. TDM PON is the commonly accepted technique for resource sharing. For the next generation PON, hybrid-multiplexing solutions (WDM/TDM, WDM/OCDMA...), will be

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[5]Partners: Thalès R&T (leader), CNRS-LPN, IEMN, Télécom SudParis, Télécom ParisTech

considered as well as source-less of color-less ONUs, long reach PON, and private networking. Our research in PON architecture and components is facilitated through collaboration and 2 successive Thesis with FT-Orange labs on new generation PON including extended PON, WDM PON, etc [379, 279]. The former thesis presents a complete study of expended PON solution and established design rules for such networks. Although large amount of the research field of WDM-PON is presently concerned with the matching of proper components or devices structure for obtaining the performance in terms of budget and splitting ratio, distance (see previous part)... specific techniques can be accessed embracing the overall architecture.

The ANR-SUPERCODE[6] project started off combining WDM and OCDMA by designing a supercontinuum pulsed source which can be shared among many users by being sliced into WDM channels, each of which supports multiple users through all-optical encoding and decoding. It also demonstrated the use of spectral phase encoding (SPE-OCDMA), which makes a better use of the bandwidth of the optical fiber, as in the long-haul context, by using the phase of the optical field instead of just the amplitude. Enhanced FBG-based encoders developed for this project were shown in a proof-of-concept SPE-OCDMA demonstration[358], which also used an all-optical power thresholder at the receiver. The latter is the last non-cost-effective piece of the puzzle, which will require higher-nonlinearity materials to fully enable this technique in the access network.

In addition we propose a novel decentralized scheme supporting multiple optical private networking (PNs) over ring-based PON taking benefit of asynchronous OCDMA technique. This technique leads to interconnect optical network units (ONUs) in the same PN sharing the same codeword while other PNs benefiting from different code words. We have experimentally demonstrated the feasibility of 2-active PNs over ring at 625 Mbps. [315].

The network scalability and throughput performance of the proposed scheme have been analyzed and its bit error rate (BER) performance have been experimentally demonstrated. Finally, the network scalability and throughput performance of the proposed scheme are analyzed. Impact of time and wavelength domain crosstalk on capacity performance of a WDM/Optical CDMA have been investigated [254]

Optical Digital communications techniques for next generations of Metropolitan and Core networks

Today's processing capability allows performing digital signal processing for optical communication systems at high bit rates. In close collaboration with the Digital Communications group, the potential and future trends of electrical signal processing techniques to mitigate e.g. noise accumulation, linear and nonlinear distortions are beginning to be investigated.

Under the project ANR-ECOFRAME[7] we have modelled and simulated the physical channel of an optical ring WDM network architecture. We provide the parameters of the statistical distribution χ^2 and estimate the performance in collaboration with XLIM working on FEC implementation. An extension of the concept to mesh networks has been proposed.

Optical signal propagation simulations performed in the case of a new concept of packet ring network reveals that the Gaussian model is not sufficiently accurate to constitute a valuable model of noise-corrupted optical systems. We have proposed an alternative Chi-square model, which is more accurate and corrects deficiencies of the Gaussian model. In such specific channel, we design a FEC scheme based on Low Density Parity Check (LDPC) codes in the case of soft decoding. The performance of a Chi-square-based LDPC soft decoder and a Gaussian-based one are compared, both applied to a real Chi-square optical channel. We point out that the design can be done assuming an AWGN statistic but that considering the real channel statistics is essential to achieve optimal performance. [? 372]

The convergence of digital communications and optical transmission is a key enabling factor to increase the capacity and flexibility of optical networks. Progresses in digital signal process-

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[6]Partners: Institut Carnot de Bourgogne (leader), CNRS PhLAM, XLIM
[7]Partners: ALU (leader), Orange, Prism Laboratories, XLIM

ing 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.

The project ANR-TCHATER[8] concerns the design of a real-time coherent receiver at 40Gbit/s using a FPGA implementation. Our contribution concerns the design of hard and soft FEC solutions adapted to optical coherent systems. We have proposed an original construction of low-density parity-check (LDPC) code suitable for high bit-rate implementations and that have good performance compared to the codes proposed in the literature [337]. To improve the performances of the FEC, it is very important to consider the specificities of the channel. In particular, coherent and direct detection systems both require differential modulation and this degrades the performance. We have proposed a new structured interleaving of the FEC codewords with a corresponding decoding scheme, in order to reduce the penalties introduced by differential modulation [**?**]. Moreover, the proposed scheme allows decoding complexity reduction and redundancy decrease without any performance loss [270].

We have investigated the interest of space-time codes for optical transmission systems. They have been developed for MIMO wireless channels but can be employed in polarization multiplexed optical systems. However their implementation requires the use of optical orthogonal frequency multiplexing (OFDM). For the first time, we have shown that space-time coding can efficiently mitigate polarization dependent loss impairments. We have also shown that their performance is very different than in wireless transmission and explained the reason [335, 334]. In collaboration with Karlsruhe Institute of Technology, we have proposed for the first time an experimental implementation of Polarization-Time code for optical communications [338, 336]. The performance of Silver, Golden and Alamouti PT codes for PDL mitigation are compared to the uncoded case.

Taking into account recent advances in ADC and DSP circuits, real-time implementation of polarization multiplexing coherent receiver is currently available at 40Gb/s and 100Gb/s. The implemented algorithms in circuits running are well adapted for QPSK formats. As higher modulation formats are more sensitive to signal distortions, accurate estimators and more robust equalizers are still required for QAM formats. Our contribution concerns the development of robust Digital Signal Processing (DSP) tools specific to the optical channel. A new adaptive blind and decision-directed equalizers based on Pseudo-Newton gradient-descent algorithm that are well adapted to QAM and that offers a better convergence speed with only a little extra computational load has been introduced [348]. According to the fact that the channel is very slowly time varying (compared to the data rate), we have proposed block-wise implementation of the blind-time CMA equalizers [347]. We have shown that block-wise version outperform the sample-per-sample adaptative CMA approach in term of convergence speed only at a moderate expense of computational load [350]. Moreover, a new CFO estimator very adapted to QAM modulation yields remarkable performance and enables the system to work without penalty [**?**]. Our proposed algorithms should be tested using a simulation setup of an optical transmission system using coherent detection and validated with off-line processing of real measurements in collaboration with HHI in the framework of the European NoE EURO-FOS and Orange Labs respectively. We are currently investigated in the project FUI9 100GFlex, dedicated to metropolitan and core transmissions systems based on multi-band OFDM approach for 100Gb/s in 50GHz. Particularly, the concept of optical sub-band switching can be use advantageously to realize a multi-band OFDM-based reconfigurable optical add-drop multiplexer (ROADM). A very high-baud transmission platform is currently in developing, including a 100Gb/s transmitter/receiver and a 400 km recirculating loop. This versatility and upgradability will enable us to investigate different aspects of digital optical communications: Tx/Rx characterization, propagation techniques, new detection schemes, digital processing and coding techniques dedicated to the optical channel.

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[8]Partners: ALU (leader), E2V semiconductors, INRIA Lyon, ENS Lyon

Analysis of High Bit Rate Optical Signals in amplitude and phase

The asynchronous optical linear sampling of very high rate ($>$100Gbps) optical signals with advanced modulation formats, especially in phase (x-PSK), by short laser pulses source ($<$1ps) is a low cost technique, very competitive constellation oscilloscope market. It allows extracting amplitude and phasing information and displaying it in a constellation diagram, for system design characterization and survey. In the frame of the OCELOT project, aiming the development and the technology the transfer from a research industry, we have start to perform the identifications of the basics limit and the utilization range for this technique, as well as the associated signal processing. [308]. Classical real time phase and frequency signal measurement schemes have been revisited [271] following renew demand for signal assessment in new specific application in particular access networking components in collaborative project (MODULE, TRILOB)

Optical switching

The evolution of optical networks toward more efficient and more flexible architectures leads to tasking optical systems with more work than just what the physical layer requires, tending towards a "cross-layer" approach. The prime research axis in this direction is to route data packets or bursts directly on the optical layer.

In collaboration with Columbia University, we demonstrated a fast-failure-recovery-enabled architecture in an optical packet switching matrix based on a bandwidth-flexible wavelength-striping packet format and semiconductor optical amplifiers used as gates [262]. Other avenues for cutting across the classical network layers are being pursued.

Also, following previous work on packet switching architecture, a whole addressing architecture based on the OCDMA technique and a flip-flop operation has been proposed and has been tested within a co-tutelle thesis in collaboration with Sup'Com Tunis. Within the frame of FP7-EUROFOS full scale experiments have been performed] leading to a demonstration of the feasibility of the architecture including flip-flop operation [287] . and OCDMA addressing [289, 288]

4.2.3 Quantum Optics and application in Communications and Cryptography

Faculty P. Gallion.

Project ANR-HQNet (12/06—11/09)[9], collaboration CICISE-Mexico-BC

Balanced homodyne detection (BHD) system implementation

We have implemented an all fiber one-way QPSK quantum key distribution system at 1550nm using both photon counting and balanced homodyne detection (BHD) configurations. It include an automatic optoelectronic feedback loop is implemented for the interferometric phase drift compensation an a dual-threshold decision scheme for the BHD signal post-detection. Experimental comparison point out that BHD is potentially more effective in terms of quantum key generation rate and system flexibility.

We have also investigated the security issues of the BHD QKD system under two main individual attacks: intercept-resend attack and intermediate-base attacks. A mixed attack strategy of signal power modification has also been analyzed. [**?**]. As the use of decoy states improves the security, facing the photon number splitting (PNS) attacks, we have generalized the standard QKD security analysis to the proposed systems based on coherent detection. [**? ?**].

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[9]Partners: GEORGIA TECH, FEMTO, PHOTLINE

Optical carrier recovery for weak optical signals (WCS)

Access to the optical carrier phase is important in a diversity of applications, not only in coherent telecommunications but also in other fields such a coherent optical sensor and instrumentation, coherent Lidar, etc., that require the measurement of the two field quadratures. Costas loops or decision driven loops that detect both field quadratures simultaneously, require 2 BHD receivers at the expense of additional measurement uncertainty is introduced due to the vacuum fields that leak through the unused ports.

We implemented a receiver structure in which a sequential measurement scheme alternatively switches the local oscillator phase between 0° and 90° to sequentially beat with the signal. We implemented our digital Costas loop in the signal processor block, and we obtained good long-term stability. The measurements on the post-detection statistics were close to the uncertainty limit, especially for small values of the photon number. Similarly our measurements of BER were close to the standard quantum limit for low photon numbers. [**? ?** 266].

Space quantum communications

Optical communications with in low photon number for each transmitted symbol constitutes an expanding field in a diversity of applications. Beyond cryptography, many applications requiring power economy frequently deal with these quantum level signals, such as quantum communications for airborne, space to ground and inter satellite scenarios.

By using the quantum coherent state model of the radiation field, we have compared the different quantum receiver implementations and derived the minimum signal energy required to achieve a given bit error rate, or a given bit erasure rate in high bit rate, quantum level communications [361]. We have implemented an optical Costas loop at 1550 nm based on polarization splitting of the laser field to detect I and Q quadratures simultaneously. We have obtained results on the performance in phase error and bit error rate and compare with corresponding quantum limit [362].

Holistic quantum security approach

The security of quantum communications is traditionally considered as limited only by the basic principles of physics and not, as in merely conventional safety, in terms of resources that Eve could realistically have. However the needs of a time independent truly unconditional security will be very limited and it is not proven that its cost will be finite, making the widely used unconditional security limitation discussion under risk of confining into academics or thought experiments, with weak economics or societal interest. Furthermore an unconditional security of the quantum layer is not sufficient to achieve an end-to-end security up to the application layer. The only way for quantum security to keep a credible role and to create a wide industrial application range is a progressive infiltration into the classically secured system technologies and culture, including in an end-to-end security approach and to clarify its compatibility with optical fiber technologies and systems. In collaboration with local Electronics group and the Computer Science Department we have developed a holistic approach of quantum security. [333, 311]

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Part II

Network and Computer Science

Chapter 5

Interaction, Cognition and Complexity (IC2)

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5.1 Objectives

The IC2 team is working on several research problems in computer science, belonging to human-computer interaction, databases and web data management, cognitive computing, business intelligence, and complex systems and protocols. The activity of the team is organized in four institutional projects, their objectives are presented in the following.

Advanced Interaction and Visualization (VIA Project)

This project is devoted to fundamental and applied research on Human Computer Interaction (HCI). It focuses on the double challenge of representing and manipulating more and more data, and to allow this not only on standard computers but also on small, mobile and non traditional devices. Our main contributions take place in the following domains:

- Novel interaction techniques and principles, which an emphasis on the leveraging of input dimensions that had been overlooked so far;

- Mobile interaction, with a special effort toward increasing the "interaction bandwidth" between users and their devices;

- Information visualization, and more specifically interactive visualization, which aims at allowing users to explore and manipulate the data actively;

- Fundamental HCI research on simple reaching movements, overwhelmingly frequent in HCI, with a project aimed at providing a more general understanding of the Fitts' law;

- End-user programming and reverse engineering, specifically with aims at giving end users more control over the functionality of and interaction with their software.

Databases and the World Wide Web (DBWeb Project)

In this project, we study the fundamental issues raised in modern data and knowledge systems, especially on the World Wide Web and in collaborative contexts oriented towards peer-to-peer networks. Research interests cover theoretical foundations, as practical solutions, applications, and cognitive aspects of data and knowledge management systems. The main challenges we are interested in are:

- Web data management, with a special focus on information extraction, Web sources selection, and Web archiving;

- Query optimization over structured or semi-structured data, possibly with restricted access patterns (deep Web);

- Probabilistic databases;

- Relevance in communication and its applications in modern knowledge systems;

- Social web and social networks, with an emphasis on signed (trust–distrust) networks and collaborative applications, inference of signed links, access control, search and recommendation in social applications.

Business Intelligence (BILAB Project)

The activity of the BILab Project covers several aspects of the Business Intelligence field in relation to both theoretical approaches and industrial applications. A major activity during the period has been related to data stream processing. As a matter of fact, one of the main challenges today is the burst of the volume of available data that feed BI systems. One solution which has been studied intensively recently is to process data *on the fly* as they arrive instead of storing them beforehand in a data warehouse. This approach is referred as Data Stream Querying (if the goal is to query data) or Data Stream Mining (if the goal is to mine data).

Within this context, the BILab Project has acquired skills in this research domain which is very active in the USA but not in Europe, and developed an activity on summarizing the history of data streams. Indeed, all existing data stream processing approaches can only provide results from the part of the stream posterior to the definition of queries or mining tasks.

Since 2007, most of the activity related to BI is inscribed into a new joint research laboratory with the research centre of EDF (Electricité de France). This laboratory is called the BILab (see `http://bilab.enst.fr`). This collaboration enables closer relationships with a large industrial company.

Complex Systems and Protocols (CSP Project)

In this project, we study systems and communication protocols that can be described as complex, which means that their global behavior cannot be easily deduced from the properties of their components. The main goals are:

- to develop complex systems and protocols which emerging properties can be used to enhance computing and communication;

- to study complex systems and to build mathematical models for them.

Our research works focus on overlay protocols to ensure routing resilience, on the development of a novel method based on Complex System theories to define and measure the capacity of Air Transport Management (ATM) resources, and, finally, on the study of the World Wide Web properties. Our experimental studies are taken from the industrial collaborations we developed with EDF Research & Innovation, Eurocontrol Experimental Centre and with Hadopi Research.

5.2 Main Results

5.2.1 Advanced Interaction and Visualization (VIA)

Faculty E. Lecolinet, Y. Guiard, J. Eagan

Main events and external collaborations Official launching of the DIGISCOPE Equipex project (2011); Ongoing collaborations to the UBIMEDIA joint lab. with Bell Labs ; various research collaborations (1 PhD, several scientific papers) with LIG IIHM (Grenoble) and INRIA/Aviz & INRIA/InSitu (Orsay) ; Industrial collaborations with Technicolor, Movea and Archos.

Projects NIU project with Alcatel-Lucent Bell Labs (2008–), OSEO Quaero/PVAA (2008–), ANR TennisServer (2006-09), Cap Digital ENEIDE (2006-2010) and QUATRO 2 (2010–).

Our work on novel interaction techniques have led us to develop new kinds of Marking menus, such as LeafMenus [420], Wavelet Menus [411] and Finger-Count and Radial-Stroke Shortcuts [397]. These techniques, based on gestural interaction, allow users to easily learn in novice (i.e., closed-loop) mode and later quickly execute in expert (i.e., open-loop) mode fairly large sets of commands. Recently we have extended this work by considering 3D gestures for increasing the interaction bandwidth with mobile devices [419] [396] and gesture-aware remote controls [398].

In the context of Interactive TV, we have also investigated free-hand interaction techniques [399] using the Kinnect.

Our work on gestural interaction includes the leveraging of input dimensions that have been overlooked so far, such as pseudo-pressure for improving navigation in long lists [442]. We have also proposed several techniques that exploit the shape and the kinematics of gestures to enrich the input vocabulary of tactile surfaces. Thanks to rolling gestures, MicroRolls [421] make it possible to interact very efficiently with the thumb. Motion-Pointing [410] and Cyclostar [416] rely on elliptical oscillatory gestures: Motion-Pointing allows selecting targets without pointing, CycloStar is a powerful approach for improving navigation tasks such as panning and zooming. Interestingly, most of these techniques are very well adapted for facilitating the interaction with mobile devices.

During this period we have also worked on augmented classrooms by developing the U-Note system [480] [417]. By using digital pen and capturing events that occurs during the class, U-Note allows to leverage the advantages of paper while letting teachers and pupils benefit from the richness that digital media can bring to a lecture.

We have also expanded our research focus into the area of end-user programming and reverse engineering, particularly with regards to aiding end-users and third-party programmers at modifying the functionality and interaction of existing software applications to better suit their needs. This direction is off to an auspicious start with the first prototype system, Scotty [409], having received a notable paper award at UIST 2011.

Finally, we have started casting some new light on Fitts' law, a famous empirical regularity of experimental psychology. In particular, we have clarified in what sense Fitts' law constitutes an instance of a speed-accuracy tradeoff [522]. We have also shown that the traditional definition of the independent variables involved in the law suffers a high degree of indeterminacy, and suggested a novel way of defining the basic dimensions of the problem [414].

For working on these subjects, we have developed long-term collaborations with several industrial and academic partners: Alcatel Lucent Bell Labs (and the UBIMEDIA joint research laboratory), LIG / IIHM (Grenoble), INRIA InSitu and Aviz projects (Orsay), etc.

Finally we are also part of the DIGISCOPE EquipeX which is a high-performance visualization infrastructure for collaborative interaction with extremely large data sets. DIGISCOPE involves 10 academic partners (CNRS LRI and LIMSI, INRIA, CEA, ECP...) and will foster lasting collaborations between them and the industrial parters that are associated to the project.

5.2.2 Databases and the World Wide Web (DBWeb)

Faculty T. Abdessalem, B. Cautis, J.-L. Dessalles, P. Senellart, M. Vazirgiannis (40%).

Main events and external collaborations J.-L. Dessalles visited the Tokyo University of Foreign Studies (6 months) in 2009–2010.

P. Senellart organized the ACM SIGMOD programming contest in 2010 [523]; he chaired the Industrial track of EDBT 2011 and the tutorials of ICDE 2011.

Ongoing collaborations with the database groups of the University of California San Diego (B. Cautis and A. Deutsch), Renmin University (T. Abdessalem, B. Cautis, P. Senellart and J. Lu), and the University of Oxford (P. Senellart, M. Benedikt, G. Gottlob and D. Olteanu).

Projects FP7 IP ARCOMEM (2011–), COOPOL VMS3D (2010–), ANR DataRing (2009–), ANR ISICIL (2009–), MODIM Chair (2010–), ANR LPOD (2008–2010), ANR PANIC (2010–2012), Advanced ERC Project DIADEM (2010–), Advanced ERC Project Webdam (2009–).

Relational and semi-structured databases.   We study the problem of querying data sources that accept a limited set of queries, such as sources accessible by Web services which can implement very large (potentially infinite) families of queries. For the relational data model, we revisit in [383] a classical setting in which the application queries are conjunctive queries and the

source accepts families of (possibly parameterized) conjunctive queries specified as the expansions of a (potentially recursive) Datalog program with parameters, under the assumption that sources satisfy integrity constraints. For semi-structured databases, we study in [402, 384] the problem of querying XML data sources that accept only a limited set of queries, such as sources accessible by Web services which can implement very large (potentially infinite) families of XPath queries. We also consider the problem of answering queries under access pattern restrictions (deep Web), in [413] where we characterize the complexity of determining if a given source is relevant to a query.

We have done extensive research on the management of probabilistic databases, and probabilistic XML in particular. In [381], we present a common model for and compare the expressiveness of different ways of organizing probabilistic information in trees. We also investigated the complexity of aggregate queries over probabilistic XML [495, 394, 382], introducing in the process the possibility of representing continuous distributions of data values. We proposed an alternative model for probabilistic XML based on recursive Markov chains [401] that allow for trees of arbitrary depth and width, which is akin to XML schemas [496, 395]. We researched the complexity of a number of other probabilistic XML data management problems: updates [470], join queries [471], mining [517]. We study in [497] the complexity of query answering using views in a probabilistic XML setting, identifying large classes of XPath queries – with child and descendant navigation and predicates – for which there are efficient (PTime) algorithms. Finally, we looked at practical aspects of implementing a probabilistic XML database engine, in particular with the help of approximation algorithms [505, 422].

Web data.   We propose in [392, 405] a novel approach for extracting structured data from the Web, whose goal is to harvest real-world items from template-based HTML pages (the structured Web). It illustrates a two-phase querying of the Web, in which an intentional description of the data that is targeted is first provided, in a flexible and widely applicable manner. The extraction process leverages then both the input description and the source structure. Our approach is domain-independent, in the sense that it applies to any relation, either flat or nested, describing real-world items. Extensive experiments on five different domains and comparison with the main state of the art extraction systems from literature illustrate its flexibility and precision.

We study in [474, 418] the inference of a signed network (a "web of trust") from interactions on user-generated content in Wikipedia. We investigate mechanisms by which relationships between Wikipedia contributors – in the form of signed directed links – can be inferred based their interactions. Our study sheds light into principles underlying a signed network that is captured by social interaction. We look into whether this network over Wikipedia contributors represents indeed a plausible configuration of link signs. We assess connections to social theories such as structural balance and status, which have already been considered in online communities. We also evaluate on this network the accuracy of a learned predictor for edge signs, obtaining strong evidence that our network does reveal an implicit signed configuration and that it has similar characteristics to the explicit ones, even though it is inferred from interactions. This trust network can then be used to annotate Wikipedia articles with confidence information in each revision, a task that we handle using probabilistic XML [393, 441].

Similar graph mining algorithms are also applied to determining truth values of facts stated by independent sources [499, 412] and to a probabilistic approach to the matching of very large ontologies [506, 423].

We propose in [439] an access control model for online social networks, where access control rules are expressed as reachability constraints. Our work generalizes access constraints by taking into account the properties of the users, the indirect connections between these users, and is able to express complex relationships. The main idea is the specification of the target audience of each access rule in terms of a reachability constraint, which is expressed as a path expression over the social network graph. Thus, the enforcement of an access rule consists in the evaluation of a path, which should be computed on the fly when the resource is requested by the seeker.

We propose in [500] a matrix factorization technique that aims at improving the accuracy of recommender systems. Matrix factorization models allow a high quality of rating prediction. However, a major drawback of the existing techniques is their static nature that results in a progressive declining of the accuracy of the predictions after each factorization. Matrix factorization can not be done very often because of its high computational cost. The goal of our work was to enable online integration of new ratings, in order to maintain a good quality of the predictions between two factorizations. We proposed a solution that combines clustering and users' biases in order limit the computational cost.

Finally, we have conducted a number of research works in the field of Web archiving. One line of work considers using semantic clues from RSS feeds to extract and archive the main content of a Web page [502, 478]. We have also surveyed the methods used for estimating the dynamics and freshness of Web pages [479], which is of great importance in Web crawling. We are currently investigating the introduction of intelligent, adaptive, behavior, in archival Web crawler, in particular in the context of the archiving of the social Web.

Cognitive computing.   We propose in [386, 513, 433, 432, 462, 431, 511, 512, 514, 387, 434] a consistent model of social communication. Altruistic communicative acts are possible when agents maximize their own benefit (in contrast with cooperative models), if they provide reliable clues about some quality that is socially in demand. In this model, relevant communication is profitable to the emitter because it advertises definite qualities (relevance) that are appraised by listeners. This model crucially relies on the role played by communication in building and preserving of social networks.

We focus in [430, 406, 407, 408] on the simplicity theory (see `http://www.simplicitytheory.org/`) and we show that the interesting events are unexpected. Unexpectedness is formally defined as cognitive complexity drop. This law correctly predicts that events close in time and space are more likely to raise interest. It also explains in detail why coincidences are experienced as fascinating; it predicts story rounds, and several other spectacular aspects of spontaneous communication.

Additional and up to date information on DBWeb main results and publications can be found on the project web page `http://dbweb.enst.fr/`

5.2.3   Business Intelligence (BILab)

Faculty B. Burtschy, A. Danzart, G. Hebrail, C.Potier, F. Rossi.

Main events and external collaborations A joint research laboratory with EDF R&D was created in 2007 for four years (2007-2011). The BiLab was headed by G. Hebrail until 2010, and by F. Rossi in 2011.

Industrial collaborations with Orange Labs (1 CIFRE PhD student), with Lokad (1 CIFRE PhD student).

Projects ANR MDCO MIDAS (2008-2010).

Data stream management.   Our main activity related to data stream processing focuses on summarizing structured data streams: this requires the summaries to be built incrementally with little computation for each record and bounded or slowly growing disk space for storage [488]. We have developed several new approaches to summarize one or several structured data streams [515, 459],[490, 465, 458] and designed solutions to query the summaries both on the history of the stream and on the current stream [491, 403, 466]. We have extended the temporal sampling approach called 'Master' developed in 2008. Master builds an optimized summary of a large number of distributed streams produced by remote sensors. A clustering strategy was introduced to Master and gave rise to Clusmaster (clustering on master). Clusmaster applies a clustering method to the SSE (Sum of Square Errors) matrix in order to identify similar sensors before

the execution of the optimized summarization phase. Experiments with time series from electric power meters were carried out and are described in [404, 385].

Also, we have analyzed data streams describing the working phases of a nuclear power plant [518]. The goal is to detect periods of dysfunctional states. The approach applied is a clustering based on non-overlapping windows to monitor system and detect changes in evolving data [509]. The main novelty in this approach concerns the change detection strategy which is based on the clustering extension, i.e., individual memberships reflecting the current system state.

Most of the work on data stream management has been done within the MIDAS ANR Project from 2008 to mid 2011. The BILab team was the leader of this project. The main result of the project is a demonstration platform which has been designed and integrated by the BILab team (see `http://midas.enst.fr`).

Finally, a new approach has been designed for forecasting the generation of photo-voltaic (PV) electric power. The goal is to forecast local production at a very short term (a few hours). The approach uses the history of the local production and is enhanced by a collaboration between neighbor sites [468, 501].

Time series and functional data mining. BI deals frequently with time varying objects. Such objects are not standard data described by a fixed set of numerical and/or nominal values. They are better understood as functional data: each object is described by some functions that map time to appropriate values describing the object on a given dimension at the specified date.

We provide exploratory analysis of functional datasets via a combined clustering and segmentation approach. Functions are clustered into homogeneous clusters with the specific property that each cluster is represented by a simple functional prototype, for instance a piecewise constant function. The complexity of the prototype set is globally optimized by an efficient dynamic programming scheme [469, 520, 388]. Related work include [472] in which a piecewise constant approximation of functional data is built in a supervised manner: one finds a simplified representation optimized according to an external criterion (such as the ability to separate efficiently two classes of functions). We have also continued our work on supervised modelling of functional data, in particular on the use of derivatives to capture some shape aspects of functional data [**?** 391].

In [510], we handle time varying data in a quite different manner: in this case, the evolution through time of an unique system (a web server) is studied. A time aware clustering algorithm is used to track the evolution of the web server usage patterns.

Graph exploratory analysis. We have been developing graph/network exploratory analysis techniques, with a focus on social networks. We have proposed in [481**?** , 390] a new topological quality measure for graph clustering, inspired by the self organizing map algorithm. Our deterministic annealing based algorithm optimizes this way a tradeoff between a graph clustering quality measure (Girvan and Newman's Modularity measure) and a visualization quality measure. The method results in a coarse grained graph that is both a faithful simplification of the original graph and easy to draw. We have used this method and similar graph clustering techniques to analyze successfully real world networks in the genetic domain [473], in the epidemic domain [958, 957] and in the historical domain [504]. We have also modelled information propagation in social networks and used similar visualization technique to display local propagation in important clusters [1042].

Large scale data analysis. Large scale data analysis has recently gained interest in database and data mining communities, and in the information industry. Processing and analyzing large volumes of data provides both opportunities and challenges. In France, the forthcoming deployment of new communication power meter (Linky) in 35 million households until 2020 will generate massive load curves in real time. New approaches are needed in order to deal with such a voluminous and dynamic data. A proactive work has been initiated in collaboration with EDF R&D in

order to look for solutions to storage and manage massive time-changing data series. A proto-type solution based on HDFS (Hadoop distributed file system) for distributed storage and Hadoop ecosystem (Pig, Hive, Hbase) for massive data analysis has been designed and tested in a private cloud at EDF R&D. In addition, cloud based implementation of data mining techniques have been studied in collaboration with Lokad [463, 498].

5.2.4 Complex Systems and Protocols (CSP)

Faculty P. Bellot

Main events and external collaborations Conference organizations (IEEE RIVF 2009 and 2010). Best research paper award at WebTech 2010.

Ongoing collaboration with EDF Research (Chatou, STEP departement), Eurocontrol Experimental Centre (Brétigny sur Orge), and Hadopi Research (Paris).

Projects ANR HQNET (2006–2010), EUROCONTROL (2009).

One of our main results is the design and implementation of ROSA (Robust Overlay with Self-Adaptive topology) [427, 449, 447, 448, 446, 445, 443, 453, 444]. Overlay networks offer a way to bypass the routing characteristics of the underlying network. ROSA used this property to offer a resilient routing to critical applications. Unlike other overlay networks dealing with the routing resilience issue, we oriented our research towards building a locally robust overlay network topology instead of a robust routing function. Resilience is an emerging property of the system. ROSA is basically an unstructured overlay network. We proposed a structure, called Chain of Lumps (CoL) which provides the advantage of structuring ROSA. Once ROSA endowed with the structure, we proposed a reliable storage system deployed over ROSA. We showed using simulations and the Watts and Strogatz model, that the routing algorithm of ROSA, based on a DHT, is a case of small-word phenomenon. This is interesting from a routing point of view. Indeed, a routing algorithm with the small-world property is not influenced anymore by the size of the network. That means that the number of virtual hops to route a message is nearly constant and does not depend on the size of the network. In the post Fukushima context, we have set up a collaboration with EDF Research & Innovation to study the possibility of using ROSA as an emergency routing algorithm for an intelligent and autonomous middleware for the orchestration of contextual services of the nuclear plant control command.

In collaboration with Eurocontrol, the European Organisation for the Safety of Air Navigation, we develop a new method, based on Complex Systems theories, to define and evaluate the capacity in terms of ATM resources availability [400, 484, 425]. Measurements and analysis of traffic flow characteristics and controllers activities provide meaningful indicators to evaluate the intrinsic difficulty of the ATM tasks as well as the methodologies to quantify these indicators impact on the system performance. An hybrid model of the availability of system resources is currently built embedding a macroscopic level of controller cognition. Mechanisms that are used to balance cognitive complexity and desired system performance will be described. We hope that the proposed model and mechanisms not only can estimate the available capacity but will also provide an effective way to allocate traffic to traffic management.

Complementary to the previous works, we have developed a toolkit named SAW-SDK (Stand Alone Web application SDK) [452, 429, 451, 450, 428] for an easy Java development of efficient Web and Mobile applications. Available at `http://www.infres.enst.fr/saw`, it has been used for the IEEE RIVF 2010 conference that can be seen at `http://www.infres.enst.fr/rivf2010`. It is used internally to provide a Web and a mobile Android application for students evaluation. One of its avatar will probably be incorporated in the middleware we are currently developing with EDF Reasearch & Innovation for services implementation.

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Chapter 6

Mathematics of Information, Communications and Computation (MIC^2)

Team leader L. Decreusefond (01/09–11/11), O. Hudry (11/11–)

Faculty B. Meyer (09/11–), I. Charon (P.) (–06/11), G. Cohen (P.), L. Decreusefond (P.), O. Hudry (P.), A. Lobstein (CR CNRS), D. Madore (Ass. P.), H. Randriambololona (Ass. P.), J. Sakarovitch (DR CNRS), A.S. Üstünel (P.).

PhD students P.-Y. Angrand (09/08–), D. Auger (10/07–06/10), I. Camilier (07/07–09/10), C. Cardenas (01/07–), E. Ferraz (01/09–01/12), I. Flint (11/10–), J.-P. Flori (09/08–), B. Kindarji (09/07–06/10), R. Lassalle (09/09 –), J. Valentin (04/09–), A. Vergne (10/10 –), T. Vu (09/08–).

Post-docs, engineers and sabbaticals

External collaborators H. Chabanne, N. Puech, G. Zémor.

6.1 Objectives

Our research is devoted to concepts, methods and models coming from mathematics and computer sciences. Our works are twofold: on the one hand, we apply abstract and generic mathematical results to the computer real world (biometry, optical networks, quantum networks, mobile networks). On the other hand, we consider new mathematical problems raised by the applications (differential geometry, algebraic geometry, automata, infinite dimensional calculus). For instance, classic tools of combinatorial optimization, such as graphs and linear programming, are revisited for their applications to the design of optical networks. We also strongly believe in the necessity to develop abstract theories like algebraic geometry or infinite dimensional analysis, in order to forge the tools which will be used in a near future to model and analyze more and more complex phenomena.

6.2 Main Results

The main research results obtained during the period 2009-2011 are presented below for the research areas of the MIC^2 team.

6.2.1 Probability, Stochastic Modeling

Faculty : L. Decreusefond, E. Ferraz, I. Flint, R. Lassalle, **A.S. Üstünel**, J. Valentin, A. Vergne, T. Vu.

Projects : *Projet structurant :* MONGE

- MASTERIE, ANR blanc (10/10–10/13)
- CRE Orange Labs (01/11 – 12/13)

Historically, the team was interested in analysis in infinite dimension, mainly Malliavin calculus and nuclear spaces, and its applications to telecommunications networks.

The optimal transportation problem dates back to the eighteenth century. Its modern approach was introduced in the forties by Kantorovitch as an optimization problem in a space of probability. A full solution for the quadratic cost was found in the nineties by Y. Brenier. Because of its numerous applications, for instance to functional inequalities, it is sensible to look at a generalization of this problem to infinite dimension spaces. The optimal transportation problem for a singular quadratic cost on the Wiener space was solved a few years ago. We are now in position to develop consequences and applications. In particular, we found necessary and sufficient conditions for a perturbation of the identity to be invertible in the Wiener space. We also gave some applications to filtering theory. In [41], Üstünel found a simple result: a causal process on the Wiener space is the unique strong solution of a SDE (stochastic differential equation) if and only if the kinetic energy of its drift is equal to the relative entropy of the law of the process with respect to the Wiener measure. Applications and extensions of this result is the subject of the PhD of R. Lassalle. At least, three papers are in the course of publication. During last year, Üstünel also extended Talagrand's transport inequality to general diffusion processes with Lipschitz continuous diffusion coefficient and with a very singular drift coefficient, in such a way that this inequality applies to Wigner process which is of fundamental importance in the topics of random matrices and Riemann's conjecture. In financial mathematics, the quasi-linear inequality for American options pricing has already been solved by Üstünel a couple of years ago in the hypoelliptic case with smooth coefficients, using the stochastic calculus of variations of Paul Malliavin [42]. In his Ph.D. thesis, J. Valentin extended these results to the diffusions whose (degenerate) coefficients possess only some Sobolev regularity by making some deep applications of harmonic analysis in this frame.

The mathematical properties of point processes are well known only for a very few number of processes. Unfortunately, in real life, it is seldom true that the real phenomenon can be modeled precisely by one of the known processes. It is thus of the utmost importance to increase the set of "known" point processes. In [25], we established the basis of the stochastic calculus with respect to determinantal and permanental point processes. In particular, we computed an integration by parts formula in the sense of Malliavin calculus. This work is now continued in the thesis of I. Flint who is interested in the further properties of these point processes.

Several years ago, we started a collaboration with P. Martins (NMS team) on new mathematical paradigms for the performance evaluation of telecommunication systems. Using concentration inequalities (see [45] for an introduction to this formula in the context of point processes), we developed robust dimensioning formulas for LTE radio-systems like OFDMA [60] and then further evaluated the energy consumption of such systems (see the thesis soon to be defended of T.T. Vu). Another line of thought is the usage of algebraic topology for sensor and cellular networks. For randomly located points, representing either mobiles, base stations orsensors, etc. we construct not only its proximity graph (there is an edge between two nodes if they are less than some distance apart) but also its *proximity complex*. A proximity complex is a list 3-uples, 4-uples and so on such that an n-uple $[x_1, ..., x_n]$ belongs to this list if and only if the intersection of the balls centered on the n points $(x_1, ..., x_n)$, with the previous distance as a radius, is not empty. Such a construction contains much more information on the underlying topology of the cloud of points. We know from algebraic topology that we can then recover the number of connected components but also the number of *holes*: the number of domains of the plane which are not *covered*. E. Ferraz in his thesis to be defended soon, computed some characteristcs of such random complexes using Malliavin calculus formulas [27] and concentration inequality. The thesis of A. Vergne continues this work. We devised an algorithm based on these ideas to optimally switch off some sensors in order to save some power with coverage maintained. The mathematical analysis of this algorithm is our current work.

6.2.2 Discrete Mathematics, Communication, Information

Faculty : P.-Y. Angrand, D. Auger, **I. Charon, G. Cohen**, J.-P. Flori, **O. Hudry**, B. Kindarji, **A. Lobstein, D. Madore, H. Randriambololona, J. Sakarovitch**, R. de Souza, G. Zémor.

Projects : *Projet structurant* : COOPT

- European grant VIPBOB
- ANR project Computational Social Choice n° ANR-09-BLAN-0305-03

Algebraic Geometry, Number Theory and Cryptography

One research direction is the approach to problems of arithmetic nature (transcendence, Diophantine equations) by geometric methods (algebraic geometry, Arakelov geometry, Hermitian lattices). But of equal importance is also the application of these same geometric methods to concrete problems in combinatorics, coding theory, cryptography, analog and digital modulations, quantum information theory, etc.

We gave new proofs, and then improvements, of some results about the number of solutions of systems of polynomial equations over finite fields. We then gave applications of these new results to problems in coding theory.

We studied the quantification problem for the state space of a MIMO channel. In particular we compared results obtained from models based on various quantification methods, some of which naive, some others sophisticated, relying on the very differential geometric properties of the natural structure of Hermitian symmetric space carried by the space state of the channel.

We constructed a space-time code for 2×2 MIMO channels that is optimal both for maximum likelihood decoding and for iterative decoding. This construction was made possible by the use of

objects from various branches of mathematics: matrix groups, quadratic forms, algebraic number theory, generalized quaternions.

In public-key cryptography, we began to explore the possibilities of finding cryptosystem not relying on the hardness of the discrete logarithm or the factorization, and if possible, efficient. That is why we are studying the potentialities of objects stemming from algebraic geometry such as algebraic tori, semi-abelian varieties, cubic hypersurfaces, in existing cryptosystems (especially on elliptic or hyperelliptic curves, e.g., pairings). We also study links with coding theory (e.g. toric codes) and information theory (secret sharing) and the possibility of applying combinatorial game theory to cryptographic protocols (so as to formalize them).

The results of these works can be found in [38, 37, 16, 61, 30, 39].

Combinatorics and Optimization

The external co-authors are L. Belgacem (FuturMaster), Y. Ben-Haim (University of Tel-Aviv, Israel), S. Gravier (CNRS, Institut Fourier, Grenoble), I. Honkala (University of Turku, Finland), B. Leclerc (École des hautes études en sciences sociales, J. Moncel (University Toulouse 1), B. Monjardet (University Paris 1))

Once we realize that any technological system will eventually suffer errors or failures, it is necessary to develop tools to handle such events. For instance, in a multiprocessor architecture, we may want to locate the malfunctioning processors. The so-called identifying codes in graphs are one of the best possible ways to achieve this goal. Hence, we studied the properties of these codes, as well as the ones of the graphs admitting identifying codes, called twin-free graphs. Different aspects are considered: structural and combinatorial properties [4, 7, 21], study of special graphs [17, 13], complexity and algorithmic issues [6, 3].

The study of identifying codes of a graph G for a radius r greater than 1 can be related to the study of identifying codes of the r-th power of G for a radius equal to 1. This led us to study the powers of graphs and their properties [8, 9].

Another direction of research deals with mathematical aspects of the aggregation of preferences, through the linear ordering problem for tournaments and consensus procedures [33, 19, 51]. More specifically, this includes complexity issues [31, 32, 48] and comparisons between different methods [20].

A last topic is about combinatorial optimization and more generally operations research [49]. This includes works on the design of exact methods [44] or of some metaheuristics [18] in order to solve NP-hard problems [50]. An application can be found in [53, 12] for the resolution of the so-called Routing and Wavelength Assignment Problem.

Information Theory

Our contribution to the field can be divided into 3 main themes:
1. Combinatorial coding

Our work on identifying codes as continued [17]; a new notion of identification has been put forward: that of witness, where we want a code such that its codewords can be recognized by inspecting a small window acting as a "witness" [57, 58]. From a more graph-oriented perspective, we have been interested in zero-error capacity issues in various spaces [14, 23]. Finally, in a more classical coding concern, we have studied thresholds in on of the most used classes of codes, the Reed-Solomon codes [56] and cardinalities of codes under weight constraints [11].
2. Cryptography and biometry

This application of coding theory to biometrical identification is potent. However, a number of questions needed to be addressed. In practice, the distribution of biometric traits is far from uniform and the scheme is liable to leak undesirable partial knowledge to an unauthorized third party. It was thus desirable to have a protocol for which zero information leakage to potential eavesdroppers is guaranteed. We dealt with this issue by considering the information leakage as a wire-tap channel problem [54].

Then, we explored the possible applications of this approach to devise biometric identification techniques, in the framework of cooperation programs and joint PhD students with SAGEM/Morpho [55, 15].

3. Codes and cryptography

The intersection of these two fields was for us bent functions, related to Reed-Muller codes, and of use in symmetric cryptography. Our approach was arithmetical and combinatorial [30, 36].

In addition to the publications, the results include the following:

- Invited talks

   - Information and coding theory in biometrics, CryptoBiometrics for Enhanced Trusted Identity Management (Turbine project), Brussels, 17-18 Jan, 2011.

   - IMS-NTU Workshop on Coding and Cryptology, Singapore, 23-27 May. 2011.

   - On the link of some semi-bent functions with Kloosterman sums (with S. mesnager) IWCC2011, Qingdao, 30 May-3 June 2011, LNCS 6639, pp. 263-272, 2011.

   - Workshop on coding theory, EPFL Lausanne, 25-29 July 2011.

   - Dagstuhl Seminar Coding Theory, 13-18 Nov 2011.

- Meeting organization

   - ITW 2010 Dublin, invited session Coding and information-theoretic methods in cryptography

   - SETA 2010, member of the Technical Program Committee

   - ISIT 2011, Saint Petersbourg, Russia, member of the Technical Program Committee

- Recent thesis supervision

   Bruno Kindarji: Protection de données biométriques,Sept 2007- 2010.

   Jean-Pierre Flori: Méthodes algébriques, combinatoires et géométriques en sûreté de l'information, Sept 2008-2011.

   Zizhu Wang: Novel protocols for quantum networks, 2009-2012 Multi-party quantum cryptographic primitives in realistic environments.

   Alain Patey: Distributed secure biometric matching, 2011-2014.

- Recent contrats SAGEM/Morpho:

   - Bourse CIFRE Sagem Bruno Kindarji 2007-2010 (15 KE/an).

   - Bourse CIFRE Morpho Alain Patey 2011-2014 (15 KE/an)

   - Partenaire de l'ANR COCQ (domaines emergents 2008-2011) (67 KE).

Automata Theory

The activity in this domain is conducted by J. Sakarovitch, his PhD student (P.-Y. Angrand) and several external collaborators, mainly S. Lombardy. It may be described under three themes: synthesis, research, and construction of software for handling finite automata.

Two chapters ([47, 52]) in collaborative books have been published. The research activity may be illustrated by a work on weighted transducers ([62]) that allowed to answer a problem that was stated 30 years ago and by the study of a variant of the derivation of expressions ([34]) that may reverse the construction of expressions from automata ([34]).

As for the software activity, the development of VAUCANSON, a C++ platform for computing with weighted automata and transducers written in collaboration with a team from EPITA, has been carried on. A first stable version, VAUCANSON 1.4, has been released and will serve both as a test suite and a milestone for future versions. The bases for a completely new design of the core have been defined. The realisation of a new version following these new specification will be conducted in the framework of an ANR project attributed in October 2010 (starting March 2011).

6.3 References

Below is the full list of articles published, since January 2009, in international journals, in books, or in proceedings of international conferences by current members of the team). The full list of publications of the team is available at the following URL:

`http://www.infres.enst.fr/wp/mic2/publications/`

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Chapter 7

Computer science and networking department (NIS)

Team leader A. Hecker (MdC).

Faculty xxxx xxxxx xxxx

7.1 Introduction

Modern ICT technologies are increasingly software-driven. Software components in networks and infrastructures account for more flexibility in operations, but also render the infrastructures more complex in their behavior and, *in fine*, more vulnerable. In current systems, the fragility of the software predominates even in high-availability infrastructures. The proliferation of the generalized connectivity (locally, through short range radios and xDSL technologies and globally through the democratization of the Internet) on the one hand, and the abundance of personal digital devices on the other hand (smartphones, netbooks, tablets, portable PCs) are responsible for the ongoing opening of previously closed and often isolated, "private", ICT infrastructures. It becomes increasingly more and more difficult to address the cyber-security through the classical security methodology, which studies the impacts of events on an asset from its environment, since, in practice, both the environment and the actual ICT system per se are not fixed, but rather react and adapt in mutual interdependency.

The current situation is rather worrisome. Since software has found its way in almost all activities of the modern society, no industry sector can ignore software security problems. Furthermore, since the ongoing trend to the generalized networking and continuous connectivity is rendering all these installations generally accessible through different means, no industry player can feel secure facing the challenges of cyber-security.

Indeed, alone for 2011, the press has reported major cyber-security breaches in such branches as electronics, gaming, commerce, banking, defense, energy production, water supply and traffic control. States increasingly feel the pressure of the cyber-security risk and start programs spanning from protective measures and obligations over emergency trainings to the troubling notion of "cyber warfare", i.e. of a coordinated big-scale counter-attack.

Needless to say, ordinary citizens have long been lost in the maze of security settings and security warnings of all kinds. Ignoring both what is on stake and how to mitigate it, they often make fatal decisions with regard to their privacy, reputation and their civil or financial responsibilities.

Networking is at the heart of all these developments. For systems to be secure, system architectures – i.e. today, including networks – have to address some security questions at the earliest stages.

That is why, the Computer Science and Networking department has opted for the creation of a research group dedicated to questions of Networks and Information Security (in French even

more explicitly called "Sécurité et Réseaux"). Gathering security-oriented researchers from different other groups, this new research group has been established at January, 1, 2010 at the *CS and Networking* department with an explicit focus on networks and security. As of December 2012, members of this group include 2 full professors, 5 associated professors, 2 CNRS researchers, about 20 faculty (post-docs, engineers, PhD students) and 1 professor emeritus

7.2 Main research subjects

The current research subjects of the group are presented along the following research activities:

7.2.1 Security of Internetworking and of Its Typical Applications

- Internet infrastructure security

- Internet Applications security

7.2.2 Internet of Things, M2M and Identity Management with Trustworthy Devices

- Internet of Things and M2M communications

- Smartcards and smart tokens

7.2.3 Infrastructureless Networking

- Vehicular networks

- Security of mobility, ad hoc

7.2.4 Quantum Information

- Theoretical aspects (quantum generation, optics)

- Quantum cryptography

- Quantum key distribution networks, experimental facilities

7.2.5 Security policies, risk and threat analysis, security models

7.2.6 Document security

7.2.7 Security management, operational security evaluation, resilience of open

infrastructures

- Critical infrastructures & processes security

- Operational security evaluation

In the following, we will present every activity in more details.

7.3 Security of Internetworking and Its Typical Applications (–AS–)

The objective of this activity is dedicated to the improvement of the security of internetworking and of its typical protocols. Consequently, the body of work in this domain is of a tremendous thematic span, going from specific provisions in the authentication phases of the protocols as required by the corresponding services and to the architectural decisions regarding service overlay levels and Internet infrastructure security

Three main achievements can be presented at this point.

- We have defined and elaborated a new approach to communication protocol security based on the addition of new semantics to the protocol runs [106][101][102][103][26][27][28][29]. By relying on a semantic interpretation of the available data elements of standard protocol executions, our approach remains fully interoperable with the existing implementations – a non-negligible fact when facing a broad industry acceptance and deployment. Moreover, such an interpretation is not required from all entities. However, the supporting entities can benefit from the new properties provided by our method at the service level. Concretely, we use the random data, so called "nonces", used e.g. in SIP (Session Initiation Protocole) or HTTP (HyperText Transfer Protocol). Our research has concentrated on a secure way to give a meaning to this opaque blocks in order to improve the security level and to offer new security services, e.g. 1) capability for a user to verify communication billing by the service providers 2) capability to counter " *bye* " and " *cancel* " attacks on the SIP protocol, 3) capability to optimize the authentication phase of SIP resulting in a gain of one RTT (round trip time) for an equal security level. We formally verified all results using AVISPA. Besides, we implemented and tested our proposals in open source platforms, e.g. for SIP using modifications in the Jain API or in the widely deployed Asterisk server The perspective is to add these capabilities to SSL/TLS. These contributions have been published academically [26][27][28][29][30][31][32][33], and have resulted in three patent applications [101][102][103] and the PhD thesis of Thomas Guillet [106]

- To improve the Internet infrastructure resilience, we continued our work on IP traceback, necessary to stop distributed denial of service attacks. We concentrated on a specific Internet traffic using the ICMP protocol, and notably its ping service (echo-request/echo-reply). We have proposed a probabilistic marking solution to efficiently trace this kind of traffic " *in-band* ". To validate our approach, real-scale experiments have been conducted and a simulator using real traffic data has been implemented [34]

- We continued working on P2P control, optimization and security. Our objectives here are twofold: we would like to make some overlay parts private, while improving the transport characteristics over the typical multi-AS system like the Internet without any central authority. The most prominent P2P protocols right now are DHT-based approaches (used for data organization and search) and Bittorrent (used for an efficient data retrieval). DHTs are hash tables projecting a common identification space; the latter is distributed, according to the used algorithm, over all participating nodes. To obtain an ID of a node responsible for an object, classically, a usual hash function is calculated over the object identifier to determine the identifier of the researched object in the DHT. Then, the mechanisms permit to route to such an identity. In such a way, every object remains essentially universally searchable and universally accessible. Our objective was to make some objects private: to do that, we needed to cut the ID space in virtual slices, the access to which needed to be controlled. Our solution relies on the usage of a keyed HMAC function instead of the normal hash function. In the resulting proposal, only a group knowing the secret key can locate the objects in the virtual space. Yet, our method does not affect other principles of the DHT (routing, retrieval, etc.) and therefore remains transparent. We have validated this proposal through large-scale simulations, and we could show the advantages namely for peering between

different AS in the Internet [36][35][37] Finally, to improve the actual data retrieval, we have adapted an FEC (Forward Error Correction) mechanism for bittorrent by using it on data segments in order to reduce the latency in data access. We have validated our approach in [35]

7.3.1 Internet of Things, M2M and Identity Management with Trustworthy Devices (–PU–)

The goal of this activity is to tackle practical security issues in the networks, the Internet, the Internet Of Things (IoT) and the emerging Machine to Machine (M2M) infrastructures. The tentative solutions rely on tamper resistant devices, based on secure microcontrollers such as smart cards or more generally speaking a Secure Element (SE).

Three PhD students are currently working on these subjects, another thesis ended in 2010 and deals with the security in SIP [50]. Other doctoral works target privacy for the IoT and Identity for the Cloud Computing and Mobile Services.

In fall 2009, the ANR project T2TIT (Things to Things in the Internet of Things) [85], which ended in the beginning of 2010, won the **Cartes'2009 Best Software Award**. The HIP-RFID protocol [51] issued from the T2TIT project is currently a **working item group** [82] at the IRTF (Internet Research Task Force), which should be finalized by the end of 2012, and whose editor is P. Urien. The T2TIT team also published two books in 2010 [77] and 2011 [78], targeting RFIDs and the IoT.

In January 2010, the demonstration detailed in the paper [48] received the **Best Demonstration award** from the IEEE CCNC conference, and demonstrated **the first OPENID infrastructure based on smartcards**

A paper [49] co-written with Christophe Kiennert, a CIFRE student funded by EtherTrust Company (Spinoff of Telecom ParisTech, [99]), won a **Best Paper award** at the ICDT 2010 conference. A new prepayment architecture was designed for a big player and is detailed in [52]. Secure channels are managed between secure elements located in bearers' cards and merchants' terminals. This platform was successfully tested with a set of beta-test users, and is a step towards trusted computing for M2M networks.

In 2011, two new research contracts were won, OnDemand and Secfunet. Ondemand [86] is a French FEDER project addressing security for on demand virtual networks. SecFuNet [87] is a European and Brazilian FP6 project targeting Identity for virtual networks.

The EtherTrust spinoff created in 2007, won **the OSEO award** in fall 2009 [99]. It engaged three employees in 2010 (among them one CIFRE, linked to INFRES department), and two others in 2011. Main industrial achievements are prepayment system designed for a big player, and mobile identity model (SIMply Me!) developed in a partnership with Morpho company.

7.3.2 Infrastructureless Networking (–HL–)

This research activity is dedicated to the infrastructure-less networks and their specific needs. As infrastructure-less networks we understand vehicular networks or sensor networks. This networks are formed by independent nodes and often have to be self-organized, even though a portal connection to an infrastructure may be available in more specific scenarios. The self-organization in a changing environment spanned over simplistic nodes requires secure and robust yet rapid and simple mechanisms for routing, sensing, data plane organization and application APIs.

The contributions of this research activity can be expressed as follows:

- Routing optimization: regarding the routing in vehicular networks, we have proposed new routing mechanisms based on trajectories of nodes. Our trajectory-based routing shows good results compared to position-based routing, geographic protocols and opportunistic mechanisms [62][63][64][65]. This work has been conducted in the French national project ANR TRAFIC [96]. We currently work on the security of these routing mechanisms, notably in cases of cooperative mobility.

- Beyond this work, we studied a dedicated architecture for intelligent transportation systems (ITS). Our current proposal is a hybrid fixed/wireless/sensor/VANET architecture that supports group mobility management and end-to-end routing mechanisms so as to enable ITS services in an efficient manner [64][65] In a related effort, we proposed a global security architecture for hybrid ad hoc networks [22]

- We conceived an Adaptive Traffic Signal control system based on inter-vehicular communication (V2V). This system permits to diminish risks of traffic jams, limit crossroads waiting times and increase the fluidity of the transportation traffic [20][69][79]

- In the ongoing national project VELCRI [97], we currently conduct research on secure electrical vehicle charging. This will become part of an innovative, end-to-end security architecture, currently under development in cooperation with Renault.

- Regarding data sensing and retrieval in wireless and autonomic environments, we worked on the combination of data aggregation with routing, specifically in wireless sensor networks [66][67][68]

- In order to tackle a related problem of resource allocation in NEMO, we proposed an optimization of the resource reservation in these kinds of networks [70]. We conducted an analytical research of the intra-domain handover mechanism in multi-homed NEMO [21]

7.3.3 Quantum Information (–RA,ED,DM,IZ–)

A team of researchers of the NIS group is focusing its activity on different aspects of quantum information science, ranging from fundamental problems related to entanglement theory or theoretical aspects of quantum cryptographic protocols, to experimental work on quantum communications and practical quantum cryptography, with an important effort towards the development of quantum key distribution technology.

The team, composed of four permanent members (Romain Alléaume, Eleni Diamanti, Damian Markham, Isabelle Zaquine) is also actively participating in the scientific life of the community, through the organization of scientific workshops and conferences [113][112], including the conference series QuPa, which have gathered speakers and participants from research groups interested in quantum information in the Paris area [114]. Finally, the dynamism of our activity is also illustrated by an important number of collaborations, as well as the participation in scientific committees at a national and international level [111]

- **Quantum key distribution (QKD)**

Our team has a recognized expertise in the field of QKD, illustrated by several important publications [4][54][10][16], as well as a network of collaborators [92][90][89] that are key players in the European and international QKD community. These collaborations date back from the beginning of the FP6 European project SECOQC [2004-2008] and have fruitfully developed into new projects and research themes, ranging from the experimental development of continuous-variable QKD systems, to theoretical studies on QKD security models [7] or QKD networks [5][17], as well as a theme of growing importance: the practical security of QKD systems.

Practical security of QKD systems: side-channels, attacks, counter-measures

QKD is the first technology emerging from quantum information science that reaches a level of maturity that is sufficient to target industrial development and commercial applications. However, this transition is far from easy, as QKD has mainly been thought and developed as an exciting and stimulating playground for the development of quantum communication techniques, with a (too) distant eye on cryptography and security questions. The challenge for QKD, in order to become a recognized security technology is twofold.

- One has to better understand how QKD compares to other crypto technologies and this was the purpose of our review paper [4], studying how QKD could be used, in combination with other

cryptographic primitives, to achieve different security functions, while comparing it with classical cryptographic alternatives.

- More importantly, one has to study not only the theoretical security of QKD, but also the practical security of QKD implementations. As a matter of fact, while several QKD protocols are proven to be unconditionally secure, if the practical implementation differs from the ideal model used in the proof, this can open the door for effective attacks on the systems, as this has been demonstrated in the last years.

The ambition of the project Q-CERT [90], in which we collaborate with world leaders in QKD (University of Geneva and IdQuantique) is precisely to study, on our experimental platform [88] some family of vulnerabilities of QKD systems in order to develop counter-measures and thus move forward towards the security certification of QKD.

Continuous-Variable QKD (CVQKD)

The research on CVQKD has been initiated at the Institut d'Optique in collaboration with Thales Research and Technologies, teams with which we have a history of close collaborations and joint work [10][9][16]. The goal we are now pursuing is to study the material security of CVQKD, but also to improve the systems in order to reach higher performances. Following ideas developed earlier in the group and in collaboration with SeQureNet, the expected performance of the systems in terms of maximal key distribution distance, which was up to know strongly limited by the error correction efficiency, has been considerably increased, from 30 km to 150 km [12]

Valorization: intensive collaboration with a spin-off company

The start-up SeQureNet [100] was founded in 2008 and has considerably developed its activities during the period 2009-2011 following the recent recruitment of two full-time employees: Sébastien Kunz-Jacques, technical director, and Paul Jouguet, R&D engineer.

SeQureNet [100] develops and commercializes quantum cryptography systems, specializing in particular in the technology of continuous variable quantum key distribution. It exploits a patent held by CNRS/Thales, for which it has signed a licensing agreement, and is in the process of negotiating a licensing agreement for a second patent, held by CNRS/Institut Télécom. SeQureNet is in close collaboration with the quantum information research activities within NIS, in particular via joint participation in several projects: FP7 Q-CERT, ANR Frequency, and ANR Hipercom. SeQureNet is planning to produce in 2012 its first quantum cryptography product, which will be of interest to research laboratories.

Experimental platform [88]

An experimental platform "Sécurité Quantique" is currently under development with funding from Region Ile-de-France, Institut Télécom and CNRS. It serves the purpose of examining the practical security of quantum key distribution systems [90][89] and testing new quantum cryptographic protocols in two and multi-partite settings [92][94]

• **Quantum cryptography and entanglement**

There is great subtlety and great potential in the use of multipartite quantum states for information processing. Almost all of the known applications of quantum information to date either involve two parties (for example Quantum Key Distribution), or a large number of systems (quantum computing - currently well beyond the best technologies). In fact there is a wealth of unexplored variation in the behavior of quantum systems between these two extremes.

Our goal is to understand and exploit multipartite quantum states for information processing in a distributed network setting. There are two parts to this; one is to understand the great subtleties of the quantum mechanics of multiparty entangled states. The other part is to understand how we may apply this in a useful manner. Indeed these parts are often much intertwined and both necessitate and support the other.

We have studied how two broad classes of entangled states can be used for quantum information processing: graph states and symmetric states. Both these classes are at the forefront of experimental implementation, and we are working closely with the top experimental groups around the world to implement our findings. For graph states we have developed the theory of quantum secret sharing to a high degree [55][13][56], so that we are now working at how we

can both implement proof of principle experiments, and theoretically how these protocols can be integrated into more involved many party schemes (such as multiparty secure function evaluation [57]. For symmetric states we are still at an earlier stage of understanding what the key quantum features of use are. We have shown how these states exhibit a full range of entanglement features, with deep relationship to the symmetries involved [14][53][6]. We then went on to explore how this entanglement can be used to perform non-local tasks in the forms of extended Bell inequalities [61]. Currently we are working on both implementing first proof of principle experiments and also how these protocols can be understood deeper in an information theoretic sense, for example their ability to reduce communication complexity and their power as quantum games. Much of this work has contributed to the project [92]

As multipartite quantum states are of great importance in multiple applications in a network setting, a fundamental question is whether the users can trust the source that generates the states or whether they can efficiently verify that the right state is produced and distributed. We have studied this problem for the so-called GHZ states, and we have shown these can be efficiently verified in the adversarial model, even in the presence of multiple malicious players [59]

For all the above protocols, the role of entanglement is crucial. Exploring the exact role of entanglement in the performance of quantum computation and cryptographic protocols is in fact very interesting. Some tasks do not require entangled resources; we have developed for example a practical quantum coin flipping protocol with security guarantees strictly better than any classical protocol can achieve [15]. This protocol can be implemented with standard technology, using for example attenuated laser pulses, over up to 20 km of optical fiber and work is currently underway in our experimental platform [88] for the practical implementation of the proposed protocol in a two and multi-partite setting [94][92].

- **Entangled-photon sources and quantum repeaters**

The quantum repeater is one of the major challenges towards long distance quantum communications.
It requires entangled photon pairs and the possibility of storage of the photonic qubits in a quantum memory. Our goal is to build a source of entangled photon pairs based on spontaneous parametric down conversion (SPDC) that is suitable for long distance propagation in telecom optical fibers and also compatible with the quantum memory. This objective is pursued in collaboration with experimental groups in Nice and Orsay [93]. In order for the quality of entanglement to be conserved, in spite of the necessary filtering, fiber coupling and various causes of losses, the design of the source must be optimized. We have calculated the respective weights of these various possible contributions to source quality degradation, and shown how to find the best compromise, providing a "users guide" to the design of narrowband pulsed SPDC sources [18]. We have also shown a simple way to evaluate the quality of entanglement that can be obtained with a given source, using very simple measurements [19]. We are also investigating the possibility of multi-user distribution of entangled photon pairs, with only one source. Using commercial telecom DWDM filters, we can take advantage of the natural wide band of SPDC sources, to improve the photon rate and prepare the way to cheap quantum communication networks.

7.3.4 Security management, operational security evaluation, resilience of open infrastructures (–AH–)

This research activity is dedicated to a vision of a *rational and quantifiable security*, i.e. to reasoning about the conformity, cohesion, quality and efficiency of the security mechanisms deployed in an operational networked IT environment. The goal is to provide network and security administrators with a set of tools for a better handling of security mechanisms of their systems. We believe that current tools are rather inadequate and often very specific; they do not permit security management at the system level. Instead, system administrators have to tinker with specialized tools for device-level configurations to achieve system-wide results at the service level. Given the inextricability of the existing real-life IT installations, we currently advocate an empirical approach

to this problem, as opposed to the "security by design" approach based on a formal transformation process. Contrary to formal methods, usable for new designs, we would like to render more resilient the existing, deployed systems. In IT security, a lack of knowledge of the local administration with regard to the security posture of the managed system is well-established. The main idea is therefore to render the existing security *resiliently manageable* and, through this provision, to ultimately render the overall system more resilient, in spite of the undeniable presence of faults and attacks in modern networked IT systems.

It is difficult to evaluate conformity in an operational, distributed environment. Even more difficult is the evaluation of cohesion (i.e. the mutual non-disturbance) and of the efficiency of the deployed security mechanisms. Testing, pentesting, fuzzing and other approaches need to be used from different topological points without disturbing the control traffic required to launch the tests and to gather results. We studied and elucidated the related problems in the European research project Celtic Bugyo Beyond [83], which the team has successfully finished in October 2011, and through publications on the distributing monitoring and evaluation framework. We studied the fundamental problems related in our early work [45]. They can be roughly subdivided in "how to measure resiliently" i.e. in spite of faults, reconfigurations and attacks, and "how to make sense of the gathered data", i.e. how to evaluate such data. More specifically:

- The first part of the problem has been extensively studied: we have formulated functional requirements and a layered model for an operational measurement framework in this context [1][43]. One of the crucial requirements on such frameworks is resiliency with respect to node and path failures of all kinds. To address these issues, we have developed a dedicated P2P-based overlay for simple, server-less, resilient communications [1]

- The latter problem is mainly related to the information model. For security to make sense, such models require profound understanding of both the objectives and the realizations. Since both vary a lot, this does not have an easy solution. We proposed a viable midway through the use of patterns called Assurance Profiles [39]. This approach has found a strong echo within the standardization community: ETSI TISPAN WG7 *is about to standardize* the format of the proposed profile as TR 187 023 [81]

- To fulfill partly contradictory requirements on P2P structures in this context (resiliency, efficiency, furtiveness), S. Ktari (who defended her PhD on this subject under the supervision of A. Hecker and H. Labiod) has developed a rewiring method for current overlays [109]. With slight changes, the proposal [2] can provide a generalized P2P overlay, capable of dynamically adjusting its structure (from equally distributed over decentralized, hub-based to fully centralized) to the perceived criticality level. Implementations of the proposed PowerDHT approach are based on our previous work in [44][46][47]. Interestingly, in our approach, the topologically important elements emerge from the structure, and do not need to be chosen in advance.

- To study incident propagation effects and impacts on the behavior of our proposals, we have designed and implemented a network virtualization tool, VIRCONEL [3][40], capable of deploying real software (OS, servers, clients, etc.) in a given network topology; it also enables us to alter any link, any node and any defined service element as of a scenario definition. This permits us to evaluate different IT service realizations under attacks and fault scenarios. VIRCONEL is available an open-source software [80]

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PhD Thesis

1. Thomas Guillet, "Sécurité de la téléphonie sur IP". Thèse Informatique et Réseaux, INFRES, Télécom ParisTech, October 2010.

2. R. Saad " A Service Provider oriented Peer to Peer architecture ". Thèse Informatique et Réseaux, INFRES, Télécom ParisTech [ENST], September 17, 2010.

3. M. Fayçal, " Optimisation du trafic P2P sur les réseaux d'opérateurs ". Thèse Informatique et Réseaux, Télécom ParisTech, May 28, 2010.

4. Salma Ktari, "Interconnexion et routage dans les systèmes pair à pair". Thèse Informatique et réseaux, Télécom ParisTech, December 14, 2009

5. Nitin Maslekar, "Adaptive Traffic Signals Control System Based on Inter-Vehicular Communication", December 2, 2011 (*ce n'est pas une these de l'école*).

Outstanding events, organized workshops, conferences

1. Steering committee of the GdR "Information Quantique: Fondements et Applications", program committee for the international conferences: DCM 2010, DCM 2011, CLEO Europe/EQEC 2011, QCRYPT 2011

2. High Performance Coherent Quantum Communications (HIPERCOM) kick-off meeting and Continuous-Variable Quantum Information Processing (CV-QIP'11) workshop, Télécom ParisTech, Paris, September 2011

3. Workshop on Post-Quantum Security Models (PQSM), Télécom ParisTech, Paris, October 2010

4. Quantum Information in Paris (QuPa) workshop series (8 so far), Institut Henri Poincaré and Télécom ParisTech, Paris, May 2009-present

5. Organization of 4th IFIP NTMS (New Technologies Mobility and Security), Paris, February 2011, 4th edition (success: 335 submitted, 104 accepted, acceptance ratio=31%)

Chapter 8

Networks, Mobility & Services (NMS)

[NMS]

Team leader Maurice Gagnaire (P).

Faculty Thomas Bonald (MC), Nadia Boukhatem (MC), Claude Chaudet (MC), Marceau Coupe-choux (MC), Philippe Godlewski (P), Daniel Kofman (P), Philippe Martins (MC), Dario Rossi (MC), Jean-Louis Rougier (MC), Noëmie Simoni (P).

Faculty [IT, CNRS]	[11, 0]
PhD students	30.4
Post-docs, engineers and sabbaticals	16
Defended PhD theses	???
Defended HDR	3
Journal papers	33
Papers in conference proceedings	84
Chapters and books	6
Patents and software	2
Grants [public, private, european] (k€)	[1229, 831, 1103]

8.1   Scientific Environment, Positioning and Objectives

Services have evolved very quickly during the last years. In particular, we have assisted to a fast development of virtualization and the outsourcing of services 'in the cloud'. In this new environment, the global service that are offered to customer need to be composed from unitary services involving a whole chain of stakeholders (Content provider, Software providers, Data Center provider, Network providers etc.) — a composition that has been extensively studied in our team. Market-oriented parameters inherent to the multi-tenant environment of Cloud have a close interaction with the resource allocation procedure. For confidentiality purposes, network operators do not provide the Cloud Service Provider (CSP) a real view of their infrastructure. We

have evaluated these two aspects of Cloud computing Finally, the legacy fixed client/server model is no longer valid in this new environment and more flexible service and network architectures (like overlay networks) need to be designed. The activities of the group related to cloud, service architectures and service applications are summarized in section 8.2.1 below.

At the same time, the fast development of mobile applications (in particular with the advent of sophisticated smart-phones) has led to the saturation of wireless access networks. The demand for capacity is particularly challenging and new access methods and radio network architectures had to be designed. Our group has a strong expertise in the modeling and dimensioning of wireless network and has thus contributed to these network evolutions from this point of view. As frequency bands are limited by nature, the concept of cognitive radio has also arisen as a means to better use these scarce radio resources. We have made several contributions in this area. Finally, the services need to be ubiquitous in heterogenous network environments (3G, 3.5G, 4G, Wimax, Wifi, ...). In particular, the handover and simultaneous access management in this heterogeneous network environment has been deeply investigated. All these contributions related to wireless networks and mobility are outlined in section 8.2.2.

With its extraordinary success and growth, the Internet is confronted with difficult scalability and limitation issues. In particular, the Internet needs to be rethought with the advent of the so-called 'Internet of things', where an extremely large number of objects, in particular sensors, are expected to be connected to the Internet. Furthermore, the TCP/IP stack is not adapted to such 'things' with very limited resources and need to be adapted. Our group has started to investigate these issues and to propose solutions. Furthermore, carriers seem to have difficulties in offering advanced added-value services on top of the global Internet. One of the reasons is that the current Internet business model offers little incentives for ISPs to collaborate in order to offer end-to-end services. On a technical point of view, one of the main issues is related to Internet routing architecture (based on BGP) where end points are offered a single, best effort route. It is acknowledged that the addition of multi-path capabilities would bring more robustness and traffic engineering features. We have several contributions in this area (towards a multi-path internet) at both the routing and transport layers. Once offered, the route diversity can be exploited using multi-path transport protocols and Dynamic load balancing (DLB) mechanisms, that were also studied extensively. Finally, there is a growing need in IP networks for 'on the fly' flow identification in order to dynamically allocate resources in the network (in particular for value-added services). All these contributions are presented in section 8.2.3.

Ever increasing Internet traffic demand challenges the use of electronic switching in today's networks. The routing bottleneck can be alleviated by means of transparent optical switching, which enables payload to be carried exclusively in the optical domain. The activities of the team on optical networks are focused on failure monitoring, quality of transmission-aware routing, wavelength assignment and Optical Burst Switching — they are briefly presented in section 8.2.4.

Finally, The NMS group has a transversal activity concentrated on energy efficiency (also nicknamed as 'green networking' activity), on both IP, cellular/wireless and optical networks. Our main results are summarized in section 8.2.5.

The team is greatly involved in national and international collaborative research projects (financed by the FP7, the ANR and national competitiveness clusters). Our group was the initiator of the PF7's European Network of Excellence Euro-NF and has chaired this NoE's Steering Committee (in particular responsible for coordination of all research activities) since it was created.

Moreover, by way of an example, during this period the team participated in several European projects (FP7 BONES, DICONET, EuroNF, ETICS, NapaWine, TIGER2, TRANS) and in the ANR (3MING, DIAFORUS, ECOFRAME, SUN, TEROPP, UBIS) among others. The team is actively involved in the System@tic (trust platform) and CapDigital (wireless high-speed Internet) competitiveness clusters.It is also involved in numerous bilateral research contracts with industrials, and particularly with Orange, SFR, Alcatel-Lucent and Thales.

The NMS group also maintains close links (joint works, double Ph.D. program, co-advisorship, sabbaticals and visits) with various international laboratories, including UCLA (USA), University of Waterloo (Canada), UPC (Barcelona, Spain), Politechnico of Turino and Politechnico of Milano (Italy), Université Catholique de Louvain and University of Ghent (Belgium), NCRL (National

Mobile Communications Research Laboratory, Nanjing , China), NTU (Singapore).

The team is also one of the cofounder of the LINCS laboratory (Laboratory of Information, Network and Communication Sciences), a common lab with ALBLF (Alcatel-Lucent Bell Labs France), INRIA and UPMC (LIP6).

The members of our group are deeply involved in the ANR's VERSO program, as technical experts or chairman of the expert committee. Moreover, the team regularly responds to requests for expertise from various French and European institutions.

8.2 Main Results

8.2.1 Cloud and Services Architecture, Applications Services

Faculty Maurice Gagnaire, Dario Rossi, Noëmie Simoni.

Projects FP7 NAPAWINE; ANR UBIS; Systematic CompatibleOne, CARIOCAS, TIOSAFE; CapDigital Sebastian 2.

Service Architectures.   Integration of new usages in the field of mobility and ubiquity has led to the redefinition of the means of how content should be delivered. In this concept, our work have concentrated on the design and engineering of service-oriented architectures that allows to offer a seamless continuity of services.

Our main outcome is the definition of an 'autonomous service', insuring a 'user centric' approach and that represents an excellent candidate for the 'Cloud' architectures. More precisely, our system is designed as a self-managed composition of services (application, network, hardware and presentation services) in order to meet the expectations of users that evolve in a mobile environment (encompassing the mobility of users, terminal, networks and services). Our approach is also based on QoS models for the management of end-to-end services, insuring a continuity of services with maximal transparency. The personalization of the user workflow (which is now in the heart of the mechanism) leads to a cross-organizational context where session mobility must be handled.

In the context of the ANR UBIS project, we have proposed a new cross-organizational structure of personalized services, based on dynamic service composition under QoS constraints in a generalized mobility context [**? ? ? ? ? ? ? ? ? ? ? ? ? ? ?**]. Self-management is introduced through the management of the interest communities and through QoS management at the level of each service component. The global organization relies on an ubiquitous and mutualized service composition. The main originality of our approach is to move away from the legacy client-server model, by proposing to implement a user centric service logic (workflow) in a single mobile session based on mutualization of service components. We have proposed in particular the SIP+ protocol that allows for integration of application services. Our results led us to propose our expertise for the FNS CloudForce project that has been accepted (2012-2015).

Cloud Computing.   Two aspects of Cloud Computing are strongly related: market-oriented constraints and computing/storage/networking resources allocation [**?**]. In this matter, we have considered a discrete time approach for dynamic resource allocation under flexible scheduled traffic in the context of layer-2 virtual privates networks (VPN). Our objective was to exploit the end-users time requirements in order to provide a fair management of the various resources while in considering the economical constraints of the CSP. For that purpose, we have introduced a weighted cost function enabling a service differentiation relying on time constraints disparities between customers' requests. This cost function has been itself introduced in an ILP formulation considering the various constraints and objectives of the problem [**?**], [**?**], [**?**]. In the context of the Sebastian2- research project, we have considered the same type of problem applied to an original application: the collaborative production of digital high definition movies via a private

Cloud. For that purpose, we have introduced two additional innovative services: multicast stream data transfers and distributed storage [**?**]. In the context of the Compatible-1 research project, we proposed extensions to bin packing strategies enabling to take into account the dynamicity of computing, storage and networking resources consumption. In accordance with one of our industrial partners in this project, we have assumed that each job could be characterized statistically by a specific resource consumption profile. We have exploited such traffic profiles to define a quadratic distance enabling to optimize the fit of each job (each Virtual Machine) onto a physical machine [**?**], [**?**]. We have also worked in the context of the BONE Network of Excellence with the team of Prof. Dimitra Simoneidou (Essex University) on the impact of the level of abstraction of the network resources onto the efficiency of the resource allocation problem.

Peer-to-peer (P2P) Applications. Recently, BitTorrent has changed its file transfer algorithm, such that most of BitTorrent traffic is now transported by LEDBAT (on top of UDP) and no longer TCP. Our recent works concentrated on this congestion control dedicated for low priority traffic defined within the LDBAT IETF working group. In particular we have identified a weakness ('latecomer unfairness', where the latest flow can monopolize network ressources) in the original algorithm [**?**], and proposed some solutions to overcome this problem [**?**]. These solutions have contributed to the evolutions of the LEDBAT protocol (and are cited in the IETF document). We have also compared LEDBAT with similar proposals (e.g., TCP-LP, NICE) [**?**] and studied the performance of the implementation of this protocol made by BitTorrent [**?**]. Finally, we studied the impact of LEDBAT on the bitTorrent system, in particular regarding the download completion time (the main performance metric in this system). These on-going works [**?**] have allowed to discover some possible solutions to further reduce the downloading times (that shall be explored in the future).

With the increase of P2P traffic in the 2000s, it has become very important to better understand the nature of P2P traffic and its impact on networks. We have contributed to this issue with the design and development of the Sherlock software [**? ?**]. The recent explosion of video traffic has led us to particularly focus on P2P-TV applications. We have studied the topological awareness[1] of the most widely used P2P-TV applications [**?**] and their impact on the Internet [**?**].

8.2.2 Wireless Networks and Mobility

Faculty Thomas Bonald, Nadia Boukhatem, Marceau Coupechoux, Philippe Godlewski, Philippe Martins.

Projects ANR 3MING, TEROPP; SYSTEMATIC URC,NimbleNet; External research contracts with Orange Labs and Cassidian.

Cellular Network Dimensioning. We are working with Orange Labs with the aim of deriving easy-to-use outage probability formulas in multi-cellular networks. These formulas are taking into account path-loss, shadowing and fast fading [**?**], assume Alamouti MIMO transmission [**? ?**], Zero-Forcing Beamforming [**?**], or best server policy [**?**]. They have been efficiently used to evaluate the capacity or coverage loss when base-station transmit power is reduced in so called green cellular networks [**?**]. There are all based on a fluid model developed at Orange Labs [**?**]. We also had a special attention to OFDMA networks (WiMAX, LTE, LTE-Advanced). For example, dimensioning rules with multi-profile traffic have been proposed in [**?**]. Frequency reuse schemes are analyzed in [**? ?**]. LTE uplink control is optimized in [**?**]. As relay based cellular networks will be part of future systems (IEEE 802.16j and LTE-Advanced), we have started performance evaluations assuming the presence of relay nodes in [**?**] in collaboration with NTU (Singapore).

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[1]By topology awareness, we mean the potential capability of an application to consider in priority peers that are close geographically or within the same Autonomous System, which would reduce ISP transit costs.

In the context of a joint work with S.E. Elayoubi, A. El Falou, J.B. Landre (Orange Labs), we study the radio capacity improvement provided by an HSPA+ key feature, dual-cell, combined with MIMO [**?**]. The proposed method combines drive test measurements, link-level simulations, and a queuing theory- based statistical capacity model, thereby providing a reliable estimate of the network radio capacity. Simulation results show that dual cell combined with MIMO and non-linear receivers using Successive Interference Cancellation (SIC) significantly increases network radio capacity. These results confirm that HSPA networks evolutions are promising.

Spatial models for wireless networks. Algebraic topology is a branch of topology that tries to classify topological spaces according to the number and to the features of their areas of discontinuity (commonly referred as "holes"). That methods have recently arise significant interest in the community of wireless and mobile communications. Our contributions lay in the design of decentralized algorithms that do not require location information on sensor nodes. The results obtained have been in published in [**? ?**] and submitted [**?**]. This is a joint work with L.Deucreusefond from the MIC2 team of Telecom ParisTech.

Stochastic geometry and Point Process theories can be used to design capacity and to obtain dimensioning models for mobile communications networks. Our contributions in that area are twofold. On the first hand, new dimensioning methods have been proposed for OFDMA networks. Concentration inequalities have been applied to obtain an analytical upper bound of the loss probability in terms of resources blocks or sub-channels. The upper bound is less accurate than classical approximation methods such as Gaussian or Edgeworth expansions. However it is more robust to systems parameters inaccuracy [**?**]. Other works, carried out in cooperation with NCRL (National Mobile Communications Research Laboratory, Nanjing , China), have proposed average transmission capacity and upper bound transmission capacity expressions, for cognitive radio systems in a primary/secondary network scenario [**? ?**].

Dynamic Spectrum Management and Cognitive Radio. We have studied inter-operator spectrum sharing schemes within the URC project [**?**]. In [**? ?**], we have proposed optimal, Q-learning based and heuristics algorithms for the dynamic spectrum allocation problem that take benefit from the time heterogeneities of the traffic. Spatial heterogeneities have been then taken into account in [**? ?**]. In the ANR project TEROPP, we have studied distributed radio resource allocation schemes for cognitive radio networks in collaboration with LRI - University of Paris XI Orsay [**?**]. We have first proposed an auction mechanism [**? ?**]. We have then proposed and analyzed an algorithm that both solves the Multi-Armed Bandit problem and controls the switching cost of secondary users [**?**]. We are now working on large populations scenarios [**? ?**].

Random access schemes. In conjunction with M.Feuillet (INRIA), we analyze the performance of CSMA in multi-channel wireless networks, accounting for the random nature of traffic [**?**]. Specifically, we assess the ability of CSMA to fully utilize the radio resources and in turn to stabilize the network in a dynamic setting with flow arrivals and departures. We prove that CSMA is optimal in ad-hoc mode but not in infrastructure mode, when all data flows originate from or are destined to some access points, due to the inherent bias of CSMA against downlink traffic. We propose a slight modification of CSMA, that we refer to as flow-aware CSMA, which corrects this bias and makes the algorithm optimal in all cases.

We also worked on wireless mesh networks with UMPC/LIP6, where we designed OFDMA based MAC protocols [**?**].

Handover management in heterogeneous and simultaneous access. We have developed expertise in the field of mobility and handover management in heterogeneous and simultaneous mobile access. Studies on dynamic interface selection, considering various attributes such as network characteristics, applications requirements, and user preferences, were carried out [**?**]. A prototype (a linux based mobile terminal with Wi-Fi and 3G) has been developed with

the collaboration of Bell Labs France for performance evaluation and validation. The prototype implements the IEEE 802.21 standard to discover network parameters.

Layer-2 handover solutions have also been investigated. The developed solutions take advantage of multi-homing to enable soft handover and make-before-break handover in the integrated and tight coupling architectures of WiMAX and UMTS. The solutions aim at achieving lossless and short latency handover procedures [**? ? ?**].

While the integration of heterogeneous radio access is seen by the network operators as a solution for providing their customers with a large variety of services with a seamless access, the simultaneous access provides many interesting benefits enabling traffic to be distributed over the available networks taking into account the application requirements and/or network congestion situations.

The problem of distributing simultaneously multiple applications to the suitable network interfaces while maximizing terminal global utility is first addressed. Stochastic heuristic optimization methods are studied and a novel diversification technique of the Tabu search has been proposed [**?**]. We have also investigated the flow/interface association strategies using evolutionary game theory [**?**]. In the game, the terminals compete for common network resources and seek for maximizing their utility by associating the application flows to the radio interfaces. The network orients the association choices of the terminals while seeking for optimizing the system global utility.

8.2.3 Future Internet, Internet of Things

Faculty Thomas Bonald, Claude Chaudet, Nadia Boukhatem, Daniel Kofman (?), Jean-Louis Rougier.

Main events Organization of EuroNGI 2010.

Projects CELTIC TRANS; FP7 EuroNF, ETICS; ANR DIAFORUS, 3MING, SUN; External research contract with Orange Labs; I-GATE (Institut Telecom/ Futures et Ruptures).

Wireless Sensor Networks / Internet of Things. Our objective is to create distributed algorithms that are lightweight alternatives to the functions of a classical network. Solutions shall be efficient in terms of energy, complexity and memory usage to be embarked on low-cost, low-power and low-capacity nodes. Our contributions are on the topics if network self-organization, localization and on experimental platforms.

We participate in the DIAFORUS project in the conception of a middleware for wireless sensor networks, designing an efficient publish/subscribe-based communication brick that relies on an overlay of brokers. We compared various criteria to build this overlay in order to optimize energy efficiency, memory space and raw performance [**? ?**]. We are currently working on a distributed algorithm that builds and maintains such an overlay.

We also work in the smart home environment to provide accurate indoor localization techniques for wireless terminals without adding dedicated hardware. We show that in an indoor environment, the signals captured by the radio interface cannot be correlated with distance without calibration of the environment and of the node and constant update of this calibration parameters. Localization algorithms using RF signals for trilateration are bound to be imprecise unless a strong collaboration exists between a large number of nodes. We are currently looking at alternative, using RF signals to deduce relative positions rather than absolute distance measures. Within the SUN ANR project, we investigated location management systems and developed an IP-based RFID architecture for indoor location management [**? ?**].

We have started in 2011 to build a federated platform that aims at becoming a reference for mobile sensor networks. The platform will be composed of fixed and mobile sensors and will focus on the interactions between the environment (composed of LEDs and sound generators) and the sensors. At the first stage, Telecom ParisTech is conceiving a scenario description language that aims at being simple, descriptive and provable in order to automate experiments.

Towards a multi-path Internet   Routing diversity has been identified as essential for both network robustness and traffic engineering. The Internet possesses by its very nature a large path diversity. However this diversity cannot be fully exploited due to several architecture limitations, in particular at the level of routing protocols (namely BGP) and transport layers. Our contributions covers both the routing and transport aspects.

On routing aspects, our work first concentrated on possible collaboration schemes between providers. Today, each carrier uses selfish routing policy (e.g. preference of a free peering link over a transit link) in order to choose the route used to transit traffic. If it is quite natural for 'best effort' traffic, this approach clearly limits the range of potential inter-domain services that can be offered in the Internet. We have formulated a simple but realistic non-cooperative routing framework that arises between two ISPs on their peering links. Our approach allow to select pareto-efficient routes, which allows to greatly reduce congestion and improve route stability. At the same time, our approach is based on non-collaborative game theory, thus protecting operators' independence and incentives [? ?]. We proposed an multi-path extension of this approach which further improve performances [? ?]. This is a joint work with Prof. A.Patavina (Politechnic of Milano, Italy) funded by ANR ACTRICE and IGATE projects. The proposed approach was also enhanced to offer a high resiliency against network failures [? ?], in collaboration with H.Ma and Prof. B.E.Helvik (NTNU, Norway).

We also studied a higher level of collaboration between carriers within a alliance of carriers. In this context, a routing architecture for end-to-end MPLS services was proposed [?] where disjoint routes are computed for resiliency purposes. We also studied how the distributions of incomes within this context of an alliance can be naturally linked to network dimensioning [?].

In the context of the european ETICS project, we are currently studying solutions based on a *maps-and-encaps* scheme to by-pass current BGP limitations in order to use arbitrary paths and thus utilize the inherent Internet path diversity.

Exploiting path diversity   We also focused on multi-path transport layer solutions able to utilize route diversity. We developed a forward predictive scheduling mechanism which alleviates the out-of-order data reception problem. It estimates the delays incurred to data on each path, and then schedules the transmission of a data packet such that the re-ordering cost is minimized [? ?].

The scheduling scheme has been integrated to both SCTP and MPTCP (multi-path TCP) implementations. A prototype was developed with the collaboration of BearsTech Enterprise within the 3MING project[?]. In collaboration with UPMC/LIP6, a cross-layer extension of the scheduling algorithm has been proposed. It contributes to accurate path delay calculations using layer-2 information for 802.11 wireless links [?].

Dynamic load balancing (DLB) also represents a powerful traffic engineer tool as it leads opportunistically to an optimal network utilization without any prior knowledge of traffic (e.g. like traffic matrices). Most existing DLB mechanisms are however based on simple unrealistic cost functions (such as M/M/1 delay formulae). We proposed instead new load balancing schemes based on cost functions measured through non-parametric regression [? ?]. Thanks to modern learning heuristics and proposed enhancements, we also proved that our DLB mechanism is very robust w.r.t. abrupt traffic variations. Finally, our proposal is compared on realistic network topologies with robust routing (the most common alternative TE mechanism) [? ? ?].

We obtained approximations for various performance measures in a multi-rate link sharing bandwidth under an insensitive sharing mechanism called balanced fairness [?]. Balanced fairness can be viewed as the large system limit of proportional fairness. For a large system, we obtain closed form expressions for the calculation of long run fraction of time that the system is congested, the probability that an arriving flow will not obtain its maximum bit rate and the average fraction of time that an arriving flow is not allocated its maximum bit rate while in the system. The techniques are based on local limit theorems for convolution measures. This is a joint work with J-P. Haddad and R. Mazumdar (U. Waterloo, Canada)

Classification of Internet Traffic There is a growing need in IP networks for 'on the fly' flow identification in order to dynamically allocate resources in the network. This is important to insure a certain quality of expectation to critical flows, for instance. Our method is based on both knowledge of the network, P2P systems and on learning theory (like Pearson's statistical Chisquare test, bayesian inference or support vector machines). Our contributions are twofold:

The first approach relies on similarities with verbal communications, with a new class of methods called 'Stochastic Packet Inspection' (SPI), which ca be seen as a statistical extension of the well-know DPI. SPI starts with a keyword search in traffic (e.g. like 'GET' for Web traffic or 'BT' for BitTorrent) like in DPI, and uses statistical tools to automatically define stochastic signatures [**?**]. First designed for UDP traffic, this method was extended for TCP traffic [**?**].

Our second approach analyses the behavior of applications solely on traffic characteristics, regardless of the content of packets. The similarity with human interactions is here particularly relevant: e.g. a 'shy' application prefers long communications with a limited number of hosts while 'hearty' applications rather prefers short exchanges with many hosts. This analysis technic, named Abacus [**?**], as it only keeps track on the number of packets exchanged, is particularly appreciated by network operators as it can directly be applied to Netflow [**?**] and robust to sampling [**?**].

A software implementing both technics has been provided to the scientific community [**?**]. It allowed to compare both technics [**?**]. These technics are now used for the observation and classification of network traffic in several european Internet Service Providers (ISP) [**? ?**].

With the constant increase of traffic volumes, ISPs are required to use sampling for monitoring traffic. We have thus studied the impact of sampling on the monitoring of different variables [**?**] and on performances of traffic classification [**?**].

8.2.4 Core Networks

Faculty Thomas Bonald, Maurice Gagnaire.

Projects FP7 DICONET, BONES; ANR ECOFRAME; FIMOBA (Institut Telecom/Futurs et Ruptures).

Transparent WDM network design. A translucent WDM optical network can be viewed as a transparent optical network in which sparse nodes proceed to electrical regeneration either form traffic grooming or quality of transmission (QoT) purposes. Considering mesh topologies with finite optical channels capacity per fiber and static traffic matrices, we have investigated the most efficient way to proceed to electrical regeneration in order to guarantee an admissible Bit Error Rate (BER) at the end of each established lightpath [**?**]. Four transmission impairments (namely: amplified spontaneous emission, chromatic dispersion, polarization mode dispersion, and nonlinear phase shift) have been considered in our studies. Electrical regenerators are costly and power consuming. The originality of our approach consists in trying to minimize simultaneously the total number of regenerators while minimizing the number of regeneration sites [**?**]. We have shown how these two parameters have a strong impact on the cost of investment and operation and maintenance of the network. In a first step, we have proposed an original heuristic called COR2P (Cross Optimization for RWA and Regenerator Placement) achieving this double objective [**?**], [**?**] . We have then extended this optimization problem in considering the time-space correlation of the traffic demands. Our objective was to optimize regenerators' utilization [**?**]. We have outlined the fact that, whatever the traffic matrix, the nodes with the highest physical degree are good candidates to be regeneration sites [**?**]. We have proposed an original exact ILP formulation of this problem. In contrast with existing exact approaches that rely on linear approximations of the signal degradation, we have made use of a realistic estimate of the optical signal quality taking into account the simultaneous effect of the four impairments mentioned above. We have also investigated a tradeoff between optimized network costs on one hand, and flexibility against traffic uncertainty on the other hand. To this end, we have extended our ILP formulation to

multiple traffic forecasts. Our concern is to judiciously deploy regenerators so that network design remains optimized under different traffic forecasts [**?**], [**?**], [**?**]. These works have been carried out either in the context of the DICONET European project [**?**] or within the BONE European Network of Excellence. In collaboration with the Univ. of Barcelona (UPC), we have contributed to the hardware implementation of the COR2P control plane in FPGA. An experimental testbed has outlined the efficiency of the COR2P algorithm.

Fault management and traffic engineering in transparent WDM networks. Two techniques have been recently proposed in the literature for single failure detection in translucent WDM networks: monitoring cycles (m-cycles) and monitoring trails (m-trails). We have proposed an original meta-heuristic called MeMoTA (Meta-heuristic for Monitoring Trail Assignment) enabling to determine the number of m-trails and their routes that is able to deal with very large networks and under dense traffic matrices [**? ? ?**]. Our algorithm is inspired from the Tabu Search meta-heuristic. It has been accepted as a European patent [**?**]. The main drawback of the m-trail approach is its inherent cost in number of required out-of-band optical channels. We have developed the concept of "monitoring-tree" that considerably increases network capacity while enabling a non-ambiguous single failure localization. The concept of m-tree has been the subject of a European patent [**?**]. An ILP formulation has been proposed to determine the most efficient tree to be mapped onto any meshed network topology. In parallel, we have investigated dynamic lightpath rerouting strategies that can be used after a fiber cut. The same strategies can also be used in order to provide a better usage of the network resources while the network is active [**?**]. The originality of this study consists in considering simultaneously three types of traffic: permanent, scheduled and random.

Optical burst switching. We analyze different network architectures based on optical burst switching for metro networks [**? ? ?**]. In particular, we propose a novel MAC protocol for a ring slotted WDM network. The protocol is based on both opportunistic access ensuring efficient utilization of slots and dynamic reservations that maintain a certain degree of fairness between stations. We show that, while a purely opportunistic access scheme is perfectly efficient, the impact of introducing the proposed reservation algorithm is limited in terms of lost capacity in any realistic traffic scenario. This is a joint work with R-M. Indre, S. Oueslati and C. Rolland (Orange Labs).

Radio over Fiber We have worked on the specification of an innovative all-optical WDM access infrastructure that could be used as a Next-Generation Radio Access Network (RAN). This infrastructure relies on traditional Passive Optical Networks considered today to connect fixed broadband users to the Internet. Thanks to reflective modulators, optical add-drop multiplexers and a low-cost AWG optical router, we exploit the potentialities of analog Radio-over-Fiber to distribute in parallel to fixed traffic, radio carrier frequencies(RF) to a set of antennas connected to the leaves of the optical tree. Optical sub-carrier modulation is considered to transport RFs from the Central Office to the antennas' sites. The main originality of our works consists in designing an ad hoc control plane enabling to redistribute radio equipment between different geographical areas according to their traffic load fluctuations. This control plane operates in a cross-layer mode since the physical layer constraints must be considered imperatively, both in the optical and in the radio domains [**?**].

8.2.5   Green Networking

Faculty Claude Chaudet, Marceau Coupechoux, Maurice Gagnaire, Philippe Godlewski, Dario Rossi, Jean-Louis Rougier.

Projects CELTIC TIGER2; FP7 DICONET, BONES; external collaboration with Orange Labs.

Minimum Energy Routing in IP Networks. We have studied green networking technologies and issues focusing on fixed networks [**?**]. One of the main issue we encountered was the lack of reliable figures on energy consumption and the lack of standard measurement methods and evaluation metrics. In particular we pointed out the incongruence of several results published and made several proposals in order to overcome these issues [**? ? ? ?**].

We then concentrated on the 'resource consolidation' approach, which consists in concentrating traffic on a subset of nodes/interfaces when utilization is low, thereby allowing to put other equipments in sleeping (low power) modes or simply to switch them off. We formulated the problem of minimum energy routing [**?**] and derived results with realistic energy models and network topologies. Results showed that potential energy savings strongly depend on the type of network studied, ranging from very low (in particular for core IP networks) [**?**] to significant (e.g. in redundant access networks). We then concentrated on the tradeoff between energy savings and network resiliency. We have proposed a new method for computing the importance of nodes/links in a network, which is based on a collaborative game theory approach (namely on the Shapley value). This ranking is used to decide which nodes/links should be switched off [**?**]. Results highlighted better network resilience properties with similar energy gains.

Our previous solutions to the 'resource consolidation' problem were centralized. We have then started to investigate distributed green routing mechanisms ('à la' OSPF) [**?**], which result easier to be deployed when considering current and foreseen network devices.

Power aware routing in optical networks In current WDM networks, transceivers are powered-on permanently, whatever the activity of the data sources at the electrical layer. Our objective is to minimize network's power consumption in considering the transceivers with fixed data rates actually deployed in carriers' networks. In this context, we have proposed an optimal mapping of a set of scheduled traffic demands at the electrical layer onto an optical mesh infrastructure. The number of optical channels per optical fiber being upper-bounded, this mapping also enables to minimize connection rejection. This optimization problem has been solved by means of an ILP formulation [**?**].

Green cellular Networks. In the field of green cellular networking, we have started a study with Orange Labs with the aim of evaluating the impact of power reduction on the coverage and the capacity of cellular networks [**?**]. Power reduction is directly beneficial on energy consumption, potential risks for health and on interference mitigation, which stimulates the deployment of opportunistic radios in the same spectrum. Power control is however likely to degrade network performances. We have established closed form formulas of outage probability by taking into account shadowing, thermal noise and base stations (BS) transmitting power impacts. We have shown that transmit power can be significantly reduced without affecting the quality of service and that increasing the BS density results in a reduction of the global power density in the network.

8.3 References

8.3.1 ACL: Articles in ISI-Indexed Journals

8.3.2 ACTI: Articles in Proceedings of International Conferences

8.3.3 OS: Books and Book Chapters

8.3.4 AP: Other Productions: Reports, Registered Software, Registered Patent, . . .

Part III

Economics and Social Sciences

Social and Economic Sciences (SES)

The department of economic and social sciences (which composes one single "team" for the purposes of this evaluation document) is an interdisciplinary department for teaching and research, At the 1st of November 2011, it is composed of 29 permanent members in teaching and/or research positions (among which 4 researchers from CNRS and 1 from INRIA), 8 associate researchers, 28 ongoing Ph.D projects, 19 non permanent members and post-doc (among which four visiting professors from abroad for various durations), and 3 persons employed in administrative capacities.

It is original in the French landscape by being highly multi-disciplinary: it involves researchers in economics, management sciences, sociology, information and communication sciences, cognitive psychology and ergonomics, liable to several sections of the CNRS, 29, 34, 36, 37, 40 and 44, as well as CNU section 71 (not represented in CNRS). Its focus is therefore not disciplinary but thematic. It aims to cover the Information and Communication Technology (ICT)"human"-oriented perspectives, with two sets of equally stringent, and sometime cross-cutting exigencies: operating at the cutting edge of each disciplinary field, while also participating to collaborative and innovative research projects (involving cooperation either between social sciences or between social science and more 'technology-oriented' departments and industries) which directly benefit from the involvement of multiple disciplines. But in this particular domain, trying to satisfy both exigencies as much as possible is a key to original, innovative research which may shed new light on the uses of ICTs, for these are usually oriented with respect to multiple normative orders, economic, social, technological, etc.

For management purposes, the department is organized in three research groups, two in Paris and one in Sophia Antipolis. Its research activities are structured around three axes which are deliberately not congruent with the boundaries of the three groups (because they aim towards stimulating various forms of interdisciplinary collaboration). These three research axes each explore significant issues regarding mediated interactions and transactions, but at several scales. At the "macro level" Axis 1 one looks at regulation and innovation-related phenomena in the telecommunication sector. At the "meso level", Axis 2 studies the production, circulation and reception of media and cultural contents with an eye towards the blurring of the boundaries between producers and consumers, professional and amateurs, etc. At the "micro level" Axis 3 focuses on mediated interactions and the local management of situations and activities relying on communication technologies and services.

8.4 Regulation and Innovation (RINNO)

Faculty animators Maya Bacache (MdC) and Marc Bourreau (P).

Faculty members Maya Bacache, David Bounie, Marc Bourreau, Myriam Davidovici-Nora, Dana Diminescu, Laura Draetta, Valerie Fernandez, Laurent Gille, Thomas Houy, Rémi Maniak , Gerard Pogorel.

External Research associates : Michael Ballé, Philippe Barbet, Godefroy Beauvallet, Abel Francois, Chiraz Karamti, Tommaso Valletti.

Doctoral students : Yassine Bouhdaoui, Benjamin Chevalier, Joeffrey Drouard, Germain Gaudin, Christian Grèce, Tania Horquin, Lionel Janin, Yun Jiang, Bruno Karoubi, Carine Khalil, Laurie Marrauld, Serge Pajak, Raphael Raieb, Lilia Rebai, Dominique Vian, Winston Maxwell.

Post-doctoral students : Frago Kourandi (2010-2011), Mattia Nardotto (2010-2011).

Visiting researchers : Carlo Cambini (2010), Martin Peitz (Nov. 2011).

Research contracts

SportViews European project, COST Action IS0605 EconTel (2008-2011), Research contracts with the Department of Regulatory Affairs of France Telecom (2007-2011), Research contracts with the Groupement Cartes Bancaires "CB"(2005-2011), Contracts with regulatory authorities in developing countries, Chaire "Regulation and Innovation in Digital Services" Orange-Ecole Polytechnique-Telecom ParisTech, Contract with the Department of Justice (2011-2012), Project LETTI (2009), CNRS ANR Corpus -Mobitic (2007-2010)

PhD projects

Yassine Bouhdaoui, (started 2010): "Currency systems, technological changes and the social cost of cash."

Benjamin Chevallier (started 2006, ended 2010): "The structuration of new market services and the management of regulation costs by mediated communities."

Joeffrey Drouard (started 2006, ended 2010): "Competition and investment in telecommunications."

Germain Gaudin (started 2009): "Innovation and regulation in the telecommunication industry."

Christian Grece (started 2006): "Management and pricing of the hertzian spectrum."

Tania Horquin (started 2007): "The forms of emergence of the markets for teleservices."

Lionel Janin (started 2009, ended 2011): "Competition and regulation."

Yun Jiang (started 2004, ended 2010): "The structuration of the value chain for mobile technology in the context of the growth of multimedia technologies: which economic models?"

Laurie Marrauld (started 2010): "Mobilité équipée par les TIC : analyse de comportements émergents."

Bruno Karoubi (started 2006): "Economics of payments."

Carine Khalil (started 2008, ended 2011): "Les méthodes de développement agile et les dynamiques d'organizing : une approche par la pratique."

Serge Pajak (started 2007, ended 2011): "Intellectual property and innovation strategies."

Raphael Raieb (started 2011): "Gouvernance des communautés médiatiées : le cas d'un collectif d'auteurs de livres scolaires numériques."

Lilia Rebai (started 2004, ended 2009): "Identifying relevant telecom markets in Tunisia."

Dominique Vian (started 2006, ended 2010): "From the assessment of invention to its transformation in innovation: cognitive processes."

Winston Maxwell (started 2011): "Achieving audiovisual policy objectives via telecommunications regulation."

Alexis Maingard (started 2009): "Reforms, sector outcomes and economic growth in Telecommunications in Africa".

Hai Xiaodong (started 2009): "Pricing strategy for App stores"

Aude Shoentgen (started 2011): "Risk assessment in valuation of telecom investments in Africa".

8.4.1 Context and objectives

The dynamics of ICT industries are influenced by a tension between innovation and regulation ([634]). Indeed, these industries are characterized both by a high pace of innovation (affecting the supply side and the demand side), and strong regulation (through intellectual property, the scrutiny of competition authorities, and sector-specific regulation). On the one hand, due to the endogenous relationship between technological progress and industry structure, regulatory policies clearly affect the speed of technological change, via two different channels (see Bourreau and Doan, 2001[2]). First, price regulations (e.g., the regulation of interconnection charges and retail prices in telecoms, the regulation of the interchange fee in the payment industry, the control of prices in the health sector, etc.) alter industry profits, and hence the incentives to innovate. Secondly, both price and entry regulations (e.g., spectrum licenses, patents, banking licenses. . .) change the terms of entry, and hence innovation decisions regarding new entry. But on the other hand, to the extent that technological changes alter the organization of the industry, the speed of innovation – particularly in the new markets – should also be reflected in any regulatory intervention. If regulatory authorities cannot respond fast enough to follow the rapid change of the market, many regulatory measures then become either inefficient or obsolete.[3]

Consequently, new flexible forms of regulation are called for. Indeed, though a regulation which would not adapt fast enough to changes in technologies or market structures would be inefficient, an unregulated environment would probably also lead to inefficient outcomes, as the current economic crisis illustrates. We therefore need to rethink public policy, by taking into account innovation dynamics and the institutional constraints (Bacache and Maynéris, 2006)[4].

This research project tackles the two dimensions of the relation between innovation and public policy through two different areas of research:

Sub-theme 1: Innovation in Regulated Industries. In this second area of research, we study innovation strategies in industries where regulatory constraints are binding (intellectual property, constraints on R&D collaboration in Europe and US, specific regulations, etc.).

Sub-theme 2: Regulation in Innovative Industries. In this first area of research, we study the design of public policy in innovative industries. In particular, we examine how sector-specific regulation should be designed to take into account its effects on innovation strategies.

8.4.2 Sub-theme 1: Innovation in Regulated Industries

In this area of research, we focus on innovation strategies, and on the effects of innovation on the industrial organization of specific markets.

Innovation strategies, value and organization

A first research project focused on the impact of a modular product design on (i) component-sharing between competitors ([**?**]), and (*ii*) cooperation strategies at the R&D stage ([547, 660]). The main idea behind this research is that sharing technologies may bring forth some benefits in terms of economies of R&D costs, but also has costs due to lower possibilities of differentiation. We have therefore explored the consequences of these benefits and costs on market competition.

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[2] Bourreau, M. and P. Doan, 2001, "Regulation and Innovation in the Telecommunications Industry," *Telecommunications Policy*, 25, 167-184.

[3] This calls for an ever evolving regulation. This is somehow done in practice. In particular, in Europe, the so-called "Review" aims at adjusting regulation every four years (see: Pogorel and Gassot, (2006) [**?**]).

[4] Bacache et Mayneris, 2006, "Le rôle de l'Etat : fondements et réformes", Bréal, Paris.

We have also continued our research on the different regimes of value, which was started by Laurent Gille 10 years ago with a book on the sources of value (published at L'Harmattan in 2006). This reflection is going forward, with questions of trust and complementary currencies as the main areas of interest, and it should result in a book in 2013.

We recently expanded our research program about value in the management science discipline. This led us to settle the concept of "Full Value" which designates the indirect profits generated by one or several companies selling an innovative product – in analogy to the "full cost" logic. We initiated this research program with two communications ([697, 698]). It is now the foundation of two research contracts initiated in the automotive industry, and one public research program (with ADEME, to be confirmed). We build methodologies to evaluate the provisional profitability of innovations regarding a wide spectrum of values, in one firm or in one innovative ecosystem. At least one article and one book are in the pipe regarding this research program.

Regarding the issue of "organization for innovation", we ended a 5-year research program initiated with the Innovation Management Chair of Ecole Polytechnique, which compared the organizational settings for innovation of 9 carmakers based on the detailed study of 26 innovative features. We submitted an article in the best specialized journal –the "Journal of Product Innovation Management"— to promote the results ([534]). A book is also currently under editing.

Money, payments, and technological innovations

The payments industry has experienced profound changes in the last decades, due in part to many technological innovations: debit and credit cards, electronic money, private money, electronic payment systems on the Internet, mobile phone payments, ATMs, automated compensation procedures, etc. These innovations affect consumer choices in terms of payment instrument and in turn affect economic, monetary and banking activities.

First, the characteristics of payment instruments (in terms of cost, safety, etc.) impact the willingness to pay of consumers and, therefore affect how (well) markets can operate. Second, the use of payment instruments determine partly banks' income, the magnitude of deposits and, in turn, the possibilities of financial intermediation. Third, and finally, the use of payment instruments orient the demand for money (both cash and central bank money) of economic agents. While these questions were for long considered as a by-product in the economic model of the bank, our research has shown that the payment instruments, that lie at the intersection of the economic, banking and monetary spheres, constitute a field of original and fundamental research for banking and monetary economics.

Our contributions have focused on three areas. First, prior to analyzing the impacts of technological innovations, it is important to understand first what are the determinants of the consumer choice between payment instruments. As a first step, we have regrouped the contributions that seek to validate and extend the theoretical models explaining consumer choices in the use of payment instruments ([541]; [542]). Then, in a second step, we have evaluated how technological innovations associated with payments affect the economic, monetary and banking spheres ([**? ?** 543]). Finally, in a last step, we question the effectiveness and cost of cash payments primarily in the context of the development of new competing payment technologies ([541**? ?** , 536, 535]).

A final research project, still ongoing, is to study innovations in payment systems, how they can diffuse and how to encourage firms to develop and implement these innovations. We are particularly interested in mobile payment technologies. In this area, we have shown that there are different business models, whose main characteristics is the degree of dependence with the three pillars of a mobile payment offer: access to the payer's bank account, access to the acceptance network, access to the mobile terminal. ([553])

ICT and the health sector

ICT innovations profoundly affect both the supply, demand and market structure of care ([**?**]). Our research has attempted to address two general questions: what could be the right market design

(particularly in relation to issues of technology standards and interoperability of technological systems)? What are the factors of emergence of business ecosystems for a market of e-health?

First, we look for recommendations for innovative projects in the medico-social sector. Our research (Houy) stresses that, in order to create a business model able to support the deployment of a device, one needs to anchor the technological device in an area, to develop a business model which incorporates the key skills of the health ecosystem, and to clarify the value proposition of the innovation.

Second, we analyzed what are the characteristics of the health ecosystem in the medium- and long-term and what role will ICT play in the future health ecosystem. Our research (Houy) emphasizes the possible emergence of a "duty of health" in compensation for the "right to health", which represents a possible displacement of the cursor to a more preventive and restorative medicine.

Third, we have investigated what are the mechanisms of formation of business ecosystems focused on a technology. Our research ([685]) shows that the conditions that affect the emergence of business ecosystems are: the complexity of relationships between the high number of players around a technology, the existence of strong regulation, but which is questioned by the emergence of technological innovations, and the difficulty to identify ex ante the contributions to the value created by the technological device.

Fourth, we have analyzed how the characteristics of demand and supply of care in France will evolve over time. The answer to this question depends on our mastery of emerging health risks, new regulations of the productive sphere, acceptance by the population to undergo preventive courses, the sustainability of the system of risk pooling. We proposed different scenarios of evolution (Houy, 2010). The answer to the question of the evolution of supply will depend on the nature of the relationship between patients and health professionals, the path followed by the organization of the production of care, the place of the protocols in medicine, and the position of health players in the value chain.

Finally, we studied the specificities of the management of hospital information system (HIS) (Fernandez, Houy-study contract GMSIH and publications in progress). The issues are those of governance of increased interoperability, the constraints created by the nature of supply of HIS, a change management which is atypical and opportunistic use of the structuring effect of IS.

Information systems and lean management

Lean management is a radical innovation in the production and management process ([**?**]). What are the specificities of lean management in terms of Human Resource Management? We focus on middle managers in support of production, upstream from other support services, on new tasks operators have in charge with respect to their role in the dynamics of improvement of production processes of the company.

We also analyzed whether the acquisition of a demand forecasting tool by a company can be considered as a substitute for stockpiling by the same company. Counter-intuitively, using a heuristic model, we show that there are situations where protective behaviors (precautionary stock) and prediction behaviors (acquisition of a demand forecasting tool) are complementary to a company ([**?**]).

The "lean" philosophy is also used for the management of computer science projects ([689], [687], [688]). It is argued that these approaches are in line with the "interactionist" current in Management Science that highlights the managerial issues of "Organizing."

8.4.3 Sub-theme 2: Regulation in innovative industries

Regulation, competition and investment

A first research project was interested in the functioning of wholesale markets in network industries, where many companies have an infrastructure of its own. The results of this research ([551])

showed that network competition on the wholesale market may not emerge. In a similar vein, we studied foreclosure incentives in input markets ([597]).

A second research project concerned the so-called ladder of investment in telecoms. This approach has been popularized by the British economist Martin Cave (2004) to regulate access to telecommunications networks. It allows new entrants to enter the market rapidly while building an infrastructure gradually ([548], [549]). The research project (Marc Bourreau, Maya Bacache, Pinar Dogan (Harvard Kennedy School), Germain Gaudin (PhD) and Matthieu Manant (Université Paris XI, Sceaux)) had an empirical component and a theoretical component. First, we tested empirically, from a database of 15 European member States, if the ladder of investment approach has favored the deployment of new access networks by new entrants, as is often claimed. Our results show that this has not been the case. We have also adopted a theoretical approach by modeling the impact of this type of regulation on investment.

We focused more recently on the relationship between regulation and deployment of fiber optic networks. On this subject, our research (a collaboration between Marc Bourreau, Pinar Dogan (Harvard Kennedy School), Carlo Cambini (Politecnico Torino), and Steffen Hoernig (University of Lisbon)) has focused on (*i*) the relationship between the regulation of traditional (copper) networks and the migration to fiber, (*ii*) the differentiation of access remedies according to the geography and its impact on the deployment of fiber networks, and (*iii*) strategies of co-investment in fiber and the relationship between the regulation of access and co-investment decisions ([613], [544], [545]).

We have also a specific interest in the economics and telecommunications regulation in Africa ([635]). The explosion of demand for services in Africa raises specific business model and regulation issues to address the very specific characteristics of these markets and their context. Whether through the work of students in our courses ("Badge en régulation des télécommunications" opened in sub-Saharan Africa), through specific contributions (Communication to the ITS 2010 Biennial in Tokyo), in researches related to contractual problems of network's interconnection, or the organization in October 2011 of the first edition of the CARET conference (African Conference on Regulation and Economy Telecommunications - 200 participants), research on the conditions for the development of networks and services in Africa is progressing. A textbook is also being prepared.

We have finally examined the paradigmatic example of the taxi market and the impact of the regulation of entry into the market on competition. Bacache and Janin have quantified the sensitivity of demand for taxi to the waiting time, and therefore to the number of taxis, and they have shown that an increase of over 70% of the number of taxis would not be sufficient to rent that is due to the barrier to entry [581]). Implications are drawn in terms of public policy and the political determinants of such policy.

Territorial governance of ICT

Our thesis is that the question of strategic management of ICT in their relationship to space (and the specific forms of spaces, such as territories and places) requires the use of new analytical tools. In terms of territorial governance, for example, the object is not to question the classical opposition public vs. private, but the issue of new management methods in synergy between these two spheres ([626]).

Political economy of regulation

The normative study of public policy must be associated to a positive study with a political economy approach ([576]). The regulator has introduced ICT in its relation to the user. Our research question ([529]) is whether e-government was granted to users who have the highest demand for public services or whether, because of a digital divide, it has benefited to the wealthiest. We show by an econometric study controlling for selection bias that the users of e-government are the beneficiaries of social transfers.

A second question concerns the specific methods of economics of human resources in the public service. Bacache shows the negative effects of variable compensation on equal treatment

of users ([528]) and Bacache and Audier (2009) shows the transformation of the business of regulator, in particular that of prosecutor.

Finally we are concerned with the paradoxical situation of the European market of mobile broadband, or rather the absence of such a market. The European regulatory framework for telecommunications has resulted in a fragmented market, with as many markets as member states. The construction of a European telecommunications sector has not occurred and operators located in several markets are benefiting from this fragmentation, to the detriment of consumers and businesses. The lack of access to pan-European services makes that Europe is lagging behind the U.S. and China, and that it is losing the leadership achieved at the time of GSM. We have made proposals that go beyond those of the European Commission to remedy this situation and create a single market for mobile broadband.

8.5 Mutations of Cultural Industries in a Digital World (MICEN)

Faculty animators : Nicolas Auray (MdC) et Patrick Waelbroeck (MdC)

Faculty : Nicolas Auray (MdC), Maya Bacache (MdC), Valérie Beaudouin (DE), David Bounie (P), Marc Bourreau (P), Antonio Casilli(MdC), Myriam Davidovici-Nora (MdC), Olivier Fournout (IE), Isabelle Garron (MdC), Michel Gensollen, Annie Gentès (MdC), Ludovic Lebart DR CNRS émérite), Dominique Pasquier (DR CNRS), Patrick Waelbroeck (MdC),

PhD students *Defended (dates are for the defense):*

Post-docs, engineers and sabbaticals : Brigitte Bleuzen, Michael Bourgatte, Fanny Georges.

External collaborators : Serge Proulx (UQAM)

Research contracts:

- ANR (program "Content and Interaction") PANIC : "User as Prosumer, active audiences and digitization of Cultural Industries" (2008-2011).

- Contract with the Adami (the french civil society for the administration of the rights of artists and musiciens), M. Bacache, M. Bourreau, M. Gensollen

- Contrat with the Ministry of Culture on the evolution of cultural diversity: M. Bourreau, M. Gensollen

- Contrat with the Département des Etudes from Ministry of Culture, July 2011 to January 2013, " Rise of amateur critics and new forms of cultural recommendations: AlloCiné ";D Pasquier

- FUI (Fonds unique Interministériel) SOLEN : " Interoperable mobile electronic reading " (2010–2012**)** ; I. Garron

- FUI (Fonds unique Interministériel) CINECAST 2010-2012, Film annotation systems - V. Beaudouin

- DIME SHS (Equipex), Platform for the collection and dissemination of data for qualitative and quantitative research in SHS, leadership: IEP Paris, Valérie Beaudouin.

PhD thesis

- Bora Eang, supervisors : P. Waelbroeck, D. Bounie, *Economics of electronic commerce*

- Sébastien François (Futur and Ruptures), supervisor : D. Pasquier, *Fan fictions and derived texts*

- Irène Bastard (CIFRE Orange), supervisor : D. Pasquier, *Readership contribution in the press industry*

- Bruno Vétel (CIFRE Orange), supervisors : M. Bourreau, N. Auray, *Virtual currencies in videogames*

- Benjamin Chevalier, supervisor: M. Gensollen, D. Bounie, *Communities of practice and consumers.* Graduated in 2010.

- Etienne Chantrel, supervisor : M. Bacache, *Competition and Innovation in the press industry*

- Sisley Maillard (CIFRE Orange), supervisor : M. Bourreau, *New forms of cultural assessments*

Research assistants:

- Stagiaire : Marlène Plard (Paris 1) 3 mois Juin-sept 2011 Financement ANR Panic

- Stagiaire : C de Vulpian (Paris 1) 1 an 2009-2010.

- Tomas Legon (EHESS) 18 mois 2011 -2012.

8.5.1 Objectives

The research project studies the transformation of media content and cultural activities in the
digital era. Although some cultural activities have already experienced disruptive technological change, today's fast and easy access to digital content over the internet has revolutionized all cultural industries. Moreover, productivity gains associated with digital copies and internet communications go beyond the productive system and have generated new activity and participation from audiences. This leads us to question the linear model of production

Beyond the empirical studies detailed below, the project proposes a multidisciplinary approach to the understanding of new forms of coordination and cooperation between authors, editors, producers, retailers and broadcasters, as well as an in-depth study of the transformation of formats linked to new forms of interactions between producers and consumers. The strength of MICEN lies in a comparative analysis of the main cultural industries: music, books, movies, videogames, and press. Three approaches complement each other in this project; each of them has met international standards of visibility and publications.

Cultural economics to understand how cultural industries supply and consumer demand adapt to new forms of digital communication;

A pragmatic approach that analyzes culture as performance, and that seeks to understand how material conditions affect cultural activities and how consumer tastes and amateur work are reflected by different forms of attachment between an individual and an artistic object.

A sociological approach to cultural audiences that analyzes the collective dimensions of the process by which cultural products and performances are perceived in a community.

The axis is led by researchers who have already studied the four main cultural industries (music, movies, book, videogames) and therefore offers a perspective on how different supports have adapted to the media convergence. The interdisciplinary component and the competence across different cultural industrial sectors allow this project to target a comparative analysis, which is promoted by regular seminars. In 2011 we have organized 5 sessions:

- March 2011 : general presentation of the research in the axe

- June 2011 : presentations by Valerie Beaudouin on film annotation, Maya Bacache on public subsidies to multimedia artists and David Bounie on the electronic commerce of cultural goods

- October 2011: Presentation by Marc Bourreau on self-releasing entrepreneurs in the music industry.

- November 2011: Presentation by Nicolas Auray on the sociology of overchoice

- December 2011: Presentation by Antonio Casilli on the use of algorithms in sociology

8.5.2 Open Innovation and "economy of contribution"

he digitization of cultural industries allows some users to adjust, transform, or co-create cultural products. This section proposes empirical studies of the new creative role of readers, viewers and listeners as well as a review of "open innovation" strategies which allow spillovers and avoid cannibalization.

Beaudouin identifies the mechanisms that have gradually made the consumer an active participant in the process of producing cultural commodities [(VB:dyn-09) and (VB:communications-2010)].

In videogames industry, Davidovici-Nora studies the control of open innovation and the strategies of promotion by editors (MDN:CS-09). "Open innovation" leads to the topic of the new forms of organizations of online communities. Auray studies the governance issues and the management of online communities [(AURAY:GOV-11) and (NA:COMM-11)]. Auray has studied the three main explanations of the contribution and participation to online communities (NA:WEBS-10).

8.5.3 Autoproduction, autopromotion and the professionnalization of amateurs

The structure of cultural industries traditionally modeled as an oligopoly with a competitive fringe is challenged by the digital transformation of the value chain. Lower entry barriers allow amateurs to build their own reputation and reach their audiences. The diffusion and promotion of cultural products now includes the self promotion of niche artists.

Bacache, Bourreau, Gensollen and Moreau study the impact of digital technologies on musicians. Using a survey of French professional musicians, they show that adopting digital technologies allow musicians to increase their revenues. Besides, they show that digital tools increase the propensity of artists to self-release their music, both for star artists and for musicians with less notoriety (BBGM:ADAMI-09).

François studies challenges in identity construction among fanfiction writers (SF:RES-09).

Beaudouin and Fréard study how careers of online writers evolve over a period of 10 years. They distinguish among star contributors who do not update frequently their content and newcomers who experiment new formats. (VB :11-PANIC)

8.5.4 Transformation of practices, new formats and new esthetics

This section analyzes newly invented formats related to the increased participation of active audiences. Pasquier analyzes the evolution of press coverage of cultural events and releases in two newspapers on the time period 1960-2000 (dp:grips-09). She also studies how cultural practices may be used for gendered presentation of self in youth society (dp:ethnofr-10) . Next, Auray and George investigate the organizational schemes of a "digital culture" where users enrich contents produced by publishers of video games: the machinima avantgarde. (NAFG:HON-11). Beaudouin and Garron study how new reading technologies such as the iPad changes editorial strategies and content creation (V.Beaudouin et I.Garron Les revues à l'ère du Web et de l'ipad, manquant dans la base). Finally, in an article submitted to peer-reviewed journal, and arising from the CINECAST contract, Beaudouin and Fournout show how users of a film annotation technology collaboratively interact to produce a new way to watch movies.

8.5.5 Parallel distribution by consumers

Bacache, Bourreau, Gensollen and Moreau study whether the opinions of artists on piracy are in line with their economic interests. Using a survey from French musicians, they show that those who do more live performances are more tolerant of piracy, whereas the attitude of self-released artists is closer to that of the record companies –they are less tolerant of piracy (référence?). Bounie and Waelbroeck use survey data from the INSEE to analyze the impact of piracy on the purchase of legal online audio-visual content (PW:EP-11).

8.5.6 New forms of recommendation

The increasing visibility of online communities allows consumers to broadcast and share their views and comments. Audiences are becoming more active, often led by expert consumers. This process is interactive and self-reinforcing as the frontier between consumers and artists, between amateur and professional critics has become blurred.

Pasquier, in a forthcoming book, analyzes advice networks on plays and groupings for theater going (D.Pasquier, *Le théâtre, une sortie sociale,* Paris DEPS Questions de Culture, 2012). In parallel, she characterizes forms of sociabilities in a group of female theater goers in France (D.Pasquier - " Les sociabilités de la culture cultivée : étude des groupes d'amis du théâtre de Chaillot " in PJ Benghozi et T. Paris (eds), Howard Becker et les mondes de l'art, Paris, L'Harmattan, sous presse 2012). Finally, Pasquier studies how families regulate the use of Internet by their children.

Beaudouin, Bleuzen and Garron study how communities of readers influence the way people read content on iPads as well as books recommendations. In a related research, Auray examines search engines and their influence on the exploratory behavior of members of online communities, such as folksonomies (NA-COMM11).

Finally, Bourreau, Gensollen and Moreau have measured how the diversity of consumption of music has evolved over the last decade (Bourreau, M., Gensollen, M. et F. Moreau, working paper, manquant dans la base).

8.5.7 New business models

Research in the section analyzes how online distribution technologies have transformed the value chain in cultural industries and their Impacts on business models. Researchers associated with contract PANIC have published a book on the transformation of four cultural industries in the digital era (PA:NIC-11).

Bounie, Eang, Sirbu and Waelbroeck analyze online price dispersion of cultural products sold on various Amazon marketplaces. They show that internet users do not necessarily purchase form the seller with the lowest price (BOU:RFE2011). They also argue that new online platforms that gather buyers and sellers represent an opportunity for producers of niche orold cultural products (Bou:RE2010). Finally, they compare online to physical sales of books and show that new online distribution channels segment the demand for books (DBPW:10a).

Auray studied the construction and reception of "unlimited" commercial offers. Users trade off between curiosity and anxiety, under anomic dynamics (NA:RFSE-11).

8.5.8 Elements of visibility

Scientific Committees; Editorial Boards, Research Fundings:

- N.Auray, Scientific Board of *Game and Entertainment Technologies* (IADIS) 2011, *Genre et Jeu Video Conference* (Lyon 1, 2012)

- N.Auray, Scientific Board of *Reset* (Recherches en sciences sociales sur Internet)

- M. Bourreau, co-editor of *Information Economics and Policy*, member of the editorial board of *Telecommunications Policy* and *Communications & Strategies*.

- D.Pasquier, Scientific Board of *Réseaux*, *Northern Lights*, *Popular Communication*, *Journal of Children and Media, Télévision*.

- D.Pasquier - Vice-chair of comité de suivi de l'appel d'offre " Formes et mutations de la communication " ANR, 2008-2012

- D.Pasquier - Présidente du comité d'évaluation de l'appel d'offre " Communication and Information Sciences" de la Fundação para a Ciência e a Tecnologia (Portugal), 2007, 2009, 2010, 2011

- D.Pasquier -Responsable de l'équipe française du programme de la Commission Européenne " EUkids Online ", 2009-2011.

- D.Pasquier, Guest Editor of the special issue- " Les séries télévisées ", Réseaux 2011, n˚ 165 (avec O Donnat)

- D.Pasquier, Guest Editor of the special issue- " Enfance et cultures " Réseaux, 2011 n˚ 168/169 (avec S Octobre)

- P. Waelbroeck, member of the editorial board of the Journal of Cultural Economics

- P. Waelbroeck, member of the board of the association European Policy for Intellectual Property

- M. Bourreau & P. Waelbroeck, member of the scientific committee of the Telecom ParisTech international conference on the economics of ICT, 2009, 2011

- P. Waelbroeck, member of the scientific committee of the Applied Econometric Association on the econometrics of the internet, 2009

Organization of workshops and seminars:

- I.Garron, Workshop coordinator for the Chair " Modélisation des Imaginaires"(mars-avril 2011)

- D.Pasquier - Co organisatrice du colloque international " Enfance et cultures ", Paris, 15-17 décembre 2010

- M. Bourreau & P. Waelbroeck, co-organisateurs du workshop recherche du groupe économie et gestion,

- P. Waelbroeck, co-organisateur du séminaire "économie et économétrie de l'innovation avec U. Paris 1, U. Paris 2, Mines ParisTech

8.6 Interaction, technology, activity (INTERACT)

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PhD students *(starting - ending)*

> Jeremy Boy (end 2011-), Maria Ianeva (2007-), Stéphane Couture (2007-), Aude Guyot (2011-), Anne-Marie Hébert (end 2008-), , François Huguet (2011-), Caroline Jullien (2008-), Laurie Marrauld (end 2011-), Cédric Mivielle, (2011-), Claudine Nguyen (2009-), Cyril Thomas (2009), Magali Prost (2009-), Stéphanie Vidal, (2010-), Hanene Jomaa (- 2009), Ian Hing Ting (- 2010), Dominique Vian (- 2010), Dimitri Voilmy (- 2011)

Post-docs, engineers : Dominique Fréard, Julien Figeac, Caroline Guillot, Yoriko Inada, Marie-Christine Legout, Maud Verdier

Visiting researchers and sabbaticals Charles Crook (*Nottingham U, UK*), Christian Heath (*King's College London, UK*), Kari Kuutti (*U. of Oulu, Finland*), Paul Luff (*King's College London, UK*), Rod Watson (*previously at U. of Manchester, UK; now associate professor at Telecom ParisTech*)

Research contracts
As principal Coordinator
ANR: EPE "Ecologies end politics of writing" (2006-2009); CCCP-prosodie (2009-2012)
CNRS : Graphic ecologies of public spaces (2009);
Others : Géovélo Nantes (2011); Géovélo Paris (2011-2012); Paris Métropole (2011)
As active funded participants
ANR: COMUT (2009-2011); PLUG (2009-2009); Myblog3D (2007-2010); MOBITIC (2007-2009); e-diasporas-atlas (2008 -2012); ADAM (2010-2013); INTERMED (2008 – 2011); UrbanD (2010-2012); PROSE (2010-2012)
FUI : Turbulences (2009-2011) ; WITE2.0 (2010-2012)
European projects : Mignet (2009-2013), 3DLife (2010-2013), Bridge IT (2008-2011); Avidicus 2 (2011-13)
Institut Supérieur de Communication du CNRS : MOTISTAR (2008-2009)
Joint Research laboratory : Alcatel-Lucent Bell Labs- Institut Télécom "Ubimedia"
Others : GIP justice
Chaire
Modélisations des imaginaires, Innovation et Création, Pierre Musso (coord), (Télecom Paris-Tech, U Rennes 2, Dassault Systèmes, Ubisoft, Orange, PSA Peugeot-Citroën)

8.6.1   Objectives

The INTERACT research axis deals with the a) way people interact, collaborate and move in complex information ecologies; and b) the ways in which artefacts and larger scale infrastructures supporting interaction and mobility are designed as collective endeavours. On the one hand this research axis is the locus for fundamental research on the dynamics of interaction, mobility and infrastructure (Part 1). On the other, it uses the growing expertise on these topics to support and initiate transverse thematic cutting edge research projects which interweave these themes (Part 2), such as "Migration and communication", and more recently, "Reflexive technologies".

This axis is interdisciplinary in several respects. First it actually combines research done in psychology, ergonomics, sociology, information and communication sciences, management sciences. Second, through its strong orientation towards the direct observation of practice it combines several qualitative methodologies (participant observation, video recording, explicitation interviews, auto-confrontations, as well as more traditional forms of interviews and surveys) and explores their interplay and its limits. Third it tries to treat human practice and the information ecologies it unfolds in symmetrically. Hence there is an autonomous focus on infrastructure studies and design, and an effort to collaborate with technology-oriented specialist fields. Within this project there is a high potential for developing a dialogue between social and human sciences on the one hand and computer sciences on the other.

8.6.2 Fundamental research on interaction, mobility and infrastructure

Sub Theme 1: Collaboration, emotion and presence in technology-mediated contexts

Human-human interaction either in co-presence or at distance is more or less transformed by ICT. Our research is focused on three fundamental mechanisms on which technology mediation may operate: collaboration processes as related to collective knowledge elaboration, relations between social, affective and cognitive dimensions of interactions, and the formats of presence.

Collaboration and knowledge co-elaboration in online communities .

Collaboration and cooperation, between humans through technology mediation and between humans and machines, is a first topic of research addressed to understand new forms of knowledge co-elaboration at a distance, online epistemic communities [**?**] and technology-mediated design [703, 704] as compared to presential design situations [693, 600, 708] [650] [709], as well as new forms of services offered to customers through speech interaction [656]. Fundamental research issues addressed in two ANR projects (CCCP Prosodie; Intermed) on online communities concern: the new forms of "open regulations" [**?**]; the interplay between design and regulation activities [691**?**]; design-use mediation [671] [532, 654]; inequality of participation and digital divide.

As a transversal issue, research for understanding quality or "qualities" of collaboration [662, 670, 704] is conducted for better approaching the relationship between collaboration, its outcomes and characteristics of tools that mediate collective action. An international workshop [**?**] was organised by F. Détienne and M. Baker on this theme in mid-2010, that has given rise to the coordination of a journal special issue (CoDesign Journal, ed Taylor & Francis, to appear in 2012).

Emotion and affective regulation in interactions Emotions are an integral part of human activities, they frequently give orientation to action, reflexion and relations towards others [556]. Research carried out on the topic of interaction and emotion aims to understand how different types of technological mediation exert influence on the interactive circulation and regulation of emotions [672], and on the way that different collective activities like risk management or online social support [644] are carried out. In this context, there is a need to further develop methodological approaches for understanding the relations between social, affective and cognitive dimensions of interactions [603]. A workshop funded by the European Science Foundation was organised by M. Baker on this theme in mid-2009, that has given rise to the publication of a book [**? ?**].

Furthermore, a promising avenue of research that is being explored concerns the interrelations between the analysis of the dynamics of emotions as observed in interactions, and the reflexive study of emotions experienced by interactants, using explicitation interviews, or autoconfrontation [557, 696]. Since 2008, this research topic has been reinforced in LTCI by B. Cahour's coordination of one of the five themes (emotions and cognitive load in activity) of the CNRS G.D.R. "Psycho Ergo".

The formats and repertoires of presence. The development of ICT and the proliferation of the modalities of electronic communication also transform the formats and repertoires of presence. One direction of research has been to promote videoconference and its technology-augmented variants as a way to achieve the promise of remote presence or "telepresence", that is a way for remote participants of " being there " that might dense enough to mimic co-presence to some extent. We have launched a large scale study of the uses of video communication regarding both interpersonal and professional or institutional communication. We have constituted several corpora of Skype-based video calls, mobile video calls, meetings in advanced telepresence rooms at OrangeLabs, and Second Life meetings. Our research has highlighted the sequential importance of the 'talking heads' format in mobile video communication [595], the organization

in family-based multi-party video calls, through which participants are "doing being a family" and the interrelation between participation frames and uses of communication media in professional second life meetings [673]. This has led to new studies being under way, such as how participants are using video communication and camera motions to show or point at something and the management of heterogeneous participation frames in video communication.

A large scale research has also been launched regarding the introduction of video conference technologies in the courtroom for remote testimonies and interrogations. Judiciary settings offer an interesting field to study the articulation of communication technologies and institutional concerns into new politics and regimes of presence. We have been authorized to video record courtroom hearings, which is exceptional, and to constitute a unique corpus of distributed courtroom hearings, in the frame of two successive projects funded by the G.I.P. Justice. This has led to a systematic study of the development of video communication in French courtrooms [569, 588], of the way distributed judicial hearings are accomplished as multimedia performances requiring specific competences, and of the way some formal speech acts characteristic of the judiciary ritual could be omitted in distributed hearings [590]. Current research focuses on the pragmatics of mediated appearances and interactions in the courtroom, on how participants handle the choice between appearing in presence or through the video, and specific problems regarding the dual mediation of the video technology and the use of an interpreter (the latter through participation to the European project AVIDICUS).

The limits of the classical model of presence: from focused engagements to multi-activity
Beyond efforts to constitute a sense of presence as a capacity for involvement, the development of ICT also seems to weaken it. For instance, the explosion of communication resources lead to the proliferation of calls and notifications, which threaten the very possibility of keeping focused commitments in a given activity. Presence seems to waver between the kind of layering and fragmentation which characterize multi-activity and its fading away through ever increasing levels of sheer dispersion. We have been studying the design and accomplishment of technology-related dispersive events such as notifications or 'mediated appearances' and shown how their proliferation might lead to a "crisis of the summons" [586, 589]. The occurrence of such mediated events in increasing number also seems to favor the development of 'multi-activity'. In the framework of the ANR project COMUT, we have been studying both its positive and negative facets, on one hand the skillful and methodical management of multiple engagements and, on the other hand, negatively valued dispersion.

Theme 2: Mobility and locative media

Communication and mobility practices are deeply interwoven and affected by the current development of ubiquitous computing, and this sub theme explores their various articulations.

Innovative methodologies for studying mobile uses on the move. The direct observation of users on the move requires innovative methods. In the frame of this project, a growing expertise has been developed in the recording of mobile terminals (phones, smartphones, iphones) activity, combined with the video recording of contextual information (with mobile users wearing various forms of camera or glasscams). We are currently trying to build on this expertise to develop a mobile multimedia recording facility which will be available for teaching and research alike.

Mobility as an accomplishment in transport situations. This methodological expertise in recording mobilities as an accomplishment has led us to assemble a growing corpus of mobility situations. Though progress is being made on the study of public transport situations, the most advanced domain of study in that respect today is car driving in various innovative configurations:

- The experience of driving in GPS-augmented cars.

- Fundamental research in the use of verbalization techniques to study car driving as an activity.

- The use of the battery gauge as an affordance in the experience of driving electric cars [700], in the frame of collaborations with Renault (through the Institut de la Mobilité Durable).

- Autololib and car sharing experiments, via the participation to large scale projects just submitted (Sysmo 2015, Vedecom)

Mobile communication. In the frame of this methodological expertise, we have started to build several corpora of mobile phone conversations, Skype-based video communications, and mobile video communication. This serves as a basis for a thriving effort at understanding better the specific dynamics of mobile communication, as well as the way mobile talk refer to space and place [596**?** , 593]. Our research has also oriented towards mobile communication organization and the practices of mobile workers, based on interviews and mobility diaries, within the frame of the MOBITIC project and one PhD [690].

Mobile communication and locative media. We have done ethnographic studies aiming at understanding the ways in which various forms of location awareness or proximity awareness supported urban sociality and the development or avoidance (due to privacy concerns) of mediated encounters encounters between acquainted or non-acquainted users, either in a GPS-tracking case like the uses of the Mogi game in Japan [**?** 640, 591], or a proximity-sensitive game in France and Japan. These studies provide a global and advanced picture of how locative media are rehaping our sense of mutual proximity and the social implications of such an awareness.

Sub Theme 3: Infrastructures, design and the production of space

Amongst the researches that analyze the role of artifacts in social life, more and more studies have highlighted the importance of infrastructures and design, which give forms and consistence to the material and technological texture of exchanges. We address three main issues in this domain: the nature of work in the backroom of information production, the political stakes of design and infrastructures in urban settings, and the renewal of accountability through ICT.

Since this domain is emerging in our department, we both present here our first results and point to ongoing projects.

Invisible work has long been an essential issue in science and technology studies, and is today deeply renewed. In a time where information services draw on such notion as transparency and immateriality, there is a urge to conduct in-depth studies about the nature of the work done in the backstage of information and to study the "**back-offization**" of the world it leads to [**?**]. Analyzing work and its invisibility is notably a way to re-address the question of the sociomateriality of information. Thus, our first results in the domain show that **fragility** can be an important mode of existence for information technologies [**? ?**] and emphasize the role of **maintenance** in the day-to-day production of our "information society" [561].

Nowadays, more and more information technologies tend to become infrastructure for **public settings**: present, but invisible for users ("pervasive", "ubiquitous"). Numerous researches in our department address this phenomena, trying to understand how such devices produce new geographies, and to study the **fabric of territories by ICTs** at the articulation of infrastructures and uses [626]. Several issues are analyzed in this perspective: the emergence of new forms of **urban fragmentation** [571]; the production of specific **attention politics** in public displays [**?**]; the **tension** between **civic inattention** and **connectedness** in pervasive technologies [592]. We are also working on a research project on Distributed Architecture and Multiple Multimedia Services, studying **mobile P2P networks** aiming at harnessing contextual resources in communicative environments (Project ADAM, Gentes, Huguet).

Finally, we question the configuration and uses of ICTs dedicated to **accountability** and **visualization** in/of public settings. We recently studied their ability to equip **sustainable practices** such as transportation [677], and deal today with several under way projects: a study aiming at understanding the **mobilitiy of things** its transformation through the use of RFID-based tracking technologies (FUI project ASPECT, Delanoé, Draetta, Kornig and Licoppe); an analysis of the role of design and ICTs in the renewal of **urban heritage** (Project "Mémoires Métropolitaines", Gentes, Bourgatte); or a study of the emergence of **new geographical knowledge** through the use of participatory devices (Projects Geovelo — Nantes and Paris, Denis).

8.7 Transverse projects

These are large scale thematic projects which cover important or strategic issues and which builds on the kind of expertise developed above on the dynamics of communication and mobility, infrastructure and design. One is well developed and mature ("Migration and ICT") and one is currently emerging as a significant domain of research ("Reflexive technologies").

8.7.1 Migration and ICT

Studying Migration & ICT is a natural transverse project between the axes mobility and interaction at distance as well as infrastructural and web studies. The development of communication practices —from simple 'conversational' methods where communication compensates for absence, to 'connected' modes where the services maintain a form of continuous presence in spite of the distance — produced the most important change in migrants' lives, their experience of mobility, their relational design and integration social strategies. (Diminescu & Pasquier 2010), [543] (Diminescu & Renault 2011).

In the frame of the FP7 Mignet project we have been looking at how video-communication technologies influence everyday-life patterns of communication in transnational milieus. Based on empirical case studies conducted in the three partner cities (Paris, Athens and Ljubljana) the research will exemplify the complex combinations of global media use and face-to-face encounters that emerge in response to the specific needs of transnational populations and bring about new global forms of "being at home".

The Internet has displaced both the space of diaspora (from physical geography towards network topology) and the media of collective memory (from oral and written traditions to digital formats and networked, media environments). In the ANR Project atlas of e-diasporas, we have adapted and developed web cartographic tools We have thus archived 28 corpus of diasporas; we propose a innovative digital methodological chain, we developed tools like Navicrawler and Gephi and we have design a collaborative platform (http://ks20876.kimsufi.com/eda_proto_final/) to map and analyse the occupation of the web by diasporas. We have thus archived 28 corpus of diasporas through the collaboration of more than 80 persons from 14 countries, several institutions, involving a close dialogue between developers, designers and social scientists.

8.7.2 "Reflexive Technologies"

Digital network activities always leave traces. There is a growing interest in the way these traces could be used to induce new forms of awareness for users regarding their own practices (hence the concept of 'reflexive' technologies) as well as that of related relevant others, and thus set in motions bottom-up forms of behavioral regulation [557]. This could be particularly useful in domains for which public policies are insufficient or inadequate such as sustainability issues, as well as in settings in which individual users' willpower fails them such as weight control. Such regulatory system always articulate advanced data-mining infrastructures (to construct real-time representations of practice), interface design (to frame the visibility of such representations and shape users' awareness) and ethnographic observations (to understand how users relate to such

reflexive affordances). Work has started in this field in the domain of energy consumption through the Gridteam project, funded by the PACA region via the PACALABS, whih was awarded the "Prix de la croissance verte".

8.7.3 Modelizing imagination, innovation and creation

The Chair of Research and Training was founded in late 2010 for a period of five years by two academic institutions, Telecom ParisTech and Rennes 2 University. Four industrial partners follow us in this project: Dassault Systemes, Ubisoft, PSA Peugeot Citroën and Orange, later joined by Alcatel Lucent Bell Labs. The "official" launching was on October 6 at the Palate of the Discovery in Paris. The financing has been brought by Paris-Tech Telecom, Rennes University and by the partners.

Imagination and imaginary refer here to the many stories and complex dynamic worlds that shape technical objects in the innovation process. Information technology and communications are saturated with social representations, fictions and images, producing differentiation or mimicry. These "technologies of the mind" such as video games, virtual worlds or 3D world, seize the "raw material" of the imaginary, model and transform it. Conversely, those imaginaries are always more technological producing an intensification and an acceleration of innovation. But another temporality acts deeply, that of social representations that operate over very long periods, such as a memory broadcasts, informing imaginaries of actors and objects. At the intersection of those trajectories, social and cultural representations are crystallized in concepts and objects, aggregating themselves into "new artificial worlds", in turn feeding on new imaginaries. The challenge of this new chair is to explore the possibility of modeling those worlds at the intersection of computer science, design and the humanities.

8.8 References

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Part IV

Signal and Image Processing

Chapter 9

Audio, Acoustics and waves (AAO)

Head G. Richard (P)

Permanent staff R. Badeau (MC), B. David (MC), Y. Grenier (P), N. Moreau (P, until March 2010), S. Essid (IE), J. Prado (MC);

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PostDocs, engineers and sabbaticals M. Lagrange (Postdoc,10/08-09/09), T. Fillon (Postdoc,10/08-), B. Mathieu (Engineer,10/08-12/10), A. Dielmann (PostDoc, 11/10-03/11), A. Drémeau (PostDoc, 09/11-).

External collaborators L. Daudet (ESPCI ParisTech), O. Derrien (LMA-Marseille), E. Vincent (IRISA), L. Devillers (LIMSI-CNRS), T. Sikora (Technical Univ. of Berlin), L. Girin (GIPSA-Lab), N. O'connor (Dublin City University).

Permanent staff [*Institut ; CNRS*] ; post-docs	[6.3 ; 0] ; 1.9
PhDs	9.3
Defended PhDs	9
Defended HDR	1
Journal papers [published, in press]	[23 ; 0]
Chapters and books [published, in press]	[7 ; 1]
Conference papers	57
Patents and software	[1 ; 1]
Contractual income 2005–2009 (june) [Private ; Public ; European] (k€)	[?; ? ; ?]

The AAO (**A**udio, **A**coustical and waves) research group is now focused on the activities previously reported under the Audio Signal Processing (*AudioSig*) project. The activities of the Optical Signal Processing (*TOS*) project have been transferred to the INFRES department in March 2009 and are entirely reported in section **??**.

9.1 Objectives

The aim of this research group is to develop digital audio signal processing methods in order to propose innovative solutions to the main problems linked to audio (speech, music,...) in multimedia applications. Our interests encompass the complete processing chain from sound capture and transmission to sound restitution. Work is conducted on both a methodological level to develop new sound representations and models especially for musical signals on their application to practical problems. In particular, the group is interested in Adaptive methods for high resolution sinusoidal components tracking, sparse representations, Non-Negative Matrix factorization or hierarchical models and on their application to practical problems such as automatic indexing, compression or EEG signal processing. *Source separation* also appears to be at the heart of this research group with contributions at the methodological level and with applications in nearly all the individual research themes. *Audio and multimedia scenes analysis and indexing* currently is the central research theme of the group and includes topics such as broadcast streams segmentation into broad classes of audio events (speech/music/silence/singing,...), musical signals automatic analysis, decomposition and understanding (polyphonic audio source separation, rhythm extraction, multiple fundamental frequencies estimation, main melody extraction,...). Concurrently, a novel research direction on biological signals for Brain computer Interfaces is receiving a growing interest and will be further strengthened with the arrival in march 2012 of a new associate professor in the group.

On a different level, the group has initiated the development of a multimedia indexing and mining platform (called PLATO) which now involves several other groups and has developed a number of software tools, some of them being distributed in open source (YAAFE - an audio feature extractor[**?**], DESAM toolbox - a set of tools for spectral analysis of musical audio [786],[730], ...).

The group is also maintaining tight links and collaborations with both academics (Queen Mary University of London, Dublin City University, Technical University of Berlin, Institut Langevin, IRCAM, INRIA-IRISA, LABRI-CNRS, GIPSA-Lab,...) and industry (RTL, INA, Audionamix, Arkamys, Parrot, ...).

9.2 Results

9.2.1 Audio and multimedia scenes analysis and indexing

Researchers R. Badeau, B. David, S. Essid, Y. Grenier, J. Prado, G. Richard;

Highlights :
> **Collaborations:** With industry (RTL, INA, Audionamix) and academics (Queen Mary University, Dublin City University, Institut Langevin, IRISA, IRCAM, LABRI,...)
> **Projects** Network of Excellence IST-Kspace (*Knowledge Space of Semantic Inference for Automatic Annotation and Retrieval of Multimedia Content*), Network of Excellence 3DLife (*Bringing the Media Internet to Life*), OSEO-QUAERO (*Towards multimedia and multilingual search engines for professional and general public applications*); ANR DreAm (*Active music listening*);
> **Prize** PhD prize in 2010 (jointly awarded by EEA club, GRETSI and ISIS) (N. Bertin)

Models and signal representations

This activity is following several research axes. The first direction, which is on a rather methodological level, aims at developing generic signal models and representations with a specific focus on audio signals, recently extended to multimodal signals. An increased effort was dedicated to

sparse signal representations with a particular interest on those based on Matching Pursuit (MP), Probabilistic Latent Component Analysis (PLCA) or Non-negative Matrix factorisation (NMF), that allow to decompose a signal using a limited number of atoms or basis functions. Several very interesting results were for example obtained for NMF concerning the stability of multiplicative update algorithms ([711, 749], or the description of beta-divergence as a subclass of Bregman divergence [727]. Several extensions of the NMF were also explored including the introduction of a new generalized model for High-Resolution NMF [748], the extension to multichannel [882], and the proposal of a general formulation of underdetermined source separation as a problem involving Gaussian Processes [734]. The applicability of these methods to generic problems such as audio indexing in the (scalable) compressed domain [743], audio source separation or music signal indexing was demonstrated by introducing specific constraints deduced from the audio signal properties (use of harmonicity or temporal constraints for music transcription [714, 751, 746], use of source production or timbre models for source separation [718, 717], use of time-frequency activations to model non-stationary audio events [726],...). This methodological effort explores both deterministic and statistical approaches.

Audio indexing and blind source separation

The second direction concerns the different facets of audio indexing and audio source separation which are two intricate problems. Indeed, efficient source separation eases the transcription of the resulting sources and efficient audio indexing facilitates the source separation. In music signal transcription, the group is directly interested in the four main problems which are *multiple fundamental frequencies estimation* (e.g. detection of simultaneous notes in a polyphonic musical recording [723, 746, 766]), *rhythmical information tracking* (tempo and beat estimation [784], *harmonic information estimation* (recognition of the chords sequence [813, 880, 881]) and *timbre recognition* (musical instrument recognition in polyphonic audio [728]). Whenever possible, the results obtained are submitted to national or international evaluation campaigns. In particular in 2011, our group has obtained the best results in several subtasks of the Quaero competitive internal evaluation campaigns.

Source separation approaches were developed for specific music transcription tasks such as piano transcription [723]) and main melody estimation (by use of a NMF-based source-filter model for separating the singing voice from the musical accompaniment [717]) but also for specific audio rendering tasks such as stereo signal remastering [882]. A novel research direction was also pursued along these lines for situations where prior information is available about the sources [735]. This so called *Informed Source Separation* problem bares several similarities with multichannel audio coding in the extreme cases where the sources are available at the coding side and a novel framework was recently proposed to close the gap between audio source coding and source separation domains [805].

Multimedia streams segmentation

The third research direction is dedicated to the multimedia streams segmentation into broad classes of events with application to *broadcast multimedia streams* (speech/music segmentation [806], TV show structuring [812, 745]) and *musical streams* (Audio fingerprint [762], musical sound objects decomposition for electroacoustic music [771], music similarity [764, 765, 732], audio-to-score alignment [729] or more recently to dance performance analysis [768, 760]). At the methodological level, our efforts in this field is mostly based on statistical discriminative approaches and a special interest has been directed to kernel-based methods (Support Vector Machines, sequence kernels, probabilistic distances, kernel change detection, kernel LDA,...) and more recently to hybrid kernel and Bayesian network based methods. Our emphasis is targeted to the incorporation of prior knowledge on the nature and structure of the streams processed, typically temporal dependencies and/or inter-stream correlations/dependencies, both at the signal

level and the semantic level, possibly using ancillary information attached to the content (available meta-data, tags, notices,...) and/or user interaction (relevance feedback).

9.2.2 Sound capture, separation and rendering

Researchers B. David, Y. Grenier, J. Prado, S. Essid, G. Richard;

Highlights :
   Collaborations: K. Abed-Meraim (STA), European project partners
   Projects CapDigital-ROMEO (*a project within "pôle de compétitivité CapDigital, lead by Aldebaran Robotics and aiming at creating a humanoid robot*), Network of Excellence 3DLife (*Bringing the Media Internet to Life*), FP-7 Reverie (*REal and Virtual Engagement in Realistic Immersive Environments*)

The objective of this theme is to improve sound field analysis and synthesis capabilities by developing specific digital signal processing methods.

Current work tackles the difficult problem of humanoid robot audition which needs, using a limited number of sensors, to be robust to movements of the robot and to highly variable environments.

This work is part of the Romeo project that aims at building a humanoid robot (Romeo) that can act as a comprehensive assistant for persons suffering from loss of autonomy. Our approach follows a two-stage blind source separation strategy. The first stage consists in a fixed beamforming preprocessing to reduce the reverberation and the environmental noise. Due to the highly constrained context of robot audition, pre-recorded Head Related Transfer Functions (HRTFs) are used to estimate the beamforming filters. The use of the HRTF to estimate the beamformers allows to capture the head and torso effect on the manifold of the microphone array. The second stage is a blind source separation algorithm based on a l_1 norm minimization sparsity criterion. Promising results were obtained with several different configurations and highlighted the merit of the fixed beamforming preprocessing for improving the separation performances [793, 736]. A recent extension was also proposed by using a modified l_p norm blind source separation criterion based on the source sparsity in the time-frequency domain. We followed a tempered approach where the sparsity constraint could be reinforced by varying the parameter p of the l_p to dynamically change from l_1 to l_0 norm. This variation is driven by a sigmoid function which allows to obtain smooth transition and to avoid the divergence of this tempered approach. The merits of this method were demonstrated and compared to more classical scheme [792].

Another axis in this domain relates to signal capture in reverberant environment using a single sensor and a dedicated collaboration with the company Arkamys has been recently started to develop novel dereverberation algorithms. Finally, under the framework of the two European projects 3Dlife and Reverie, a growing effort has been dedicated to multimedia scene capture (e.g. dance scenes) using a large variety of heterogeneous sensors. Such parallel heterogeneous data captures imply complex synchronization mechanisms but permit to tackle unexplored directions for complex multimedia scenes analysis and interpretation. This was already highlighted by the two preliminary studies on dance scene analysis that were selected as finalist for the 2011 Grand Challenge of the ACM Multimedia [768],[760].

9.2.3 Sound sources compression and informed source separation

Researchers N. Moreau, G. Richard, R. Badeau

Highlights ANR-Dream, academic collaborations (Univ. of Toulon, INPG Grenoble, ESPCI ParisTech, IRISA-Rennes)

In audio compression, the work was mostly dedicated to low to medium bit rate parametric audio coding. For low bit rate music coding applications, parametric coders are an efficient alternative to transform coders. In particular, sinusoidal modeling is widely used in response to the fact that most real-world audio signals are dominated by tonal components. Less used, the exponentially damped sinusoidal model (EDS) combined with a variable-length time segmentation is however considered as more powerful, but at the cost of an increased number of parameters. Our work has shown, however, that it is possible to design a joint scalar quantizer for amplitude, damping and phase parameters and obtain increased coding capabilities compared to the more traditional sinusoidal model [756].

On the other hand, investigations were pursued to develop highly scalable transform coders which can seamlessly operate from very low bit rate up to transparency. To that aim, sparse overcomplete representations are used to decompose the audio signals over a redundant union of bases (such as Modified Discrete Cosine Transform bases at different scales). It was also shown that the high flexibility of the signal representations used in this coder allows to tackle various audio indexing tasks (such as beat tracking or musical genre recognition) directly in the transform domain [743] or to perform a large variety of music similarity tasks or structural-based audio coding [795, 796]. More recently, a novel Random Matching Pursuit algorithm was designed which allowed to simulate a local search in a larger dictionary while operating at the cost of a search in a sub-sampled dictionary. On a more transversal axis, a comparative study of sparse greedy algorithms that were separately introduced in speech and audio research communities was conducted. It was in particularly shown that the Matching Pursuit (MP) family of algorithms (MP, OMP, and OOMP) are equivalent to multi-stage gain-shape vector quantization algorithms previously designed for speech signals coding. Following this unified view, a new family of algorithms was introduced based on cyclic minimization principles and on the recent Cyclic Matching Pursuit [721].

In parallel, our work on Informed source separation allowed us to propose a novel framework to link the two domains by exploiting source separation models and principles for multichannel audio coding. This novel method lead to higher performance than those possibly achievable by standard approaches such as the standardized Spatial Audio Object Coding (SAOC) [805].

9.2.4   Biomedical signals analysis

Researchers   J. Prado, S. Essid, Y. Grenier;

Highlights   DGA Project MEEGAPERF (*Monitoring EEG pour l'Anticipation des PERFormances* European Project FP7-Verve (*Vanquishing fear and apathy through E-inclusion: Personalised and populated Realistic Virtual Environments for clinical, home and mobile platforms*)

The other research direction is dedicated to the analysis of biomedical signals and especially electroencephalogram (EEG) signals recorded on asleep subjects using a single pair of sensors. Our approach to this problem has two technological breakthroughs since it aimed at an automated analysis (and not only visual) and uses a single channel EEG. The efficiency and robustness of the method developed have been measured and experimentally validated. Another application of interest concerned the analysis of biological data about colonic transit time (CTT). In particular, a dedicated approach was designed to robustly estimate this colonic transit time even in situations where the patient omits to ingest the radiopaque markers for one or two days [715].

The effort of the group in the domain of biological signals processing (and especially multichannel EEG analysis) has been recently strengthened with the acceptation of two research projects. The first project (MEEGAPERF), started in september 2009, aims at automatically providing information in real time on the psychological state of a patient from the analysis of cerebral activity using portable devices. The second project (FP7-Verve) aims at developing dedicated tools to support the treatment of people who are at risk of social exclusion due to fear and/or apathy associated with a disability. Our planed work is to automatically analyze the user's emotional state based on the processing and fusion of various biological signals, be it the audio-visual

stimuli presented to the patient, or the signals captured by the different audio-visual, motion and biological sensors (including EEG and ECG electrodes) used to monitor him/her. The arrival of a new associate professor in biomedical signal processing for Brain Computer interfaces will also allow to further develop this research direction.

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Chapter 10

Statistics and Applications (STA)

UPDATE PHD POSTDOC SAB (period is july 2009 - december 2011)

Team leader F. Roueff (P, on sabbatical leave at Univ. Catholique de Louvain, Belgium, 09/2010–12/2010).

Faculty K. Abed Meraïm (MC), G. Blanchet (DE), P. Bianchi (MC), O. Cappé (DR CNRS), J-F. Cardoso (DR CNRS), M. Charbit (P), S. Clémençon (P), C. Févotte (CR CNRS), G. Fort (CR CNRS), A. Garivier (CR CNRS), J. Jakubowicz (MC, until 10/11), C. Lévy-Leduc (CR CNRS), E. Moulines (P), J. Najim (CR CNRS), F. Roueff (P).

PhD students A. Attaya (11/10–), S. Audière (10/08–12/11), S. Barembruch (10/07–09/10), A. Bader (12/10–), E. Chautru (10/09–), A. Dematteo (10/11–),M. Depecker (10/07–12/10), M. Jala (11/10–, also with Orange Labs Issy-Les-Moulineaux), E. Kaufmann (09/11–), M. Kharouf (01/07–06/10), O. Kouamo (09/07–01/11, also at Univ. Yaoundé 1, Cameroon), N. Ksairi (10/08–03/10, also with Supélec), S. Le Corff(10/09–), A. Lefèvre (10/10–, also with INRIA/Sierra) A. Lung-Yut-Fong (10/08–12/11), N. Mahler (02/08–12/11, also at ENS Cachan), G. Morral Adell (10/11–), S. Philippi (10/07–11/10), S. Robbiano (10/09–), P. Sendorek (04/11–),A. Schreck (09/2011–), N. Sokolovska (11/06–02/10), M. Thameri (10/10–), J. Villard (11/08–12/11, also with Supélec), T. Wohlfarth (02/10–), J. Yao, R. Zhang (10/10–), B. Zheng (02/10–).

Post-docs, sabbaticals T. Rebafka (12/09–09/10), O. Dikmen (02/10–01/12), C. Dhanjal (11/09–10/11), B. Miasojedow (10/11–08/12), R. Gaudel (09/10–08/11), A. Kammoun, L.-V. Lozada (02/10–08/10,02/11–08/11, N. Mahler (08/11–), L. Oudre (10/11–01/12), D. Rohde (07/10–06/11), A. Saumard (11/10–11/11); M.S. Taqqu (Prof. at Boston Univ., 3 months), V. Reisen (MC, Vitória Univ., Brazil, 3 months).

Faculty [IT, CNRS]	[5.5, 5.3]
PhD students	7.2
Post-docs, sabbaticals	4
Defended theses	6
Defended HDR	4
Journal papers [published, to appear]	[75,32]
Papers in conference proceedings	96
Grants [public, private, European] (k€)	[?,?,?]

10.1 Objectives

During the last twenty years, scientific discovery has become increasingly dependent on the collection and interpretation of data and, more generally, quantitative information. There's a general consensus that the core academic disciplines that are most relevant to the information society encompass computer science, mathematics and statistics. The Statistics and Applications (STA) group at LTCI plays an important role in this context by focussing on statistical methods and their application in domains relevant to the information society at large.

The members of the STA group are actively participating to teaching, typically at the master level and in the fields of probability, statistics, signal processing, machine learning and applied mathematics, at Télécom ParisTech but also in several other Grandes Ecoles of the ParisTech institute (Ecole Polytechnique, ENSAE) and universities (M2 *Modélisation aléatoire* at Paris 7 Denis Diderot, M2 *Modélisation Vision Apprentissage* at ENS Cachan, M1 *Mathématiques de la Modélisation et de la Décision* at University Paris-Dauphine).

The STA group has developed long term research collaborations with several academic Parisian partners such as Univ. Paris 7 Denis Diderot (LPMA and ADAMIS), Univ. Paris 10 Nanterre (MODAL'X), Univ. Paris-Est (IGM), Institut d'Astrophysique de Paris, Univ. Paris-Dauphine (Cérémade), research groups in other ParisTech schools (CMBIO, Mines and CERMICS and CERTIS, Ponts) and with the Ecoles Normales Supérieures Ulm (INRIA projects TREC and WILLOW) and Cachan (CMLA). Such collaborations are essential to the group for achieving long term research programs, and, more generally, for exchanging ideas and views within a stimulating academic environment.

These academic relationships parallel industrial partnerships. The latter have been developed in the framework of national research projects (ANR), bilateral contracts, or the funding of PhDtheses (through CIFRE conventons). Beside favoring our financial autonomy, such partnerships bring practical applications which are helpful for our opening and to remaining active on new research prospects. In the last years, regular industrial partners include the Commissariat à l'Energie Atomique (CEA), Thales Avionics, Renault, France Télécom R&D and Direction Générale de l'Armement (DGA), Amesys, Natixis, Liligo.com.

The group enjoys a high national and international recognition with editorial board members in high quality journals such as Bernoulli, ESAIM P&S, Stoch. Proc. and their Appl. (E. Moulines) and the Journal of the Royal Statistical Society, Series B (O. Cappé), DSP journal (K. Abed Meraïm) as well as regular participation as program comity members in the major international conferences(IEEE ICASSP, IEEE statistical Signal Processing workshop, International Conference on Machine Learning, Neural Information Processing Systems, European Signal Processing Conference) or associate editors of special issues (Journal on Advances in Signal Processing). The group regularly organizes or co-organizes scientific events such as the summer school (C. Févotte, *Ecole d'Eté en traitement du signal et des images* in Peyresq (2010)), special sessions in international conference (G. Fort, AMSDA 06/11); national workshop (G. Fort, GDR ISIS

11/11, P. Bianchi, GDR ISIS 02/12), as well as recurrent scientific seminars in the Parisian region (*séminaire parisien de statistiques*, ParisTech Machine Learning reading group *Smile*). E. Moulines received the Silver Medal of CNRS in October 2010, for his work on Probabilities applied to Signal Processing and Machine Learning. He was awarded the FRANCE TÉLÉCOM award of the french Science Academy (grand prix de l'Académie des sciences).

C. Lévy-Leduc and F. Roueff were invited to give talks at the 58th World Statistics Congress of the International Statistical Institute (2011) and at the "Journées MAS" in 2010. P. Bianchi was invited to give talks at the 5th ICST International Conference on Performance Evaluation Methodologies and Tools (2011) and at the "Journées MAS" in 2010, along with C. Lévy-Leduc and F. Roueff.

10.2 Main results

10.2.1 Statistical Learning

Contributors O. Cappé, A. Garivier, S. Clémençon, C. Févotte, C. Lévy-Leduc, E. Moulines, F. Roueff.

Projects ANR projects MGA (Graphical Models and Applications, 2008–2011), BEMOL (Prediction of internet users' behavior, simulation and collaborative filtering, 2008–); Contracts with France Telecom R&D (two theses) and and Liligo.com (1 phd thesis), Renault (1 phd thesis).

The group has a long standing interest in **graphical models** and, more generally **Bayesian methods**. In the context of the MGA project, we contributed both to general methodological questions (in particular regarding the online learning of parameters [1039, 1028]) and to the advance of methods for statistical natural language processing. On the latter topic, as a follow up to our work on the use of Lasso (or L1) type regularization for training of large scale conditional random field (CRF) models [894], we developed an highly efficient software called `Wapiti` [1007]. `Wapiti` is faster than existing alternatives and is highly competitive for sequence tagging tasks as demonstrated, in particular, by the independent evaluations posted on MLcomp `http://mlcomp.org/`, a community website for objective comparison of machine learning programs. On the other hand, we have continued our statistical investigations on Variable Length Markov Models (see for instance [859]).

Since 2007, the group has a raising interest in **reinforcement learning** and its applications to telecommunications. The PhD of Sarah Filippi (2007-2010), funded by Orange Labs, was motivated by cognitive radio problems [833] and targetted internet advertisement [985]. These non-stationary applications brought us into investigating adapted bandit algorithms [988]. We also strongly defend the use of Kullback-Leibler divergence in optimistic algorithms: we proved in [987] the optimality of a resulting upper-confidence bound algorithm for bandit problems, and we proposed in [953] an improved algorithm for reinforcement learning in discrete Markov Decision Processes. Recently, we joined the ANR project Bandhits and co-advise a new PhD thesis on Bayesian methods for bandit problems. Moreover, in the PhD thesis of Marjorie Jala funded by Orange Labs, we propose active learning methods for the estimation of upper quantiles of the exposition to electromagnetic fields which are strongly inspired by bandits algorithms.

In the context of supervised learning, significant advances in the ranking problem from practical and theoretical perspectives both at the same time have been made in [843], [844], [839] and [840]. Strong empirical evidence supporting the efficiency of the techniques thus developed are presented in the PhD thesis defended by Marine Depecker (2007/10, in collaboration with Renault Technocentre). This work is now prolongated by the PhD thesis of S. Robbiano, currently considering "multi-class" extensions and plug-in approaches, see [969].

Unsupervised ranking, termed "rank aggregation" sometimes, is also . It is a crucial issue in e-commerce, in database middleware or in information retrieval. In the context of the Digiteo project

Bemol (in collaboration with ENS Cachan and the company "Mille-Mercis"), novel techniques for rank aggregation have been developed in [968], [967] and [989], offering promising alternatives to the classical "median approach". In the unsupervised domain, theoretical grounds for pairwise clustering methods are set in [956].

Statistical learning based on functional data is another emerging topic of the group. Whereas, the PhD thesis of N. Mahler (2008/10, in collaboration with ENS Cachan and Strategic Risk Management) and that of R. Zhang (2010/13, in collaboration with ENS Cachan and BNP Exane) deal with applications of machine-learning to Finance, where input and output data are naturally multivariate time-series, the PhD thesis of Till Wohlfarth focuses on travel price forecasting, *cf* [1031] and [1032], and also faces issues raised by time-series in the context of nonparametric prediction. Extensions of recently developed nonparametric scoring methods have also been proposed in the functional situation, see [959]. More generally, techniques for dealing with structured data such as graphs have also been studied within the group (projects ANR Viroscopy, Digiteo Bemol), see [964], [957], [958], [1042] or [965].

Finally, the design of model selection techniques based on data-dependent complexity penalization is a future line of research of the group, see [1030] (Futur & Rupture "Meta-Rank" 2010/11, Digiteo project "Crank-Up" in collaboration with the Lip6 of UPMC 2011/12).

10.2.2 Blind Source Separation and Identification

Contributors K. Abed Meraïm, J-F. Cardoso, C. Févotte, M. Charbit, E. Moulines, A. Garivier, P. Bianchi.

Projects ANR project TANGERINE (Theory and applications of nonnegative matrix factorization, 2009–), research contract with CEA, PEA project AINTERCOM with DGA/Amesys (Plan d'étude amont, 1 phd thesis), Cap Digital project ROMEO funded by Ile-de-France region (1 thesis with AAO team), research contract with WITHINGS (Master thesis).

Blind source separation is an important topic of statistical signal processing. In the ROMEO project, in collaboration with AAO team, our task is focused on the blind source separation (BSS) topic using a microphone array. Source separation is a very important step for human-robot interaction: it allows latter tasks like speakers identification, speech and motion recognition and environmental sound analysis to be achieved properly. Within this framework, we focused on the challenging problem of blind source separation in a real reverberant environment using combined beamforming and sparsity based BSS techniques [793, 792].

Data is often nonnegative by nature, consider for example pixel intensities, amplitude spectra, occurrence counts, food consumption, user scores or stock market values. Nonnegative matrix factorization (NMF) is a linear regression technique with growing popularity in the fields of machine learning and signal/image processing. NMF, and its extension to nonnegative tensor factorization (NTF), are young research topics that call for answers to many open problems. The background for most of the research on NMF in the Stats group is the ANR project TANGERINE. The following topics have been addressed: model selection and learning algorithms [855],factorization with structural constraints [803, 1011, 981], online and stochastic algorithms [1012, 982]. Several applications have been considered such as music transcription [880, 881], audio source separation [? 1040] and identification of dietray behaviors [841].

A final field of interest for non-cooperative communications is **blind signal source identification** (or detection). It is assumed that the signal coming from an unknown transmitter has been intercepted. In the context of AINTERCOM project, we developed blind demodulation approaches using approximate Maximum Likelihood methods [820], [819].

10.2.3 Sensor Networks

Contributors K. Abed-Meraim, P. Bianchi, M. Charbit, G. Fort, J. Jakubowicz, E. Moulines, J. Najim, F. Roueff.

Projects ANR projects SESAME (consistent estimation and large random matrices), SVELTE (Système d'évaluation de la dépense énergétique et de la condition physique pour la prévention et le traitement de l'obésité), C-FLAM (Coordination Flotilla Localization and Mapping), research contracts with THALES-Valence (1 phd Thesis).

Our interest lies in applications of mathematical and statistical tools to the performance evaluation and the optimization of sensing and communication systems. The term *sensor* should be understood in a wide sense, including physical sensors (accelerometers, microphones, etc.), smart phones, processors or mobile robots. Both centralized and decentralized network architectures have been investigated. Centralized systems are characterized by the existence of a fusion center which gathers and processes the sensors' observations as a whole. On the opposite, decentralized systems are formed by autonomous sensors and rely on distributed algorithms to achieve the global mission. A large part of the results in this theme have been obtained in collaboration with the COMNUM research group (COMELEC) (see [7, 872, 941] for some examples of joint works).

In the framework of **centralized systems**, a special attention has been devoted to applications to **source detection and localization**. In the context of a joint work with the CEA and CNRH-hospitals (ANR project SVELTE), signal processing and classification methods have been applied to accelerometric data collected by body sensors [921]. An industrial contract with CEA leaded to original algorithms for the localization of infrasound sources and the estimation of their angles of arrival [**?**].

Motivated by application to *cognitive radio* and sensor networks (ANR project SESAME), we investigated several problems related to hypothesis testing in centralized sensor networks. We analyzed the error probabilities of different test statistics for various probabilistic model [7, 828, 830, 921]. In the later references, original methodological tools are developed in the asymptotic regime where the number of sensors tends to infinity, allowing to obtain closed form expressions of the **error exponents** associated with the tests. In particular, the design of relevant quantizers maximizing the error exponent is an important issue, which has been studied in [921]. On the otherhand, **random matrix theory** has been used as a central tool for the analysis of detection problems in large sensor networks. For instance, the study of the fluctuations and the large deviations of the extreme eigenvalues of sampled covariance matrices are crucial to characterize error exponents [828]. In parallel, random matrix theory has also been extensively used for solving wireless communication problems. We have recently been able to complete the performance analysis of *Ricean* Multiple Input Multiple Output (MIMO) channels [**?** 864]. The analysis of Ricean channels is difficult because of the presence of a line-of-sight component. A thorough study of the mutual information of Ricean channels has been performed, culminating with the computation of the ergodic capacity.

In the framework of **decentralized systems**, we investigated the issue of distributed optimization and distributed statistical estimation by means of **gossip algorithms**. Gossip algorithms provide efficient cooperation techniques which allows the sensor to exchange messages and share their local information in an efficient fashion, in such a way that a consensus is eventually achieved in the network. We study the convergence of these algorithms in [942] and in a recent journal submission, and analyzed the asymptotic behavior of the estimation error in [941] where we also discuss application to power control. Applications to smart grids have been investigated in [973]. In the context of ANR project C-FLAM, we also investigate an application to motion coordination of autonomous underwater vehicles in a recently submitted paper. In the scenario of large wireless communication networks, we also investigated distributed resource allocation in [872]. Finally, a new communication protocol for *relay channels* has been proposed and analyzed in [1004] and in a journal paper currently in revision.

10.2.4   Monte Carlo Methods

Contributors O. Cappé, S. Clémençon, G. Fort, E. Moulines.

Projects ANR Projects `BigMC` (Issues in large scale Monte Carlo, 2009–2012), `C-FLAM` (Coordination Flotilla Localization and Mapping, 2008–2011); `Siminole` (Large-scale simulation-based probabilistic inference, optimization, and discriminative learning with applications in experimental physics, 2011–2014) and `Viroscopy` (Stochastic modeling and statistical inference for propagating infectious diseases: from micro to macroscopic behavior , 2008–2011). Digiteo project `Bemol` (2009–2011).

The group has acquired a high reputation in the domain of Monte Carlo methods by working on Sequential Monte Carlo (also called Particle Filtering), Markov chain Monte Carlo (MCMC) and novel Monte Carlo approaches at large. The group contributes actively to methodological and theoretical advances in Monte Carlo methods and also works on selected applications, most often in the context of collaborative projects.

New challenges in MCMC methods deal with adaptive methods and interacting Monte Carlo processes. The group has a strong expertise in convergence analysis of classical MCMC algorithms; in the past two years, the group answered to some of these new challenges by developing new tools for the theoretical study of these new MCMC samplers. These works have been developed in collaboration with researchers from Paris 6, Univ. Paris Est (in the context of the `BigMC` project), and Univ. of Michigan (USA) [815, 816, 1038, 857].

In the context of the ANR project `C-FLAM`, lead by the LIRMM, the group developed new Simultaneous Localization and Mapping algorithms. Our approach consists in answering the Localization problem by using Sequential Monte Carlo methods, and the Mapping problem by adapting online Expectation-Maximization algorithms (previously proposed by our group [832, 1039]) [1009, 986].

Interacting and branching particle system techniques and sequential Monte-Carlo methods have been developped and used for *rare event simulation/probability estimation* in the context of food risk analysis and that of mathematical epidemiology (ANR project `Viroscopy` - 2008/11), see [842] and [826]. In [989] (Digiteo project `Bemol` - 2009/11), dedicated MCMC techniques have been developed in the purpose of rank aggregation.

Following our past experience in the context of the ANR project `ECOSSTAT`, where the group contributed to the development of an original adaptive importance sampling scheme [922, 869] (with associated distributed software implementation [869]) for Bayesian analysis of multi survey cosmological data, we launched a new project in this field in 2011. This project called `Siminole` and also funded by the ANR is lead by the LAL in Orsay and our contribution is focused on the exploitation of cosmic ray data gathered in the context of the Auger experiment.

10.2.5 Time Series

Contributors O. Cappé, M. Charbit, S. Clémençon, C. Lévy-Leduc, E. Moulines, F. Roueff.

Projects Research contract with Natixis (1 phd thesis), Research contract with Echosens (1 phd thesis), CNRS-FRS-WBI mobility program, Project DGA REI (Recherche Exploratoire et Innovation) ISREPTMu (Interception de signaux radar en présence de trajets multiples), ANR project Mataim (Anisotropic models for textures with applications to medical imaging).

Following the thorough analysis of semi-parametric Wavelet methods for estimating the **long memory parameter** that we conducted in the past years, we have explored new directions in this topic: robust estimation of the memory parameter ([870]), non stationary (change-point and locally stationary) long memory modelling ([1041, 871, 891]), non-Gaussian and non-linear long memory processes ([837, 888]). We have studied the asymptotic properties of a new robust estimator of the autocovariance of Gaussian processes having either short or long-range dependence in [876]. These results have been established thanks to the asymptotic properties of general U-processes in the long-range dependence context of [875]. A large part of these works were conducted in a long standing collaboration with M.S. Taqqu (Boston Univ.).

We also pursued our work on the topic of **change point** detection. The method proposed in a previous research project for centralized anomaly detection in the Internet traffic has been

extended to deal with a decentralized anomaly detection approach in [878] and [1017] in which a robust change-point detection method based on multivariate rank statistics is proposed. Finally, we proposed a multiple change-point estimation with LASSO in [865].

The Markov assumption being among the weakest assumptions involved in time series modelling, renewal theory for **Markov processes** has been used for analyzing the (asymptotic and non asymptotic) behavior of sample means, U-statistics and extreme-value statistics based on general Markovian data, in [824], [838] and [825]. Preliminary extensions to Hidden Markov Chains are developped in [966].

Ongoing applications in statistical signal processing based on time series or random fields modelling include radar processing and medical diagnosis [1026, 1213].

10.3 References

10.3.1 ACL: Articles in ISI-Indexed Journals

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10.3.2 INV: Invited Talks

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10.3.4 OS: Books and Book Chapters

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Chapter 11

Image processing and understanding (TII)

Team leader I. Bloch (P).

Faculty A. Almansa (CR1 CNRS, HDR), E. Angelini (Assoc. P, HDR in 2011, on leave in Australia for six months in 2010), I. Bloch (P), T. Boubekeur (Assoc. P), H. Brettel (CR1 CNRS, HDR), M. Campedel (Assoc. P), J. Delon (CR1 CNRS, HDR in 2011), E. Eisemann (Assoc. P, since 12/09), Y. Gousseau (P, HDR in 2009), S. Ladjal (Assoc. P), H. Maître (P), P. Memari (CR2 CNRS, since 10/11), J.-M. Nicolas (P), S. Rital (Research Engineer), M. Roux (Assoc. P), H. Sahbi (CR1 CNRS, HDR in 2011), T. Tanzi (P, until 2010), J. Tierny (CR2 CNRS, since 10/10), F. Tupin (P).

PhD students *Defended (dates are for the defense):* E. Aldea (12/09), J. Anquez (9/09), C. Le Men (9/09), D. Lesage (10/09), J. Rabin (12/09), N. Sabater (12/09, with ENS Cachan).
J. Baussé (10/10), M. Bredif (5/10), D. Cerra (5/10), N. Chenouard (1/10), D. Craciun (7/10), G. Fouquier (2/10), B. Galerne (12/10, with ENS Cachan), G. Lehureau (4/10), C. Mallet (11/10), F. Mosca (10/10), T. Napoléon (7/10), G. Palma (2/10), A. Shabou (11/10), H. Sportouche (12/10), N. Widynski (11/10, with UPMC), J. Wojak (12/10).
S. Audière (12/11), P. Birjandi (9/11), P. Blanchart (9/11), M. Bouali (6/11), E. Bughin (10/11, with ENS Cachan), C. Deledalle (11/11), V. Duval (6/11), G. Facciolo (3/11, with Univ. Pompeu Fabra), G. Hochard (3/11), M. Marim (4/11), B. Petitpas (12/11, with Univ. Marne la Vallée), H. Soubaras (1/11), M. Tepper (3/11, with Univ. Buenos Aires), C. Vanegas (1/11), G.-S. Xia (3/11).
Current (dates are for the beginning of PhD): C. Aguerrebere (4/11), N. Bourdis (1/10), B. Buchholz (10/09), J. Caron (10/08, with Univ. Amiens), F. Dellinger (10/10), N. Faraj (12/09), M. Gargouri (11/11), N. Geeraert (9/11), I. Ghorbel (2/09), A. Graciano (9/08, with Univ. Sao Paulo), T. Guillemot (10/10), C. Herold (12/10), M. Hollander (1/10), J. Huang (10/09), Q. A. Le (10/09), Y. Le Montagner (10/10), B. Mazin (9/10), A. Newson (9/10), G. Pizaine (6/09), J.-B. Poisson (10/10), G. Quin (9/10), A. Roman Gonzalez (9/09), L. Schemali (1/11), P. Schmitt (10/11), X. Su (10/11), G. Tartavel (10/11), J.-M. Thiery (10/09), Y. Traonmilin (7/11), G. Vialaneix (12/09), U. Verma (10/10), P. Vo (10/10), Y. Yang (10/10), F. Yuan (9/10-9/11).

Post-docs, engineers and sabbaticals J. Anquez (1/10-6/10), L. Babou (7/09-2/11), A. Bretto (1/10-8/10), F. Cao (9/10-4/11), S. Chevallier (3/11-8/11), S. Dahdouh (10/11-12/11), J.-P. De la Plata (8/09-7/11), E. Erdem (7/09-3/10), F. Fayard (5/10-4/11), G. Fouquier (7/09-3/11), M. Horta (4/11-9/11), S. Lee (7/09-2/11), X. Li (6/09-6/10), M. Lindenbaum (3/11-8/11), K. Loquin (3/10-10/11), A. Marquez (9/9-10/10), M. Moghrani (9/09-8/10), V. Pascucci (6/11), Y. Pinto (3/11-10/11), T. Ritschel (5/10-9/11), X. Rondeau (10/09-3/11), Y. Rouchdy

(10/09-12/10), H. Sportouche (4/11-12/11), O. Tankyevych (1/11-8/11), C. Vanegas (1/11-4/11), A. Zureiki (7/09-10/09).

External collaborators M. Datcu (CoC chair, until 6/10).

Faculty [IT, CNRS]	[11, 4,6]
PhD students	29
Post-docs, engineers and sabbaticals	10
Defended PhD theses	36
Defended HDR	4
Journal papers [published, in press]	[97, 17]
Papers in conference proceedings	172
Chapters and books	24

11.1 Objectives

The objective of the group is to develop methodologies and theoretical tools for image, scene and 3D object processing and interpretation. The main approach consists in solving globally complex problems, based on rigorous theoretical bases, and integrating multiple and complementary techniques, for deriving interpretations from data. Applications focus on medical imaging, aerial and satellite imaging, natural image analysis. Contributions of the group can therefore be found at theoretical level (knowledge and information representation and modeling, in 2D as well as 3D, processing, interpretation and reasoning on spatial data), at algorithmical level (in particular to implement the developed models for large and complex data sets), and at applicative level. The group is well recognized, in both academic, institutional and industrial domains. It has numerous collaborations with other universities, and is supported by grants and contracts. The different research activities are closely linked together, which is one of the strong features of the group.

Over the last two and a half years, two professors left, one to join a research team in Sophia-Antipolis at Mines ParisTech, and the other at the end of the CoC joint laboratory with CNES and DLR. On the other hand, during this period the group has benefited from the appointment of two CNRS researchers and one associate professor, strengthening research axes mainly in computer graphics, but also in medical imaging. The good reputation of the group and its visibility, in France as well as at an international level, are confirmed by the number of publications, but also by the number of collaborations, mentioned below for each research axis, and by its attractiveness for CNRS candidates, post-docs and PhDs.

The scientific animation of the team includes a general seminar and several specific ones (medical imaging, compressed sensing, radar imaging, 3D and computer graphics...). PhD candidates are invited to present their work at the end of the first year of their PhD, so as to gather comments from the whole team and initiate discussions among them, thus favoring cross-fertilization of ideas. A mid-term evaluation is also organized for all PhD candidates. We also pay attention to the accompanying process of the PhD theses, beside the direct scientific supervision, including a help to prepare their future.

11.2 Main results

The main research results obtained during the period mid-2009-2011 are presented below for the research areas of the TII team, both from a theoretical and methodological point of view, and

from an application perspective.

11.2.1 Mathematical methods for images

Faculty A. Almansa, I. Bloch, J. Delon, Y. Gousseau, S. Ladjal, H. Sahbi, F. Tupin.

Projects ANR projects (CALLISTO, MATAIM, OTARIE, FREEDOM), FUI (9th call) CEDCA, Cifre and CNES PhD fundings, CNES research funding, DGA/REI MRIS and Tracking, ECOS Sud (U06E01), STIC AmSud (MMVPSCV).

Collaborators L. Alvarez (U. Gran Canaria, Spain), J.-F. Aujol (U. Bordeaux 1), F. Cao (DxO Labs), V. Caselles (UPF, Spain), T. Buades, A. Desolneux, S. Durand, B. Galerne, T. Hurtut, L. Moisan (U. Paris Descartes), S. Dubuisson (UPMC), M. Lindenbaum (Technion, Israël), S. Masnou (U. Lyon 1), J. Darbon, J.-M. Morel, M. Nikolova (ENS-Cachan), L. Denis (U. Saint-Etienne), P. Musé (U. de la República, Uruguay), J.-C. Olivo-Marin (Institut Pasteur), A. Pardo (U. Catolica, Uruguay), M. Mejail (UBA, Argentine), P. Pérez (Technicolor, Rennes), G. Peyré and J. Salomon (U. Dauphine), J. Rabin (U. Caen), J. Salmon (U. Denis Diderot), M. Sigelle (Télécom ParisTech), A. Sobolevskii (Poncelet Lab., Moscou), L. Vese (UCLA, USA), W. Wang (U. Wuhan, China), A. Bretto (U. Caen).

Texture and natural images modeling

This research theme deals with the stochastic modeling of natural images. First, generative models taking into account scaling phenomena in natural images have been developed. These models (dead leaves, shot-noise, transparent models) are grounded in the theory of marked point processes, whose marks are geometrical structures. The most recent works in this area are concerned with texture synthesis using spot-noise models, see [1100] and the companion online IPOL demo [1], as well as the stochastic modeling of transparency [1099]. Much effort has also been devoted to the study of the impact of various restoration image models on the textured aspects of natural images, as explained below, see [1071, 1084, 1085]. An important achievement is that a model previously developed in our team, the *scaling dead leaves model*, has been retained by the company DxO to evaluate the ability of imaging devices to preserve textures in natural images, and as such is routinely used by the main industrial actors in the domain, ranging from Nikon to the NASA. Oriented toward public audience, the model has appeared in the 2011 FNAC summer catalogue for DSLR cameras.

Image analysis and computer vision.

These last years, we have developed or applied various mathematical tools for the analysis, indexing or matching of images.

Among these tools, let us first mention optimal transportation equations. These equations enable the definition of metrics between weighted features and yield elegant ways to compare images. We have recently proposed two complementary studies on the subject of optimal transportation on the circle, one in a continuous setting [1074] and the other one in a discrete setting [1133, 1135]. This last study compares for different retrieval tasks the transportation metrics with the classical distances used in computer vision.

Another methodological aspect of our researches deals with *a contrario* methods, developed by Desolneux et al. to automatically fix detection thresholds for image analysis. In particular, we applied these methods to the problem of image matching. We have developed a complete chain for the matching of images from local descriptors (such as SIFTs). This procedure encompasses the descriptors themselves, a transportation metric adapted to circular histograms (relying on optimal transportation), an unsupervised matching criterion, and a validation, RANSAC-like

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[1] http://www.ipol.im/pub/algo/ggm_random_phase_texture_synthesis

step [1133, 1335]. In the particular case of block-matching of epipolarly-rectified stereo pairs, the *a contrario* methodology, complemented with more classical criteria to avoid self-similarity and fattening effects has proven very efficient to build up dense sets of reliable matches [1140]. This yields disparity maps computed up to an unprecedented accuracy level, closely matching our theoretical accuracy estimation [1141]. Check also the accompanying online demo [2]. The a contrario methodology also allows for parameterless and unsupervised graph-based clustering [1148] without any shape prior. Applications ranging from high-dimensional data analysis to restoration of images and 3D data are being explored.

Another approach for point matching was developed for change detection problems: a change detection algorithm was introduced, based on a new interest point matching approach combined with the epipolar geometry. The main contribution of our method includes: (i) a statistical-based criterion combined with the geometry of scenes, able to reliably detect changes in pairs of images and (ii) the extension of the method in order to handle archives of videos where the temporal coherency is exploited to further enhance the performances. In this context, the validity of our method is demonstrated through a realistic ground truth including many labeled changes [1229].

Still in a probabilistic framework, during the PhD of A. Shabou, new graph-cut based optimization approaches of Markovian models have been proposed. They rely on a random sampling of sub-sets of states for three global moves (expansion, swap and jump) with associated graph constructions. They allow an efficient compromise between memory size and quality of the obtained optimum [1348].

Among the other tools that we have investigated and applied, let us quote topographic maps. This tool turns out to be particularly efficient for the indexing of satellite images [1118], the indexing of texture [1154] or the analysis of artistic line-drawings [1108], even in the presence of a wide range of geometrical and radiometric changes. The method developed in [1154] is an extension of the classical granulometry from mathematical morphology.

Restoration of images and image sequences

In the last few years, our group has become quite active in the field of image restoration.

In the case of single-frame restoration, many denoising problems have been tackled. We have proposed several extensions and in-depth studies of Non-Local Means methods. In [1085], we propose an in-depth study of such denoising methods and give a method for the automatic and local setting of parameters. In [1071], it is proposed to use adaptive and generic patches to improve denoising results. In [1069], the method is extended in a probabilistic approach, allowing to process images for which a distribution of the parameters of interest is available (Poisson, Gamma, Wishart distributions...). This framework also permits to process vectorial data [1070].

In the domain of impulsive degradations, we have conducted an extensive study of the popular TV-L1 model, showing that it is equivalent to some morphological filtering and acts as a granulometry [1084]. The TV regularization model under local L2 constraints showed effective in the context of irregularly sampled blurred and noisy data [1094, 1205]. It was also shown useful for destriping MODIS images [1123].

In order to restore larger and more extreme degradations of images, we also took interest in image inpainting. We developed an approach relying on the automatic combination of patch-based methods and geometrical interpolation [1056], permitting the restoration of both the texture and the geometry of images over large regions. This subject has also been addressed in a related work on the variational interpretation of copy-paste methods [1112]. Some of the previous works require an accurate knowledge of internal camera parameters like the intrinsic blur kernel (PSF). In [1068] we showed that accurate estimation of the PSF is well posed, without regularization, provided an appropriate white noise image is used for calibration. See the accompanying IPOL demos [3] [4].

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[2] http://www.ipol.im/pub/demo/bms_binocular_stereo_pipeline/

[3] http://www.ipol.im/pub/algo/admm_non_blind_psf_estimation/

[4] http://www.ipol.im/pub/algo/damm_blind_psf_estimation_from_scaled_image_pairs/

Recently, we have oriented an important part of our restoration activity toward multi-frame restoration. This research direction is intimately related to different research projects, in particular one ANR project (ANR FREEDOM JCJC 2007-2011) on movie restoration, one collaborative project with the firm DxO Labs, and one PHD thesis supervised in collaboration with the firm Technicolor. As part of the research project FREEDOM, we have proposed two contributions related to contrast and color: the first one concerns the restoration of local radiometric problems in image sequences [1072], and the second one is an efficient method for the removal of artifacts [1134] introduced by contrast and color changes. Another contribution deals with the detection and restoration of occluding defects in movies [1233].

Tracking

Another contribution based on probabilistic methods addresses tracking issues in image sequences, by incorporating different types of information in the probabilistic model [1091, 1153]. Our approach is based on particle filtering, and we have proposed original ways to introduce spatial relations, represented in a fuzzy set framework (see Section 11.2.2), either between different positions of one object during time, or between several objects for multiple object tracking problems (PhD of N. Widynski). In this case, we also proposed a ranked partitioned sampling method, so as to handle the most visible objects first. Multiple appearance models and adaptive fusion of multiple cues have also been proposed. These new models and the associated algorithms provide better results than state of the art methods, in terms of accuracy of tracking, object association, and handling partially occluded objects. Multiple object tracking has also been addressed using multiple hypotheses methods, for biological applications in cluttered environment [1244, 1245] (collaboration with Institut Pasteur).

Another topic is multi-view tracking of objects in video surveillance, which consists in segmenting and automatically following objects through different camera views. In this work, we present a multi-view object matching and tracking approach based on canonical correlation analysis. Our method is purely statistical and encodes intrinsic object appearances while being viewpoint invariant. We have shown that our technique is easy-to-set, theoretically well grounded and provides robust matching and tracking results for traffic surveillance [1279].

Tracking has also been exploited in segmentation problems, in particular for elongated structures such as blood vessels, using particle filters and minimal paths according to adaptive metrics (see also Section 11.2.5).

A new project on multi-view tracking has also been launched, based on particle filter, to estimate the shape parameters and the pose of a face for authentication based on face matching (collaboration with LIP6 and Morpho, PhD of C. Herold).

Mathematical morphology

In parallel to the work mentioned above on granulometry and TV restoration, our contribution in mathematical morphology concerns the representation and handling of qualitative and imprecise information in different settings, such as formal logics [1043, 1212], including description logics for ontological reasoning, fuzzy sets [1051], and more recently hypergraphs [1226] and bipolar information [1224, 1052, 1296] to model both positive information (observations, preferences) and negative information (constraints). In all these frameworks, we proposed appropriate complete lattices and connectives, leading to good properties of mathematical morphology operations. These operations can then be used for various tasks, such as preference modeling and spatial reasoning.

11.2.2   Image understanding and spatial reasoning

Faculty I. Bloch, M. Campedel, H. Maître.

Main events CIARP 2010 conference.

Projects ANR DAFOE, CNES PhD thesis and research projects funding, collaboration with J. Atif (LRI), C. Hudelot (ECP), J. Inglada (CESBIO), R. Cesar (U. Sao Paulo, Brazil).

Our work on modeling spatial relations within the fuzzy set framework has evolved towards complex relations such as *along*, *surrounds*, *to go across*, *parallel to*, both for individual objects and for groups of objects [1147, 1198, 1361]. New fuzzy connections have also been proposed, and applied to filtering problems [1128, 1132]. These relations are based on mathematical morphology operators, and their use for spatial reasoning was formalized in different settings (PhD of G. Fouquier, C. Vanegas, A. Graciano). One relies on graph-based reasoning, where a graph modeling the available knowledge about a scene (on objects and their spatial relations) guides a sequential segmentation and recognition process [**?**]. The order in which structures are segmented is adapted to each image, by combining spatial relations and saliency information. In case of failure of a segmentation step, a backtracking procedure was proposed as well. Another approach relies on the search for a global solution by expressing the recognition as a constraint satisfaction problem [1129, 1198], or as an inexact graph matching problem [1130]. Finally ontological reasoning was proposed, by introducing mathematical morphology operators in description logics in order to define spatial relation concepts [1296]. In the same line, a preliminary work associating description logics, formal concept analysis and mathematical morphology was developed. The first reasoning service we proposed within this framework is abduction, in order to provide the best explanation of a scene according to the available knowledge [1212].

During the project DAFOE4app (ANR project, 2007-2010), an engineering collaboration between Telecom ParisTech and Mondeca has been initiated. The common goal was to create and develop an interactive tool to assist satellite image interpreters. Results have been obtained, with the support of CNES, in the creation (and free diffusion) of two OWL ontologies: the image ontology is able to describe the image content and the feature extraction process whereas the scene ontology identifies land cover classes; these ontologies integrate spatial relationships between image objects as well as other semantic relationships. A prototype of the annotation tool, based on Mondeca technology has also been proposed. However further engineering development would have been necessary to make it really operational. Such a tool is an ideal way to demonstrate the usefulness of both low-level image processing algorithms and semantic reasoning in the context of satellite image interpretation.

11.2.3 Learning, indexing and retrieval

Faculty M. Campedel, M. Datcu (until 2010), H. Sahbi.

Projects Infomagic, K-space.

Besides recognition and spatial reasoning, spatial relations have also been used in structural learning for image classification, based on original graph kernels including spatial relations [**?**] (PhD of E. Aldea).

Two important projects were completed during this period, Infomagic and K-space, leading to the publications of two books [1388, 1392], as major outcomes of the work carried out within these projects.

This research theme was also developed specifically in the context remote sensing imaging, as described in Section 11.2.6.

Most of the work in machine learning during this period was devoted to visual recognition and search, along three main lines.

Image annotation in interconnected networks & activity recognition. In this work, we introduced a novel image annotation and retrieval approach based on support vector machines (SVMs) and a new class of kernels referred to as context-dependent (CD). The main contribution of our method includes (i) a variational approach which helps designing our CD kernel using both intrinsic features and the underlying contextual information, and (ii) the proof of convergence of the CD kernel to positive definite fixed-point, usable for SVM training and other kernel methods.

When plugged in SVMs, our CD kernel consistently improves the performance of image annotation and retrieval, compared to context-free kernels, on hundreds of thousands of Flickr images [1343, 1142, 1344]. We also extended this CD kernel in order to handle activity indexing and recognition in video sequences [1379].

Conditional random fields for Object Class Segmentation (OCS). In this work, we proposed a novel superpixel-based framework for object class segmentation using conditional random fields (CRFs). The framework proceeds in two steps: (i) superpixel label estimate, and (ii) CRF label propagation. Step (i) is achieved using multi-scale boosted classifiers over superpixels and makes it possible to find coarse estimates of initial labels. Fine labeling is afterward achieved in Step (ii), using an anisotropic contrast sensitive pairwise function designed in order to characterize the intrinsic interaction potentials between objects according to 4-neighborhoods. Finally, a higher-order criterion is applied to enforce region label consistency of OCS. Experimental results demonstrate the effectiveness of the proposed framework [1309].

2D to 3D object retrieval. In this work, we introduced a complete "2D to 3D object" retrieval framework. Given a (collection of) picture(s) or sketch(es) of the same scene or object, the method allows us to retrieve the underlying similar objects in a database of 3D models. The contribution of our method includes (i) a generative approach for alignment able to find canonical views consistently through scenes/objects, and (ii) the application of an efficient and effective matching method used for ranking. The results are reported through the Princeton Shape Benchmark and the Shrec benchmarking consortium evaluated/compared by a third-party. In the two gallery sets, our approach achieves good performance and outperforms the other runs [1127].

11.2.4 Computer graphics, digital geometry and rendering

Faculty T. Boubekeur, E. Eisemann, J. Tierny (and P. Memari since October 2011).

Main events Eurographics Young Researcher Award (E. Eisemann), Honorable mention of the Dirk Bartz Prize for Visual Computing in Medicine [1067].

Projects IP Reverie, NoE 3DLife, ANR Ispace&time, MediaGPU, CeCil, KidPocket, FETUS, CIFRE EDF, CIFRE Useful Progress, "Chaire Modélisation des Imaginaires".

The computer graphics team of the TII group conducts its research activities in 3D geometric modeling, rendering, perception, visualization and computer vision.

In modeling, the group has developed several fast methods for surface simplification, filtering and reconstruction based on linear and adaptive stochastic approaches [1053], separability [1365], locality principles, and variational geometry [1146]. A structuring-curve system has been proposed for deformation, 2D painting [1215], and shape learning to reconstruct scans [1110]. A quad remesher for polygonal surfaces as well as an interactive one has been designed to integrate user constraints in real time [1150]. Another approach has been presented to reuse examplar databases for generating new quadrangulations from predefined styles [1149]. Some of these contributions have been applied for realistic anatomical modeling (see Section 11.2.5).

In rendering, the group has developed new algorithms for global illumination on GPU [1106], in screen- [1295], object- [1138] and hybrid [1338] spaces, and has proposed a new static [1055] and/or spatio-temporal scene analysis for expressive [1235], amortized [1292], and stereo rendering [1263]. A new real time geometry synthesis stage has also been proposed [1387, 1294]. Optical phenomena stemming from virtual cameras (depth of field, lens flare, motion, etc.) have been studied in detail to improve realism but also to offer artistic control [1107, 1114]. Finally, a remote rendering system has been developed [1131].

Several projects have been conducted on the perceptual component of rendering techniques and have led to new methods offering a higher (perceived) screen resolution than the physical one [1078], and a better detail preservation [1079], as well as higher quality stereo rendering [1080].

In visualization, a new approach was proposed to explore interactively large-scale simulations based on a topology pre-analysis [1054]. Also, a new method for topological verification was

able to illustrate the shortcomings of various realizations of isosurface-extraction methods that are publicly available [1093].

In computer vision, a benchmark and a visual research engine [1087] based on a new set of local descriptors and a machine-learning approach have been developed, built around a new system for interactive 2D [1088] and 3D [1146] design, to discover and create content from huge data bases. Another technique registers photos and 3D terrain models to perform automatic geo-localization, object recognition and to add annotations [1214].

11.2.5 Medical imaging

Faculty E. Angelini, I. Bloch, T. Boubekeur, J. Delon (and P. Memari since October 2011).

Main events Joint Lab with Orange Labs (WHIST), Honorable mention of the Dirk Bartz Prize for Visual Computing in Medicine [1067].

Projects ANR (FETUS, Kidpocket, IPHOT), Visiting Scientist fellowship at CSIRO (Australia), MINIARA, CIFRE PhD theses funding. Collaborations with Siemens, Philips, General Electric, Dosisoft, Fovea, Orange Labs (J. Wiart), Institut Pasteur (J.C. Olivo-Marin), ISEP (F. Rossant), U. Columbia (A. Laine), hospitals (Cochin - Saint Vincent de Paul, Bicêtre, XV-XX, Lariboisière...).

Our work on segmentation of normal and pathological brain structures is strongly related to our research in spatial reasoning (see Section 11.2.2), where anatomical knowledge is represented using structural formalisms, and used to guide the segmentation and recognition [**?** 1129] (PhD of G. Fouquier). These ideas have also been exploited in other medical applications. Analysis of longitudinal changes of brain pathologies has been an important focus of research, supported by very active collaborations with several academic and clinical sites. The project on low-grade brain tumor growth has matured [1046, 1206] and has led to the launch of a new PhD co-supervised with the Hospital Lariboisière. A new collaboration with CSIRO was launched, on the topic of longitudinal analysis of brain white matter lesions on Alzheimer patients. Quantitative longitudinal image analysis is likely to become a major field of investigation for our group, with close links being built with the University Paris Descartes, specialized in human and small animal vascular and tumoral imaging for longitudinal evaluation and identification of biomarkers.

Anatomical modeling has also benefited from great activities and new strong links between the medical imaging and the computer graphics teams (see Section 11.2.4). Several joint supervisions of PhD students, post-doctoral fellows and research engineers have led to the strengthening of this activity, focusing on the segmentation of obstetrical images in US and MRI [1207, 1208, 1209] (PhD of J. Anquez), and the design of dedicated modeling tools for the construction of pregnant women bodies from segmented medical images [1047, 1048, 1067], deformed in various positions for dosimetry simulations. In the same line, segmentation of whole body MRI children images for anatomical modeling at different ages is currently addressed [1281]. These works were carried out in close collaboration with Orange Labs, within the joint laboratory WHIST.

Vascular imaging was also an important focus of research, with a collaboration with Siemens Corporate Research (PhD of D. Lesage) and then Philips Healthcare (PhD of G. Pizaine). Stochastic, discrete and continuous methods were investigated for the segmentation of small and large vessels [1308, 1333], with various types of geometric constraints and various levels of supervision and training. A new direction of investigation focuses on the combination of geometric constraints and vessel tree labeling constraints. The long-term collaboration with Columbia University has led to the graduation of a jointly supervised PhD student working on IVUS images, for the segmentation of coronary vessels [1298, 1299, 1300] and the joint supervision of a PhD candidate on the quantification of myocardial strain from 3DUS images. We have also continued the work on the reformulation of deformable models with Surface Function Active [1082, 1083] for real-time segmentation performance.

During this period, the MINIARA project on oncological applications was completed, with contributions on the segmentation of tumors and organs at risk, exploiting complementary information

from PET and CT data (PhD of J. Wojak), and on the follow-up of patients, using constrained level sets approaches [1373]. Dedicated registration tools for protontherapy were also developed (PhD of J. Baussé).

In mammography, we focused on the analysis of tomosynthesis images and developed original filtering [1132] (see Section 11.2.1), and segmentation methods, dedicated to masses, using fuzzy approaches, and spiculated lesions, using *a contrario* approaches [1210, 1325, 1328] (PhD of G. Palma).

A few years ago, a new research track was investigated in biological imaging, in collaboration with Institut Pasteur (PhD of N. Chenouard), with new results on multiple objects tracking in cluttered environment, both in 2D and in 3D [1244, 1245] (see Section 11.2.1). Regarding the activity in optical imaging, the group has launched a fruitful collaboration with Institut Pasteur and the ESPCI/Institut Langevin for the exploitation of Compressed Sensing in microscopy imaging. The Phd of M. De Moraes Marim has led to breakthrough publications introducing CS-based denoising [1315], temporal acquisition schemes and digital holography imaging [1318, 1121] for fast image sampling and efficient image reconstruction in realistic microscopy imaging setups. This work has received a best student paper award at the conference ISBI 2010 [1318]. A new PhD student is now working on the optimization of the image reconstruction process dedicated to temporal CS microscopy imaging [1304, 1306].

A close collaboration with ISEP and XV-XX hospital was launched on eye imaging, using multiple modalities. In optical coherence tomography (OCT) we proposed an original method to detect all retinal layers, using parallel deformable models, which applies in normal and pathological cases, and from which quantitative measures are derived, supporting the analysis of retinal structure variability and the early detection of alterations [1102] (PhD of I. Ghorbel). A recent technique based on adaptive optics was then exploited to detect photoreceptors and estimate their density [1311]. Finally, eye fundus images were used for the segmentation of blood vessels and their classification into arteries and veins [1139].

A new topic was recently launched within the WHIST lab, on brain-computer interfaces (BCI), for large public applications. The first contribution concerns the detection of eye movements and blinking in EEG signals, and their use as control signals for BCI tasks (PhD of Y. Yang). Optimal selection of spatial filters and of the number of electrodes is now addressed.

11.2.6 Aerial and satellite imaging

Faculty A. Almansa, M. Campedel, M. Datcu (until 2010), J. Delon, Y. Gousseau, H. Maître, J.-M. Nicolas, S. Rital, M. Roux, F. Tupin.

Projects CNES PhD theses and research projects funding, ANR EFIDIR, REI-DGA, Magellium, CIFRE Thales, Terra Numerica. Collaborations with DLR (A. Reigber), U. Parthenope II Italy (G. Ferraioli), U. Sao Paulo Brazil (T. Perciano, M. Horta), CEA (R. Binet), U. UPEMLV, IGN.

Within the TerraNumerica project (CapDigital), we extended our work on the processing of **3D point clouds** [1380]. The analysis of 3D point structures with the Hough transform associated to an entropic measure led to the detection of parallel planes and allowed the separation of building facade elements (walls, balconies, windows and doors).

Another axis was the analysis of full-waveform **lidar data** for the automatic classification of urban areas on one side and littoral scenes on the other side. This work demonstrated the contribution of radiometric calibration features to high classification accuracies [1119, 1120] (PhD with MATIS, IGN).

Concerning the generation of **3D models from multiple images**, our focus was the construction of a low cost system allowing non-specialists to make 3D measurements with minimal set of constraints on the image acquisition [1331]. The concerned applications are related to surface roughness and dendrometric parameters measurements (PhD with UPEMLV).

In **stereovision**, recent research focused on high precision and subpixel approaches, in particular by estimating meaningful matches in order to improve disparity maps [1140, 1141].

For **SAR imagery**, research is led at different levels: at the signal level with the development of statistical models and denoising approaches, and at the region or object level, particularly for the fusion of radar and optical imagery.

At the signal level, works on the statistical modeling of SAR images based on Mellin transform have been completed with the introduction of Meijer distributions which allow the definition of a unifying framework [**?**]. Concerning denoising approaches, non-local means extended to a probabilistic framework are very efficient either for amplitude images [1069], or interferometric / polarimetric data [1070] (PhD of C. Deledalle, see also Section 11.2.1). A Markovian formalism and different estimators with adapted optimization approaches define an elegant context for the fusion of multi-channel interferometric data [1098, 1143] (PhD of A. Shabou, REI project).

For pattern recognition and image interpretation, many efforts have been dedicated to the fusion of SAR and optical images (PhD of G. Lehureau, PhD of H. Sportouche) with SVM methods or with explicit object detection and likelihood optimization [1145]. Network extraction has also been investigated with Markovian approaches for SWOT images of rivers (CNES project) and for road detection in a multi-temporal and multi-sensor framework (PhD of T. Perciano). In the PhD of G. Hochard, the analysis of long temporal series on the Serre-Ponçon dam has led to a selection method for interferograms which could be applied for change detection applications.

During the EFIDIR project (ANR MDCO, 2008-2011), theoretical works have been conducted to better understand the problem of complex data interpolation and phase vortex. Concerning glacier monitoring, correlation based approaches on amplitude images have been developed with adapted similarity criteria [1095] (PhD of R. Fallourd). Man-made corner reflectors have been positioned on Argentiere glacier to serve as ground truth and help understanding the backscattering mechanisms of metric resolution images like TerraSAR-X and Cosmo-SkyMed.

The **joint CNES-DLR-Télécom ParisTech Competence Center (CoC)**, created in June 2005, ended in June 2010. Its activities were focused on information extraction and satellite image understanding for both optical and SAR images. Numerous PhD theses have been defended since 2009 on a high variety of subjects going from low level image description [1049], classification [1116] to (semi-) supervised active learning tools [1050] and knowledge representation [1198].

Even if this project is now finished, strong collaborations with CNES[5] are maintained on specific applicative projects (called EXITER, SAFER European project and KAL-Haïti ANR), which were initiated from 2008 to 2011, in the context of rapid mapping [**?**], or more methodological ones, for instance based on hypergraph representations [1266, 1137]. Close relationships with expert interpreters from SERTIT[6] were also developed to better promote the competence center results related to the quick production of relevant land cover maps. SERTIT and CNES provided us with rich datasets to scientifically evaluate information extraction and classification tools and also to derive new products (as processing chains) to be used by interpreters. Hence scientific and applicative evaluations were performed exploiting platforms like KEO (ESA platform) as well as public tools like OTB (Orfeo Toolbox[7]) and GIS (Geographical Information System). Not restricted to engineering tasks, the rapid mapping application leads to research problems like: how to combine information from different images of the same scene? At different times? How to exploit different sources of information like old maps and images? How to integrate object description, semantics and reasoning in interpreters tools like GIS?

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[5]http://www.cnes.fr
[6]http://sertit.u-strasbg.fr/
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