Team GRANIT

# Adaptive algorithms and architectures for energy-efficient wireless systems

*Lannion*

*Activity Report*

*2019*

# 1 Team

| Name | Forename | Position |
|---|---|---|
| BERDER | Olivier | Full Professor, UR1 (IUT Lannion) |
| CARQUIN | Émilie | Research Assistant, UR1 (ENSSAT Lannion) |
| COURTAY | Antoine | Associate Professor, UR1 (ENSSAT Lannion) |
| DEMIGNY | Didier | Full Professor*, UR1 (IUT Lannion) |
| GAUTIER | Matthieu | Associate Professor (HDR), UR1 (IUT Lannion) |
| GERZAGUET | Robin | Associate Professor, UR1 (ENSSAT Lannion) |
| ROCHER | Romuald | Associate Professor, UR1 (IUT Lannion) |
| SCALART | Pascal | Full Professor, UR1 (ENSSAT Lannion) |
| THÉPAULT | Joëlle | Research Assistant, UR1 (ENSSAT Lannion) |
| VRIGNEAU | Baptiste | Associate Professor, UR1 (IUT Lannion) |

* Associate member

Table 1: GRANIT permanent members

The GRANIT team comprizes 7 permanent research members: 2 full professors (*Professeur des Universités*) and 5 associate professors (*Maître de conférences*). There are currently 5 PhD students in the GRANIT team. Table 1 lists the permanent staff and table 2 the current PhD students and other staff.

Didier DEMIGNY is considered as an associate member of GRANIT since he still has a research activity with some of GRANIT members, but its administrative and teaching tasks are very time consuming. Didier Demigny was director of the Institute of Technology of Lannion and is now vice-president of University of Rennes 1.

# 2 Overall Objectives

## 2.1 Overview

General purpose wireless devices as smartphones already have to carry more and more data while keeping their autonomy as long as possible, but the next challenge they will face is the ubiquity of users. This ability to be connected everywhere in a continuous and transparent way, keeping the same quality of services (QoS) whatever the environment, implies that devices can deal with different wireless standards, furthermore choosing for each of them the most energy efficient configuration. In this connected world, even the smallest sensors will be able to send their data over what is called Internet of Things (IoT), such that every user in the world could reach it. The problem that designers will face is then the autonomy of such sensors, since radio is very energy consuming, and obviously, the more sensors we place, the less we want to change batteries.

In such a context, the GRANIT team purpose is to design algorithms and architectures able to adapt to environment parameters, such as propagation channel characteristics, wire-

| Name | Forename | Status | Period |
|---|---|---|---|
| Djidi | Nour el hoda | PhD | Since 10/2018 |
| Kazdoghli Lagha | Marwa | PhD | Since 10/2017 |
| Lacroix | Marie-Anne | PhD | Since 10/2018 |
| Lavaud | Corentin | PhD | Since 10/2018 |
| Roux | Nicolas | PhD+ | Since 10/2016 |
| Gleonec | Philip Dylan | PhD | 10/2015 - 03/2019 |
| Caresmel | Clément | Research Engineer | Since 03/2019 |
| Courjault | Jules | Research Engineer | Since 10/2019 |
| Le Gentil | Mickaël | Research Engineer+ | Since 09/2016 |
| Mabon | Malo | Research Engineer | Since 01/2018 |
| Carer | Arnaud | Research Engineer+ | 01/2012 - 02/2019 |
| Hallé | Pierre | Research Engineer | 07/2019 - 09/2019 |
| Diallo | Mamadou Lamarana | Post-doc | 01/2018 - 02/2019 |

+ Shared with CAIRN team

Table 2: GRANIT other staff

less traffic conditions network topology or possibilities of energy harvesting, while respecting applications requirements in terms of data rate, reliability, latency, and most of all, life time of involved systems, etc. As represented by Fig. 1, the quantitative target of GRANIT over the next ten years is to decrease the energy of radio transmission by several orders of magnitude to reach 1 pJ per bit. The GRANIT members have a strong experience on wireless sensor network (WSN) protocols (MAC and PHY layers) and hardware architectures, and developed several WSN platforms and demonstrators for various areas monitoring applications or dedicated to human body. As energy can now be scavenged from the direct environment of sensor nodes (light, heat, vibrations, etc.), a harvesting board can be added to WSN platforms. One of the objectives of the GRANIT team is then to design power management strategies, coupled to above-mentioned adaptive algorithms in order to reach real energy autonomy of the sensor nodes. Cooperation between nodes, either through distributed computing to find the best radio/computation trade-off or through the choice of the best cooperative relaying schemes, represents also a key challenge for the design of energy-efficient wireless systems. The GRANIT team will continue to investigate this very promising field at both physical and medium access layers. Last but not least, the aim of GRANIT team is also to efficiently implement these algorithms onto different targets, from low power microcontrollers and/or low power FPGAs for WSN solutions to powerful system-on-chip and multi-core systems for more computing-intensive applications. To answer the demand of agile devices, software defined radio solutions (SDR) will especially be considered, not only for high data-rate mobile standards such as 5G, but also for wireless sensor networks, enabling testbeds for low power adaptive and/or cooperative solutions.

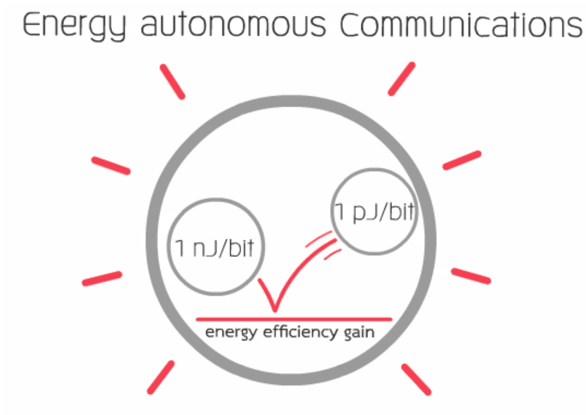


Figure 1: Transmission Energy efficiency target for the next decade

## 2.2 Key Issues

Wireless communications represent obviously the major domain of applications for the adaptive algorithms and/or architectures proposed by the GRANIT team. The range of devices that fall within this denomination is however very large, and our developments will mainly address two different targets, namely next generations of wireless sytems (4G, 5G,...) and wireless sensor networks. In addition to analytical derivations and simulations, the GRANIT team clearly aims at using platforms to evaluate our research performance, but also to reach what could be called a platform-based design, meaning that the constraints of the envisaged platforms are taken into account very soon in the design process. Upon this basis, the research topics of the GRANIT team can be represented as Figure 2.

Focusing on the baseband processing of the physical layer, two main issues are raised by the new requirements of wireless communications: (i) What are the signal processing techniques that could help improving the link quality, the spectrum usage and the energy efficiency? (ii) What kind of hardware could associate energy efficiency and high-performance computing of these signal processing techniques? A huge effort is currently spent on proposing new physical layers and many digital communication techniques have been widely studied.

Taking into account the specificities of the targets envisaged for the adaptive algorithms, we will adapt the latter to design very energy-efficient wireless transmissions. To a certain degree, we claim that software-based systems will provide the flexibility to adapt to new requirements and make it easier to introduce innovation in the architecture[1]. Thus, our proposal relies on high-level synthesis (HLS) in order to bridge the gap between high-level specifications and hardware implementation[2]. Depending on the hardware target, hardware/software partitioning, reconfiguration capability or power management will be included in the design flow.

[1] J.F. Jondral, Software-defined radio: basics and evolution to cognitive radio. *EURASIP J. Wireless Commun. Netw.*, 2005, pp. 275-283

[2] P. Coussy, D. Gajski, M. Meredith, A. Takach, An Introduction to High-Level Synthesis, *IEEE Design & Test of Computers*, 26 (4): 8-17, 2009

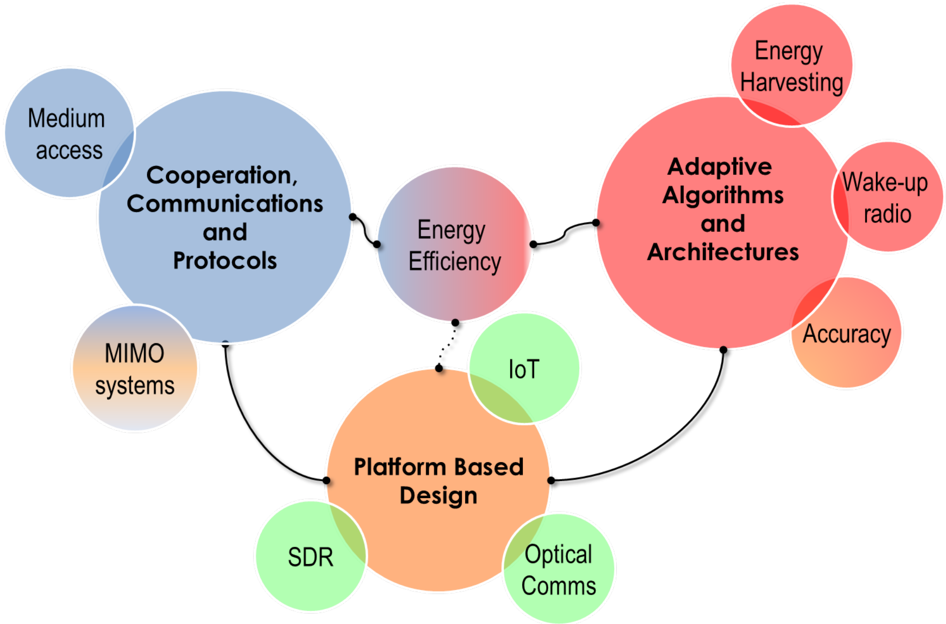


Figure 2: GRANIT Research Topics

# 3 Scientific Foundations

## 3.1 Positioning in Architecture Department of IRISA

GRANIT belongs to D3 department of IRISA dedicated to Architecture and takes place besides PACAP and CAIRN teams. While these latter teams aim to design new architectures and associated compiling tools, the approach of GRANIT is more user or application-centric, i.e. our research will mostly rely on existing hardware platforms (even though some specific designs will still be achieved) and take into account the constraints that they incur to develop efficient algorithms. This interaction between architecture and algorithms is explored from both angles of adaptivity and cooperation.

## 3.2 Adaptive algorithms and architectures

One of the purposes of the GRANIT team is to consider algorithmic-level optimizations for energy savings. More precisely, the relationship between computation and communication will be studied from the energy point of view, in order to enable dynamic energy management. Reducing power due to radio communications can be achieved by two complementary main objectives: (i) to minimize the output transmit power while maintaining sufficient wireless link quality and (ii) to minimize useless wake-up and channel hearing while still being reactive. For this purpose, this project aims at defining and implementing new power-aware techniques that can dynamically adapt at run-time:

- the chosen algorithms of the radio physical layer (e.g. modulation, spreading, bit-rate, cooperative strategies, etc.),

- the wake-up interval of the MAC protocol,
- the accuracy (bit-width) of signal processing algorithms,
- the transmit power,

depending on some parameters such as:

- radio channel conditions,
- quality-of-service (QoS) required by the application,
- harvested energy,
- topology of the networks.

The global framework of such an optimization can be represented as in Figure 3.

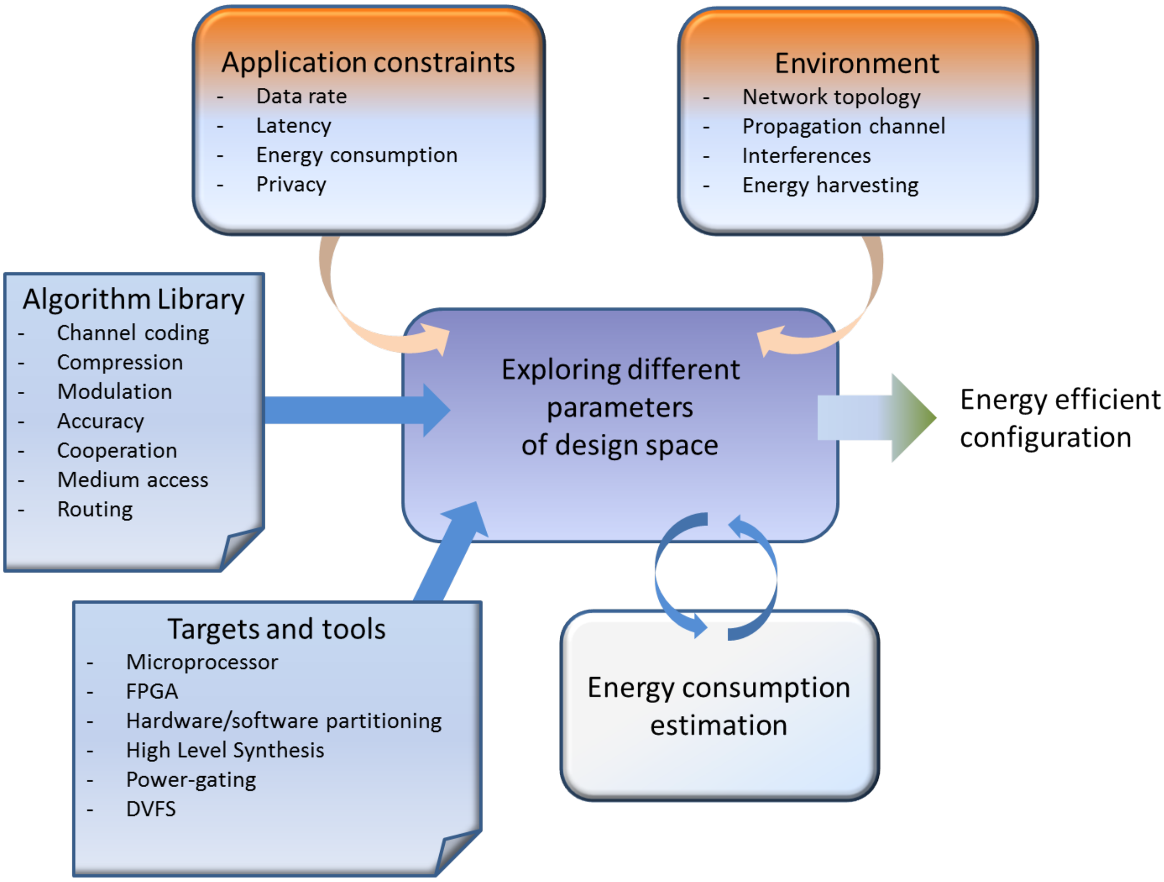


Figure 3: GRANIT Optimization Methodology

**Energy harvesting and Power Management** Advancements in renewable energy sources, such as solar, thermal or wind, are increasing the attention in autonomous Wireless Sensor Networks (WSN). Everlasting energy harvesting allows long-term operations of wireless nodes, which can extremely reduce the cost of battery charging or replacement. Moreover, it has opened a new paradigm for designing Power Managers in self-powered autonomous nodes. Instead of minimizing the consumed energy to maximize the system lifetime as in battery-powered nodes, the PM dynamically adapts the consumed energy according to the fluctuations of the harvested energy, leading to Energy Neutral Operation (ENO)[3].

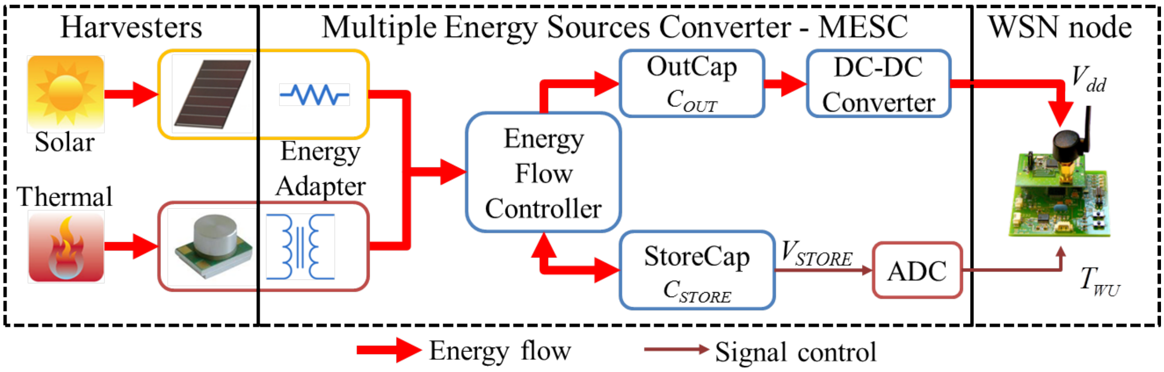


Figure 4: GRANIT Hardware Architecture of our Energy Harvesting Nodes

The GRANIT team activities in EH-WSN aim at designing and implementing new PM (Fig. 4) able to deal with the environment constraints and ensure ENO by tuning sensing, processing and communication parameters.

**Software Defined Radio** Software Defined Radio (SDR) is a flexible signal processing architecture with reconfiguration capabilities that can adapt itself to various air-interfaces. It was first introduced by [4] as an underlying structure for Cognitive Radio (CR). The FPGA (Field Programmable Gate Array) technology is expected to play a key role in the development of Software Defined Radio (SDR) platforms. FPGA-based SDR is a quite old paradigm and we are fronting this challenge while leveraging the nascent High Level Synthesis tools and languages. Actually, our goal is to propose methods and tools for rapid implementation of new waveforms in the stringent flexibility paradigm. We propose a novel design flow for FPGA-based SDR applications. This flow relies upon HLS principles and its entry point is a Domain-Specific Language (DSL) which partly handles the complexity of programming an FPGA and integrates SDR features. Our studies include :

- defining a Domain-Specific Language for high-level descriptions of radio waveforms,

[3] A. Kansal, J. Hsu, S. Zahedi, and M. B. Srivastava, Power management in energy harvesting sensor networks, *ACM Trans. Embed. Comput. Syst.*, vol. 6, no. 4, Sep. 2007

[4] Joseph Mitola J. Mitola III and G. Q. Maguire, Jr., Cognitive radio: making software radios more personal, *IEEE Personal Communications Magazine*, vol. 6, nr. 4, pp. 13-18, Aug. 1999

- generating hardware description (RTL) through the automatic synthesis of the DSL,
- including design constraints in the description through Design Space Exploration of the architecture,
- allowing Dynamic Partial Reconfiguration in the design process,
- validating the design flow from testbed with developments on the GRANIT platforms for multiple standards.

**Fixed point arithmetic** Fixed-point architectures manipulate data with relatively small word-lengths, which could offer the advantages of a significantly lower area, latency, and power consumption in embedded systems. However, fixed-point arithmetic introduces quantization noises which modify computation accuracy and, so, the application integrity. Our approach consists in studying fixed-point accuracy privileging analytical methods. These ones reduce drastically the conversion time compared to methods based on simulation during the floating-point arithmetic to fixed-point arithmetic conversion process of the application.

Our studies include :

- Efficient implementation of equalization and synchronous algorithms for digital applications
- Adaptive precision scaling: modifying precision according to channel and environment modifications
- Multi-constraints implementations of digital communication applications: the idea is to find a satisfying implementation according to different constraints (multi accuracy, and/or latency, and/or cost)
- Sampling frequency effects on computing accuracy
- Study of new arithmetics for digital applications (approximate computing, vectorial quantization. . . )

### 3.3 Cooperative Communications and Protocols

In most of wireless sensor networks, the radio in both transmit and receive modes consumes the bulk of the total power consumption of the system. The diversity achieved by cooperative communications represent a very promising opportunity to decrease the transmit power. To illustrate this statement, let us consider a Wireless Body Area Network (WBAN), where the channel conditions are very different if we consider an on-body transmission or a transmission towards a distant base station. Within the WBAN, signals will experience strong shadowing effects due to body motion and the propagation loss is no more directly proportional to the distance between the transmitter and the receiver. In this context, the instantaneous position of the nodes can have a great impact on the link reliability and cooperative relaying schemes and opportunistic protocols are very useful to keep the same QoS without increasing the transmission power. On the other hand transmissions from the WBAN to base stations can be considered as less time-varying. Considering the possibility for nodes on-body to know the channel state information, distributed MIMO precoders can be designed in order to decrease the energy required for this kind of transmissions.

Another domain of application is the cooperation in order to take a local decision about the data to be sent. Unlike a centralized architecture where all data are loaded in a server leading to a significant transmission consumption, a local cooperation will take the advantage of sensor diversity and will send only the pertinent data in order to save energy with the best radio-computation trade-off, and eventually harvesting. It is also a solution to respect the privacy.

In spite of this ability of cooperative schemes to increase the energy efficiency of WSN, there is still very few practical experiments since they need both hardware and software improvements. The existing MAC layer protocols are not well suited to cooperative schemes and cooperative MAC protocols have to be designed. Cross-layer optimizations will then be investigated in our team to reach the maximum energy efficiency.

**Cooperative MIMO and relay techniques** The transmission mode classically used in wireless sensor networks to transmit a message from a source to a destination separated by a fairly large distance is multi-hops or multi-stages. However, some cooperative techniques allow an increase in the radio range of devices or a reduction in energy spent to reach the same distance.

- Relay techniques: Amplify-and-Forward (AF) and Decode-and-Forward (DF)
- Cooperative MIMO strategies (Fig 5)
- Opportunistic routing

The GRANIT team addresses these different possibilities taking especially into account the energy criterion, the most important constraint in wireless sensor networks. Besides performance evaluation through analytical derivations, the cooperative strategies are also simulated through network simulators. This implies the design of dedicated MAC protocols, but makes us able to estimate with accuracy the real gain of cooperation. Among the metrics we use, the energy-delay trade-off is very interesting for wireless sensor networks.

**Cooperative and opportunistic protocols** Although there is obviously an enormous interest in cooperative techniques in the research community, most of the performance analysis for cooperative communication is widely studied at physical layer. In order to make cooperative techniques be able to be utilized in the next generation of wireless networks, the higher layer protocols such as medium access control (MAC) layer or routing layer, must be thoroughly considered. Among the higher layers, MAC layer is responsible for regulating the shared wireless medium access of the networks, therefore, it has great influences on the network performance. In addition, MAC layer is also expected to improve throughput or energy efficiency, reduce delay while keeping the collisions to a minimum.

On the other hand, opportunistic routing aims at exploiting sporadic radio links to improve the connectivity of multi-hop networks and to foster data transmissions. However, the benefit

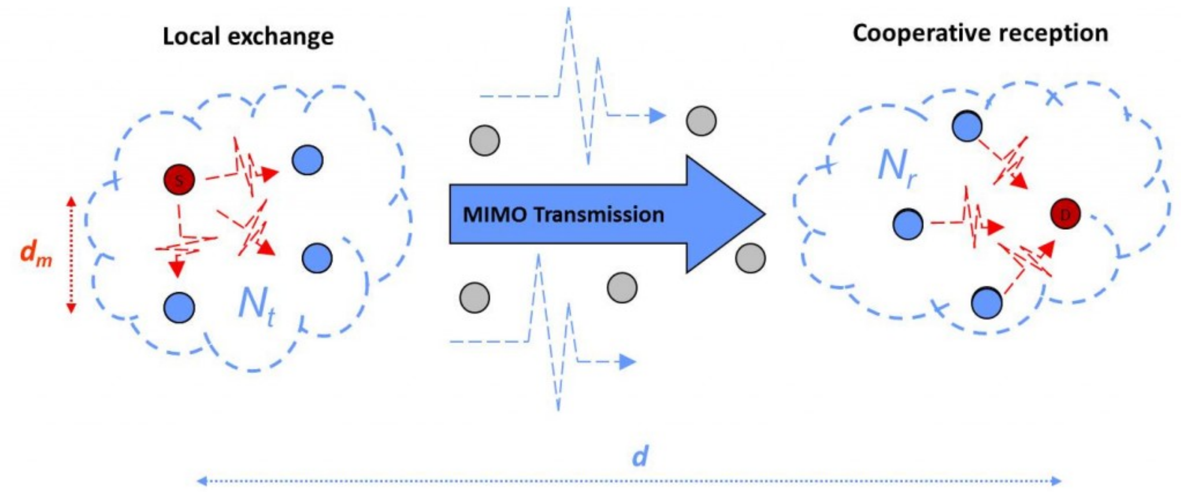


Figure 5: Cooperative MIMO transmission. Phase 1: the source exchanges information with its neighbors. Phase 2: synchronous MIMO transmission towards the destination group. Phase 3: the receiver sends the received signals towards the destination which combines the signals received.

of opportunistic relaying may be counteracted due to energy increase resulted from multiple active receivers. Therefore, we are conducting thorough analysis of opportunistic relaying efficiency under the different realistic radio channel conditions, to find the optimal tradeoff between two objectives: energy and latency minimizations, with a hard reliability constraint.

**MIMO precoding** In the last decades, MIMO systems were exploited to offer spatial diversity and precoders were designed for a closed-loop solution with the channel state information at the transmitter through a feedback link. Some well-known solutions optimize the capacity, the mean square error, the signal to noise ratio or the minimum distance. Nowadays, it exists a lot of different precoders with pros and cons and, according to the environment and quality of service, the challenge is to choose the most energy-efficient solution. The main concerns of our research are the performance evaluation and the decrease of the complexity thanks to approaches based on the minimum distance (dmin) and its probability density function (pdf).

Hereafter are some of the research paths we are following :

- Obtain the pdf of dmin for any precoder : modulation size, number of substreams, even a cooperative scheme with synchronization error
- Consider several channel statistics (Rayleigh, Rice, correlation), ie BAN, indoor, or outdoor context
- Propose new quantization methods of the feedback link in order to adapt the method from the open-loop to the full CSI and associated architecture solutions for precoders
- Propose new estimates of the bit error rate and extend it to channel coding with soft or iterative decision

Precoding techniques can also be used in a cooperative manner for wireless sensor networks. As stated here above, when propagation channels are varying slowly enough, it makes it even possible to distribute the precoding among cooperative nodes to dynamically adapt the signal transmission to the propagation channels and avoid deep fading.

# 4 Application Domains

## 4.1 Next generation of mobile communications

The next generation of wireless communications, namely 5G, will address a new kind of user: in addition to connect people, the next breakthrough is the connectivity of machines with other machines, referred to as 'M2M', which is the basis of the IoT paradigm[5]. Thus, in addition to a massive increase in the number of accesses (i.e. throughput increase) and current spectrum crisis issues, new requirements must be taken into account. A claimed advantage of M2M is remote steering and control of real and virtual objects. Hence, the required latency of such communications must be low enough to enable a round-trip delay from devices through the network back to devices of approximately 1ms. Another requirement we want to highlight is the flexibility the connected objects must have to respond to the number of standard modes. Indeed, in order to meet the time and space fluctuations of a service (i.e. throughput), in order to make several classes of objects connect together and in order to answer the spectrum scarcity issue, it is claimed that the new generation of wireless communications must be able to change their features in real time. Finally, reducing energy consumption is an on-going major challenge for two reasons: the first is the total energy consumption of ICT (Information and Communications Technologies) infrastructure that must be reduced; the second is the life cycle of new types of devices (e.g. Wireless Sensor Network node, IoT device) that must significantly increase to be massively deployed and used.

## 4.2 Wireless Sensor Networks

Wireless Sensor Network (WSN) technologies are also fast becoming a major part of our life with applications ranging from mobile health, smart homes, energy efficient buildings, environmental/context monitoring, assisted living, etc. The progress in this area is fast paced with power consumption reduction being one of the main challenges. One of the major promising advances is in the area of smart sensors where the computation is close to the sensor and only information or a command is being transmitted. This concept promises drastic savings of power, improvements in security, but also brings new challenges in areas such as ultra low power acquisition platforms, novel signal processing, and ultra low power reliable communications. Wireless Body Area Networks (WBAN) are a subclass of WSN, where the sensors are close to the body. This characteristic brings some of the biggest constraints in designing these networks in terms of power, size, security, reliability, etc. Despite these constraints, WBAN are listed as one of the most promising applications of WSN with many potential applications in health, rehabilitation, sports, and entertainment.

[5] G. Fettweis, The Tactile Internet - Applications & Challenges, *IEEE Vehicular Technology Magazine*, March 2014

# 5 Hardware and Software

## 5.1 PowWow platform for WSNs

We have proposed and developed PowWow (Power Optimized Hardware and Software Frame-Work for Wireless Motes), a hardware and software platform designed to handle sensor networks and related applications. The main innovating features of the platform are: an energy-efficient MAC protocol (15x less power than the ZigBee standard was reported for equivalent applications), a much more light memory usage, a low-power FPGA for acceleration of part of the software stack (energy reduction of two orders of magnitude was reported for error control and correction) and, more recently, a board including small-scale energy harvesting features, as illustrated on Fig. 6. Our work takes benefit from PowWow to perform power measurements that can be directly introduced in energy consumption models, leading to very precise predictions for the class of preamble sampling MAC protocols. We strongly rely on this platform for the prototyping of future research in this domain.

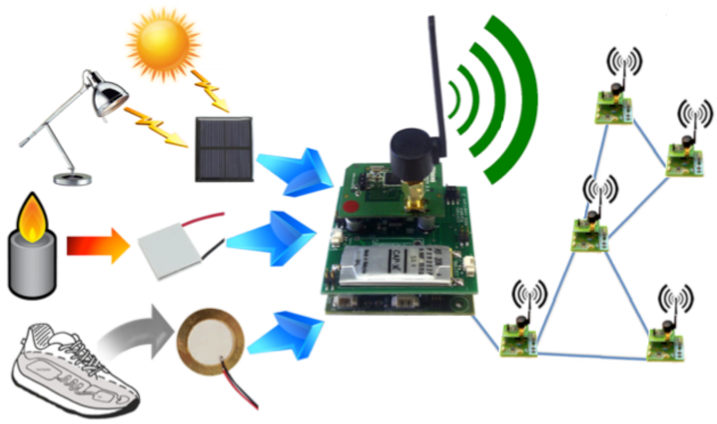

Figure 6: PowWow WSN Platform with Energy Harvesting

## 5.2 Energy autonomous LPWAN nodes (AMALO)

The board AMALO (AutonoMous energy hArvesting LOng range) has been made as part of the collaborative project ALAMO with local companies (Europrocess and CG Wireless). The main aim of this system is to have a platform interfaced with several sensors that can harvest energy and transmit information with a long range radio module. We choose to use the LPWAN LoRa technology mainly because of its flexibility. It can be used in standalone (LoRa) or as part of a standardized protocol (LoRaWAN) with private or public network.

On the block diagram on the left of the Fig. 7, two features can be identified: Energy Harvesting and Processing. Firstly, the Energy Harvesting block is made up of the energy manager chip (SPV1050), the energy source (solar panel, Peltier module, etc.), an energy storage (a super-capacitor and/or a battery) and a chip able to measure the battery current and voltage. Secondly, the Processing block consists of the Murata CMWX1ZZABZ-078 chip and the sensors (with the click-board header and/or the buses header). Click-board header allows us to easily update sensors like temperature, humidity, motion, etc. or add new radio modules and controller. We can see the different elements of the AMALO board on the described board picture (on the right of the Fig. 7).

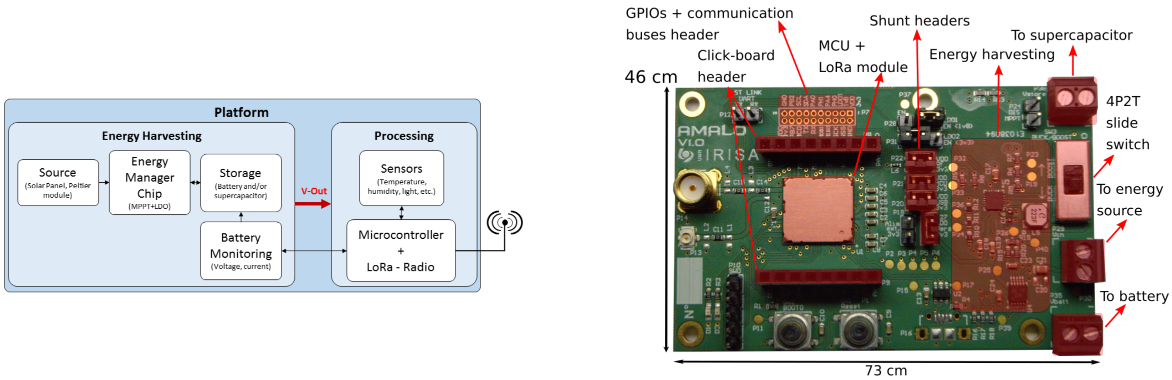


Figure 7: AMALO Block diagram (left) and described board picture (right)

One of the objective of this project was also to define a methodology for sizing energy harvesting components. The proposed methodology must define both energy storage devices (i.e. sizes of battery and capacitor) and harvesting components (i.e. solar panel area) of the AMALO platform. These elements depend on QoS parameters, hardware characteristics and environmental harvesting conditions. The AMALO board and sizing methodology are detailed in [5] in addition to experiments.

## 5.3 Wireless Body Area Networks (Zyggie)

Zyggie is a motion capture platform design within the labex Cominlabs BoWI project. It consists of a set of electronic components (nodes) arranged on a part or the whole body of a person. The Inertial Measurement Unit (IMU) embedded in these nodes can duplicate the movement on an avatar moving on an Android tablet, as shown by Fig. 8. Communication between nodes is performed by radio and extensive energy optimization allows them an operating autonomy of 20 hours. As recharging nodes batteries also occurs wirelessly, it is therefore possible (even if this is not the case for current prototypes) to embed them in a waterproof box.

This state-of-the-art platform has enabled to thoroughly analyze BAN sensor network related challenges dedicated to motion capture. Our work focused primarily on opportunities to dispense with the energy intensive gyroscope, using radio power information received by the sensor network. The applications are animation, functional rehabilitation, optimization of sports movements, robotics, non-verbal communication in fighting situations.

A new version of this platform was recently designed with high integration constraints as shown by Fig. 9. The system embeds Bluetooth communication, new IMU with high rate data fusion and memory chip to deal with fast motion applications. A motherboard was designed to charge the battery with C-type USB connector and interface other sensors.

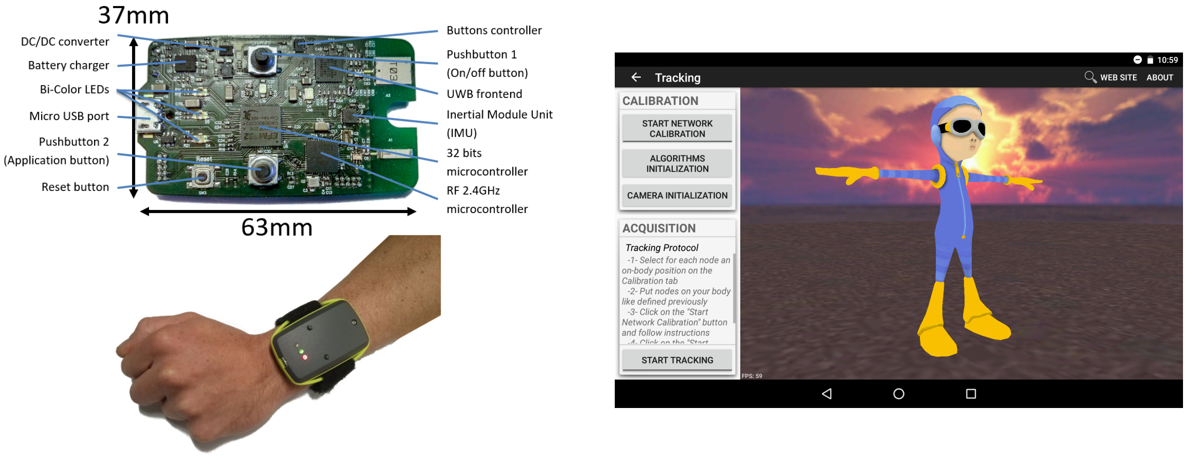


Figure 8: Zyggie V2 and avatar application

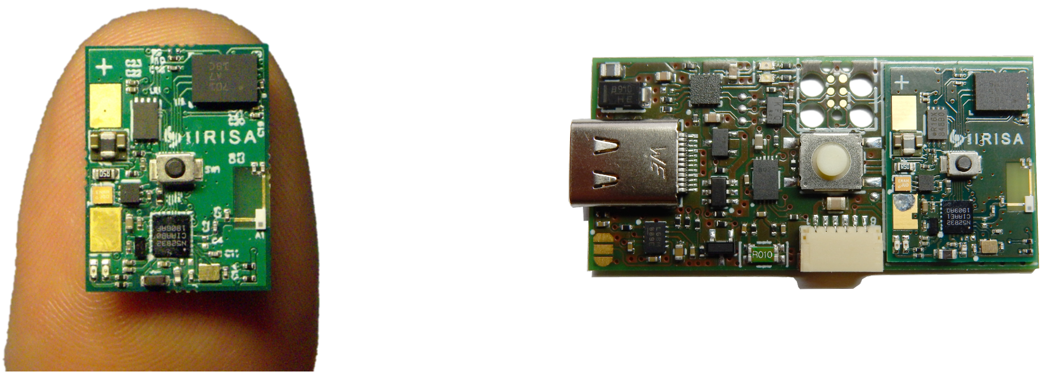


Figure 9: Zyggie Light and its motherboard

### 5.4 SDR platforms

In the context of SDR paradigm, GRANIT team studies the rapid prototyping of flexible radio waveforms leveraging High Level Synthesis. Both algorithms and architectures are taken into account to target heterogenous (software and hardware) SDR platforms. During the Equipex FIT, GRANIT members have experienced the Nutaq Perseus platform to validate our research by targeting two standards (IEEE 802.15.4 and IEEE 802.11a). We currently use Zynq-based platform from Xilinx to achieve the above mentioned heterogeneity.
The ROSE platform (Software Defined **R**adio Platform for I**o**T heterogeneou**s** **e**mbedded systems) has been deployed in 2017. The platform is composed of several USRP-310 devices from Ettus. These SDR belong to the new generation where the architecture is based on both a PS (processing system, here a dual core CPU) and a PL (programmable logic, e.g an FPGA); based on Zynq platform. The SDR platform has been partially funded by the Brittany region (CD22) and by the University of Rennes.

### 5.5 Real-time FPGA processing for optical access networks

Designed during the ANR FAON project, this platform is a prototype for 1Gbit/s QAM receiver for the optical access networks with Frequency Division Multiplexing (FDM). This prototype is based on a Virtex 7 FPGA and four analog to digital convertors sampling at 1 Gsps. This real-time prototype validates our algorithms for equalization and synchronization, but also a new FPGA design flow based on HLS (High Level Synthesis) and finally, the feasibility of frequency multiplexing for access networks. The prototype has been realized in collaboration with UMR CNRS FOTON for the RF front-end and Orange Labs for the integration in the system and the tests. The GRANIT team has designed the algorithms for demodulation as well as the FPGA implementation.

### 5.6 FICOP: Foton Irisa Common Optical Platform

To achieve the vision of a distributed, programmable and flexible infrastructure facing the ever growing data volume and the cloudification of services, there is a necessity to investigate, design and experiment transport networks with high bandwidth capacity and agility for smart adaptation to application needs, based on reconfigurable optical systems controlled by software-defined networking (SDN) approaches.

To explore those issues a new optical platform was created between IRISA and Foton laboratories to merge skills of both teams, respectively on digital signal processing and optical communications. This platform was founded with CPER project and allows off-line 30GHz communication link. With 100Gsps Oscilloscope and 88GHz arbitrary waveform generator this equipment is use to design and test new algorithms to enhance next generation optical links.

## 6 New Results

### 6.1 Highlights

- Matthieu Gautier has defended his Habilitation to conduct research on May 19th [1]

- Alamo project has been awarded at the Test & Plug challenge organized by Images & Réseaux Competitivity Cluster

### 6.2 Software Defined Radio

**Participants**: Robin Gerzaguet, Matthieu Gautier, Romuald Rocher.

Software Defined Radio (SDR) aims to revisit the paradigm of RF architectures. Classic RF architectures are massively integrated, hardware oriented, and can not cope with various bandwidths and carrier frequencies. SDR deports the processing in a software part through the use a general purpose processor (GPP) or digital signal processor (DSP). The processing can be done with the use of high level language such as C++ and Python. This paradigm change allows to use flexible devices that are able to address a wide frequency range (typically from 100MHz to 3-6 GHz) and different services and applications.

As this flexibility is at the price of real time performance, new high performance SDR now embed hardware accelerator, mainly based on FPGA in a SoC architecture. However, how to use efficient design flow and take advantage of the hardware accelerator are still open questions. To this aim, Roux et al. [14] propose an exploration method for partitioning accelerators between software and hardware cores considering energy efficiency constraints. With addition to the use of hardware resources, it is also necessary to envision the benefit of efficient software methods. Albeit being far less efficient than hardware methods (less bitrate, higher energy consumption...), software algorithms can seriously ease the prototyping effort. To allow better performance, using fixed point approach with optimisation of the accuracy is often necessary. We have proposed in [7] a review of the most popular stochastic algorithms used in classic parametric estimation where the fixed point implementation has been thoroughly investigated.

Using (software defined) radios that can be modified by means of both hardware and software reconfigurations pave the way for flexible spectrum use and multiservice multiplexing. These different services aim to target various use-cases with different performance indicators (rate, latency, ...). It requires for the physical layer (i.e the waveform) to be flexible and capable to handle different configurations. One key element is to allow the coexistence of several numerologies. Albeit being promising, this technique leads to strong interference with the classic waveforms used in every wireless standard. For this perspective, we have developed in [3] a new mathematical model associated to a new proposed waveform, called block-Filtered Orthogonal Frequency Division Multiplexing (BF-OFDM) which is in this paper, modeled as filterbank waveform, fully compatible with 5G-NR but offering better performance in the multiple service coexistence.

### 6.3 Energy Harvesting and Power Manager Design

**Participants**: Olivier Berder, Matthieu Gautier, Philip Dylan Gleonec, Malo Mabon.

The advent of the Internet of Things has enabled the roll-out of a multitude of Wireless Sensor Networks. These networks can be used in various fields, such as agriculture, industry or the smart city, where they facilitate fine optimization of processes. These devices are often powered by primary or rechargeable batteries, which limits their battery life. Moreover, it is sometimes not possible or financially viable to change and/or recharge these batteries. A possible solution is to harvest energy from the environment to power these sensors. But these energy sources are unreliable, and the sensor must be able to prevent the complete depletion of its energy storage. In order to adapt its energy consumption, the node can match its quality of service to its energy capabilities. Thus, the device can continuously operate without any service interruption.

The thesis of Philip-Dylan Gleonec [2] presents new methods used for the conception of a completely autonomous sensor, powered by energy harvesting and communicating through a long range LoRa network. In order to ensure its power supply, a board has been designed to harvest energy from multiple energy sources simultaneously. A power management software module has then been developed to calculate an energy budget the sensor can use, and to choose the best way to spend this budget over one or multiple tasks. This work has enabled the development of an energy autonomous industrial sensor prototype.

Emerging Low Power Wide Area Networks (LPWAN) represent a real breakthrough for monitoring applications, since they give the possibility to generate and transmit data over dozens of kilometers while consuming few energy. To further increase the autonomy of such wireless systems, an original methodology was proposed in [**?**]to correctly dimension the key elements of an energy autonomous node, namely, the supercapacitor and the battery that mainly give the form factor of the node. Among the LPWAN candidates, LoRa is chosen for real field experiments with a custom wireless platform that proves its energy neutrality over a finite horizon. Different LoRa configurations are explored, leading to adequate dimensioning. As an example, it is shown that, for the same quality of service, the size of the solar panel needed to keep a LoRa node autonomous in the South of France is less than half of the size required in North of France.

A collaboration with the consortium of the ANR SpatialModulation allow to power a Backscatter tag with solar energy harvesting. A demonstration of such system has been made at INFOCOM conference [16].

### 6.4 Wake-up radio

**Participants**: Olivier Berder, Antoine Courtay, Matthieu Gautier, Nour Djidi.

In the recent years, ultra low power Wake-up Receivers (WuRx) have emerged as a possible solution to achieve both energy efficient communications and low latencies. Indeed, these devices allow continuous channel monitoring while consuming orders of magnitude less power than traditional transceivers, therefore enabling "pure-asynchronous" communications.

Connected devices using LoRaWAN standard achieve low energy consumption by leaving their sleep state only to send their data. However, this technique induces a high downlink latency that is not compatible with applications that require a low latency such as remote control or actuator-type applications. To overcome this tradeoff between power consumption and latency, we propose in [12] a MAC protocol design leveraging an heterogeneous network architecture composed of both long-range and ultra low power short-range wake-up radios. The proposed protocol does not change the LoRaWAN standard but at each uplink, a node operating in LoRa class A becomes an opportunistic cluster head and thus the gateway takes the opportunity of its receive windows to send commands intended to other nodes. Thanks to this novel network architecture and appropriate MAC protocol, the latency can be reduced while maintaining or even increasing the energy efficiency. Considering clusters of ten nodes, gains of 3.33 and 2.11 can be achieved in latency and power consumption, respectively

### 6.5 Long range communications performance

**Participants**: Olivier Berder, Baptiste Vrigneau, Matthieu Gautier, Jules Courjault.

In the last years, LoRa has emerged as a high potential candidate among several standards for the Internet of Things (IoT) subject to an exponential development. LoRa modulation is based on a classical chirp spread-spectrum technique and permits wireless data transmission up to 50 kbps over several kilometers with a high energy efficiency. Although a well-known principle, its performance in terms of symbol or bit error probability has been theoretically analyzed in few recent papers only. Recently, closed form approximations of Bit Error Probability (BEP) for additive white Gaussian noise channels and Rayleigh fading channels were proposed. We introduce in [8, 9] a new approach using Marcum function for approximating the LoRa BEP. The latter is available for both Additive White Gaussian Noise channels and Rayleigh fading channels and the approach should deal with a variety of fadings. Simulations and comparisons with the state of the art show that the proposed approximation is almost ten times more accurate and may be considered as a numerical reference.

### 6.6 Indoor Localization

**Participants**: Olivier Berder, Arnaud Carer, Antoine Courtay, Mickaël Le Gentil, Pascal Scalart.

Nowadays, there is a high demand for human and/or objects monitoring/localizing in the context of applications like Building Information Modeling (BIM), automated drone missions, contextual visits of museum or sports monitoring for instance. While for outdoor positioning accurate and robust solutions (i.e. GPS) exist for many years, indoor positioning is still very challenging. There is also a need of gesture/motion tracking systems that could replace video solutions. *Zyggie* is a hardware/software platform developed by IRISA that combines both Ultra Wide Band (UWB) technology and Received Signal Strength Indicator (RSSI) for low power accurate indoor positioning and Inertial Measurement Unit (IMU) utilization for motion tracking. Very few industrial/academic existing solutions can simultaneously perform indoor positioning and motion tracking and none of them can do both under low power, low cost and compacity constraints addressed by our platform. As *Zyggie* has the capability to estimate distances w.r.t other platforms in the environment and quaternions (which represent the attitude/orientation) users can test/enhance state of the art algorithms for positioning and motion tracking applications.

A positioning algorithm named Best Anchor Selection for Trilateration (BAST) based on position prediction and noise estimation was proposed in [10]. An experimental testbed using real cases experiments on *Zyggie* shows that BAST can give from 1.26 up to 4.17 times better accuracy than low complexity state of the art algorithms when the mobile/person is in movement (e.g. tennis player).

If Ultra-wideband radio is a promising technology, its robustness still suffers in noisy environment and most of localization algorithms keep a prohibitive complexity to be embedded on target nodes. The Newton-Gauss algorithm represents a good trade-off between positioning performance and processing needs at the node level. As some recent wireless body area networks (e.g. *Zyggie*) embed inertial measurement unit, the target direction can be used to further enhance the accuracy while keeping an acceptable complexity. In fact, the direction allows to narrow the research area of the mobile position. Thanks to this additional information, our direction-aided Newton-Gauss algorithm proposed in [11] allows a gain of more than 14% in terms of accuracy over classical Newton-Gauss algorithm.

### 6.7 Non Intrusive Load Monitoring

**Participants**: Nicolas Roux, Baptiste Vrigneau.

Knowing the plug-level power consumption of each appliance in a building can lead to drastic savings in energy consumption. Non-Intrusive Load Monitoring (NILM) is a method for desegregating power loads in a building to the single appliance level, without using direct sensors or electric meters. This paper addresses the issues of inaccuracy of NILM in commercial and industrial buildings, by deploying a low-cost, non-dedicated, smart sensors network in our lab: the SmartSense platform. The SmartSense platform gathers environmental data and allows us to make a rough guess on the states of the monitored appliance. The simplex algorithm is used to estimate the power load values of these steady states, and transmit it to the next sliding window of data [15].

### 6.8 MIMO Precoding and cooperative Communications

**Participants**: Olivier Berder, Baptiste Vrigneau.

In [4], imperfect feedback-based linear precoding schemes are proposed for multiple-input-multiple-output (MIMO) wireless communication systems, where input symbol streams are encoded by using generalized-orthogonal space-time block codes. The imperfect feedback information drastically degrades the system performance. Therefore, to overcome the effect of erroneous feedback information, error-tolerant weighting (ETW) schemes are implemented by employing diagonal precoder. The communication links are assumed to be Nakagami-m distributed for accurately characterizing practical wireless channels under different fading scenarios. Exact and asymptotic symbol-error-rate (SER) expressions of the considered MIMO system are derived under imperfect feedback with the help of order statistics. The most appropriate values of the transmit weights of the precoder matrix are obtained by minimizing the derived average SER over fixed and adaptive signal-to-noise ratio. Further, we study the trade-off between the proposed optimal and suboptimal feedback-based precoding schemes. Moreover, the ergodic-rate of the ETW schemes is also derived with imperfect feedback for arbitrary MIMO system by using the moment generating function approach. The simulated and analytical results show that a significant performance gain is achieved by the ETW schemes as compared to the uniform power allocation and existing precoding techniques under erroneous feedback information.

### 6.9 Optical Communications

**Participants**: Robin Gerzaguet, Pascal Scalart.

This year two directions have been pursued related to algorithms [7] and methods dedicated to optical communications.

First, we have deeply investigated new methods associated to the compensation of IQ imbalance and polarization demultiplexing in a new joint methods proposed in [13]. While classical method in the literature perform the compensation of these two phenomena independently, we have proposed a single algorithm that performs a joint compensation. The main advantage of this algorithms lies in the fact that it is modulation independent (it does not require a priori knowledge on the modulation format) and it reduces the complexity of the channel equalisation overhand, as the channel compensation has only to be applied on each path of the polarization independently and not with the use of the classical butterfly 4-Finite Impulse Response filter architecture. The performance of the proposed method shows its benefits with respec to the state of the art Blind Source Separation (BSS) and Constant Modulus Amplitude (CMA) algorithms.

Secondly, we have investigated in [6] the trade-off between Chromatic Dispersion and Phase Noise Compensation when a multicarrier waveform (here FilterBank Multicarrier (FBMC) is used. Filterbank multicarrier based on offset-quadrature amplitude modulation (FBMC/OQAM) is a interessting waveform for optical fiber communication systems, thanks to its better time/frequency confinement compared to other multicarrier modulations. Among linear impairments, the compensation of fiber-induced chromatic dispersion (CD) and laser-induced phase noise (PN) in FBMC/OQAM systems induces a compromise in terms of the number of used subcarriers. Considering a fixed dedicated signal bandwidth, the number of subcarriers is expected to be large enough to allow a better frequency-domain CD compensation. On the other hand, it should be sufficiently small in order for the compensation of common phase error inherent to the PN to work properly. We have experimentally demonstrated the trade-off between CD and PN compensation that we previously highlighted by simulations. More specifically, considering a 20-GHz FBMC/4-OQAM modulation and an aggregated laser linewidth of about 200 kHz, we have shown that the maximum transmission distance reaches 3100 km with nearly 512 active subcarriers and 3-tap equalizers, when a maximum 1-dB optical signal-to-noise ratio (OSNR) penalty at a bit-error-rate (BER) of $3.8 \times 10^{-3}$ can be tolerated. Moreover, we have proposed and validated a frame structure and an integrated synchronization/channel equalization architecture to implement a standalone demodulation system.

# 7 Contracts and Grants with Industry

## 7.1 CIFRE PhD Grant Wi6Labs

**Participants**: Olivier Berder, Matthieu Gautier, Philip Dylan Gleonec.

This is a Cifre contract with Wi6labs compagny that includes the supervision of Philip Dylan Gleonec. The goal of this thesis is the design and the implementation of power management strategies for long range radio modules equipped energy harvesting.

## 7.2 Orange

**Participants**: Arnaud Carer, Antoine Courtay, Mickaël Le Gentil, Clément Caresmel.

This work was done with Orange in order to design an autonomous robot for Wifi network supervision. The designed robot can autonomously move in a building environment following some predefined paths, and hold some Wifi connected devices such as smartphones, tablets and/or computers. These devices can connect/disconnect to several Wifi access points in the environment. Tests were done by humans following these trajectories.

## 7.3 SNCF

**Participants**: Pierre Hallé, Mickaël Le Gentil, Antoine Courtay, Olivier Berder.

The goal of this contract is to help SNCF localize precisely a target (e.g. a maintenance robot) in an unknown area, near the train tracks, possibly in a tunnel. To reach this goal, we use UWB communications and develop custom localization algorithms and dedicated protocols suited to the Zyggie platform. The first task is to deploy anchors and develop a protocol that make them able to position themselves with respect to a reference anchor whose position is known. Then a positioning algorithm for the robot is developed, taking into account information from IMU.

# 8 Other Grants and Activities

## 8.1 International Collaborations

- **EU CELTIC+ SENDATE TANDEM (2016-2019)**

  **Participants:** Olivier Berder, Arnaud Carer, Pascal Scalart

  TANDEM is sub-project from the CELTIC+ SENDATE project. TANDEM addresses the challenge for a new network infrastructure with reference to high volatile data traffic of mobile linked up objects. A dynamic switching and a reliable transport of huge amounts of data as well as a handover of sensible, time critical application data without any interruptions must be provided between data centers.

Within the metro area, essential elements are virtualized: integrated nodes consisting of traditional DCs (RAM, processor) but also e.g. virtualized DSL- and radio access (vRAN) network elements or IP-router and optical network elements like cross-connects. Virtualization shall lead to a flexible arrangement of single modules and to a dynamic provision of resources according to application demands. Here latency and bandwidth but also QoS classes and findings from simulative traffic investigations will be considered.

Furthermore a common SDN-based control-plane will be developed for an optimized control of network elements across levels. The first underlying assumption is based upon a flexible control plane and develops an application, which is able to migrate the network from one load status to another. The second assumption goes for full flexibility from scratch within definition of control plane architecture, intending to turn today's metro networks into a flexible platform for future services and applications.

Elastic Optical Networks (EON) are now widely deployed because they can reduce the number of opto-electronic regenerators, take advantage of new flexi-grid ROADMs and provide improvements in tunable laser or DSP technologies. To efficiently benefit from multiple rates in EON and to optimize the limited spectral resources over time, optical spectrum defragmentation is required. Today, we use defragmentation during maintenance windows because lightpaths must be often switched off to be able to move the wavelength over the C band. In EON, defragmentation may become challenging when using different spectrum grids. To overcome this, automation is needed. Experiments were conducted with an SDN control without studying optical hardware network elements. In [?], we propose a solution to deploy optical spectrum defragmentation automatically, with fast hardware elements and SDN control. The process may also include lightpaths rerouting without traffic interruption. We first present the architecture and depict how to allow a fast SDN-based defragmentation. We then set up an experiment and perform hardware characterizations.

The findings will be applied to a virtual communication-based Internet of Things network.

The TANDEM project involves some academics (UR1, IMT, Stuttgart, Fraunhofer) and many industrials, among which we can cite Nokia, Orange, Thales, Vectrawave, Telenor... For more details see `https://www.celticplus.eu/project-sendate-tandem/`.

## 8.2 National Collaborations

- **Images & Réseaux Competitivity Cluster - Plug&Pos (2017-2019)**
  **Participants:** Olivier Berder, Antoine Courtay, Mickaël Le Gentil
  Plug&Pos is a project focused on indoor geolocation applied to museum applications. Challenges are to create an accurate indoor geolocation system and to propose interactive information on tablets to visitors. To achieve this aim, Granit team works on geolocation algorithms for facing to environment perturbations due to distance measuring with UWB radio. The first industrial partner is Ticatag for the prototyping phase and the second partner is Klaxoon to propose contextual information with video, audio and augmented reality contents. The complete system must be installed quickly, support multi-users and be accurate with +/-20cm to differentiate nearby points of interest.

- **ANR PRCE - Wake-Up (2017-2020)**
  **Participants:** Olivier Berder, Antoine Courtay, Matthieu Gautier
  Using pure-asynchronous communication allowed by emerging Ultra-Low-Power (ULP) wake-up receivers (WUR), Wake-Up aims at proposing a low latency and energy efficient network architecture composed of heterogeneous radio nodes (long-range communication and ULP short-range WUR) with dedicated access and network protocols. A two-way cross layer optimization is envisaged in Wake-Up, since on one hand these heterogeneous network higher layers will take into account the specificities of the wake-up radio to optimize energy and latency, and on the other hand some recurrent application constraints will lead to specific wake-up radio designs. The consortium is composed of two academic partners (University of Rennes 1 an-d University of Strasbourg), one state-owned industrial and commercial establishment (CEA LETI) and one SME (Wi6Labs). The consortium will address these scientific challenges at both the node and the network levels, with controlled (FIT IoT Lab) and real-field experimental validations.

- **Labex Cominlabs Moonlight (2018-2019)**
  **Participants:** Olivier Berder, Mickaël Le Gentil, Antoine Courtay, Clément Caresmel

  In order to enhance sportsmen performance, various sensors are employed in controlled environment to monitor both physiological values and gesture accuracy. However, most of these monitoring platforms are either bulky, heavy or very expensive, which makes them not suitable for everyday monitoring in training conditions. The goal of Moonlight is to design a light wireless sensor platform for accurate sport monitoring, even in outdoor training conditions. The first intended use case is cycling, since the platform will feed biomechanics algorithms, jointly designed with M2S laboratory to quantify power transfer from the cyclist to cycle and help avoiding injuries.

- **Cominlabs Exploratory action TODEMS (2019)**
  **Participants:** Olivier Berder, Antoine Courtay, Mickaël Le Gentil, Matthieu Gautier

  The aim of TODEMS is to develop a system based on a microwave sensor, provided by LanSTICC and explore the possibilities of using the wide-frequency-band response to track one particular parameter in a complex medium. The use of a broadband response is a key to isolate each parameter response, as it can depend on sensor size and sensor/material physical and/or chemical properties. The idea is thus to develop a basic system to demonstrate the relevancy of this idea. Associated with other sensors such as Inertial Motion Unit (IMU), this type of sensor should further be able to monitor heterogeneous structures such as aircraft wings or bridges.

- **Cominlabs Exploratory action Capocochi (2019)**
  **Participants:** Olivier Berder, Antoine Courtay, Mickaël Le Gentil, Matthieu Gautier

  The aim of Capocochi is to develop a new kind of system based on a microwave sensor, provided by LanSTICC and explore the possibilities of using the wide-frequency-band response to track one particular parameter in a complex medium. The use of a broadband response is a key to isolate each parameter response, as it can depend on sensor size and sensor/material physical and/or chemical properties. The idea is thus to develop a basic system to demonstrate the relevancy of this idea. Associated with other sensors such as Inertial Motion Unit (IMU), this type of sensor should further be able to monitor heterogeneous structures such as aircraft wings or bridges.

- **Images & Réseaux Competitivity Cluster - HAD-OC (2018-2020)**
  **Participants:** Antoine Courtay, Robin Gerzaguet, Arnaud Carer, Olivier Berder, Mickaël Le Gentil

  The development of immersive technologies (augmented reality, virtual reality) offers an important opportunity in the audio field. Sound represents 50% of the immersion quality and is therefore a key factor in the user experience. However, technologies for the transmission and the processing of audio data have not evolved as fast as the virtual reality ones did. The HAD-OC project aims at developing a wireless audio transmission solution compatible with 3D professional sound requirements. The bit rate will be at least 4.6 Mbps and the latency less than one millisecond. To meet the needs of 3D sound and virtual reality, the system will allow 3D geolocation of transmitters / receivers. We will demonstrate in the project point-to-point transmission and broadcast transmission. To do so, Feichter Electronics, 3D Ouest and the Granit team will join forces to develop a method for wireless transmission of a high quality digital audio signal without latency.

- **Images & Réseaux Competitivity Cluster - Modiflu (2019-2021)**
  **Participants:** Antoine Courtay, Olivier Berder, Mickaël Le Gentil

  Collecting production data, analyzing data flows and providing a unique interface based on factory digital model should bring productivity gains to factories. Thanks to sensor disseminated in the factory and non-structured data (e.g. e-mails), the Modiflu project aims to signicantly reduce the on-time delivery indicator of Prolann, that will serve as experimentation field. Axalon is in charge of the digital twin, while Orange Labs will provide its capabilities of data mining and user-centric interfaces. GRANIT is in charge of the indoor localization system, based on UWB communications. As the factory environment is subject to severe degradation, robust localization and communication protocols have to be imagined.

# 9 Dissemination

## 9.1 Scientific Responsibilities

- O. Berder is a member of the Editorial Board of *International Journal of Distributed Sensor Networks*
- O. Berder is a member of the Editorial Board of *Wireless Communications and Mobile Computing*

- O. Berder is a member of the Editorial Board of *Sensors*
- O. Berder is a member of Technical Program Committee of IEEE PIMRC, IEEE SAS, ACM EWSN, ICT and is a reviewer for IEEE TSP, TWC, ToN, JSAC, ICC, GLOBECOM...
- O. Berder is a member of Labelling Committee (CSV) of Images & Networks cluster
- O. Berder served as an expert for CEFIPRA program
- O. Berder served as a member of the committee for the PhD defense of Hayfa Ben Thameur, *ADMM-LP Decoding of LDPC Convolutional codes : from algorithm to implementation*, defended at University of Bretagne Sud, March 15 2019
- O. Berder served as the president of the committee for the PhD defense of Taofik Bouguera, *Capteur Communicant Autonome en Énergie pour l'IoT*, defended at Université de Nantes, March 28 2019
- O. Berder served as a reviewer for the PhD of Rhajeev Piyare, *Wake-up Radio based Approach to Low-Power and Low-Latency Communication in the Internet of Things*, defended at University of Trento, Italy, April 24 2019
- O. Berder served as a reviewer for the PhD of Nicolas de Araujo Moreira, *On heterogeneus networks under non-Gaussian interferences: experimental and theoretical aspects*, defended at Université de Lille, July 11 2019
- O. Berder served as the president of the committee for the PhD of Alex The Phuong Nguyen, *Short Frame Wireless Communications: New Challenges for the Physical Layer*, defended at IMT Bretagne Atlantique, November 27 2019
- A. Courtay served as a reviewer for IJDSN, ISCAS, GRETSI.
- M. Gautier served as a reviewer for the PhD of Hajer Ben Rekhissa, *Réduction de la consommation énergétique dans les modules M2M utilisant la technologie LTE/LTE-A*, defended at University of Cote d'Azur, December 11 2019
- M. Gautier was a member of technical program committee of IEEE ISWCS, ICT, IEEE WCNC, IEEE PIMRC, IARIA SENSORCOM and IARIA AICT.
- M. Gautier served as a reviewer for GRETSI, MDPI Sensors and IEEE Communication letters.
- B. Vrigneau served as a reviewer for IEEE Communications Letters, PIMRC, ISTC, WCMC, MDPI Sensors, IEEE Trans. on Vehicular Technology, Gretsi.
- B. Vrigneau was a member of technical program committee of IEEE PIMRC and 4th International Workshop on Non-Intrusive Load Monitoring.
- Robin Gerzaguet served as a reviewer for GRETSI, IEEE EUCNC, IEEE WCNC, IEEE Access and IEEE Transaction on Wireless Communications.

### 9.2 Involvement in the Scientific Community

- M. Gautier and R. Gerzaguet did a presentation entitled "Autonomie énergétique des capteurs pour réseaux LPWAN : Expérimentations LoRa et LTE CAT-M" during the "Low-Power Wide Area Networks (LPWAN)" day, GDR RSD, July 2019
- O. Berder and B. Vrigneau are members of scientific committee of IUT Lannion.

### 9.3 Teaching Responsibilities

IUT stands for *Institut Universitaire de Technologie* and ENSSAT stands for *École Nationale Supérieure des Sciences Appliquées et de Technologie* and is an *école d'Ingénieurs.* Both are located in Lannion and part of the University of Rennes 1.

- D.Demigny is a Vice-President of the University of Rennes 1, in charge of Digital Activities.
- D. Demigny is the Head of the Physical Measurements Department at IUT Lannion.
- P. Scalart is the Head of the Electronics Engineering department of ENSSAT.
- A. Courtay is supervising the first year students of the Electronics Engineering department of ENSSAT.
- M. Gautier is the Head of the Network and Telecommunications Department at IUT Lannion.
- M. Gautier is member of the French National University Council since 2015 in signal processing and electronics (Conseil National des Universités en 61e section) - elected again in 2019.
- O. Berder is in charge of Studies Pursuit of Physical Measurements Department at IUT Lannion.
- O. Berder and B. Vrigneau are elected members of IUT Institute Council and Direction Committee.
- B. Vrigneau is in charge of the project of new department Multimedia and Internet at IUT Lannion (scheduled on September 2020).

### 9.4 Teaching

- O. Berder: signal processing, 70h, IUT Lannion (L2)
- O. Berder: sensors and control, 90h, IUT Lannion (L2) and 25h, UFAZ Bakou, Azerbaidjan (L2)
- O. Berder: digital systems, 80h, IUT Lannion (L1)
- O. Berder: IoT and connected objects, 14h, ENSSAT (L3 and M2)

- A. Courtay: digital electronics, 122h, ENSSAT (L3)
- A. Courtay: digital system design, 12h, ENSSAT (L3)
- A. Courtay: PCB conception, 14h, ENSSAT (L3)
- A. Courtay: digital electronics communication interfaces, 68h, ENSSAT (M1)
- A. Courtay: digital electronics: Laser diode driver, 16h, ENSSAT (M1)
- M. Gautier: computer architecture, 36h, IUT Lannion (L1)
- M. Gautier: telecommunications, 138h, IUT Lannion (L1)
- M. Gautier: digital communications, 30h, IUT Lannion (L2)
- M. Gautier: IoT and connected objects, 10h, ENSSAT (L3)
- R. Rocher: electronics, 44h, IUT Lannion (L1)
- R. Rocher: telecommunications, 82h, IUT Lannion (L1)
- R. Rocher: signal processing, 12h, IUT Lannion (L2)
- R. Rocher: digital communications, 48h, IUT Lannion (L2)
- P. Scalart: non-linear optimisation, 18h, Master by Research (SISEA) and ENSSAT (M2)
- P. Scalart: parametric modelization, optimal and adaptive filters, 24h, Master by Research (SISEA) and ENSSAT (M2)
- P. Scalart: source coding, 14h, Master by Research (SISEA) and ENSSAT (M2)
- P. Scalart: cellular networks, 24h, ENSSAT (M2)
- P. Scalart: digital communication systems, 32h, ENSSAT (M1)
- P. Scalart: random signals and systems, 12h, ENSSAT (M1)
- R. Gerzaguet: Micro-electronics, 46h, ENSSAT (L3)
- R. Gerzaguet: Digital Signal processing, 60h, ENSSAT (M1)
- R. Gerzaguet: Wireless network, 9h, ENSSAT (M1)
- R. Gerzaguet: Wireless communication, 20h, ENSSAT (M2)
- R. Gerzaguet: System On Chips, 22h, ENSSAT (M2)
- B. Vrigneau: computer architecture, 14h, IUT Lannion (L1)
- B. Vrigneau: enterprise telephony, 20h, IUT Lannion (L1)
- B. Vrigneau: maths, 24h, IUT Lannion (L2)
- B. Vrigneau: telecommunications, 190h, IUT Lannion (L1, L2, L3)

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