IN PARTNERSHIP WITH:
Institut national des sciences appliquées de Lyon

Activity Report 2012

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

Table of contents

Team SOCRATE

Keywords: Wireless Networks, Radio Interface, Software Radio, Cognitive Radio Networks, Embedded Systems, Network Protocols

Socrate is hosted in the CITI laboratory of INSA Lyon (http://www.citi-lab.fr/).

Creation of the Team: January 01, 2012 .

1. Members

Faculty Members

Tanguy Risset [Team leader, Professor, Insa Lyon, HdR]
Jean-Marie Gorce [Professor, Insa Lyon, HdR]
Claire Goursaud [Associate Professor, Insa Lyon]
Kevin Marquet [Associate Professor, Insa Lyon]
Florin Hutu [Associate Professor, Insa Lyon]
Nikolaï Lebedev [Associate Professor, CPE Lyon]
Guillaume Villemaud [Associate Professor, Insa Lyon]
Guillaume Salagnac [Associate Professor, Insa Lyon]

Engineers

Stéphane d'Alu [Research Engineer, Insa Lyon, 50%]
Tao Wang [Research assistant, Inria]
Leonardo Sampaio Cardoso [Research assistant, Inria]
Benjamin Guillon [Research assistant, Inria]
Abdelbassat Massouri [Research assistant, Inria]
Hervé Parvery [transfert engineer, Insavalor]
Antoine Scherrer [Research assistant, Inria, up to feb. 2012]

PhD Students

Mickael Dardaillon [Region grant, since 10/2011, 2nd year]
Minh Tien Do [Cifre grant with Sigfox, since , 06/2012, 1st year]
Paul Ferrand [MENRT grant, since 10/2009, 4th year]
Virgile Garcia [Inria/Alcatel-Lucent grant, Phd Passed March 2012]
Arturo Jimenez Guizar [Insa/ANR grant, since 09/2012 1st year]
Cengis Hasan [Inria grant, since 01/2010, 3rd year]
Aissa Khoumeri [Inria FUI Econhome grant, since 10/2011, 2nd year]
Matthieu Lauzier [Insavalor, Euromedia partnership, since 10/2011, 2nd year]
Meiling Luo [MENRT grant, since 01/2010, 3rd year]
Laurent Maviel [Cifre grant with Siradel, since , 11/2009, 4th year]
Baher Mawlawi [CEA grant, since 09/2012, 1th year]
Matthieu Vallerian [Cifre/Orange labs grant , since , 09/2012, 1st year]
Zhaowu Zhan [Insa/CSC grant , since , 09/2012, 1st year]

Post-Doctoral Fellows

Luis Goncalves [IAPP FP7 grant, iPLAN project, since 06/2011]
Dimitrios Tsilimantos [IAPP FP7 grant, iPLAN project, since 01/2010]
Dimitry Umansky [Inria grant, up to feb 2012]
Yuxin Wei [Inria grant, Econhome project since 10/2011]

Administrative Assistant

Gaelle Tworkowski [ITA Inria (part time)]

2. Overall Objectives

2.1. Highlights of the Year

2.1.1. CortexLab room construction start

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 will be composed of four main parts: a Network Operations Center (NOC), a set of Embedded Communicating Object (ECO) testbeds, a set of wireless OneLab testbeds, and a cognitive radio testbed (CorteXlab) deployed by the Socrate team in the Citi lab. In 2012 the construction of the room started in the Citi lab building basement. Photos of the room are now available on-line.

2.1.2. Socrate at Paris' Marathon

Former french cycle Champion Laurent Jalabert ran the 42,195 km of Paris Marathon, commenting lively his performances and wearing an experimental set of sensors analysing in real time data from the race (stride, heart, etc.). Data was sent by radio to a motocycle relaying information with euromedia bus and printed on the TV screen in real time (see the press release for instance). This experiment was made in a collaboration between socrate, Euromedia and HiKoB, next demostration should happen tour de France in 2013 targeting full deployment at Olympic Games of 2016 in Rio de Janeiro.

2.2. 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 of 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 which 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.* [42]

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.

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 [41], 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 [34]. The current development of the wireless industry is surely slowed down by the lack of radio resources and the lack of systems flexibility.

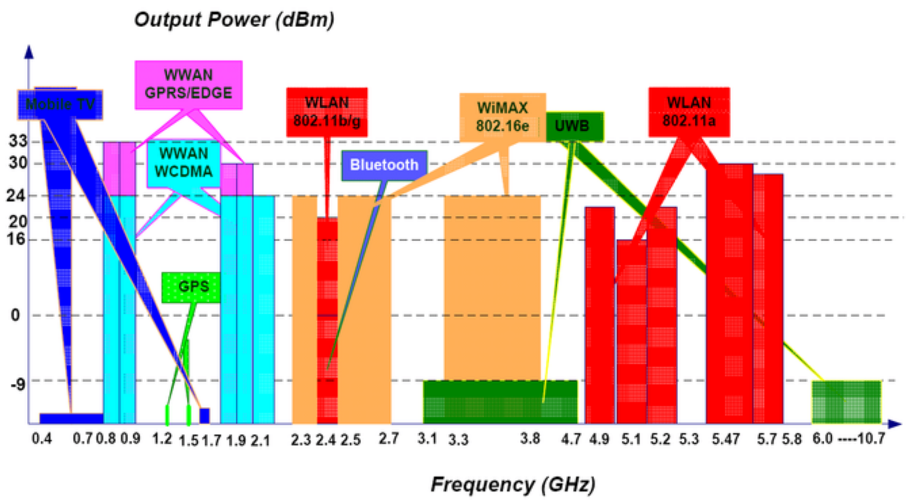

Figure 1. The most recent standards for wireless communications are developed in the UHF and VHF bands. These bands are mostly saturated (source: WPAN/WLAN/WWAN Multi-Radio Coexistence, IEEE 802 Plenary, Atlanta, USA, Nov.2007)

This technological bottleneck will be only overtaken if three complementary problems are solved : *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 [38], [39]. While implementing everything in software node 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 alreay 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 [34]. 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 which are portable from one terminal to another? Autonomous networking will only be reached after a deep understanding of network information theory, given that there will be many ways for transmitting data from one point to another, which way is the most efficient in terms of througput? 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 thematics: 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.

2.3. 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 [38], [35].

2.3.1. SDR technology

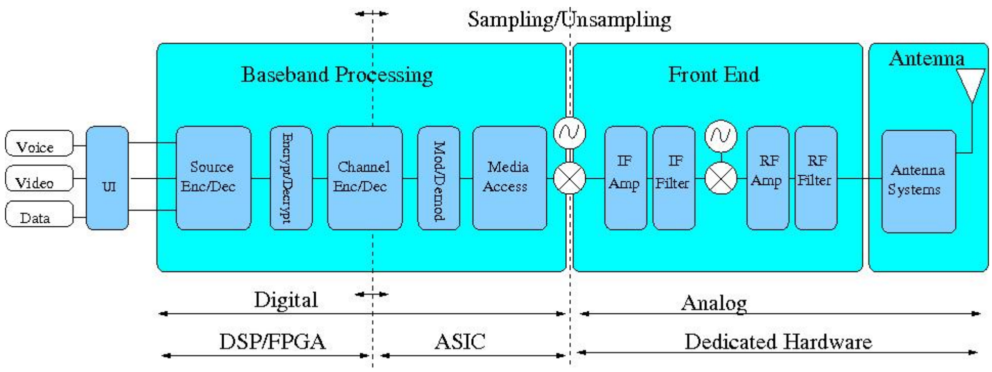

Figure 2. Radio Block Diagram, highlighting separation between digital and analog parts, as well as programmable, configurable and fixed hardware parts.

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.

2.3.2. 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 on millisecond.

The main restriction to build an ideal software radio is sampling rate: sampling at high rate is not an easy task. Following 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 a 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).

2.3.3. 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” [40]. 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 [36].

2.4. 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 [37] but this is usually not considered as a realistic choice for commercial SDR handset. The targeted frequency band has a huge impact as sampling at high rate is very expensive, and trade-offs between flexibility, complexity, cost and power consumption has 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:* This is a key issue for reducing interference, increasing capacity and reusing frequency. Hot topics such as wake-up radio or multi protocol parallel receiver 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 prototypes. Having a common programming interface for SDR system 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. Scientific Foundations

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 axis 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 physical protocols layer on these software radio machines. Figure 3 illustrates the three region of a transceiver corresponding to the three Socrate axes.

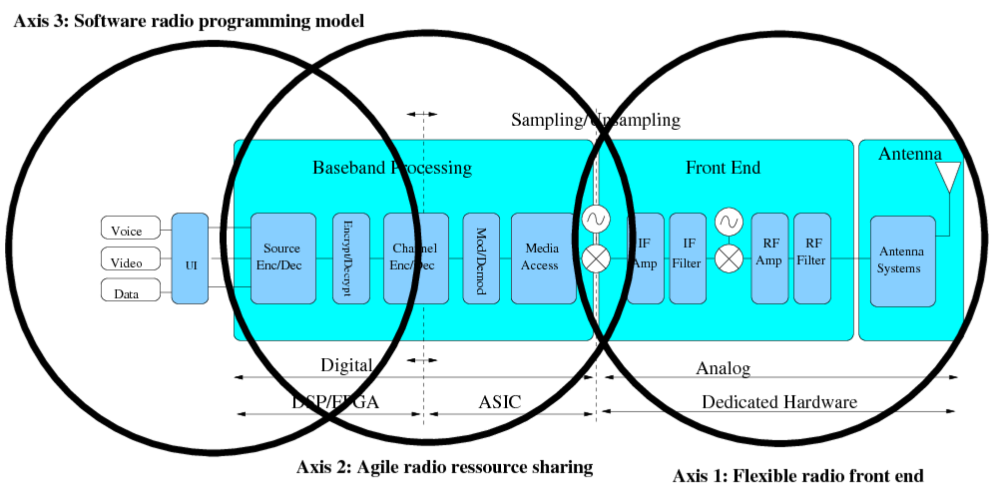

Figure 3. Center of interest for each ot the three Socrate researche axes with respect to a generic software radio terminal.

3.2. Flexible Radio Front-End

Guillaume Villemaud (coordinator), 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 amplifier which are currently studied by hardware oriented teams. The purpose of this axe is to build system level simulation taking into account the state of the art of each key components. A large part of this work will be supported in the frame of the FUI project EconHome starting in January 2011.

3.3. Agile Radio Resource Sharing

Jean-Marie Gorce (coordinator), Claire Goursaud, Nikolai Lebedev

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 agiles : 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 about 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 MANETS, 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.

3.4. Software Radio Programming Model

Tanguy Risset (coordinator), Kevin Marquet, Guillaume Salagnac

Finally the third research axis is concerned with software aspect of the software radio terminal (left of Fig 3). We have currently two action 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

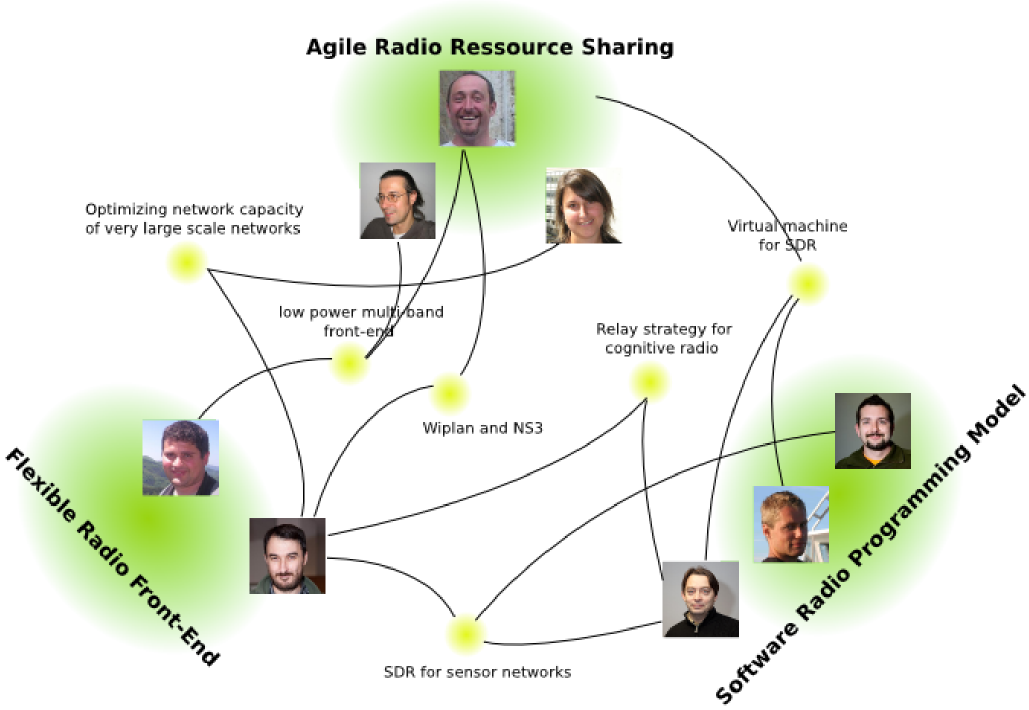

Figure 4. Inter-Axis Collaboration in Socrate: we expect innovative results to come from this pluri-disciplinary research

As mentioned earlier, innovative results will come from collaborations between these 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 axis, 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) are planned to collaborate thanks to the complementarity of their subjects.
- *SDR for sensor networks*. A master student have been hired in 2012 and a PhD should be started in collaboration with FT R&D, involving people from axis 3 (Guillaume Salagnac, Tanguy Risset) and axis 1 (Guillaume Villemaud).
- *Wiplan and NS3*. The MobiSim ADT and iPlan projects involve Guillaume Villemaud (axis 1) and Jean-Marie Gorce (axis 2).

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

- *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).
- *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 where 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. Application Domains

4.1. Example of SDR applications

SDR concept is not new and many research teams have been working on its implementation and use in various contexts, however two elements are in favor of Socrate's orientation towards this technology:

1. The mobile SDR technology is becoming mature. Up to now, Software-Defined Radio terminals were too expensive and power consuming for mobile terminal, this should change soon. For instance, CEA's Magali platform has demonstrated part of LTE-Advanced standard recently. It is important for applied researchers to be ready when a new technology rises up, opening to many new software issues.
2. Rhône-Alpes is a strategic place for this emerging technology with important actors such as ST-Microelectronics, CEA, Minalogic and many smaller actors in informatics for telecommunication and embedded systems.

SDR technologies enables the following scenarios:

- *Transparent radio adaptation:* Depending on the available wireless protocols in the air (e.g. Wifi versus UMTS), a terminal may choose to communicate on the cheapest, or the fastest channel.
- *Radio resource allocation:* In order to minimize expensive manual cell planning and achieve "tighter" frequency reuse patterns, resulting in improved system spectral efficiency, dynamic radio resource management is a promising application of SDR.
- *White space:* By sensing the air, a terminal is able to communicate using a particular frequency which is not used even if it is reserved for another kind of application.
- *Cooperation:* Using the neighboring terminals, a user can reduce power consumption by using relay communication with the base station.
- *Saturated bands:* A fixed wireless object, e.g. a gas meter sending regular data through the air, might check if the frequency it uses is saturated and choose, alone or in a distributed manner with other gas meters, to use another frequency (or even protocol) to communicate.
- *Radars:* With numerical communications, passive radar technology is changing, these radars will have to be updated regularly to be able to listen to new communication standards.
- *Internet of things:* With the predicted huge venue of wireless object, some reconfigurability will be needed even on the simplest smart object as mentionned above for facing the band saturation problem or simply communicating in a new environment.

4.2. Public wireless access networks

The commercial markets for wireless technologies are the largest markets for SDR and cognitive radio. these markets includes $i)$ the cellular market (4G, LTE), $ii)$ the Wireless Local Area Network market (WLAN, e.g. Wifi), and $iii)$ the Broadband Wireless Access market (e.g. WiMax). The key objective here is to improve spectrum efficiency and availability, and to enable cognitive radio and SDR to support multimedia and multi-radio initiatives.

The future mobile radio access network referred to as 4G (4th generation) is expected to provide a wireless access of 100 Mbps in extended mobility and up to 1Gbps in reduced mobility as defined by the group IMT-Advanced of the ITU-R(adiocommunication) section. On the road towards the 4G, IMT-2000 standards evolutions are driven by the work of the WiMAX forum (IEEE 802.16e) on the one hand and by those of the LTE (Long Term Evolution) group of the 3GPP on the other hand. Both groups announced some targeted evolutions that could comply with the 4G requirements, namely the Gigabit Wimax (802.16m) and the LTE-Advanced proposal from the 3GPP.

In both technologies, the scarcity of the radio spectrum is taken care of by the use of MIMO and OFDMA technologies, combining the dynamic spatial and frequency multiple access. However, a better spectral efficiency will be achieved if the radio spectrum can be shared dynamically between primary and secondary networks, and if the terminals are reconfigurable in real-time. Socrate is active in this domain because of its past activity in Swing and its links to the telecommunication teaching department of Insa. The developpement of the FIT plateform [36] is a strong effort in this area.

4.3. Military SDR and Public Safety

Military applications have developed specific solutions for SDR. In France, Thales is a major actor (e.g. project Essor defining inter-operability between European military radio) and abroad the Join Tactical Radio System, and Darpa focus on Mobile Ad-hoc Networks (MANETs) have brought important deliverables, like the Software Communications Architecture (SCA) for instance [37].

Recent natural disasters have brought considerable attention to the need of enhanced public safety communication abroad [35]. Socrate in not currently implied in any military or public safety research programs but is aware of the potential importance this domain may take in Europe in a near future.

4.4. Ambient Intelligence: WSN and IoT

Sensor networks have been investigated and deployed for decades already; their wireless extension, however, has witnessed a tremendous growth in recent years. This is mainly attributed to the development of wireless sensor networks (WSNs): a large number of sensor nodes, reliably operating under energy constraints. It is anticipated that within a few years, sensors will be deployed in a variety of scenarios, ranging from environmental monitoring to health care, from the public to the private sector. Prior to large-scale deployment, however, many problems have to be solved, such as the extraction of application scenarios, design of suitable software and hardware architectures, development of communication and organization protocols, validation and first steps of prototyping, etc. The Citi laboratory has a long experience in WSN which leaded recently to the creation of a start-up company, leaded by two former Citi members: HIKOB(http://openlab.hikob.com).

The Internet of Things (IoT) paradigm is defined as a very large set of systems interconnected to provide a virtual twin world interacting with the real world. In our work we will mostly focus on wireless systems since the wireless link is the single media able to provide a full mobility and ubiquitous access. Wireless IoT is not a reality yet but will probably result from the convergence between mobile radio access networks and wireless sensor networks. If radio access networks are able to connect almost all humans, they would fail to connect a potential of several billions of objects. Nevertheless, the mutation of cellular systems toward more adaptive and autonomous systems is on going. This is why Socrate develops a strong activity in this applicative area, with its major industrial partners: Orange Labs and Alcatel-Lucent Bell labs.

For instance, the definition of a *smart node* intermediate between a WSN and a complex SDR terminal is one of the research direction followed in Socrate, explicitly stated in the ADT Snow project. Other important contributions are made in the collaboration with SigFox and Euromedia and in the EconHome project.

4.5. Body Area Networks

Body Area Network is a relatively new paradigm which aims at promoting the development or wireless systems in, on and around the human body. Wireless Body Area Networks (BAN) is now a well known acronym which encompasses scenarios in which several sensors and actuators are located on or inside the human body to sense different data, e.g. physiological information, and transfer them wirelessly towards a remote coordination unit which processes, forwards, takes decisions, alerts, records, etc. The use of BAN spans a wide area, from medical and health care to sport through leisure applications, which definitely makes the definition of a standard air interface and protocol highly challenging. Since it is expected that such devices and networks would have a growing place in the society and become more stringent in terms of quality of service, coexistence issues will be critical. Indeed, the radio resource is known to be scarce. The recent regulation difficulties of UWB systems as well as the growing interest for opportunistic radios show that any new system have to make an efficient use of the spectrum. This also applies to short range personal and body area network systems which are subject to huge market penetrations.

Socrate was involved in the Banet ANR project (2008-2010), in which we contributed to the development of a complete PHY/MAC standard in cooperation with Orange Labs and CEA Leti, who participated to the standardization group 802.15.6. Recently, Inria has been added as a partner the FET flagship untitled *Guardian Angels* (http://www.fet-f.eu/), an important european initiative to develop the BANs of the futur.

We consider that BANs will probably play an important role in the future of Internet as the multiple objects connected on body could also be connected to Internet by the mobile phone hosted by each human. Therefore the BAN success really depends on the convergence of WSN and radio access networks, which makes it a very interesting applicative framework for Socrate team.

5. Software

5.1. WSnet

Socrate is an active contributor to WSnet (http://wsnet.gforge.inria.fr/) a multi-hop wireless network discrete event simulator. WSnet was created in the ARES team and it is now supported by the D-NET team of Inria Rhône-Alpes.

5.2. Wiplan

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). The discrete ParFlow equations are translated in the Fourier domain providing a wide 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 re- quests. However, we have shown that the use of a multi-resolution approach allows the main computation load to be restricted to a pre-processing phase. Extensive works have been done to make predictions more realistic. The network planning and optimization suite is based on a multi-criteria model relying on a Tabu solver. The development of the wiplan software is a part of the european project iPlan (IAPP-FP7 project). See also the web page http://wiplan.citi.insa-lyon.fr.

6. New Results

6.1. Flexible Radio Node

6.1.1. Radio wave propagation

The MR-FDPF (Multi-Resolution Frequency Domain Partial Flow) method is proven to be a fast and efficient method to simulate radio wave propagation. It is a deterministic model which can provide an accurate radio coverage prediction. In reality, radio channels have the nature of randomness due to e.g. moving people or air flow. Thus they can not be rigorously simulated by a pure deterministic model. However, it is believed that some statistics can be extracted from deterministic models and these statistics can be very useful to describe radio channels in reality. In [20], large scale fading statistical characteristics are extracted based on the MR-FDPF method. They are validated by comparison to both the theoretical result and measurement. The match also demonstrates that MR-FDPF is capable of simulating large scale fading.

In [2] we study Realistic Prediction of Bit error rate (BER) and adaptive modulation and coding (AMC) for Indoor Wireless Transmissions. Bit error rate is an important parameter for evaluating the performance of wireless networks. In this letter, a realistic BER for indoor wireless transmissions is predicted. The prediction is based on a deterministic radio propagation model, the MR-FDPF model, which is capable of providing accurate fading statistics. The obtained BER map can be used in many cases, e.g., adaptive modulation and coding scheme or power allocation.

In [4], we propose a modification of the MR-FDPF method that allows simulating radio propagation channels in a frequency range. The performance of the proposed MR-FDPF implementation has been analyzed based on different realistic propagation scenarios. We also analyze the possibility of applying the multi-resolution frequency domain approach to the well-known transmission-line matrix method. The proposed multi-resolution frequency domain transmission-line matrix method provides a computationally efficient way of modeling radio wave propagation in three dimensional space at multiple frequencies.

In [3], we consider the performance of coded wireless communication systems experiencing non-frequency selective fading channels in shadowed environments. The quality of service (QoS) in a wireless network is dependent on the packet error outage (PEO). We address the problem of finding a tractable expression for the coded PEO over Nakagami-m channels with shadowing, considering multilevel modulations, various block, convolutional channel coding schemes and hard decision decoding. In order to obtain the coded PEO, an inversion of the coded packet error probability (PEP) w.r.t. the signal to noise ratio (SNR) is needed. To this end, we propose an invertible approximation for the coded PEP w.r.t. the uncoded bit error probability (BEP) in Nakagami-m fading channels which is accurate for all BEPs of interest. The BEP itself depends on the average SNR and we hence make use of previous results on the inversion of the uncoded BEP w.r.t. the SNR in Nakagamim fading channels, holding for M-PSK and M-QAM signals. We were thus able to obtain a reliable closed form expression for the coded PEO in flat fading and shadowing channels

6.1.2. Power consumption

In [24], we propose the use of an existing opensource network simulator, WSNet, to evaluate the interest of using multi-mode relays in terms of energy consumption. We show that the combination of MIMO and multi-mode provides a solution to reduce global energy consumption, but that conclusions are really scenario-dependent. Moreover, we explain how a multi-mode MIMO terminal can improve these results using adaptive strategies.

the energy consumption in wireless sensor networks is studied. In order to minimize the consumed power at the analog and RF part, an energy recovering system combined with a wake-up radio is proposed for discussion. The proposed architecture has three activity levels : zero consumption, low and high energy consumption. In order to quantify the gain in terms of power consumption, a power consumption model state of the art is proposed. in [7] all radio channel models which can be used for MIMO heterogeneous network with small cells are described.

6.1.3. MIMO

In [28], we study MIMO and next generation system. For the past decade or more MIMO systems have been the subject of very intensive research. However in the past few years, these techniques have begun to be implemented in practice. In particular they have appeared in the standards for next generation systems such as LTE, 3GPP-LTE Advanced and WiMAX, as well as the latest versions of Wifi. This chapter, extracted from the book edited by the Cost Action 2100: “Pervasive Mobile and Ambient Wireless Communications”, brings together the MIMO systems used in next generation systems with other work on the implementation and simulation of these systems. It also describes advances in MIMO techniques in a number of areas. The first section is divided into two sub-sections dealing first with simulators and testbeds which are used in system-level simulators to evaluate overall system capacity, as discussed in later chapters of this book. Secondly the development of terminals for next generation MIMO systems is considered, especially considering the additional RF hardware required for MIMO. Section 7.2 then discusses especially precoding techniques used in many of the recent standards to implement MIMO. In particular precoding allows the implementation of closed loop or adaptive MIMO. In next generation systems there is also much increased attention on MU-MIMO and on multi-terminal MIMO in general, including so-called "network MIMO " approaches, which appear in LTE as Coordinated Multiple Point: this is covered in Sect. 7.3. Various advanced MIMO transmission and detection approaches are covered in Sects. 7.4 to 7.6, including some interesting work on MIMO techniques involving continuous phase modulation, giving advantages in terms of peak-to-average power ratio.

6.2. Agile Radio Resource Sharing

6.2.1. Wireless Multi-hop Networks

In [6], we study energy-delay tradeoff in wireless multihop networks with unreliable links. Energy efficiency and transmission delay are very important parameters for wireless multihop networks. Numerous works that study energy efficiency and delay are based on the assumption of reliable links. However, the unreliability of channels is inevitable in wireless multihop networks. In addition, most of works focus on self-organization protocol design while keeping non-protocol system parameters fixed. While, very few works reveal the relationship between the network performance and these physical parameters, in other words, the best networks performance could be obtained by the physical parameters. This paper investigates the tradeoff between the energy consumption and the latency of communications in a wireless multihop network using a realistic unreliable link model. It provides a closed-form expression of the lower bound of the energy–delay tradeoff and of energy efficiency for different channel models (additive white Gaussian noise, Rayleigh fast fading and Rayleigh block-fading) in a linear network. These analytical results are also verified in 2-dimensional Poisson networks using simulations. The closed-form expression provides a framework to evaluate the energy–delay performance and to optimize the parameters in physical layer, MAC layer and routing layer from the viewpoint of cross-layer design during the planning phase of a network.

6.2.2. Relay and Cooperative Communications

In [16], we aim at characterizing the gain induced by using relay channels in a linear network under both capacity constraint and realistic energy model. We express a general model based on a convex optimization problem. Then, we use numerical tools to obtain results on the outer and inner bounds of the capacity of the full and half duplex relay channel. We then extend this study with more complex networks based on relay channels, especially networks formed by a linear chain of nodes. We describe the Pareto optimal solutions of the minimization problem with respect to the consumed energy and latency in such a linear network. From the simple case of the linear multi-hop network, we study the gains when implementing a linear chain of relay channels and compare these results to the simpler multi-hop transmission.

In [15], we present preliminary results on achievables rates in half-duplex cooperative multiple access channels (CMAC).We show that the upper bound on the capacity of the half-duplex CMAC can be solved using convex optimization techniques. Under a Gaussian model, we study the maximal achievable rate by every node in the network. We propose a number of scenarios, encompassing existing and theoretical cooperation schemes. Using these hypotheses, we evaluate the performance of both a non-cooperative concurrent access and simple cooperative multi-hop or relaying schemes with respect to the upper bound. The performance is compared for the various scenarios, and we provide analyses of specific cases in order to illustrate how our framework may be used to answer targeted questions about the capacity of CMACs.

In [31], we aim at obtaining usable bounds on the performance of CMAC under a Gaussian model. We first show that the problem can be transformed into a convex optimization problem which makes it easily solvable using numerical tools. We propose, as a line of study, to consider the maximal achievable common rate by every node in the network. We then proceed to express closed-form bounds on the capacity region of the

CMAC in that common rate scenario. We study simple cooperation schemes based on existing results in relay channels and compare them to other medium sharing approaches. In the end, we show that using the relay-channel based protocols can be efficient for some parameters, but gets less interesting in the Gaussian case if the source-destination links are good enough.

In [30], we study the optimal power allocations in CMACs, where we aim at maximizing the rate achievable by both sources simultaneously rather than the sum of achievable rates. Separating our study between the coherent and non-coherent case, we obtain closed-form expressions for the optimal power allocations w.r.t. the outer bounds of the capacity region, as well as decode-and-forward and non-cooperative inner bounds. We point out during our resolution that the general CMAC model behaves as a multiple access relay channel (MARC), where a "virtual" relay node is introduced to represent the cooperation between the sources. This equivalent model simplifies the original power allocation problem. We finally show that the general cut-set outer bound on the capacity region of the equivalent MARC matches exactly the tightest known outer bound on the capacity region of the original CMAC.

In [17] we address the distributed power adaptation problem on the downlink for wireless cellular networks. As a consequence of uncoordinated local scheduling decisions in classical networks, the base stations produce mutual uncontrolled interference on their co-channel users. This interference is of a variable nature, and is hardly predictable, which leads to suboptimal scheduling and power control decisions. While some works propose to introduce cooperation between base stations, in this work we propose instead to introduce a model of power variations, called trajectories in the powers space, to help each base station to predict the variations of other base stations powers. The trajectories are then updated using a Model Predictive Control (MPC) to adapt transmit powers according to a trade-off between inertia (to being predictable) and adaptation to fit with capacity needs. A Kalman filter is used for the interference prediction. In addition, the channel gains are also predicted, in order to anticipate channel fading states. This scheme can be seen as a dynamic distributed uncoordinated power control for multichannel transmission that fits the concept of self-optimised and self-organised wireless networks. By using the finite horizon MPC, the transmit powers are smoothly adapted to progressively leave the current trajectory toward the optimal trajectory. We formulate the optimisation problem as the minimisation of the utility function of the difference between the target powers and MPC predicted power values. The presented simulation results show that in dynamic channel conditions, the benefit of our approach is the reduction of the interference fluctuations, and as a consequence a more accurate interference prediction, which can further lead to a more efficient distributed scheduling, as well as the reduction of the overall power consumption.

6.2.3. BAN

In [26] we present a simple Body Area Network (BAN) platform that was built to monitor the performance of a marathon athlete all along the race, meeting real-time and QoS constraints, under good transmission conditions. Data collected during the event (packet loss, signal strength) allowed us to obtain a primary knowledge about the behavior of the radio transmissions between the different links in the network. The results of this experiment and ther important disparities observed between the links point out the need to improve the transmission strategy.

6.2.4. Network coding

One of the most powerful ways to achieve transmission reliability over wireless links is to employ efficient coding techniques. In [10] investigates the performance of a transmission over a relay channel where information is protected by two layers of coding. In the first layer, transmission reliability is ensured by fountain coding at the source. The second layer incorporates network coding at the relay node. Thus, fountain coded packets are re-encoded at the relay in order to increase packet diversity and reduce energy consumption. Performance of the transmission is measured by the total number of transmissions needed until the message is successfully decoded at the destination. We show through both analytical derivations and simulations that adding network coding capabilities at the relay optimizes system resource consumption. When the source uses a random linear fountain code, the proposed two layer encoding becomes more powerful as it reduces the transmission rate over the direct link between the source and the destination.

In [27] we study the deployment of fountain codes and network coding in a wireless sensor network (WSN). A WSN is composed of sensor nodes with restricted capacities: memory, energy and computational power. The nodes are usually randomly scattered across the monitored area and the environment may vary. In the presence of fading, outage and node failures, fountain codes are a promising solution to guaranty reliability and improve transmission robustness. The benefits of fountain codes are explored based on an event-driven WSNet simulator considering realistic implementation based on standard IEEE802.15.4. Fountain codes are rateless and capable of adapting their rate to the channel on the fly using a limited feedback channel. In this thesis, we highlight the benefits brought by fountain code in terms of energy consumption and transmission delay. In addition to the traditional transmission with fountain code, we propose in this thesis to study the network coding transmission scheme where nodes are allowed to process the information before forwarding it to their neighbors. By this means, we can say that packet diversity is exploited as each individual packet is unique and contains different representations of binary data. Redundancy is thus optimized since repetitions are avoided and replaced with diversified information. This can further lead to an overall improved performance in cooperative communication where nodes are allowed to assist in relaying packets from the source the destination. We highlight in this thesis the benefits of fountain code combined to network coding and show that it leads to a reduction in transmission delay and energy consumption. The latter is vital to the life duration of any wireless sensor network.

In [9] we tackles the problem of providing end to end reliable transmissions in a randomly deployed wireless sensor network. To this aim, we investigate the simultaneous use of gradient broadcast routing (for its inherent adaptability to any network topology and its changes), fountain codes (for their universal property) and intra-flow network coding (to introduce packet diversity in redundant copies). We present the impact of the proposed strategy on a realistic network. This work permits to highlight that, compared to basic gradient broadcast routing, the strategy not only improves the reliability and the delay in the network but also clearly increases its lifetime.

6.2.5. Vehicular networks

In [22] we study a hybrid propagation model For large-scale variations caused By vehicular traffic in small cells. we present a propagation model generating time series of large-scale power variations for small-cell radio links intersected by vehicular traffic. The model combines stochastic processing and geometric computation. For each road crossing a link, a two-state process parameterized by mobility statistics represents the obstruction status. When the status is set to obstructed, a fluctuation pattern is generated. Based on previously published measurements, both mobility statistics and time series results are validated through the comparison of respectively inter-obstruction duration distributions and outage probabilities. The proposed model avoids resource consuming iterative propagation prediction while providing realistic and frequency adaptive results.

In [21], we performed measurements of large-scale variations caused by vehicular traffic in small-cell. This paper presents and characterizes large-scale variations of received power generated by vehicular traffic crossing a radio link. Measurements in the 2 GHz band for several small-cell configurations involve various transmitter heights, link distances and urban densities. Observations showed that stronger losses up to 30 dB are due to medium to high vehicles. Lower vehicles have a smaller impact in links perpendicular to traffic, but amplitude variations and duration can reach larger values when the receiver is at cell radius limits.

6.2.6. security

In [18] we study Security Embedding on ultra wideband impulse radio(UWB-IR) Physical Layer. The main goal of this work is to incorporate security in an existing ultra wideband (UWB) network. We present an embedding method where a tag is added at the physical layer and superimposed to the UWB-impulse radio signal. The tag should be added in a transparent way so that guaranteeing compatibility with existing receivers ignoring the presence of the tag. We discuss technical details of the new embedding method. In addition, we discuss embedding strength and we analyze robustness performance. We demonstrate that the proposed embedding technique meets all the system design constraints.

In [11] we study Jamming in time-hopping ultrawide band (TH-UWB) Radio. With the great expansion of wireless communications, jamming becomes a real threat.We propose a new model to evaluate the robustness of a communication system to jamming. The model results in more scenarios to be considered ranging from the favorable case to the worst case. The model is applied to a TH-UWB radio. The performance of such a radio in presence of the different jamming scenarios is analyzed. We introduce a mitigation solution based on stream cipher that restricts the jamming problem of the TH-UWB communication to the more favorable case while preserving confidentiality.

6.2.7. Network Information Theory

Fundamental performance limits of multi-hop wireless transmissions are being investigated in [33] from a multiobjective perspective where transmission decisions (i.e. relay selection, scheduling or routing decision) modify the trade-off between capacity, reliability, end-to-end delay or network-wide energy consumption. In our previous work presented in the Inria research report RR-7799, Pareto-optimal performance bounds and network parameters have been derived for a 1-relay and 2-relay network within a MultiObjective(MO) performance evaluation framework. We show in this report that these bounds are tight since they can be reached by simple practical coding strategies performed by the source and the relays. Such strategies constitute achievable lower MO performance bounds on the real MO performance limits. More precisely, we adopt a coding strategy where the source transmits a random linear fountain code which is coupled to a network coding strategy performed by the relays. Two different network coding strategies are investigated. Practical performance bounds for both strategies are compared to the theoretical bound. We show that the theoretical bound is tight: generational distance between the practical and theoretical bound for the best strategy is only of 0.0042

In [19] we revisit the problem of non-cooperativ association of mobiles to access points using game theory. We consider in this paper games related to the association problem of mobiles to an access point. It consists of deciding to which access point to connect. We consider the choice between two access points or more, where the access decisions may depend on the number of mobiles connected to each one of the access points. We obtain new results using elementary tools in congestion and crowding games.

In [23] we study stochastic analysis of energy savings with sleep mode in Orthogonal Frequency-Division Multiple Access (OFDMA) wireless networks. The issue of energy efficiency in OFDMA wireless networks is discussed in this paper. Our interest is focused on the promising concept of base station sleep mode, introduced recently as a key feature in order to dramatically reduce network energy consumption. The proposed technical approach fully exploits the properties of stochastic geometry, where the number of active cells is reduced in a way that the outage probability, or equivalently the signal to interference plus noise distribution, remains the same. The optimal energy efficiency gains are then specified with the help of a simplified but yet realistic base station power consumption model. Furthermore, the authors extend their initial work by studying a non-singular path loss model in order to verify the validity of the analysis and finally, the impact on the achieved user capacity is investigated. In this context, the significant contribution of this paper is the evaluation of the theoretically optimal energy savings of sleep mode, with respect to the decisive role that the base station power profile plays.

6.3. Software Radio Programming Model

6.3.1. Virtual Radio Machine

In [14] we present a survey of existing prototypes dedicated to software defined radio. We propose a classification related to the architectural organization of the prototypes and provide some conclusions about the most promising architectures. This study should be useful for cognitive radio testbed designers who have to choose between many possible computing platforms. We also introduce a new cognitive radio testbed currently under construction and explain how this study have influenced the test-bed designers choices.

6.3.2. Embedded systems

In [13], we explore new area/throughput trade-offs for the Girault, Poupard and Stern authentication protocol (GPS). This authentication protocol was selected in the NESSIE competition and is even part of the standard ISO/IEC 9798. The originality of our work comes from the fact that we exploit a fixed key to increase the throughput. It leads us to implement GPS using the Chapman constant multiplier. This parallel implementation is 40 times faster but 10 times bigger than the reference serial one. We propose to serialize this multiplier to reduce its area at the cost of lower throughput. Our hybrid Chapman's multiplier is 8 times faster but only twice bigger than the reference. Results presented here allow designers to adapt the performance of GPS authentication to their hardware resources. The complete GPS prover side is also integrated in the network stack of the POW-WOW sensor which contains an Actel IGLOO AGL250 FPGA as a proof of concept.

The people involved in this axes also published in the computer science flied. For instance in [1] static vulnerability detection in java service-oriented components is studied. In [12] A lightweight Hash function family based on FCSRs is studied.

7. Bilateral Contracts and Grants with Industry

7.1. Industry

Socrate has strong collaboration with Orange Labs (point to point collaboration) and Alcatel Lucent through the Inria-ALU common lab and the Green Touch initiative. Socrate also works in collaboration with Siradel, a french worldwide company working on wireless system simulations, Sigfox a french young compagny deploying the first cellular network operator dedicated to M2M and IoT, and HIKOB a start-up originated from the Citi laboratory providing sensor networks solutions. A bilateral cooperation supports the PhD of Laurent Maviel, and Siradel is a member of the Ecoscell ANR project in which Socrate is involved.

Socrate started in September 2011 a strong bilateral cooperation with the Euromedia group about Body Area Networks in which Hervé Parvery, Guillaume Villemaud and Jean-Marie Gorce are involved and the project supports the thesis of Matthieu Lauzier.

7.2. National Actions

7.2.1. Equipex FIT- Future Internet of Things (2011-..., 1.064 k€)

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).

7.2.2. ANR - ECOSCELLS - Efficient Cooperating Small Cells (2009-2012, 242 keuros)

Ecoscells is a national initiative (ANR) which aims at developing algorithms and solutions to ease Small Cells Network deployment. Theoretical studies will provide models for understanding the impact of radio channels, and permit the definition of new algorithms exploiting a full diversity (user, spatial, interferences, etc.) of such networks. The novelty of the project is not to consider the interference as a drawback anymore, but to exploit it in order to offer an optimal resource utilization. The algorithms will be based on most recent developments in distributed algorithms, game theory, reinforcement learning. Architecture and algorithms for the back-hauling network will also be proposed.

7.2.3. 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).

7.2.4. FUI ECONHOME - "Energy efficient home networking" (2010-2014, 309 keuros)

The project aims at reducing the energy consumption of the home (multimedia) data networks, while maintaining the quality requirements for heterogeneous services and flows, and preserving, or even enhancing the overall system performance. the equipments under concern are residential gateways, set-top-boxes , PLC modules, Wifi extenders, NAS. The user equipment, such as smartphones, tablets or PCs are not concerned. The approach relies on combining both individual equipments IC and system level protocols that have to be eco-designed.

7.2.5. ADR Selfnet - "Self Optimization Networking" (2008-2012, 258 keuros)

This action is a part of the common lab of Inria and Alcatel Lucent Bell Labs. This action groups several team of Inria with Alcatel teams and adresses different aspects of Self Networking: distributed algorithms, energy efficiency, mobility. Virgile Garcia has finished is PhD on distributed power management in cellular networks and

7.3. Actions Funded by the EC

7.3.1. Projet iPLAN - FP7-PEOPLE-IAPP-2008 (2009-2012, 440 keuros)

(Indoor Planning) (2009-2012, 440k€)
iPlan is an FP7 project of the FP7-People-IAPP-2008 call. The iPlan consortium is made of the Ranplan Company, the Citi Laboratory and the University of Bedfordshire and proposes the study of Indoor planning and optimization models and tools. The aim is to develop fast and accurate radio propagation models, investigate various issues arising from the use of femtocells, develop an automatic indoor radio network planning and optimization and facilitate knowledge integration and transfer between project partners, to enable cross-fertilization between radio propagation modeling, wireless communications, operations research, computing, and software engineering.

7.4. Theses, Internships

7.4.1. Theses

7.4.1.1. Theses defended in 2012

Virgile Garcia: "*Resource sharing optimisation for self-organized cellular networks*", PhD thesis from INSA LYON, Inria/Alcatel-Lucent grant,30/04/2012.

7.4.1.2. Theses in preparation

Mickael Dardaillon: "*Virtual machine for the cognitive radio*", Rhône-Alpes grant, since 10/2011.

Cengis Hasan: "*Optimization of resource allocation for small cells networks*", Orange labs grant, since 01/2010.

Paul Ferrand: "*Cooperative communications in BANET*", MENRT, since 10/2009.

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

Matthieu Lauzier: "*Design and evaluation of information gathering systems for dense mobile wireless sensor networks*", CIFRE/Euromedia, since 09/2011.

Meiling Luo: "*Fast and accurate radio propagation models for radio network planning*", MENRT grant, since 01/2010.

Laurent Maviel: "*Wireless heterogeneous networks dynamic planning in urban and indoor non-stationary environments*", CIFRE grant with SIRADEL, since 11/2009.

Baher Mawlawi: CEA grant, since 09/2012.

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

Zhaowu Zhan: "*Full-Duplex Multimode MIMO wireless communications*", CSC/China grant with , since 9/2012.

7.4.2. Participation in thesis Committees

Jean-Marie Gorce:

- Examinateur au jury d'Habilitation à diriger les recherches de Olivier Berder: "Systèmes multi-antennes et efficacité énergétique des réseaux de capteurs sans fil" (nov. 2012, Univ. Rennes1)
- Examinateur au jury d'Habilitation à diriger les recherches de Fabien Mieyeville: "Méthodes de conception hiérarchique de systèmes hétérogènes multi-physiques communicants" (Ecole Centrale Lyon, mai. 2012)
- Rapporteur de la thèse de Guillaume Viennot "Utilisation de techniques d'imagerie de synthèse pour le calcul de la propagation des champs électromagnétiques" (Université Limoges, dec. 2012)
- Rapporteur de la thèse de Hussein Kdouh: "Application of Wireless Technologies to Alarm and MonitoringSystem on Board Ships" (INSA Rennes, dec. 2012).
- Rapporteur de la thèse de Vinh Tran: "Energy efficient cooperative relay protocols for wireless sensor networks" (Université Rennes 1, dec. 2012).
- Rapporteur de la thèse de Mustapha Dakkak: "Indoor geo-location : static and dynamic geo-location of mobile terminals in Indoor environments" (Université Paris-Est, nov. 2012).
- Rapporteur de la thèse de Yougourta Benfattoum: "Network coding for quality of service in wireless multi-hop networks" (Université Paris-Sud, nov. 2012).
- Rapporteur de la thèse de Getachew Rediateb: "Cross-layer optimization for next generation WiFi" (INSA Rennes, oct. 2012).
- Rapporteur de la thèse de Dora Ben Cheikh Battikh "Outage probability formulas for cellular networks: contributions for MIMO, CoMP and time reversal features" (Telecoms Paris Tech, juillet 2012).
- Directeur de thèse de Virgile Garcia: "Opportunistic radio resource sharing for next-gen cellular networks" (Insa-Lyon, 29 Mars 212).

Tanguy Risset:

- Président de jury de la thèse d'Antoine Floch, le 8 juin 2012 (U. Rennes 1/ENS Cachan)
- Examinateur pour le jury de thèse de Naeem Abbas, 22 mai 2012 (U. Rennes 1/ENS Cachan - IRISA).
- Directeur d'Habilitation à Diriger les recherches de Marine Minier, le 31 mai 2012 (U Lyon1/Insa-Lyon)

7.4.3. Internships

- Pierre BRUNISHOLZ, “OFDM decoding on a Virtex 6 FPGA”
- Fayçal AIT-AOUDIA “OFDM decoding on a Virtex 6 FPGA”
- Moemen CHERNI “Smart radio pour réseau de capteurs”
- Borja DE RIVA SOLLA “Etude des techniques de sous-échantillonnage pour la radio logicielle”
- Thibaut VUILLEMIN “Performance analysis for /dev/random”
- Egea Pierrick “Mise en place d’une plateforme experimentale d’evolution de charges dans les systemes d’exploitation”
- Jimenez-Guzar Arturo “PHY layer network coding”
- Richelmy Marion “Algorithmes pour les self-optimized networks”
- Vasselin Virginie “Algorithmes pour les self-optimised networks”

7.5. Teaching

- Tanguy Risset and Jean-Marie Gorce and are professor in the Telecommunications department of Insa Lyon.
- Claire Goursaud is associate professor in the Telecommunications department of Insa Lyon.
- Guillaume Salagnac and Kevin Marquet are associate professors in the Computer Science department of Insa Lyon.
- Guillaume Villemaud and Florin Hutu are associate professor in the Electrical Engineering department of Insa Lyon.
- Nikolai Lebedev is associate professor in the engineering school in Chemistry, Physics and Electronics, Lyon.
- Tanguy Risset has been the vice-head of the Telecommunications department of Insa Lyon until september 2012.
- Tanguy Risset is the responsible for the Networking program of the Master Mastria from University of Lyon.
- Jean-Marie Gorce is the responsible for the Telecommunications program of the future Master EEAP from University of Lyon.
- Guillaume Villemaud is responsible for international relations in the Electrical engineering départe-ment of Insa Lyon

8. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

[1] F. Goichon, G. Salagnac, P. Parrend, S. Frénot. *Static Vulnerability Detection in Java Service-oriented Components*, in "Journal in Computer Virology", September 2012 [*DOI :* 10.1007/s11416-012-0172-1], http://hal.inria.fr/hal-00740858.

[2] M. Luo, G. Villemaud, J.-M. Gorce, J. Zhang. *Realistic Prediction of BER and AMC for Indoor Wireless Transmissions*, in "IEEE Antennas and Wireless Propagation Letters", December 2012, http://hal.inria.fr/hal-00737358.

[3] P. MARY, M. DOHLER, J.-M. GORCE, G. VILLEMAUD. *Packet Error Outage for Coded Systems Experiencing Fast Fading and Shadowing*, in "IEEE Transactions on Wireless Communications", October 2012, p. 1-12, 12, http://hal.inria.fr/hal-00758643.

[4] D. UMANSKY, J.-M. GORCE, M. LUO, G. DE LA ROCHE, G. VILLEMAUD. *Computationally Efficient MR-FDPF and MR-FDTLM Methods for Multifrequency Simulations*, in "IEEE Transactions on Antennas and Propagation", December 2012, http://hal.inria.fr/hal-00737356.

[5] L. WANG, C. GOURSAUD, N. NIKAEIN, L. COTTATELLUCCI, J.-M. GORCE. *Cooperative Scheduling for Coexisting Body Area Networks*, in "IEEE Transactions on Wireless Communications", 2012, to appear, http://hal.inria.fr/hal-00758573.

[6] R. ZHANG, O. BERDER, J.-M. GORCE, O. SENTIEYS. *Energy-Delay Tradeoff in Wireless Multihop Networks with Unreliable Links*, in "Ad Hoc Networks", 2012, vol. 10, n^{o} 7, p. 1306 -1321, http://hal.inria.fr/hal-00741560.

Invited Conferences

[7] G. VILLEMAUD. *Coverage Prediction for Heterogeneous Networks: From Macrocells to Femtocells*, in "Femtocell Winter School", Barcelone, Spain, February 2012, http://hal.inria.fr/hal-00737341.

[8] G. VILLEMAUD. *Realistic Prediction of Available Throughput of OFDM Small Cells*, in "6th Small Cell and HetNetWorshop", Londres, United Kingdom, June 2012, http://hal.inria.fr/hal-00737344.

International Conferences with Proceedings

[9] A. APAVATJRUT, K. JAFFRÈS-RUNSER, C. GOURSAUD, J.-M. GORCE. *Combining LT codes and XOR network coding for reliable and energy efficient transmissions in wireless sensor networks* , in "35th IEEE Sarnoff symposium", Newark, United States, May 2012, http://hal.inria.fr/hal-00758580.

[10] A. APAVATJRUT, K. JAFFRÈS-RUNSER, C. GOURSAUD, J.-M. GORCE. *Impact of intra-flow network coding on the relay channel performance: an analytical study*, in "IEEE Wimob - The 8th International Conference on Wireless and Mobile Computing, Networking and Communications", Barcelona, Spain, October 2012, http://hal.inria.fr/hal-00758582.

[11] A. BENFARAH, B. MISCOPEIN, C. LAURADOUX, J.-M. GORCE. *Towards Stronger Jamming Model: Application to TH-UWB Radio*, in "IEEE WCNC - Wireless Communications and Networking Conference", Paris, France, April 2012, http://hal.inria.fr/hal-00758577.

[12] T. P. BERGER, J. D'HAYER, K. MARQUET, M. MINIER, G. THOMAS. *The GLUON Family: A Lightweight Hash Function Family Based on FCSRs*, in "Progress in Cryptology - AFRICACRYPT 2012", Ifrance, Morocco, Springer, 2012, http://hal.inria.fr/hal-00749143.

[13] M. DARDAILLON, C. LAURADOUX, T. RISSET. *Hardware Implementation of the GPS authentication*, in "ReConFig - International Conference on ReConFigurable Computing and FPGAs", Cancun, Mexico, December 2012, http://hal.inria.fr/hal-00737003.

[14] M. DARDAILLON, K. MARQUET, T. RISSET, A. SCHERRER. *Software Defined Radio Architecture Survey for Cognitive Testbeds*, in "Wireless Communications and Mobile Computing Conference (IWCMC), 2012 8th International", Limassol, Cyprus, September 2012, http://hal.inria.fr/hal-00736995.

[15] P. FERRAND, C. GOURSAUD, J.-M. GORCE. *Cooperation Scenarios in Cooperative Multiple Access Channels*, in "COST IC1004 + iPLAN Joint Workshop on "Small Cell Cooperative Communications"", Lyon, France, May 2012, http://hal.inria.fr/hal-00737839.

[16] P. FERRAND, C. GOURSAUD, J.-M. GORCE. *Energy-Delay Tradeoffs in a Linear Sequence of Relay Channels*, in "Wireless Communications and Networking Conference (WCNC), 2012 IEEE", Paris, France, April 2012, http://hal.inria.fr/hal-00737844.

[17] V. GARCIA, N. LEBEDEV, J.-M. GORCE. *Model Predictive Control for Smooth Distributed Power Adaptation*, in "IEEE WCNC - Wireless Communications and Networking Conference", Paris, France, April 2012, http://hal.inria.fr/hal-00758579.

[18] J.-M. GORCE, B. MISCOPEIN, A. BENFARAH. *Security Embedding on UWB-IR Physical Layer*, in "IEEE GLOBECOM", Anaheim, United States, December 2012, http://hal.inria.fr/hal-00758581.

[19] C. HASAN, E. ALTMAN, J.-M. GORCE, M. HADDAD. *Non-Cooperative Association Of Mobiles To Access Points Revisited*, in "WiOpt", PaderBorn, Germany, May 2012, http://hal.inria.fr/hal-00758584.

[20] M. LUO, N. LEBEDEV, G. VILLEMAUD, G. DE LA ROCHE, J. ZHANG, J.-M. GORCE. *On Predicting Large Scale Fading Characteristics with the MR-FDPF Method*, in "6th European Conference on Antennas and Propagation (EECAP) 2012", Prague, Czech Republic, March 2012, 5 pages, http://hal.inria.fr/hal-00696357.

[21] L. MAVIEL, A. CORDONNIER, Y. LOSTANLEN, J.-M. GORCE. *Measurements of large-scale variations caused by vehicular traffic in small-cells*, in "ICT - 19th International Conference on Telecommunications", Jounieh, Lebanon, April 2012, http://hal.inria.fr/hal-00758586.

[22] L. MAVIEL, Y. LOSTANLEN, J.-M. GORCE. *A Hybrid Propagation Model for Large-scale Variations Caused by Vehicular Traffic in Small Cells*, in "IEEE GLOBECOM", Anaheim, United States, IEEE, December 2012, http://hal.inria.fr/hal-00758574.

[23] D. TSILIMANTOS, J.-M. GORCE, E. ALTMAN. *Stochastic Analysis of Energy Savings with Sleep Mode in OFDMA Wireless Networks*, in "IEEE INFOCOM - The 32nd IEEE International Conference on Computer Communications", Turin, Italy, April 2013, http://hal.inria.fr/hal-00758585.

[24] G. VILLEMAUD, C. LÉVY-BENCHETON, T. RISSET. *Performance Evaluation of Multi-antenna and Multimode Relays Using a Network Simulator*, in "EUCAP 2012", Prague, Czech Republic, March 2012, http://hal.inria.fr/hal-00737362.

Conferences without Proceedings

[25] A. KHOUMERI, F. HUTU, G. VILLEMAUD, J.-M. GORCE. *Wake-up radio architectures used in wireless sensor networks*, in "COST IC1004", Lyon, France, May 2012, http://hal.inria.fr/hal-00732857.

[26] M. LAUZIER, P. FERRAND, H. PARVERY, A. FRABOULET, J.-M. GORCE. *WBANs for live sport monitoring : an experimental approach, early results and perspectives*, in "EURO-COST IC1004 - European Cooperation in the Field of Scientific and Technical Research", Bristol, United Kingdom, September 2012, http://hal.inria.fr/hal-00738786.

Scientific Books (or Scientific Book chapters)

[27] A. APAVATJRUT, C. GOURSAUD, K. JAFFRÈS-RUNSER, J.-M. GORCE. *Fountain codes and network coding for WSNs*, in "Network coding", K. A. AGHA (editor), ISTE, Wiley, 2012, p. 27-72, http://hal.inria.fr/hal-00741695.

[28] A. BURR, I. BURCIU, P. CHAMBERS, T. JAVORNIK, K. KANSANEN, J. OLMOS, C. PIETSCH, J. SYKORA, W. TEICH, G. VILLEMAUD. *MIMO and Next Generation Systems*, in "Pervasive Mobile and Ambient Wireless Communications", SPRINGER (editor), Springer, March 2012, http://hal.inria.fr/hal-00737352.

[29] Z. LAI, G. VILLEMAUD, M. LUO, J. ZHANG. *Radio Propagation Modeling*, in "Heterogeneous Cellular Networks: Theory, Simulation and Deployment", CAMBRIDGE (editor), Cambridge, January 2013, http://hal.inria.fr/hal-00737347.

Research Reports

[30] P. FERRAND, J.-M. GORCE, C. GOURSAUD. *Common Rate Maximization in Cooperative Multiple Access Channels*, Université de Lyon, Inria, INSA-Lyon, October 2012, http://hal.inria.fr/hal-00742234.

[31] P. FERRAND, C. GOURSAUD, J.-M. GORCE. *Achievable Common Rate and Power Allocation in Cooperative Multiple Access Channels*, Université de Lyon, Inria, INSA-Lyon, April 2012, http://hal.inria.fr/hal-00690407.

[32] F. GOICHON, C. LAURADOUX, G. SALAGNAC, T. VUILLEMIN. *Entropy transfers in the Linux Random Number Generator*, Inria, September 2012, n° RR-8060, 26, http://hal.inria.fr/hal-00738638.

[33] Q. WANG, C. GOURSAUD, K. JAFFRÈS-RUNSER, J.-M. GORCE. *Fundamental limits of wireless ad hoc networks: lower MO bounds*, Inria, March 2012, n° RR-7905, 22, http://hal.inria.fr/hal-00678661.

References in notes

[34] I. AKYILDIZ, W.-Y. LEE, M. VURAN, S. MOHANTY. *A survey on spectrum management in cognitive radio networks*, in "Communications Magazine, IEEE", April 2008, vol. 46, n° 4, p. 40 -48.

[35] K. BIESECKER, J. DOBIAC, N. FEKADU, M. JONES, C. KAIN, K. RAMAN. , 2008, Noblis Technical Report, for National Institute of Justice, USA.

[36] EQUIPEX. , 2011, http://fit-equipex.fr/.

[37] JOINT PROGRAM EXECUTIVE OFFICE, (JPEO), JOINT TACTICAL RADIO SYSTEM, (JTRS). , 2006, JTRS Standards, version 2.2.2.

[38] J. MITOLA III. *The software radio*, in "IEEE National Telesystems Conference", 1992.

[39] J. MITOLA III. *Software radios: Survey, critical evaluation and future directions*, in "Aerospace and Electronic Systems Magazine, IEEE", Apr 1993, vol. 8, n° 4, p. 25-36.

[40] P. STEENKISTE, D. SICKER, G. MINDEN, D. RAYCHAUDHURI. , 2009, NSF Workshop Report.

[41] M. WEISER. *The computer for the 21st Century*, in "Pervasive Computing, IEEE", January 2002, vol. 99, n^{o} 1, p. 19 -25.

[42] Q. ZHANG, F. H. P. FITZEK, V. B. IVERSEN. *Cognitive radio MAC protocol for WLAN*, in "Proceedings of the IEEE 19th International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC 2008", 2008, p. 1-6.