IN PARTNERSHIP WITH:
Institut national des sciences appliquées de Lyon

Activity Report 2015

Project-Team SOCRATE

Software and Cognitive radio for telecommunications

IN COLLABORATION WITH: Centre of Innovation in Telecommunications and Integration of services

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Networks and Telecommunications

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Project-Team SOCRATE

Creation of the Team: 2012 January 01, updated into Project-Team: 2013 July 01

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Computer Science and Digital Science:

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1.2.5. - Internet of things
1.2.6. - Sensor networks
1.5.2. - Communicating systems
5.9. - Signal processing
7.8. - Information theory

Other Research Topics and Application Domains:

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6.5. - Information systems
6.6. - Embedded systems

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2. Overall Objectives

2.1. Introduction

The success of radio networking relies on a small set of rules: *i)* protocols are completely defined beforehand, *ii)* resource allocation policies are mainly designed in a static manner and *iii)* access network architectures are planned and controlled. Such a model obviously lacks adaptability and also suffers from a suboptimal behavior and performance.

Because of the growing demand for radio resources, several heterogeneous standards and technologies have been introduced by the standard organizations or industry by different workgroups within the IEEE (802 family), ETSI (GSM), 3GPP (3G, 4G) or the Internet Society (IETF standards) leading to the almost saturated usage of several frequency bands (see Fig. 1).

These two facts, obsolescence of current radio networking rules on one hand, and saturation of the radio frequency band on the other hand, are the main premises for the advent of a new era of radio networking that will be characterized by self-adaptive mechanisms. These mechanisms will rely on software radio technologies, distributed algorithms, end-to-end dynamic routing protocols and therefore require a cross-layer vision of “cognitive wireless networking”: *Getting to the meet of Cognition and Cooperation, beyond the inherent communication aspects: cognition is more than cognitive radio and cooperation is not just relaying. Cognition and cooperation have truly the potential to break new ground for mobile communication systems and to offer new business models.* [50]

From a social perspective, pervasive communications and ambient networking are becoming part of more and more facets of our daily life. Probably the most popular usage is mobile Internet access, which is made possible by numerous access technologies, e.g. cellular mobile networks, WiFi, Bluetooth, etc. The access technology itself is becoming *transparent for the end user*, who does not care about how to access the network but is only interested in the services available and in the quality of this service.

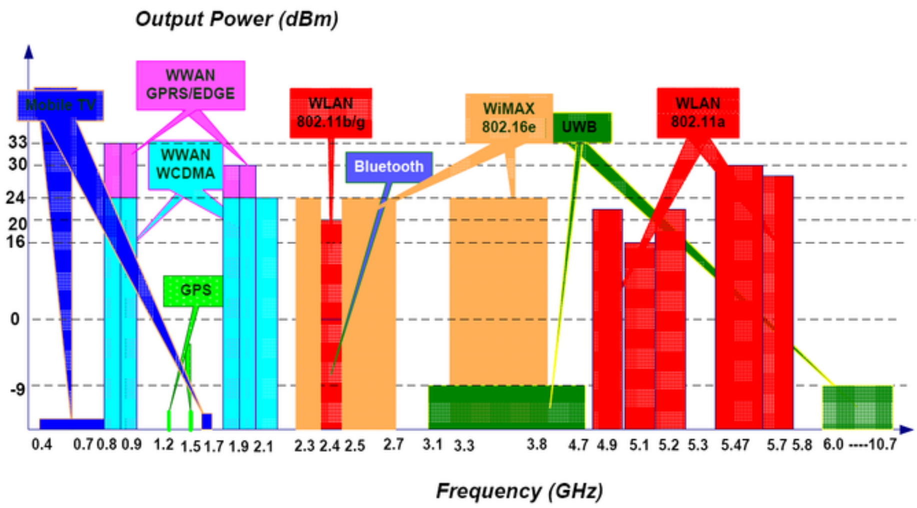

Figure 1. The most recent standards for wireless communications are developed in the UHF and VHF bands. These bands are mostly saturated (source: WPAN/WLAN/WWAN Multi-Radio Coexistence, IEEE 802 Plenary, Atlanta, USA, Nov.2007)

Beyond simple Internet access, many other applications and services are built on the basis of pervasive connectivity, for which the communication is just a mean, and not a finality. Thus, the wireless link is expected to even be *invisible to the end user* and constitutes the first element of the Future Internet of Things [49], to develop a complete twin virtual world fully connected to the real one.

The way radio technologies have been developed until now is far from offering a real wireless convergence [42]. The current development of the wireless industry is surely slowed down by the lack of radio resources and the lack of systems flexibility.

One can get rid of this technological bottleneck by solving three complementary problems: *terminal flexibility, agile radio resource management* and *autonomous networking*. These three objectives are subsumed by the concept of *Software Radio*, a term coined by J. Mitola in his seminal work during the early 90's [46], [47]. While implementing everything in software nodes is still an utopia, many architectures now hitting the market include some degree of programmability; this is called Software-Defined Radio. The word "defined" has been added to distinguish from the ideal software radio. A software *defined* radio is a software radio which is defined for a given frequency range and a maximal bandwidth.

In parallel, the development of new standards is threatened by the radio spectrum scarcity. As illustrated in Fig. 1, the increasing number of standards already causes partial saturation of the UHF band, and will probably lead to its full saturation in the long run. However, this saturation is only "virtual" because all equipments are fortunately not emitting all the time [42]. A good illustration is the so-called "white spaces", i.e. frequency bands that are liberated by analog television disappearing and can be re-used for other purposes, different rules are set up in different countries. In this example, a solution for increasing the real capacity of the band originates from *self-adaptive behavior*. In this case, flexible terminals will have to implement agile algorithms to share the radio spectrum and to avoid interference. In this context, cooperative approaches are even more promising than simple resource sharing algorithms.

With Software-Defined Radio technology, terminal flexibility is at hand, many questions arise that are related to the software layer of a software radio machine: how will this kind of platform be programmed? How can we write programs that are portable from one terminal to another? Autonomous networking will only be reached after a deep understanding of network information theory. Thus, given that there will be many ways for transmitting data from one point to another, what is the most efficient way in terms of throughput? power consumption? etc. Last but not least, agile Radio Resource sharing is addressed by studying MIMO and multi-standard radio front-end. This new technology is offering a wide range of research problems. These three topics: software programming of a software radio machine, distributed algorithms for radio resource management and multi-standard radio front-end constitute the research directions of Socrate.

2.2. Technological State of the Art

A Software-Defined Radio (SDR) system is a radio communication system in which computations that in the past were typically implemented in hardware (e.g. mixers, filters, amplifiers, modulators/demodulators, detectors, etc.) are instead implemented as software programs [46], [43].

2.2.1. SDR Technology

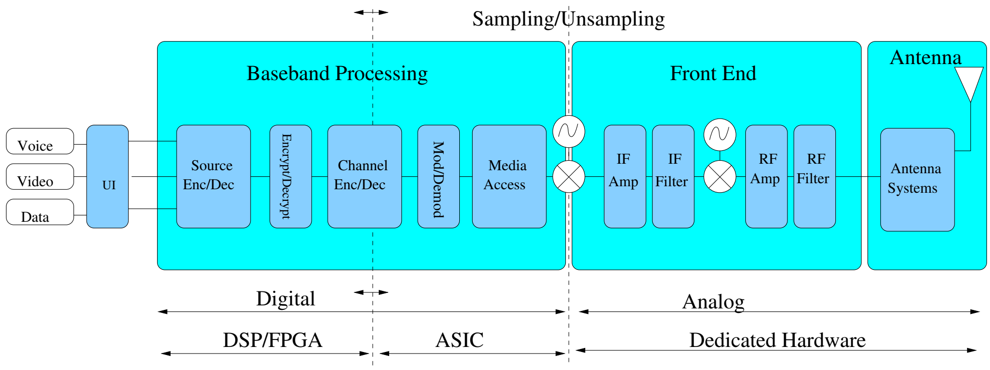

Figure 2. Radio Block Diagram, highlighting separation between digital and analog parts, as well as programmable, configurable and fixed hardware parts.

The different components of a radio system are illustrated in Fig. 2. Of course, all of the digital components may not be programmable, but the bigger the programmable part (DSP/FPGA part on Fig. 2), the more *software* the radio. Dedicated IPs. In this context, IP stand for *Intellectual Properties, this term is widely used to designated dedicated special-purpose circuit blocks implemented in various technologies: Asic,* FPGA, DSP, *etc.* are needed, for these IP it is more suitable to use the term *configurable* than programmable. In a typical SDR, the analog part is limited to a frequency translation down to an intermediate band which is sampled and all the signal processing is done digitally.

2.2.2. SDR Forum Classification

To encourage a common meaning for the term “SDR” the SDR Forum (recently renamed *Wireless Innovation Forum* (http://www.wirelessinnovation.org) proposes to distinguish five tiers:

- *Tier 0 – Hardware Radio:* The radio parameters cannot be changed, radio is implemented only with hardware components.
- *Tier 1 – Software Controlled Radio:* A radio where only the control functions are implemented in software, baseband processing is still performed in hardware, the radio is able to switch between different hardware.

- *Tier 2 – Software-Defined Radio:* The most popularly understood definition of SDR: the radio includes software control of modulation, bandwidth, frequency range and frequency bands. Conversion to digital domain still occurs after frequency conversion. It is currently implemented using a wide range of technologies: Asics, FPGAs, DSPs, etc.
- *Tier 3 – Ideal Software Radio:* Digital conversion occurs directly at the antenna, programmability extends to the whole system.
- *Tier 4 – Ultimate Software Radio:* Same reconfigurability capabilities as in Tier 3, but with a switching between two configurations in less than one millisecond.

The main restriction to build an ideal software radio is sampling rate: sampling at a high rate is not an easy task. Following the Shannon-Nyquist theorem, sampling the RF signal at a rate greater than twice the frequency of the signal is sufficient to reconstruct the signal. Sampling can be done at lower rate (decimation), but errors can be introduced (aliasing) that can be corrected by filtering (dirty radio concept). Building an SDR terminal implies a trade-of between sampling frequency and terminal complexity. For instance, sampling at 4.9 GHz would require a 12-bit resolution ADC with at least 10GHz sample rate which is today not available with reasonable power consumption (several hundreds Watt).

2.2.3. Cognitive Radio

SDR technology enables *over the air programming* (Otap) which consists in describing methods for distributing new software updates through the radio interface. However, as SDR architectures are heterogeneous, a standard distribution method has not emerged yet.

Cognitive Radio is a wireless communication system that can sense the air, and decide to configure itself in a given mode, following a local or distributed decision algorithm. Although Tier 3 SDR would be an ideal platform for cognitive radio implementation, cognitive radios do not have to be SDR.

Cognitive Radio is currently a very hot research topic as show the dozens of sessions in research conferences dedicated to it. In 2009, the American National Science Foundation (NSF) held a workshop on "Future Directions in Cognitive Radio Network Research" [48]. The purpose of the workshop was to explore how the transition from cognitive radios to cognitive radio *networks* can be made. The resulting report indicated the following:

- Emerging cognitive radio technology has been identified as a high impact disruptive technology innovation, that could provide solutions to the *radio traffic jam* problem and provide a path to scaling wireless systems for the next 25 years.
- Significant new research is required to address the many technical challenges of cognitive radio networking. These include dynamic spectrum allocation methods, spectrum sensing, cooperative communications, incentive mechanisms, cognitive network architecture and protocol design, cognitive network security, cognitive system adaptation algorithms and emergent system behavior.

The report also mentioned the lack of cognitive radio testbeds and urged *"The development of a set of cognitive networking test-beds that can be used to evaluate cognitive networks at various stages of their development"*, which, in some sense strengthens the creation of the Socrate team and its implication in the FIT project [44].

2.3. Scientific Challenges

Having a clear idea of relevant research areas in SDR is not easy because many parameters are not related to economical cost. For instance, military research has made its own development of SDR for its particular needs: US military SDR follows the SCA communication architecture [45] but this is usually not considered as a realistic choice for a commercial SDR handset. The targeted frequency band has a huge impact as sampling at high rates is very expensive, and trade-offs between flexibility, complexity, cost and power consumption have a big influence on the relative importance of the hot research topics.

Here are the relevant research domains where efforts are needed to help the deployment of SDR:

- *Antennas and RF Front-Ends:* This is a key issue for reducing interference, increasing capacity and reusing frequency. Hot topics such as wake-up radio or multi protocol parallel radio receivers are directly impacted by research on Antennas. Socrate has research work going on in this area.
- *Analog to Digital Converters:* Designing low-power high frequency ADC is still a hot topic rather studied by micro-electronics laboratories (Lip6 for instance in France).
- *Architecture of SDR systems:* The ideal technology for embedded SDR still has to be defined. Hardware prototypes are built using FPGAs, Asics and DSPs, but the real challenge is to handle a Hardware/Software design which includes radio and antennas parts.
- *Middleware for SDR systems:* How to manage, reconfigure, update and debug SDR systems is still an open question which is currently studied for each SDR platform prototype. Having a common programming interface for SDR systems in one research direction of Socrate.
- *Distributed signal processing:* Cognitive, smart or adaptive radios will need complex decision algorithms which, most of the time will need to be solved in a distributed manner. Socrate has clearly a strong research effort in that direction. Distributed information theory is also a hot research topic that Socrate wishes to study.

3. Research Program

3.1. Research Axes

In order to keep young researchers in an environment close to their background, we have structured the team along the three research axes related to the three main scientific domains spanned by Socrate. However, we insist that a *major objective* of the Socrate team is to *motivate the collaborative research between these axes*, this point is specifically detailed in Section 3.5. The first one is entitled "Flexible Radio Front-End" and will study new radio front-end research challenges brought up by the arrival of MIMO technologies, and reconfigurable front-ends. The second one, entitled "Agile Radio Resource Sharing", will study how to couple the self-adaptive and distributed signal processing algorithms to cope with the multi-scale dynamics found in cognitive radio systems. The last research axis, entitled "Software Radio Programming Models" is dedicated to embedded software issues related to programming the physical protocols layer on these software radio machines. Figure 3 illustrates the three regions of a transceiver corresponding to the three Socrate axes.

3.2. Flexible Radio Front-End

Participants: Guillaume Villemaud, Florin Hutu.

This axis mainly deals with the radio front-end of software radio terminals (right of Fig 3). In order to ensure a high flexibility in a global wireless network, each node is expected to offer as many degrees of freedom as possible. For instance, the choice of the most appropriate communication resource (frequency channel, spreading code, time slot,...), the interface standard or the type of antenna are possible degrees of freedom. The *multi-** paradigm denotes a highly flexible terminal composed of several antennas providing MIMO features to enhance the radio link quality, which is able to deal with several radio standards to offer interoperability and efficient relaying, and can provide multi-channel capability to optimize spectral reuse. On the other hand, increasing degrees of freedom can also increase the global energy consumption, therefore for energy-limited terminals a different approach has to be defined.

In this research axis, we expect to demonstrate optimization of flexible radio front-end by fine grain simulations, and also by the design of home made prototypes. Of course, studying all the components deeply would not be possible given the size of the team, we are currently not working in new technologies for DAC/ADC and power amplifiers which are currently studied by hardware oriented teams. The purpose of this axis is to build system level simulation taking into account the state of the art of each key component.

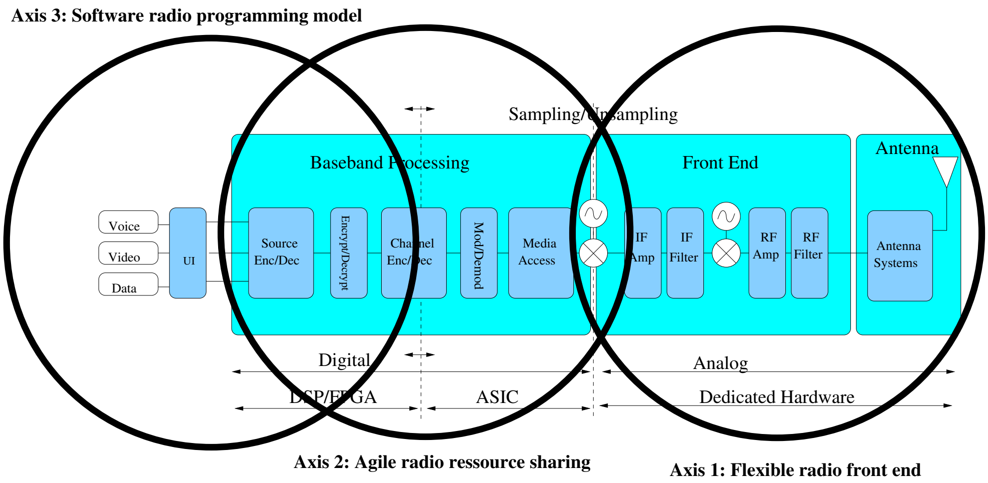

Figure 3. Center of interest for each of the three Socrate research axes with respect to a generic software radio terminal.

3.3. Agile Radio Resource Sharing

Participants: Jean-Marie Gorce, Claire Goursaud, Nikolai Lebedev, Perlaza Samir, Leonardo Sampaio-Cardoso.

The second research axis is dealing with the resource sharing problem between uncoordinated nodes but using the same (wide) frequency band. The agility represents the fact that the nodes may adapt their transmission protocol to the actual radio environment. Two features are fundamental to make the nodes agile : the first one is related to the signal processing capabilites of the software radio devices (middle circle in Fig 3), including modulation, coding, interference cancelling, sensing... The set of all available processing capabilites offers the degrees of freedom of the system. Note how this aspect relies on the two other research axes: radio front-end and radio programming.

But having processing capabilities is not enough for agility. The second feature for agility is the decision process, i.e. how a node can select its transmission mode. This decision process is complex because the appropriateness of a decision depends on the decisions taken by other nodes sharing the same radio environment. This problem needs distributed algorithms, which ensure stable and efficient solutions for a fair coexistence.

Beyond coexistence, the last decade saw a tremendous interest in cooperative techniques that let the nodes do more than coexisting. Of course, cooperation techniques at the networking or MAC layers for nodes implementing the same radio standard are well-known, especially for mobile ad-hoc networks, but cooperative techniques for SDR nodes at the PHY layer are still really challenging. The corresponding paradigm is the one of opportunistic cooperation, let us say *on-the-fly*, further implemented in a distributed manner.

We propose to structure our research into three directions. The two first directions are related to algorithmic developments, respectively for radio resource sharing and for cooperative techniques. The third direction takes another point of view and aims at evaluating theoretical bounds for different network scenarios using Network Information Theory.

The second research axis is dealing with multi-user communications focusing on resource sharing between uncoordinated nodes but using the same spectral resources. The agility relies on the nodes capability to adapt their transmission protocol to the actual radio environment. Centralized and decentralized approaches are investigated and the group is targeting fundamental limits as well as feasible and even practical implementations.

To make agile radio resource sharing a reality, two research directions are investigated. The first one aims at increasing the signal processing capabilities of software radio devices (middle circle in Fig 3), including modulation, coding, interference cancelation, sensing. The objective is to broaden the set of available processing capabilities thus offering more degrees of freedom. Note how this aspect relies on the two other research axes: radio front-end and radio programming.

Processing capabilities is not enough for agility. The second research direction concerns the decision process, i.e. how a node can select its transmission mode. This decision process is complex because the appropriateness of a decision depends on the decisions taken by other nodes sharing the same radio environment. In some cases, centralized solutions are possible but distributed algorithms are often required. Therefore, the target is to find distributed solutions ensuring stability, efficiency and fairness. Beyond coexistence, the last decade saw a tremendous interest in cooperative techniques that let the nodes do more than coexisting. Of course, cooperation techniques at the networking or MAC layers for nodes implementing the same radio standard are well-known, especially for mobile ad-hoc networks, but cooperative techniques for SDR nodes at the PHY layer are still challenging. The corresponding paradigm is referred to as opportunistic cooperative transmissions. We structure our research into three directions:

- Establishing theoretical limits of cooperative wireless networks in the network information theory framework.
- Designing coding and signal processing techniques for optimal transmissions (e.g. interference alignment).
- Developing distributed mechanisms for distributed decision at layer 1 and 2, using game theory, consensus and graph modeling.

3.4. Software Radio Programming Model

Participants: Tanguy Risset, Kevin Marquet, Guillaume Salagnac, Florent de Dinechin.

Finally the third research axis is concerned with software aspect of the software radio terminal (left of Fig 3). We have currently two actions in this axis, the first one concerns the programming issues in software defined radio devices, the second one focusses on low power devices: how can they be adapted to integrate some reconfigurability.

The expected contributions of Socrate in this research axis are :

- The design and implementation of a “middleware for SDR”, probably based on a Virtual Machine.
- Prototype implementations of novel software radio systems, using chips from Leti and/or Lyrtech software radio boards [1].
- Development of a *smart node*: a low-power Software-Defined Radio node adapted to WSN applications.
- Methodology clues and programming tools to program all these prototypes.

3.5. Inter-Axes Collaboration

Innovative results come from collaborations between the three axes. To highlight the fact that this team structure does not limit the ability of inter-axes collaborations between Socrate members, we list below the *on-going* research actions that *already* involve actors from two or more axes, this is also represented on Fig 4.

- *Optimizing network capacity of very large scale networks*. 2 Phds started in October/November 2011 with Guillaume Villemaud (axis 1) and Claire Goursaud (axis 2), respectively.
- *SDR for sensor networks*. A PhD started in 2012 in collaboration with FT R&D, involving people from axis 3 (Guillaume Salagnac, Tanguy Risset) and axis 1 (Guillaume Villemaud).

[1] Lyrtech (http://www.lyrtech.com) designs and sells radio card receivers with multiple antennas offering the possibility to implement a complete communication stack

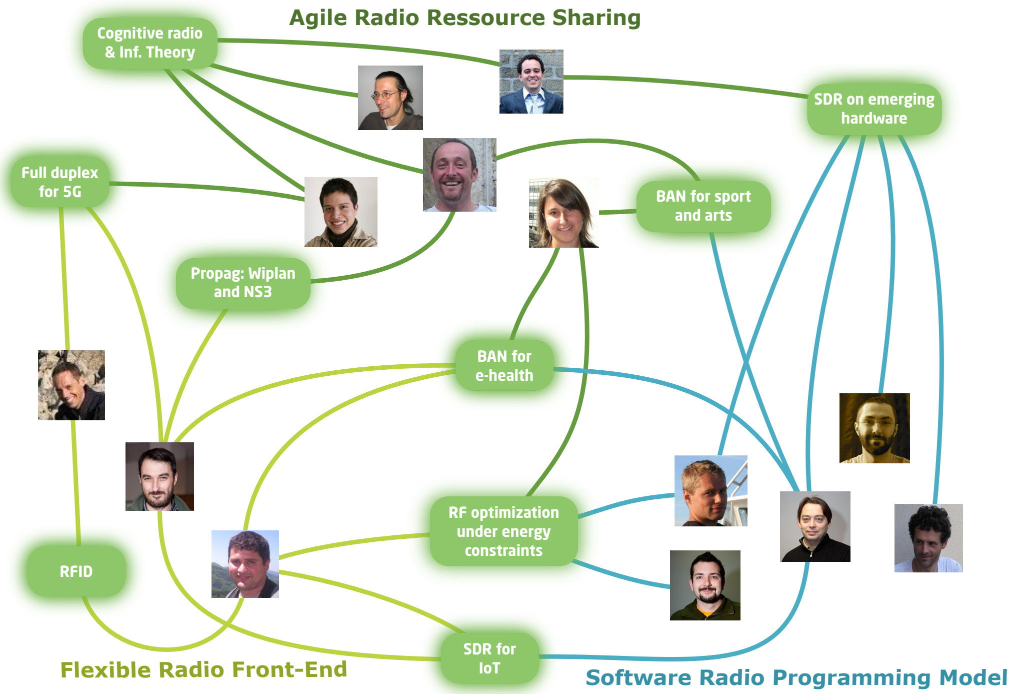

Figure 4. Inter-Axis Collaboration in Socrate: we expect innovative results to come from this pluri-disciplinary research

- *CorteXlab*. The 3 axes also collaborate on the design and the development of CorteXlab.
- *body area networks applications*. Axis 2 and axis 3 collaborate on the development of body area networks applications in the framework of the FUI Smacs project. Jean-Marie Gorce and Tanguy Risset co-advised Matthieu Lauzier.
- *Wiplan and NS3*. The MobiSim ADT involves Guillaume Villemaud (axis 1) and Jean-Marie Gorce (axis 2).
- *Resource allocation and architecture of low power multi-band front-end*. The EconHome project involves people from axis 2 (Jean-Marie Gorce,Nikolai Lebedev) and axis 1 (Florin Hutu). 1 Phd started in 2011.
- *Virtual machine for SDR*. In collaboration with CEA, a PhD started in October 2011, involving people from axis 3 (Tanguy Risset, Kevin Marquet) and Leti's engineers closer to axis 2.
- *Relay strategy for cognitive radio*. Guillaume Villemaud and Tanguy Risset were together advisers of Cedric Levy-Bencheton PhD Thesis (defense last June).

Finally, we insist on the fact that the *FIT project* will involve each member of Socrate and will provide many more opportunities to perform cross layer SDR experimentations. FIT is already federating all members of the Socrate team.

4. Highlights of the Year

4.1. Highlights of the Year

4.1.1. FIT/CortexLab Interference Alignement Demo on Green-Touch Final Meeting

Join GreenTouch in New York City on June 18th to celebrate the announcement of its final results. GreenTouch was founded five years ago with the ambitious goal to improve energy efficiency of communications and data networks by a factor of 1,000.

Socrate was invited to give one of the 15 demos of key technology to reduce power consumption. The demo gives a proof of concept and focuses on the main challenges related to interference alignment, namely the knowledge of the interference footprint and the scheduling algorithms to make use of the interference information to maximize the spectral efficiency. A wireless network is emulated on CorteXlab (http://www.cortexlab.fr), a controlled hardware facility located in Lyon, France with remotely programmable radios and multi-node processing capabilities. During the live demo, a control laptop is remotely connected to the facility, deploying software on the radios and launching an interference alignment scenario and collecting real-time performance feedback. The efficiency gain of interference alignment is then shown for various experimental conditions that can be tuned from the control laptop.

4.1.2. Awards

The article *Code generators for mathematical functions* received the best paper award of the 22d IEEE Symposium on Computer Arithmetic, Jun 2015, Lyon, France; and

The article *A parallel unbalanced digitization architecture to reduce the dynamic range of multiple signals* [28] was one of the best student paper award finalists of the 1st URSI Atlantic Radio Science Conference (URSI AT-RASC), 2015 , May 2015, Gran Canaria, Spain.

Samir Perlaza was granted with a Marie Sklodowska-Curie Individual Fellowship (2015-2016) by the European Commission and he was elevated to *IEEE Senior Member* in June 2015.

BEST PAPER AWARD:

[13]

N. BRUNIE, F. DE DINECHIN, O. KUPRIIANOVA, C. LAUTER. *Code generators for mathematical functions*, in "22d IEEE Symposium on Computer Arithmetic", Lyon, France, June 2015, Best paper award, http://hal.upmc.fr/hal-01084726

5. New Software and Platforms

5.1. FloPoCo

Floating-Point Cores, but not only
KEYWORD: Synthesizable VHDL generator
FUNCTIONAL DESCRIPTION

The purpose of the open-source FloPoCo project is to explore the many ways in which the flexibility of the FPGA target can be exploited in the arithmetic realm.

- Participants: Florent Dinechin, Nicolas Brunie, Matei Istoan and Antoine Martinet
- Partners: CNRS - ENS Lyon - UCBL Lyon 1 - UPVD
- Contact: Florent de Dinechin
- URL: http://flopoco.gforge.inria.fr/

5.2. Minus

KEYWORD: Experiment Handler , SDR

FUNCTIONAL DESCRIPTION

Handling and deployement of experiment on the Cognitive radio platform FIT/CorteXlab. On CorteXlab, the user does not have direct access to the SDR nodes, he has access to a server from which Minus deploys the programs on the different SDR nodes.

- Matthieu Imbert, Leonardo Sampaio Cardoso, Tanguy Risset
- Partners: Inria
- Contact: Matthieu Imbert
- URL: http://www.cortexlab.fr

5.3. FFTweb

KEYWORD: Spectrum Analyser , Data visualization , SDR

FUNCTIONAL DESCRIPTION

Visualisation tool use in CorteXlab to visualize the spectrum (or any kind vector signal) occuring in the CorteXlab room. FFTweb is a fundamental debugging and demonstration component for FIT/CorteXlab user.

- Matthieu Imbert
- Partners: Inria
- Contact: Matthieu Imbert
- URL: http://www.cortexlab.fr

5.4. WSNet

KEYWORD: Network simulator
FUNCTIONAL DESCRIPTION

The WSNet-3.0 project objective is to develop the next evolution of the WSNet simulator. It is a modular event-driven simulator targeted to Wireless Sensor Networks. Its main goals are to offer scalabiliy, extensibility and modularity for the integration of new protocols/hardware models and a precise radio medium simulation.

- Participants: Rodrigue Domga Komguem, Quentin Lampin, Alexandre Mouradian and Fabrice Valois
- Partner: CEA-LETI
- Contact: Fabrice Valois
- URL: https://gforge.inria.fr/projects/wsnet-3/

5.5. WiPlan

FUNCTIONAL DESCRIPTION

Wiplan is a software including an Indoor propagation engine and a wireless LAN optimization suite, which has been registered by INSA-Lyon. The heart of this software is the propagation simulation core relying on an original method, MR-FDPF (multi-resolution frequency domain ParFlow), proposed by JM Gorce in 2001 and further extended. The discrete ParFlow equations are translated in the Fourier domain providing a large linear system, solved in two steps taking advantage of a multi- resolution approach. The first step computes a cell-based tree structure referred to as the pyramid. In the second phase, a radiating source is simulated, taking advantage of the pre-processed pyramidal structure. Using of a full-space discrete simulator instead of classical ray-tracing techniques is a challenge due to the inherent high computation requests. However, we have shown that the use of a multi-resolution approach allows the main computational load to be restricted to a pre-processing phase. Extensive works have been done to make predictions more realistic.

- Contact: Jean-Marie Gorce

5.6. Platform - FIT/CortexLab

FIT(Future Internet of Things) is a french Equipex (Équipement d'excellence) which aims to develop an experimental facility, a federated and competitive infrastructure with international visibility and a broad panel of customers. FIT is be composed of four main parts: a Network Operations Center (NOC), a set of Embedded Communicating Object (ECO) test-beds, a set of wireless OneLab test-beds, and a cognitive radio test-bed (CorteXlab) deployed by the Socrate team in the Citi lab. In 2014 the construction of the room was finished see Figure 5. SDR nodes have installed in the room, 42 industrial PCs (Aplus Nuvo-3000E/P), 22 NI radio boards (USRP) and 18 Nutaq boards (PicoSDR, 2x2 and 4X4) can be programmed from internet now.

A very successfully inauguration took place on the 28th October 2014 [2], with the noticable venue of Vincent Poor, Dean of School of Engineering and Applied Science of Princeton University. Since that date, the platform is open to public experiments.

6. New Results

6.1. Flexible Radio Front-End

The contributions of members of this axis are mainly on four topics: Wake-Up Radio,Full-Duplex transceivers, SDR Gateways for Urban Networks, and Channel Estimation. In the global concept of enhancing wireless communications, those four topics are complimentary, addressing the reduction of energy consumption, the increase of throughput and/or flexibility of the transmission and the performance evaluation.

[2] http://www.inria.fr/centre/grenoble/actualites/inauguration-reussie-de-la-plateforme-cortexlab-equipex-fit

Figure 5. Photo of the FIT/CortexLab experimentation room installed and a snaptshot of the inauguration meeting

6.1.1. Wake-Up Radio

The last decades have been really hungry in new ways to reduce energy consumption. That is especially true when talking about wireless sensor networks in general and home multimedia networks in particular, since electrical energy consumption is the bottleneck of the network. One of the most energy-consuming functional block of an equipment is the radio front end, and methods to switch it off during the time intervals where it is not active must be implemented. This study [10] has proposed a wake-up radio circuit which is capable of both addressing and waking up not only a more efficient but also more energy-consuming radio front end. By using a frequency footprint to differentiate each sensor, awaking all the sensors except for the one of interest is avoided. The particularity of the proposed wake-up receiver is that the decision is taken in the radio-frequency part and no baseband treatment is needed. The global evaluation in theory and in simulation was performed, and a first testbed of this technology was fabricated.

6.1.1.1. Full-Duplex

This work studies [8] a Full-Duplex Dual-Band (FDDB) OFDM radio architecture that enables the radio transceiver to be more flexible and provides a viable radio link capacity gain. A simple but practical I/Q imbalance estimation and compensation method, based on the frequency-flat-fading behavior of the self-interference channel, is proposed. The performance of the proposed I/Q imbalance compensation method is evaluated by system level simulations conducted with ADS and Matlab. The co-simulation results show that the proposed radio transceiver could potentially increase the physical layer transmission rate by four times compared to the conventional radio link at the cost of tolerable loss of BER performance. The I/Q imbalance compensation method can effectively compensate both high and low I/Q imbalance without the problem of algorithm convergence. Application of this technique for physical layer security has already been proposed.

6.1.1.2. SDR for SRDs

The technologies employed in urban sensor networks are permanently evolving, and thus the gateways of these networks have to be regularly upgraded. The existing method to do so is to stack-up receivers dedicated to one communication protocol. However, this implies to have to replace the gateway every time a new protocol is added to the network. A more practical way to do this is to perform a digitization of the full band and to perform digitally the signal processing, as done in Software-Defined Radio (SDR). The main hard point in doing this is the dynamic range of the signals: indeed the signals are emitted with very different features because of the various propagation conditions. It has been proved that the difference of power between two signals can be so important that no existing Analog-to-Digital Converter (ADC) is able to properly digitize the signals. We propose a solution to reduce the dynamic range of signals before digital conversion. In this study [28], the assumption is made that there is one strong signal, and several weak signals. This assumption is made from the existing urban sensor networks topology. A receiver architecture with two branches is proposed with a “Coarse Digitization Path” (CDP) and a “Fine Digitization Path” (FDP). The CDP allows to digitize the strong signal and to get data on it that is used to reconfigure the FDP. The FDP then uses a notch filter to attenuate the strong signal (and then to reduce the dynamic range of the signals) and digitizes the rest of the band. Another way to relax these specifications on ADCs is an analog processing, such as companding, that should be performed before digitization. The companding technique is usually employed on one signal (and not on multiple signals that are only separated on the frequency domain). This work [36], [29] studies three companding laws to test their efficiency in relaxing the digitization constraints with multiple signals. A μ-law, a Piecewise-Linear (PL) law and a Piecewise-Linear, Constant Gain with Offsets (PLCGO) law are tested. We have described how to use a PLCGO approach to reduce ADC’s complexity, and two implementations of the compressing law are proposed.

6.1.1.3. Channel Estimation

In modern mobile telecommunications, shadow fading has to be modeled by a two-dimensional (2D) correlated random variable since shadow fading may present both cross-correlation and spatial correlation due to the presence of similar obstacles during the propagation. In our study, 2D correlated random shadowing is generated based on the multi-resolution frequency domain ParFlow (MR-FDPF) model. The MR-FDPF model is a 2D deterministic radio propagation model, so a 2D deterministic shadowing can be firstly extracted from it. Then, a 2D correlated random shadowing can be generated by considering the extracted 2D deterministic shadowing to be a realization of it. Moreover, based on the generated 2D correlated random shadowing, a complete 2D semi-deterministic path loss model can be proposed. The proposed methodology [5] can be implemented into system-level simulators where it will be very useful due to its ability to generate realistic shadow fading.

[23] presents the first implementation on software defined radio nodes in the large scale testbed CorteXlab of a radio link estimation technique based on OFDM transmissions. The purpose of this large scale testbed is to offer to the whole scientific community an open tool to test new techniques for multiuser , cooperative and cognitive radio networks in a controlled environment. As the experimentation room was defined in order to offer reproducible measurements, it is important to be able to characterize each radio link between all transceivers. Therefore, we present here the development of a channel sounder directly implemented on the software radio nodes. This paper presents the first implementation on software defined radio nodes in the large scale testbed called CorteXlab of a radio link estimation technique based on OFDM transmissions. The purpose of this large scale testbed is to offer to the whole scientific community an open tool to test new techniques for multiuser , cooperative and cognitive radio networks in a controlled environment. As the experimentation room was defined in order to offer reproducible measurements, it is important to be able to characterize each radio link between all transceivers. Therefore, we proposed the development of a channel sounder directly implemented on the software radio nodes.

6.2. Agile Radio Resource Sharing

This axis addresses the challenges relative to the network perspective of software radio. While the two other axes have their focus on the design of the software radio nodes, axis 2 deals with coexistence and cooperation in a multi-user communications perspective.

A first research direction concerns theoretical limits of different reference scenarios where trade-offs between spectral efficiency, energy efficiency, stability and/or fairness are analyzed. This work exploits multi-users information theory, game theory and stochastic geometry. This year, a particular focus has been put on the interference channel with feedback and on dense wireless networks. New problems have been also investigated with the simultaneous energy and information transmission problem for energy harvesting and some specific attacks in smart grids.

In parallel our research activities are also driven by applicative frameworks. Concerning 4G RAN, a new interference alignment scheme has been proposed, simulated and implemented on CortexLab. This work has been presented as one of the promising technologies proposed by Greentouch. IoT has been identified as a new challenge for 5G with the objective of serving a very large number of nodes per cell, in a connectionless manner and with very small packets. The original transmission technology using ultra narrow band modulation and proposed by Sigfox for large area of IoT nodes has been investigated. A multiband CSMA strategy has been also evaluated in collaboration with CEA-Leti for dense Wifi like IoT access networks. Body area networks (BANs) represent also a very challenging applicative framework, with strong dynamics, interference environments, and low energy requirements. In partnership with Euromedia and Hikob, our studies focused on dynamic algorithms for information gathering in a sport event broadcast system. Additionnally, localization capabilities at the body scale may offer interesting perspectives but require specific MAC protocols.

6.2.1. Fundamental Limits

6.2.1.1. Energy efficiency - Spectral Efficiency (EE-SE) Tradeoffs in Wireless RANs

The spectral and energy efficiency (SE-EE) trade-off in cellular networks has attracted significant recent interest in the wireless community [1]. The work in [7] studies this fundamental limit with a simple and effective method. The proposed theoretical framework is based on an optimal radio resource allocation of transmit power and bandwidth for the downlink direction, applicable for an orthogonal cellular network. The analysis is initially focused on a single cell scenario, for which in addition to the solution of the main SE-EE optimization problem, it is proved that a traffic repartition scheme can also be adopted as a way to simplify this approach. By exploiting this interesting result along with properties of stochastic geometry, this work is extended to a more challenging multi-cell environment, where interference is shown to play an essential role and for this reason several interference reduction techniques are investigated. Special attention is also given to the case of low signal to noise ratio (SNR) and a way to evaluate the upper bound of EE in this regime is provided. This methodology leads to tractable analytical results under certain common channel properties, and thus allows the study of various models without the need for demanding system level simulations.

6.2.1.2. Interference Channels with Feedback

The capacity region of the two-user linear deterministic (LD) interference channel with noisy output feedback (IC-NOF) is fully characterized in [35], [26]. This result allows the identification of several asymmetric scenarios in which implementing channel-output feedback in only one of the transmitter-receiver pairs is as beneficial as implementing it in both links, in terms of achievable individual rate and sum-rate improvements w.r.t. the case without feedback. In other scenarios, the use of channel-output feedback in any of the transmitter-receiver pairs benefits only one of the two pairs in terms of achievable individual rate improvements or simply, it turns out to be useless, i.e., the capacity regions with and without feedback turn out to be identical even in the full absence of noise in the feedback links. As a byproduct, the exact conditions on the signal to noise ratios on the feedback links to observe an improvement on either a single rate, both single rates, or the sum-rate capacity, for any IC-NOF are also fully described in [41].

6.2.1.3. Simultaneous Energy and Information Transmission

The fundamental limits of simultaneous information and energy transmission in the two-user Gaussian multiple access channel (G-MAC) with and without feedback are fully characterized in [33], [9]. All the achievable information and energy transmission rates (in bits per channel use and energy-units per channel use respectively) are identified. Thus, the information-energy capacity region is defined in both cases. In the case without feedback, an achievability scheme based on power-splitting and successive interference cancelation is shown to be optimal. Alternatively, in the case with feedback (G-MAC-F), a simple yet optimal achievability scheme based on power-splitting and Ozarow's capacity achieving scheme is presented. Three of the most important observations in this work are: (a) The capacity-energy region of the G-MAC without feedback is a proper subset of the capacity-energy region of the G-MAC-F; (b) Feedback can at most double the energy rate for a fixed information rate; and (c) Time-sharing with power control is strictly suboptimal in terms of sum-rate in the G-MAC without feedback.

6.2.1.4. Multiple Access Channel and Broadcast Channel with Linear Feedback Schemes

In [11], it is shown that for the two-user Gaussian broadcast channel with correlated noises and perfect feedback the largest region that can be achieved by linear-feedback schemes equals the largest region that can be achieved over a dual multi-access channel when in this latter the channel inputs are subject to a "non-standard" sum-power constraint that depends on the BC-noise correlation. Combining this new duality result with Ozarow's MAC-scheme gives an elegant achievable region for the Gaussian BC with correlated noises. A constructive iterative coding scheme is then presented for the non-symmetric Gaussian BC with uncorrelated noises that is sum-rate optimal among all linear-feedback schemes. This coding scheme shows that the connection between the MAC and the BC optimal schemes is tighter than what is suggested by our duality result on achievable rates. In fact, it is linear-feedback sum-rate optimal to use Ozarow MAC-encoders and MAC-decoders— rearranged—to code over the BC.

6.2.2. Low Complexity Receivers for Massive MIMO Systems

In wireless communications, Multi-user massive MIMO network is a scenario that has been recently proposed, where many mobile terminals are served by a Base Station (BS) equipped with a very high number of antennas. In such a scenario, the detection in the uplink remains a challenge, since the BS is required to detect signals transmitted from all users while trying to exploit full received diversity. The optimal detection criterion that fulfills the diversity requirement is the Maximum-Likelihood (ML) joint detection which has been proposed to detect jointly the transmitted signals. However, such a criterion is not applicable to the addressed multi-user massive MIMO scenario due to its computational complexity that increases exponentially with the number of signals to be detected. In our work paper, we have proposed a relaxed ML detector based on an iterative decoding strategy that reduces the computational cost. We exploit the fact that the transmit constellation is discrete, and remodel the channel as a MIMO channel with sparse input belonging to the binary $\{0, 1\}$. The sparsity property allows us to relax the ML problem as a quadratic minimization under linear and $\ell 1$-norm constraint. We then prove the equivalence of the relaxed problem to a convex optimization problem solvable in polynomial time. Simulation results illustrate the efficiency of the low-complexity proposed detector compared to other existing ones in very large and massive MIMO context.

6.2.3. Distributed Radio Resource Management

6.2.3.1. Interference Alignment in Cellular Networks with no-Explicit Coordination

Current networks aim to support high data rates for end users by increasing the spectral efficiency in bits-per-Hertz, at the expense of the energy efficiency of the network. Indeed, an important part of the energy consumption of mobile networks is proportional to the radiated energy, which relies on the frequency bandwidth and the transmission power. Any energy efficient transmission scheme should exploits the whole system bandwidth by allocating the entire available spectrum to each base station. Such an approach, however, leads to significant interference increase and performance degradation for mobiles located at the cell edges. The key challenge is to balance interference avoidance and spectrum use to reach an optimal spectral efficiency – energy efficiency (EE-SE) trade-off. The work achieved in the framework of Greentouch collaboration is based on the non classical interference alignement scheme proposed by Suh and Tse in dowlink mode. The key contribution relies on users scheduling with a unique criteria based as well on QoS priorities and orthogonality of precoding directions. The spectral efficiency is improved by a factor 2 for edge users and a energy saving of about 30% is made possible. This scheme has been evaluated on simulation scenarios as defined by Greentouch partners and a simplified version has been implemented on FIT/CorteXlab and demontrastrated during the final event of Greentouch (New-York, June 2015).

6.2.4. RANs for IoT : Dense and Connectionless Solutions

Internet of Things (IoT) is going to take a major place in the telecommunications market as announced in technical and public medias. The paradigm of IoT relies on the deployment of billions of objects having the capability of transmitting information about their context and environment and to create a real-time, secured and efficient interaction between the real and the virtual worlds, pushing them to evolve from the state of cousins to the state of Siamese twins. IoT revealed to be a key technology for solving societal issues such as digital cities, intelligent transportation, green environment monitoring or medical care and elderly person monitoring.

IoT has strong connections with machine-to-machine (M2M), and sometimes in literature, both terms refer to the same idea. From our point of view, IoT covers a broader scope including as well the technology and the applications. On the opposite, M2M refers to the technologies that allow machines or objects to communicate.

In any case, from the technical point of view, the main challenge of this new paradigm is to let a huge number of machine type devices (MTDs) be connected to the Internet at a low cost, with a limited infrastructure and featuring a very long life time with very small battery or energy needs [4].

In this global picture, we may consider different technical issues. M2M has first been defined to connect MTDs in their vicinity. The proposed solutions extensively rely on the research results produced over the last 20 years for ad-hoc and wireless sensor networks. Initiated 20 years ago from theoretical concepts, this very active research area has gone up to the definition of full standards (802.15.4, 802.15.6, Zigbee, Bluetooth) which have already found a market.

More recently, the IoT paradigm has been extended to the problem of connecting all these MTDs to the Internet, and through Internet to anyone or anything. The massive connection of objects spread over the world is a challenge that has some similarities with the paradigm of cellular networks which aimed at connecting people. This similarity attracted the interest of mobile network providers, to exploit such attractive potential market and IoT has been identified as a target for the future 5G.

6.2.4.1. Performance of Ultra-NarrowBand Techniques

The Ultra-narrow-band technology is an appealing solution for the low throughput wireless sensor networks (10b/s - 1 kb/s). It is complementary to the classical cellular networks thanks to its low energy consumption and very long range communication (up to 50 km in free-space) [4]. This technology has already been deployed and is proved to be ultra-efficient for point-to-point communications in Sigfoxs' network. Nodes are transmitting at a random time and random frequency carrier (random frequency division multiple access schemes : R-FDMA), so the uplink is exposed to interference. In our approach, we have proposed to model this interference for the UNB network when taking into account the path-loss and Rayleigh effects, with stochastic geometry tools. The obtained model allows us to estimate the system performance, and its capacity in terms of maximum number average of simultaneous nodes in a unique cell [37]. We have also considered the replication mechanism, and identified the optimum number of replications.

6.2.4.2. Multiband CSMA for Dense Wireless Networks in Uplink

In this approach, the objective is to mitigate the degradation of the throughput and delay performance in wireless local area networks (WLAN) that employ carrier sense multiple access collision avoidance (CSMA/CA) protocol with request to send and clear to send (RTS/CTS) mechanism, when a large number of IoT like nodes are deployed. In our approach, the overhead is reduced with a modified handshake mechanism. The medium access control (MAC) overhead caused by the RTS and CTS messages is high comparing to the total duration of successful transmission. In order to reduce the MAC overhead we propose in this work a new strategy to serve many users successively. This strategy consists on sending many RTS in parallel by different stations on different frequency sub-bands. Once the RTS messages do not collide with each other, there will be no need to resend the RTS and wait for a CTS to gain the channel access [21].

6.2.5. Algorithms and Protocols for BANs

6.2.5.1. Information Gathering in a Group of Mobile Users

Distributed decisions within any group of agents, is a very active research area and theoretical results as well as efficient algorithms have already been proposed but in the context of wireless networks, the task is made harder due to possible transmission errors, channel asymmetry, dynamic behaviour of the channel and node mobility. In this work, we consider a group of mobile agents moving roughly in a common direction. We study different algoritimic solutions allowing each agent to periodically discover its neighbours: one-hop neighbours as well as multi-hop neighbors. The reference scenario is a bike race, during which groups are susceptible to split or merge. The objective is a live gathering of information about who is present in a group for live TV broadcasting. For that, we need a fully distributed approach allowing every agent to discover with a consensus algorithm the list of neighbours participating to the same pack. This study may be of interest for various other applications such as group navigation support in crowded environments, autonomous navigation of a fleet of robots. . . This problem exhibits some similarities with a clustering problem. However, a clustering problem aims at exploiting the structure of a graph and to form some subgroups to ensure a good structure of the network for further communications while our objective is rather to estimate the groups naturally formed in the real world. Hence, we have focused on distributed decision algorithms, which are widely present in the literature. Max-consensus problem has been much less studied than average consensus. The proposed algorithms are based on the N-dimension generalization of the Random Broadcast Max-Consensus algorithm, allowing each agent to build and share the list of its muli-hop neighbors. We extend this approach to a dynamic context where the group information needs to be updated according to possible group merge or split. Experimental validation has been done in the context of a cycling race with 10 agents, equipping each bicycle with a wireless sensor node to assess the interactions between the racers and to provide a live monitoring of the dynamic evolution of the cyclists groups that form during the race.

6.2.5.2. MAC Protocols and Algorithms for Localization at the Body Scale

The purpose of this work is to evaluate the impact of the node speed on the ranging estimation for location applications with Wireless Body Area Networks (WBAN). While estimated with the 3-Way ranging protocol (3-WR), this distance between two nodes placed on the body can be affected by the human movements [30], [17]. Thus, we study theoretically the ranging error with the 3-WR, based on a perfect channel, a MAC layer based on TDMA using two scheduling strategies (Single node localization (P2P-B) and Aggregated & Broadcast (A&B)) and a PHY layer based on Ultra Wideband (IR-UWB) [31]. We demonstrate the accuracy of the model, and show that the distance error is highly correlated with the speed of nodes [16], while the associated mobility model has an impact on the design of MAC strategies by simulation [18].

6.2.6. Other Topics

6.2.6.1. Data Injection Attacks in Smart Grids

Multiple attacker data injection attack construction in electricity grids with minimum-mean-square-error (MMSE) state estimation is studied for centralized and decentralized scenarios in [34]. A performance analysis of the trade-off between the maximum distortion that an attack can in- troduce and the probability of the attack being detected by the network operator is considered. Within this setting, optimal centralized attack construction strategies are studied. The decentralized case is examined in a game-theoretic setting. A novel utility function is proposed to model this trade-off and it is shown that the resulting game is a potential game. The existence and cardinality of the corresponding set of Nash Equilibria (NE) in the game is analyzed. For the particular case of two attackers, numerical results based on IEEE test systems are presented. These results suggest that attackers perform better when they seize control of power flow measurements instead of power injection measurements.

6.3. Software Radio Programming Model

6.3.1. Data Flow Programming

Streaming languages have been proven to be a natural and efficient approach for taking advantage of the intrinsic parallelism of modern CPU architectures. The focus of many previous work has been to improve the throughput of streaming programs. In [27], we rather focus on satisfying quality-of-service requirements of streaming applications executed alongside non-streaming processes. We monitor synchronous dataflow (SDF) programs at runtime both at the application and system levels, in order to identify violations of quality-of-service requirements. Our monitoring requires the programmer to provide the expected throughput of its application (e.g 25 frames per second for a video decoder), then takes full benefit from the compilation of the SDF graph to detect bottlenecks in this graph and identify causes among processor or memory overloading. It can then be used to perform dynamic adaptations of the applications in order to optimize the use of computing and memory resources.

6.3.2. Smart Sensors

The article [19] presents the development of a wireless wearable sensor for the continuous, long-term monitoring of cardiac activity. Heart rate assessment, as well as heart rate variability parameters are computed in real time directly on the sensor, thus only a few parameters are sent via wireless communication for power saving. Hardware and software methods for heart beat detection and variability calculation are described and preliminary tests for the evaluation of the sensor are presented. With an autonomy of 48 hours of active measurement and a Bluetooth Low Energy radio technology, this sensor will form a part of a wireless body network for the remote mobile monitoring of vital signals in clinical applications requiring automated collection of health data from multiple patients.

6.3.3. Cryptography

For security applications in wireless sensor networks (WSNs), choosing best algorithms in terms of energy-efficiency and of small memory requirements is a real challenge because the sensor networks are composed of low-power entities. Previous works benchmarked 12 block-ciphers on an ATMEL AVR ATtiny45 8-bit microcontroller. In [2], most of the recent lightweight block cipher proposals, as well as some conventional block ciphers, are studied on the Texas Instruments MSP430 16-bit microcontroller . The chosen block ciphers are described with a security and an implementation summary. Implementations are then evaluated on a dedicated platform.

6.3.4. Hardware Arithmetic

6.3.4.1. Hardware Implementations of Fixed-Point Atan2

The atan2 function computes the polar angle arctan(x/y) of a point given by its cartesian coordinates. It is widely used in digital signal processing to recover the phase of a signal. The article [14] studies for this context the implementation of atan2 with fixed-point inputs and outputs. It compares the prevalent CORDIC shift-and-add algorithm to two multiplier-based techniques. The first one reduces the bivariate atan2 function to two functions of one variable: the reciprocal, and the arctangent. These two functions may be tabulated, or evaluated using bipartite or polynomial approximation methods. The second technique directly uses piecewise bivariate polynomial approximations, in degree 1 and degree 2. It requires larger tables but has the shortest latency. Each of these approaches requires a relevant argument reduction, which is also discussed. All the algorithms are described with the same accuracy target (faithful rounding) and implemented with similar care in FloPoCo. Based on synthesis results on FPGAs, their relevance domains are discussed.

6.3.4.2. Fixed-Point Implementations of the Reciprocal, Square Root and Reciprocal Square Root Functions

Implementations of the reciprocal, square root and reciprocal square root often share a common structure. The article [39] is a survey and comparison of methods for computing these functions. It compares classical methods (direct tabulation, multipartite tables, piecewise polynomials, Taylor-based polynomials, Newton-Raphson iterations). It also studies methods that are novel in this context: the Halley method and, more generally, the Householder method. The comparisons are made in the context of the same accuracy target (faithful rounding) and of an arbitrary fixed-point format for the inputs and outputs (precisions of up to 32 bits). Some of the methods discussed might require some form of range reduction, depending on the input range. The objective of the article is to optimize the use of fixed-size FPGA resources (block multipliers and block RAMs). The discussions and conclusions are based on synthesis results for FPGAs.

6.3.4.3. Fixed-Point Hardware Polynomials

Polynomial approximation is a general technique for the evaluation of numerical functions of one variable such as atan, reciprocal and square roots studied above. The article [38] addresses the automatic construction of fixed-point hardware polynomial evaluators. By systematically trying to balance the accuracy of all the steps that lead to an architecture, it simplifies and improves the previous body of work covering polynomial approximation, polynomial evaluation, and range reduction. This work is supported by an open-source implementation in FloPoCo.

6.3.5. Software Elementary Functions

6.3.5.1. Code Generators for Mathematical Functions

A typical floating-point environment includes support for a small set of about 30 mathematical functions such as exponential, logarithms and trigonometric functions. These functions are provided by mathematical software libraries (libm), typically in IEEE754 single, double and quad precision. The article [13] suggests to replace this libm paradigm by a more general approach: the on-demand generation of numerical function code, on arbitrary domains and with arbitrary accuracies. First, such code generation opens up the libm function space available to programmers. It may capture a much wider set of functions, and may capture even standard functions on non-standard domains and accuracy/performance points. Second, writing libm code requires fine-tuned instruction selection and scheduling for performance, and sophisticated floating-point techniques for accuracy. Automating this task through code generation improves confidence in the code while enabling better design space exploration, and therefore better time to market, even for the libm functions. This article discusses, with examples, the new challenges of this paradigm shift, and presents the current state of open-source function code generators.

6.3.5.2. Computing Floating-Point Logarithms with Fixed-Point Operations

Elementary functions from the mathematical library input and output floating-point numbers. However it is possible to implement them purely using integer/fixed-point arithmetic. This option was not attractive between 1985 and 2005, because mainstream processor hardware supported 64-bit floating-point, but only 32-bit integers. Besides, conversions between floating-point and integer were costly. This has changed in recent years, in particular with the generalization of native 64-bit integer support. The purpose of the article [40] is therefore to reevaluate the relevance of computing floating-point functions in fixed-point. For this, several variants of the double-precision logarithm function are implemented and evaluated. Formulating the problem as a fixed-point one is easy after the range has been (classically) reduced. Then, 64-bit integers provide slightly more accuracy than 53-bit mantissa, which helps speed up the evaluation. Finally, multi-word arithmetic, critical for accurate implementations, is much faster in fixed-point, and natively supported by recent compilers. Novel techniques of argument reduction and rounding test are introduced in this context. Thanks to all this, a purely integer implementation of the correctly rounded double-precision logarithm outperforms the previous state of the art, with the worst-case execution time reduced by a factor 5. This work also introduces variants of the logarithm that input a floating-point number and output the result in fixed-point. These are shown to be both more accurate and more efficient than the traditional floating-point functions for some applications.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

Socrate has strong collaboration with Orange Labs (point to point collaboration) and Alcatel Lucent through the Inria-ALU common lab and the GreenTouch initiative.

Socrate also works with Sigfox a important french young company deploying the first cellular network operator dedicated to M2M and IoT. A bilateral cooperation with sigfox supported the PhD of Minh Tien Do and continues with the PhD of Yuqi Mo. Socrate has also regular collaboration with HIKOB a start-up originated from the Citi laboratory providing sensor networks.

Socrate also collaborates with Euromedia group on advanced wireless techniques for sports events broadcasting systems.

7.1.1. Contractual Study - SigFox - "Standardization support" (2015-2016, 50 keuros)

SigFox is a French start-up deploying and exploiting a network for Internet of Things data collection. Their network is currently being deployed worldwide, and gaining more and more interest from customers. The network is based on a patented transmission protocol (Ultra Narrow Band and Random frequency multiple access), which is now entering standardisation process. The goal of this work is to support this standardization, by providing a deep analysis of the network performances.

7.1.2. CIFRE - SigFox - “Analysis and optimization of a bidirectional network based on UNB” (2015-2018, 50 keuros)

The goal of this thesis is to characterize and improve the network performance. To do so, the following tasks are envisioned:

1. retransmissions strategies to reach a targeted QoS;
2. feedback exploitation (acknowledgment);
3. coherent detection of signals provided by all the base stations (spatial diversity exploitation); and
4. nodes position estimation, and use of this knowledge in the access protocol.

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. Equipex FIT- Future Internet of Things (2011-..., 1.064 keuros)

The FIT projet is a national equipex (*equipement d’excellence*), headed by the Lip6 laboratory. As a member of Inria, Socrate is in charge of the development of an Experimental Cognitive Radio platform that should be used as test-bed for SDR terminals and cognitive radio experiments. This should be operational in 2013 for a duration of 7 years. To give a quick view, the user will have a way to configure and program through Internet several SDR platforms (MIMO, SISO, and baseband processing nodes).

8.1.2. ANR - Cormoran - “Cooperative and Mobile Wireless Body Area Networks for Group Navigation” (2012-2015, 150 keuros)

Cormoran project targets to figure out innovative communication functionalities and radiolocation algorithms that could benefit from inter/intra-BAN cooperation. More precisely, the idea is to enable accurate nodes/body location, as well as Quality of Service management and communications reliability (from the protocol point of view), while coping with inter-BAN coexistence, low power constraints and complying with the IEEE 802.15.6 standard. The proposed solutions will be evaluated in realistic applicative scenarios, hence necessitating the development of adapted simulation tools and real-life experiments based on hardware platforms. For this sake, Cormoran will follow an original approach, mixing theoretical work (e.g. modelling activities, algorithms and cross-layer PHY/MAC/NWK design) with more practical aspects (e.g. channel and antennas measurement campaigns, algorithms interfacing with real platforms, demonstrations).

8.1.3. ANR - MetalibM - “Automatic Generation of Function and Filters” (2014-2017, 200 keuros)

The goal of the Metalibm project is to provide a tool for the automatic implementation of mathematical (libm) functions. A function f is automatically transformed into machine-proven C code implementing an polynomial approximation in a given domain with given accuracy. This project is led by Inria, with researchers from Socrate and AriC; PEQUAN team of Laboratoire d’Informatique de Paris 6 (LIP6) at Université Pierre et Marie Curie, Paris; DALI team from Université de Perpignan Via Domitia and Laboratoire d’Informatique, Robotique et Microélectronique de Montpellier (LIRMM); and SFT group from Centre Européen de Recherche Nucléaire (CERN).

8.1.4. FUI SMACS - “SMart And Connected Sensors” (2013-2016, 267 keuros)

The SMACS projet targets the deployement of an innovating wireless sensor network dedicated to many domains sport, health and digital cities. The projet involves Socrate (Insavalor), HIKOB and wireless broadcasting company Euro Media France. The main goal is to develop a robust technologie enabling real-time localization of mobile targets (like cyclist for instance), at a low energy (more generaly low cost). The technology will be demonstrated at real cycling races (Tour de France 2013 and 2014). One of the goal is to include localisation information with new radio technology. Another subject of study is distributed wireless consensus algorithms for maintaining a neighborhood knowledge with a low energy budget that scales (more than 200 cycles together)

8.1.5. ADT Sytare (Développement d'un SYsTème embArqué faible consommation à mémoiRE persistante) ADT Inria 2015-2017

The SYTARE project aims to develop and study novel operating system mechanisms for NVRAM-based embedded systems. The term NVRAM collectively describes an emerging generation of memory technologies which are both non-volatile and byte-addressable. These two properties together make the classical RAM+ROM memory architecture obsolete, and enable the design of embedded systems running on intermittent power. This is very attractive in the context of energy-constrained scenarios, for instance systems harvesting their power from the environment. But working with NVRAM also poses novel challenges in terms of software programming. For instance, application state consistency must be guaranteed accross reboots, even though the system includes both NVRAM and volatile elements (e.g. CPU, hardware peripherals). The SYTARE project is funded by Inria via the ADT program.

8.1.6. ADT CorteXlab, ADT Inria 2015-2017

The Socrate project-team is in charge of the FIT/CorteXlab platform (section 5.6). This platform makes use of many complex technologies from signal processing to computer science through micro-electornics and FPGA. The objectiv of the CorteXlab ADT is to maintain a support to the user of the FPGA-based platform of CorteXlab and to provide tutorial and running experiment that will help them in builing experimentation using the PicoSDR machines.

8.1.7. Taiwan III - research proposal on 5G M2M 2015-2016

In the context of the MoU signed between Inria and The National Science Council of Taiwan. Taiwan's Institute for Information Industry (III) and Socrate signed a one-year contract for a research proposal containing two items: a first to study the OFDMA-based RACH access from theoretical or mathematical models and a second to set up an experiment in CorteXlab that will emulate a given number of M2M device using a narrow band radio protocol and record the resulting radio environment. This document described in more detail the research proposal.

8.2. European Initiatives

8.2.1. FP7 & H2020 Projects

8.2.1.1. CYBERNETS

Title: Cybernetic Communication Networks: Fundamental Limits and Engineering Challenges

Programm: H2020 - Marie Skłodowska-Curie Actions - Individual Fellowships

Duration: June 2015 - June 2017

Coordinator: Inria

Recipient: Samir Perlaza

This Reintegration Panel proposal, CYBERNETS, focuses on the study of Cybernetic Communication Networks (CCN). CCNs are wireless networks that are context-aware, possess learning capabilities and artificial intelligence to guarantee reliability, efficiency and resilience to changes, failures or attacks via autonomous, self-configuring and self-healing individual and network behavior. Typical examples of CCNs are beyond-5G cellular systems and critical communication systems, e.g., law enforcement, disaster relief, body- area, medical instruments, space, and indoor/outdoor commercial applications. A practical implementation of a CCN requires extending classical communication systems to embrace the dynamics of fully decentralized systems whose components might exhibit either cooperative, non-cooperative or even malicious behaviors to improve individual and/or global performance. In this context, CYBERNETS aims to develop a relevant understanding of the interactions between information theory, game theory and signal processing to tackle two particular problems from both theoretical and practical perspectives: (I) use of feedback and (II) behavior adaptation in fully decentralized CCNs. In the former, the main objectives are: (i) to determine the fundamental limits of data transmission rates in CCNs with feedback; and (ii) to develop and test in real-systems, transmit-receive configurations to provide a proof-of-concept of feedback in CCNs. For the achievement of these practical objectives, CYBERNETS relies on the world-class testbed infrastructure of Inria at the CITI Lab for fully closing the gap between theoretical analysis and real-system implementation. In the latter, the main objectives are: (i) to identify and explore alternatives for allowing transmitter-receiver pairs to learn equilibrium strategies in CCNs with and without feedback; (ii) to study the impact of network-state knowledge on scenarios derived from the malicious behavior of network components.

8.3. International Initiatives

8.3.1. CoWIN

Title: CoWin: Cognitive Wireless Networks from Theory to Implementation

International Partners:

Princeton University (N.J., United States) - School of Engineering and Applied Science - Prof. H. Vincent Poor

Rutgers University (N.J., United States) - Winlab - Dr. Ivan Seskar.

Start year: 2015

See also: https://project.inria.fr/cowin/

The objective of this team is to strengthen the research efforts on emerging software radio and cognitive radio technologies. The team will count on: first, the cognitive radio test-bed CorteXlab recently set up by the Socrate team within the FIT Equipex, second the leading position of Vincent Poor's team in the field of network information theory and third the Orbit Platform of Rutgers university. The goal is to lead research in both the information theory community and the applied research community so as to reinforce the link between both communities. This work will concern architecture and programs of software radio equipments, distributed and cognitive algorithms for radio resource allocation, cognitive radio scenario experimentations, fundamental limits of cooperative wireless channels and the set up of common experimental infrastructure and protocols for research on cognitive wireless networks.

8.3.2. Inria International Partners

8.3.2.1. Informal International Partners

Socrate has strong collaborations with several international partners.

- **Princeton University**, School of Applied Science, Department of Electrical Engineering, NJ. USA. This cooperation with Prof. H. Vincent Poor is on topics related to decentralized wireless networks. Samir Perlaza has been appointed as Visiting Research Collaborator at the EE Department for the academic period 2016-2017. Scientific-Leaders at Inria: Samir Perlaza and Jean-Marie Gorce.
- **Rutgers University**, Winlab, Orbit testbed. This cooperation with Ivan Seskar is related to experimental wireless testbed. Orbit has been one of the first wireless testbeds of its type. Tanguy Risset and Leonardo Sampaio Cardoso have visited Winlab and I. Seskar visited the Socrate team for one week. Their collaboration is on the development of tools to ease experiment handling on wireless testbeds: visualisation, synchronization etc. Scientific-Leader at Inria: Tanguy Risset
- **University of Sheffield**, Department of Automatic Control and Systems Engineering, Sheffield, UK. This cooperation with Prof. Inaki Esnaola is on topics related to information-driven energy systems and multi-user information theory. Scientific-in-charge at Inria: Samir Perlaza.
- **University of Arizona**, Department of Electrical and Computer Engineering, Tucson, AZ, USA. This cooperation with Prof. Ravi Tandon is on topics related to channel-output feedback in wireless networks. Scientific-Leader at Inria: Samir Perlaza.

- **University of Cyprus**, Department of Electrical and Computer Engineering, University of Cyprus, Nicosia, Cyprus. This cooperation with Prof. Ioannis Krikidis is on topics related to energy-harvesting and wireless communications systems. Scientific-Leaders at Inria: Guillaume Villemaud and Samir Perlaza.
- **Universidade Federal do Ceará**, GTEL, Departamento de Teleinformática, Fortaleza, Brazil. This recently started cooperation with Prof. Tarcisio Ferreira Maciel is on topics related to the optimization of radio ressources for massive MIMO in 5G and 5G-like wireless communications systems. Scientific-in-charge at Inria: Leonardo Sampaio Cardoso.
- **Universidad Nacional del Sur**, LaPSyC laboratory, Bahía Blanca , Argentina. This cooperation with Prof. Juan Cousseau is on topics related to Full-Duplex communications and Interference Alignment. Scientific-in-charge at Inria: Guillaume Villemaud.

8.4. International Research Visitors

8.4.1. Visits of International Scientists

Prof. Ioannis Krikidis from the Department of Electrical and Computer Engineering, University of Cyprus, was appointed as Visiting Professor at the Department of Telecommunications at the INSA de Lyon hosted at the CITI Lab by Samir Perlaza.

Prof. Guiseppe Durisi from the Chalmers University of Technology, Sweden was visiting our group and delivered the following talk: ”Towards Low-Latency Wireless Communications: The Art of Sending Short Packets”.

Prof. Michèle Wigger from Télécom ParisTech, France, was visiting our group and delivered the following talk: “New Results on Cache-Aided One-to-Many Compression and Communication”

Prof. Albert Guillén i Fabregas from Universitat Pompeu Fabra, Spain, was visiting our group and delivered the following talk: “Hypothesis Testing and Error Probability in Information Theory”

Prof. Iñaki Esnaola from University of Sheffield, UK was visiting our group and delivered the following talk: “The Impact of Prior Knowledge in Data Injection Attacks”

Ivan Seskar from Rutgers University, USA was visiting our group and delivered the following talk: “ORBIT Testbed”

8.4.2. Visits to International Teams

Samir Perlaza was visiting the Department of Automatic Control and Systems Engineering at the University of Sheffield, UK, hosted by Prof. Iñaki Esnaola.

Samir Perlaza was visiting the Department of Electrical and Electronic Engineering at Imperial College London, UK hosted by Prof. Deniz Gunduz.

Yasser Fadlallah was visiting the Department of Electrical and Telecommunications Engineering at the University of Naples Federico II, hosted by Prof. Antonia M. Tulino .

Jean-Marie Gorce was visiting the Electrical Departement at Princeton university, hoster by Prof. Vincent Poor Dean of School of Engineering and Applied Science of Princeton University.

Tanguy Risset and Leonardo Sampaio Cardoso were visiting the Winlab research lab at Rutgers University, hosted by Ivan Seskar Associate Director of Information Technology of Winlab.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Event Organisation

9.1.1.1. General Chair, Scientific Chair

- Samir Perlaza was one of the general chairs of the Inria – GDR-ISIS Meeting: Recent Advances in Information Theory and Coding Theory, held in the campus of Université de Lyon, Bibliothéque Marie Curie de l'INSA de Lyon, Lyon, November 29, 2015, France.
- Samir Perlaza was one of the scientific chairs of the Inria – Intech: La théorie des jeux à l'œuvre dans la société, l'économie et l'industrie, held in Inria Grenoble - Rhône-Alpes, Montbonnot, Juin 30, 2015, France.

9.1.1.2. Member of Organizing Committees

- Florent de Dinechin was a member of the following organizing committee:
  - 22nd IEEE Symposium on Computer Arithmetic
- Jean-Marie Gorce was a member of the following organizing committees:
  - colloque Objets Connectés, Entretiens Jacques Cartier (Dec 2015).
  - Gretsi 2015, September 2015, Lyon.
- Samir Perlaza was a member of the following organizing committee:
  - GDR Isis : symposium on New Advances in Information Theory.

9.1.2. Member of Conference Program Committees

- Florent de Dinechin was a member of the following program committees:
  - IEEE International Conference on Application-specific Systems, Architectures and Processors (ASAP)
  - IEEE International Conference on Field Programmable Logic and Applications (FPL)
  - IEEE International Conference on Field Programmable Technologies (FPT)
  - IEEE International Conference on Reconfigurable Computing and FPGAs (ReConFig)
  - International Symposium on Highly Efficient Reconfigurable Accelerator Technologies (HEART)
  - 22nd IEEE Symposium on Computer Arithmetic (Arith)
  - Conférence d'informatique en Parallélisme, Architecture et Système (CompAS)
- Jean-Marie Gorce was a member of the following program committees:
  - Gretsi 2015, September 2015, Lyon.
  - IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) 2015
  - IEEE International Conference on Ultra-Wideband (ICUWB) 2015
  - IEEE ICC Workshop on Cognitive Radio Networks (CRN) 2015.
  - European Conference on Antennas and Propagation (Eucap) 2015
- Tanguy Risset was a member of the following program committees:
  - IEEE Computer Society Annual Symposium on VLSI (ISVLSI) 2015.
  - Design Automation and Test in Europe (DATE) 2015.
- Samir Perlaza was a member of the following program committees:
  - IEEE ICC 2015 Workshop on Next Generation Backhaul/Fronthaul Net- works (BackNets). June 8, 2015, London, UK
  - IEEE ICC 2015 Workshop on Wireless Physical Layer Security (WPLS) June 8, 2015, London, UK
  - IEEE ICC 2015 Workshop on Small Cell and 5G Networks (SmallNets). June 8, 2015, London, UK
- Guillaume Villemaud was a member of the following program committees:

  - IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) 2015
  - International Telecommunications Symposium (ITS) 2015
  - IEEE Vehicular technology Conference (VTC) Fall 2015
- Yasser Fadlallah was a member of the following program committees:
  - IEEE Symposium on Signal Processing and Information Technology 2015.
  - International Conference on Signal Processing & Data Mining 2015.

9.1.3. Member of Editorial Boards

- Florent de Dinechin is an associate editor of IEEE Transactions on Computers
- Jean-Marie Gorce is an associate editor of Telecommunications Systems (Springer) and Journal of Wireless communications and Networking (Springer).
- Guillaume Villemaud is an associate editor of Annals of Telecommunications (Springer).

9.1.4. Tutorials at International Conferences

Samir Perlaza delivered the tutorial "Output Feedback in Wireless Communications" at the IEEE International Conference on Communications (ICC), London, UK, June, 2015. Joint work with H. Vincent Poor (Princeton University, NJ) and Ravi Tandon (Virginia Tech, VA).

9.1.5. Invited Talks

- Samir Perlaza delivered the invited talk "On the Impact of Network-State Knowledge on the Feasibility of Secrecy" at the London Probability Seminar, advances in information theory, Imperial College London, Juin 10, 2015, London, UK.
- Samir Perlaza delivered the invited talk "On the Impact of Network-State Knowledge on the Feasibility of Secrecy" at the MESCAL Seminar, Inria, Rhône-Alpes Research Centre, Mai 21, 2015, Montbonnot, France.
- Selma Belhadj Amor delivered the invited talk "Simultaneous energy and information transmission in Gaussian multiple access channels" at the Inria – GDR-ISIS Seminar on Recent Advances in Information Theory and Coding Theory, Nov 29, 2015, Lyon, France.
- Selma Belhadj Amor delivered the invited talk "Simultaneous energy and information transmission in Gaussian multiple access channels" at the SOCRATE Seminar, Inria, Rhône-Alpes, CITI Lab, Mai 21, 2015, Lyon, France.
- Victor Quintero delivered the invited talk "Noisy Channel-Output Feedback Capacity of the Linear Deterministic Interference Channel" at the SOCRATE Seminar, Inria, Rhône-Alpes, CITI Lab, Mai 21, 2015, Lyon, France.
- Victor Quintero delivered the invited talk "Noisy Channel-Output Feedback Capacity of the Linear Deterministic Interference Channel" at the Inria – GDR-ISIS Seminar on Recent Advances in Information Theory and Coding Theory, Nov 29, 2015, Lyon, France.
- Jean-Marie Gorce: energy efficiency - spectral efficiency tradeoff with distributed interference alignment strategies in 4G networks and beyond. In special session on Smart and Efficient wireless networks and technologies at First URSI Atlantic Radio Science Conference (URSI AT-RASC), May, 20th, 2015.
- Leonardo Sampaio Cardoso deliver the invited talk "Building and using the CorteXlab plaform" at Rutgers University, at Winlab research meeting June 10, 2015, New Jersey, USA.
- Florin Hutu: Energy optimization of radio transmission using wake-up radio. In First URSI Atlantic Radio Science Conference (URSI AT-RASC), May, 2015.

  Tanguy Risset is expert in the European Technology Platform for communications networks and services (NetWorld2020 http://networld2020.eu/)

9.1.6. Research Administration

Jean-Marie Gorce was a member of the Comité National des Universities (CNU) in section 61 signal processing (2011-2015).

Jean-Marie Gorce is a member of the Scientific Committee of the Inria-ALU Bell Labs common lab.

Jean-Marie Gorce is a member of the jury prix de thèse 2016 Signal Image et Vision, soutenu par l'association GRETSI, le GDR ISIS et le club EEA.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Jean-Marie Gorce is the head ot the Telecommunications department of Insa Lyon.

Tanguy Risset and Jean-Marie Gorce and are professors at the Telecommunications Department of Insa Lyon.

Florent de Dinechin is a professor at the Computer Science Department of Insa Lyon.

Claire Goursaud is an associate professor at the Telecommunications department of Insa Lyon.

Leonardo Sampaio Cardoso is an associate professor at Insa Lyon (Premier Cycle).

Guillaume Salagnac and Kevin Marquet are associate professors at the Computer Science Department of Insa Lyon.

Guillaume Villemaud and Florin Hutu are associate professor at the Electrical Engineering Department of Insa Lyon.

Nikolai Lebedev is an associate professor at CPE Lyon engineering school, Lyon.

9.2.2. Supervision

PhD in progress **Yuqi Mo** *Scaling of Iot Communication issuers*, Insa-Lyon, since 09/2015.

PhD in progress **David Kibloff** *New strategy for Physical Layer Security in wireless networks: self-jamming using Full-Duplex Transceivers*, Inria-DGA grant, since 10/2015.

PhD in progress **Coralie Saysset** *Compilation de programme data-flow pour architecture multi-coeur*, nom de l'Université, MENRT, since 09/2014.

PhD in progress **Victor Quintero** *Fundamental Limits of Decentralized Cognitive Radio Networks*, Ecole Doctoral EEA de Lyon, funded by Colciencias since 02/2014.

PhD in progress : **Arturo Jimenez Guizar**: *Cooperative communications in Body Area Networks*, ANR Cormoran grant, since 09/2012.

PhD in progress : **Matei Istoan**: *High-performance coarse operators for FPGA-based computing*, ANR Metalibm grant, since 01/2014.

PhD in progress : **Matthieu Vallerian**: "*Radio Logicielle pour réseau de capteurs*", CIFRE/Orange, since 09/2012.

PhD: **Matthieu Lauzier**: "*Design and evaluation of information gathering systems for dense mobile wireless sensor networks*", CIFRE/Euromedia, 03/04/2015.

PhD: **Baher Mawlawi**: "*Random access for dense networks: Design and Analysis of Multiband CSMA/CA* CEA grant, 26/11/ 2015.

PhD: **Minh Tien Do**: "*Ultra-narrowband wireless sensor networks modeling and optimization* CIFRE grant with Sigfox, 21/07/ 2015.

9.2.3. Juries

Florent de Dinechin

PhD Fernando Endo *Génération dynamique de code pour l'optimisation énergétique* (U. Grenoble, Sep. 2015), (as a reviewer).

PhD Martin Kumm *Multiple Constant Multiplication Optimizations for Field Programmable Gate Arrays* (U. Kassel, Germany, Oct. 2015), (as a reviewer).

PhD Dmitry Burlyaev *Design, Optimization, and Formal Verification of Circuit Fault-Tolerance Techniques* (U. Grenoble, Nov. 2015).

PhD Olga Kupriianova *Toward a Modern Floating-Point Environment* (U. Pierre et Marie Curie Paris 6, Dec. 2015).

PhD Ashraf El-Antably *Etude de la migration de tâches dans une architecture multi-tuile. Génération automatique d'une solution basée sur des agents* (U. Grenoble, Dec. 2015).

Tanguy Risset

PhD Vagelis Bebelis *Boolean Parametric Data Flow (Modeling, Analyses, Implementation)* (U. Grenoble, Fev. 2015), (as a reviewer).

PhD Farouk Mansouri *Modèle de programmation des applications de traitement du signal et de l'image sur cluster parallèle et hétérogène* (U. Grenoble, Oct. 2015), (as jury president).

PhD Andrea Enrici *Model Driven Engineering of Parallel and Distributed Embedded Systems: the Ψ-chart Approach* (Telecom-ParisTech, Dec. 2015), (as a reviewer).

Jean-Marie Gorce

- HdR Eric Simon *Estimation de canal et Synchronisation pour les systèmes OFDM en présence de mobilité* (U. Lille, June 2015), (as a reviewer).
- PhD Thi-Minh-Dung Tran *Methods for finite-time average consensus protocols design, network robustness assessment and network topology reconstruction* (U.Grenoble March 2015), (as a reviewer).
- PhD Selma Belhadj Amor *Gains en capacité dans les canaux à accès multiple et à diffusion par l'exploitation de la voie de retour* (Telecom Paris Tech, March 2015), (as the jury president).
- PhD Matthieu De Mari *Allocations de ressources dans les réseaux sans fils* (CentraleSupelec, July 2015), (as a reviewer).
- PhD Raouia Masmoudi *Télécommunications domotiques efficaces en termes de consommation d'énergie* (U. Cergy Pontoise and U. Sfax, Nov 2015), (as the jury president).
- PhD Yangyang Chen *performance analysis of mobile relays for LTE ; Telecoms Bretagne* (U.Rennes Dec 2015), (as a reviewer).

Guillaume Villemaud

PhD Nicolas Chevalier *Performances de l'optique sans fil pour les réseaux de capteurs corporels)* (U. Limoges, dec. 2015), (as a reviewer).

10. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

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[3] P. FERRAND, J.-M. GORCE, C. GOURSAUD. *Approximations of the packet error rate under quasi-static fading in direct and relayed links*, in "EURASIP Journal on Wireless Communications and Networking", December 2015, 12 p. [*DOI :* 10.1186/S13638-014-0239-4], https://hal.inria.fr/hal-01193293

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Invited Conferences

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International Conferences with Proceedings

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N. BRUNIE, F. DE DINECHIN, O. KUPRIIANOVA, C. LAUTER. *Code generators for mathematical functions*, in "22d IEEE Symposium on Computer Arithmetic", Lyon, France, June 2015, Best paper award, http://hal.upmc.fr/hal-01084726.

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