Team GRANIT

Green Radio and Adaptive Nodes for the Internet of Things

Lannion

Activity Report

2025

1 Team

Name	Forename	Position
Berder	Olivier	Full Professor, UR (IUT Lannion)
Carquin	Émilie	Research Assistant, UR (ENSSAT Lannion)
Casseau	Emmanuel	Full Professor, UR (ENSSAT Lannion)
Courtay	Antoine	Associate Professor, UR (ENSSAT Lannion)
Gautier	Matthieu	Full Professor, UR (IUT Lannion)
Gerzaguet	Robin	Associate Professor (HDR), UR (ENSSAT Lannion)
Le Gentil	Mickaël	Research Engineer, UR (ENSSAT Lannion)
Rocher	Romuald	Associate Professor, UR (IUT Lannion)
Scalart	Pascal	Full Professor, UR (ENSSAT Lannion)
Thépault	Joëlle	Research Assistant, UR (ENSSAT Lannion)
Vrigneau	Baptiste	Associate Professor, UR (IUT Lannion)

Table 1: GRANIT permanent members

The GRANIT team comprizes 9 permanent research members: 4 full professors (*Professeur des Universités*), 4 associate professors (*Maître de conférences*) and 1 research engineer, all from University of Rennes (UR). There are currently 13 PhD students in the GRANIT team. Table 1 lists the permanent staff and table 2 the current PhD students and other staff.

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, wireless 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

Name	Forename	Status	Period
Argote Aguilar	Jesus	PhD, Research Engineer[1]	10/2021 - 03/2025
Chillet	Alice	PhD, Lecturer[2]	10/2020 - 08/2025
Balti	Nidhal	PhD	02/2022 - 03/2025
Bouro	Souébou	PhD	10/2022 - 12/2025
Muller	Thomas	PhD	10/2022 - 12/2025
Chevalier	Dylan	PhD	10/2022 - 11/2025
Lounes	Gaëtan	PhD	Since 04/2023
Bothereau	Emma	PhD	Since 10/2023
Moussa	Taha	PhD, Research Engineer[3]	Since 04/2024
Kouddane	Nada	PhD	Since 10/2024
Lakhdari	Adam	PhD	Since 10/2024
Bouayed	Nour Meriem	PhD	Since 01/2025
Afi	Alexandre	PhD	Since 01/2025
Lamotte	Quentin	PhD	Since 09/2025
Khalil Khouja	Mahmoud	PhD	Since 10/2025
Kharrat	Eya	PhD	Since 10/2025
Depontailler	Corentin	PhD	Since 10/2025
Torillec	Brendan	PhD	Since 10/2025
Hajibalayev	Ahmadagha	PhD	Since 12/2025
Lacroix	Marie-Anne	Lecturer	Since 09/2024
Bazerque	Paul	Research Engineer	Since 06/2023
Top	Assane	Research Engineer	Since 04/2025

[1] Jesus defended his PhD on December 16 2024, and was a Research Engineer for 3 months
[1] Alice defended her thesis at the end of 2024 and was a lecturer until August 2025
[3] Taha was a Research Engineer and is a PhD student since October 2024

Table 2: GRANIT other staff

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

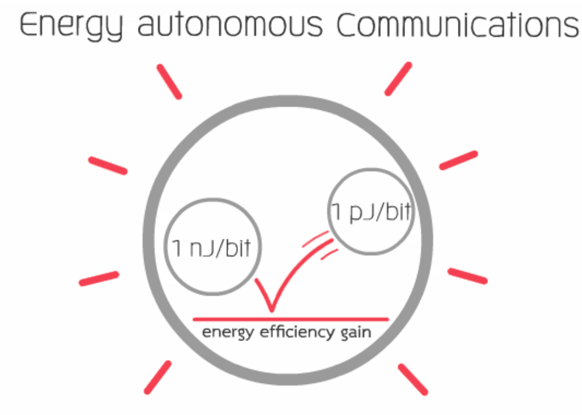

Figure 1: Transmission Energy efficiency target for the next decade

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.

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 (5G, beyond 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 re-

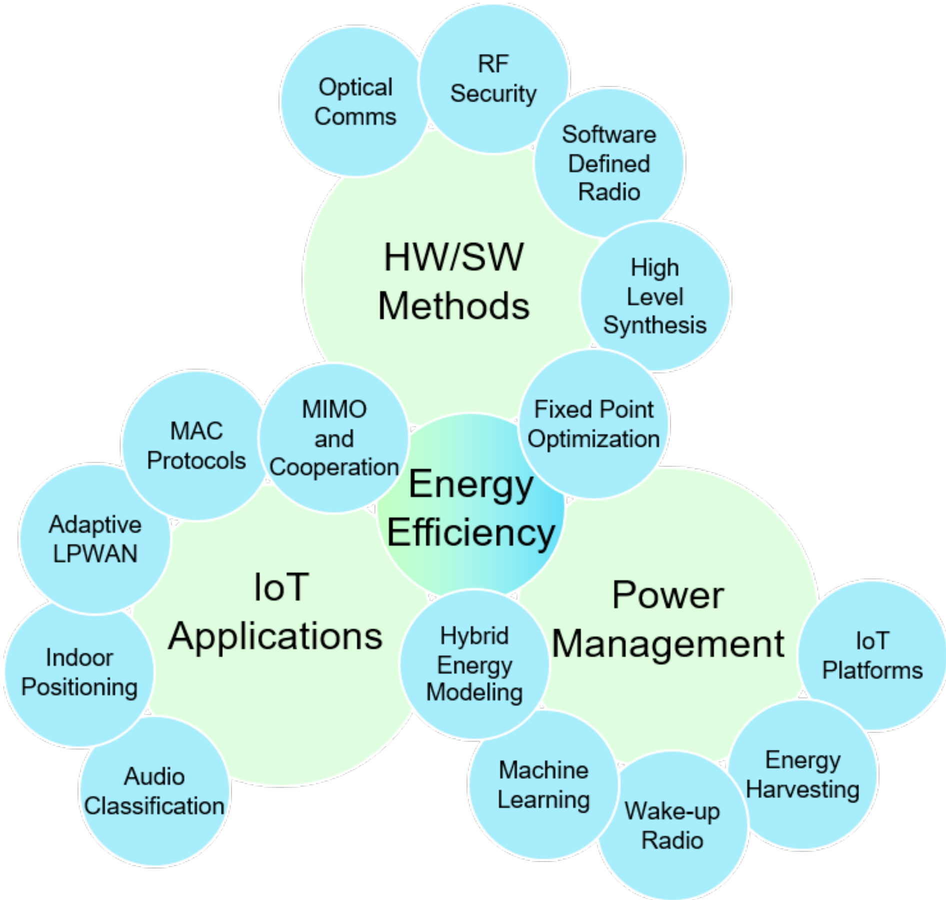

Figure 2: GRANIT Research Topics

quirements 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.

The objective of GRANIT members is mainly twofold, firstly confirm their expertise on IoT core technologies while exploring further the possibility to implement as close as possible application algorithms on hardware targets, secondly to take profit of heterogeneity of emerging software radio solutions to define new partitioning methodologies and address security and of course energy issues. As illustrated by Fig. 2, energy efficiency remains the principal concern of the team, and will be the common denominator of most of the envisioned research. This concern will feed three main topics, namely Power management, Hardware/Software (HW/SW)

[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

methods and IoT Applications. Albeit being different and complementary, the intersection between them is far from null and most of the conducted researches will be of course related to several 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 TARAN 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 components (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 Power management

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.

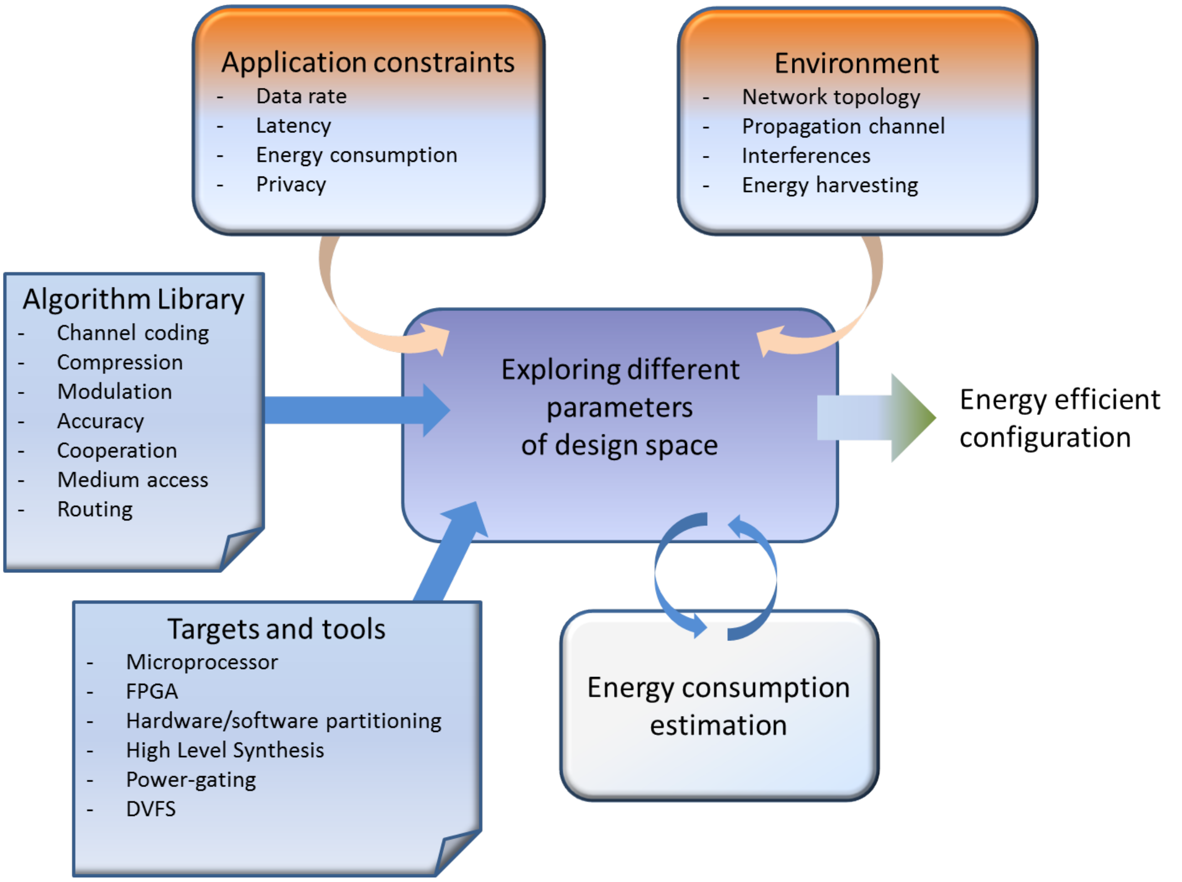

Figure 3: GRANIT Optimization Methodology

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

The first research topic therefore directly concerns power management strategies, which aims either at decreasing as much as possible the energy consumption of wireless systems (thus increasing the latter lifetime) or at using available energy as good as possible in case of energy harvesting. GRANIT team has acquired a renowned expertise in the latter case and proposed many power managers, first for periodic sources and recently for model-free cases. However, there are still many approaches to explore to propose new energy management strategies. The first step is to elaborate accurate models, using both experiments and benchmarks to feed analytical derivations, leading to what we call Hybrid Energy Modelling. If the methodology is quite generic, the obtained model relies on the IoT technology itself, which needs a strong expertise on IoT standards and platforms. The design of the latter is one of the specificities of GRANIT since the team has designed several IoT platforms with or without energy harvesting capabilities, and we really want to continue to go until this hardware design and/or integration step to validate all our algorithms. It has to be mentioned that thanks to industrial collaborations and collaborative projects, GRANIT has benefited for five years from the support of several engineers that helped researchers to maintain and design the platforms. This development team is shared with TARAN team. It is composed of four engineers in average, and is an asset for both teams that we absolutely want to preserve.

The recent development of energy efficient wake-up radios makes possible the continuous listening of wireless channels, decreasing simultaneously energy consumption and latency. But all existing wake-up radios are very application-specific and are not able to adapt themselves and find the best trade-off between energy consumption, range and latency in case of varying conditions. One of the directions we want to explore is to design smart and adaptive wake-up radios at both hardware and software levels, e.g. using light channel coding, soft decoding of addresses, adaptive preamble lengths. . . Finally yet importantly, it is not possible to avoid the investigation of machine learning for energy management. In previous works, we have shown the efficiency of reinforcement learning for energy harvesting nodes, but this has to be confirmed in industrial deployments with severe constraints. Machine learning is also very promising to help to adapt parameters at both physical layer (modulation, coding, spreading) and access layer (power allocation, wake-up interval. . .), but the overhead of such an optimization framework has to be carefully studied.

Energy harvesting 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].

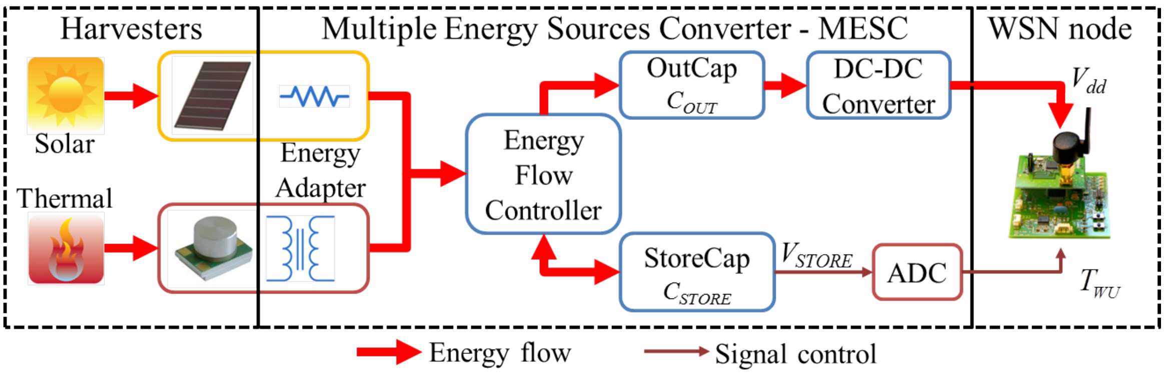

Figure 4: GRANIT Hardware Architecture of our Energy Harvesting Nodes

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,

[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

processing and communication parameters.

Wake-up radio Recently, a new consolidated technology that helps to achieve the trade-off between power consumption and latency has appeared. This technology is called Wake-up Radio (WuR). WuR is a secondary Ultra Low Power (ULP) radio subsystem that is connected to the main node. The WuR can be always on or duty cycled and its power consumption is several orders of magnitude less than that of the main node. The WuR is continuously or periodically listening to the channel while the main radio is in sleep mode, and when a specific signal called Wake-Up Beacon (WUB) is received, the WuR wakes up the main radio through an interrupt. Indeed, the WuR allows an asynchronous wake-up of the main node with a low latency. Recent circuit designs of WuR embed a decoding capability through a ULP-MCU or a correlator allowing to wake up only a specific node, thus reducing considerably the waste of energy consumption of the main radio. The fact that the WuR has an ultra low power consumption imposes hardware constraints to keep it simple. Consequently, in addition to a small bit-rate, the WuR has a low sensitivity, which induces a range mismatch between the WuR (short range in the order of 20m) and the main radio (in the order of 100m in case of IEEE 802.15.4). Furthermore, the robustness of the WuR presents also a bottleneck, it is very sensitive and therefore subject to noise perturbations, inducing false wake-up. Taking profit of the micro-controller embedded in the WuR (or further hardware modifications, e.g. external ADC), GRANIT team will explore various possibilities to make the WuR smarter. Furthermore, novel MAC protocols leveraging a heterogeneous network architecture composed of both long-range and ultra low power short-range WuRs have to be envisioned.

3.3 Hardware/Software methods

The second topic aims at defining tools and methodologies for efficient implementation of digital communications and signal processing algorithms. Most of emerging processing platforms, even those dedicated to low power applications for IoT, are indeed heterogeneous and composed of several processing units, that can be either dedicated to some resource hungry processing, fully or partly reconfigurable or general purpose. However, very few methodologies exist yet to take profit of this heterogeneity and efficiently partition processing over hardware or software resources. One key leveraging point is to have a unified methodology that can address different architectures with the same formalism (and the same programming language). Classic approaches are often based on low level languages (typically C or C++) to have efficient machine code at the price of the flexibility and the code concision. This is not always desirable due to the complexity of some algorithms (as most of machine learning frameworks). On the other hand, high level language (such as Python) offers a very appealing flexibility at the price of the performance... which often leads to the necessity to recode low level software processing blocks. GRANIT members will pay a particular attention to Julia [BEKS17], a scientific computing language that allows concise code description (e.g. fast prototyping) with high performance (just in time (JIT) compilation using LLVM [LA04]). This methodology should be particularly suited to Software-defined radios (SDR), which have been gaining interest in the last decades. SDR is radio communication system where components that have been traditionally implemented in hardware (e.g. mixers, filters, amplifiers, modulators/demodulators, detectors, etc.) are instead implemented by means of software on a personal computer or embedded system. Some recent designs are even so small and restrained in energy that they become an appealing target for IoT applications [CLK+16], widening the initial scope of SDR applications. GRANIT, with its broadened expertise on IoT standards will be an active actor on light SDR for IoT.

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,
- 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.

RF Security Information systems are now massively integrated into both industry and administration processes. Thus, their security is matter of importance especially when considering the storing and exchange of sensitive data. Sensitive data is also called 'red' data, in opposition with the non-sensitive (or protected by encryption) 'black' data. This crucial challenge is present at multiple scales, and leads to the emergence of different security fields linked to data protection (defense protocols) and to data interception (attack protocols)

Since few years, a new threat has emerged with the detection of the red data due to unwanted phenomena. This attack is done trough an over the air interception and thus is difficult to detect. These kind of attacks (called TEMPEST attacks by the NSA) consist in detecting an hidden channel that bear the sensitive information and then decode the 'red' information . This unwanted channel may exist due to different physical phenomena such as electro-magnetic coupling, radio frequency leakages, or mechanical mechanisms.

In GRANIT team we have a strong interest on these kinds of thread among three main axis:

[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

- We make thorough analysis on some potential security beaches on existing standards (Bluetooth, Zigbee…) and boards (System On Chips)
- We also conduct studies and analysis on how Software Defined Radio (SDRs) can increase the criticality of TEMPEST attacks making discrete, compact, long range interception devices handy. On this particular aspects, efficient use of SDR is of importance due the large bandwidths and the harsh real time constraints encountered.
- We investigate methods to be able to identify a transmitter only based on the distortions induced by the transmitted signal. These distortions are due to analog stages of the transmitter and are called Radio Frequency Fingerprint (RFF). The RFF can be used as a non falsifiable identifier

3.4 IoT applications

Some applications, as smart cities, connected farms or wildlife monitoring require transmission of data over long distances at a reasonable energy cost. Emerging standards known as Low Power Wide Area Networks (LP-WAN) respect these requirements by proposing trade-offs between transmission range, data rate, and energy consumption. Most of them are tunable through modulation or coding parameters, such as LoRa, and GRANIT team has acquired a highly recognized expertise on LPWAN adaptation to device environment (propagation, interference, energy harvesting…). However severe propagation constraints have still to be explored, for example for factories of the future that represent very specific environments that can vary a lot from one place to another. Indeed, the indoor environment with a lot of metallic structures and multiple reflectors may lead to severe attenuation, and specific power equipment or machine tools generate impulsive noise. In order to efficiently deploy wireless sensor nodes in factories, there is a crucial need for fast and accurate performance estimation of IoT technologies in this particular context. Based on these results, GRANIT will also explore the possibility to dynamically adapt transmission parameters thanks to reinforcement learning.

GRANIT has a historical expertise on MIMO systems, especially on precoding, whether distributed or not. Precoding aims at using the channel knowledge at the transmitter to adapt the signal to be transmitted to the propagation conditions. Widely used for cellular systems where multiple antennas are embedded on base stations (a.k.a massive MIMO) and mobile devices, precoding can also be used in a distributed and cooperative manner for small IoT nodes, and GRANIT will explore this approach in a security context. A wireless transmission is indeed naturally subject to interception (passive eavesdropping). To circumvent this and increase the secrecy of the transmission, different techniques can be used and can be greatly improved when done in a cooperative manner. In the following years, we will study on how the increasing number of antennas and how the use of precoding/beamforming strategies can improve the secrecy rate of an IoT communication link.

For most of IoT sensor nodes, the communication part is the most energy consuming, and radio activity has therefore to be reduced as much as possible, to avoid idle listening and overhearing. GRANIT will continue to explore this degree of freedom and propose adaptive MAC protocols for heterogeneous systems with several coexisting standards and technologies. For example, heterogeneous networks can be composed of LPWAN and WLAN nodes, potentially equipped with wake-up receivers, with energy harvesting capabilities... As the range and the energy autonomy of all these devices are not the same, there is a crucial need for access protocols that combine all these wireless technologies to reach the best quality of experience as possible.

Indoor positioning Among possible applications of IoT networks, let us emphasize two main topics that GRANIT members want to explore. The first one is indoor localization, useful for industry 4.0, logistics, but also museums, that all require accurate positioning (around 10 cm). In such a stringent requirement, Ultra Wide Band (UWB) based techniques have emerged as accurate solutions. Such radios combine low to medium rate communications with positioning capabilities using ranging techniques. If UWB offers outstanding accuracy, the performance significantly degrades in severe environments (multipath in crowded rooms, impulsive noise in factories). Moreover, to propose energy efficient solutions, a complete cross layer approach has to be envisaged, including hybrid algorithms combining Two Way Ranging (TWR) and Angle of Arrival (AoA) methods, as well as dedicated MAC protocols.

Audio classification The second one relates to audio processing, whether for spatialized sound transmission, in relation with localization explained hereabove, or for context recognition. More and more applications indeed need accurate context recognition to propose adequate services and acoustic sensors appear as very efficient to discriminate environments. The multiplicity of sensors in the same scene obviously enrich the information but transmitting the whole audio flux is very energy consuming. GRANIT wants to explore the possibility of deporting processing as close as possible to the sensor, which i) decreases the amount of data to be transmitted and ii) allows to guarantee a high level of privacy to users. A particular attention will be paid to the distributed implementation of convolutive neural networks. For spatialized sound transmission, no standard exists yet to transmit high quality spatialized sound with low latency, and GRANIT aims to explore with industrial partners what low power SDR can bring, eventually designing full custom systems.

4 Hardware and Software

4.1 EEWOK

EEWOK (Energy Efficient Wireless sensOr networKs) is a proteiform platform deployed and maintained by the GRANIT and TARAN team from IRISA lab. Elected Emerging Rennes 1 platform in 2022, it regroups several elements build from many years of experience in designing very low energy sensor nodes. Depending on the application, it is available in several versions that integrate the same basic elements (low-power microcontroller and several sensors) to which are added important technological innovations (low-power FPGA, energy recovery, software radios, wake-up radio, etc.). These sensor nodes are thus deployed in networks of various scales (up to several hundred nodes for Smartsense). To verify their energy efficiency, the platform has a number of measuring devices (oscilloscopes, spectrum analysers, current analysers, etc.)

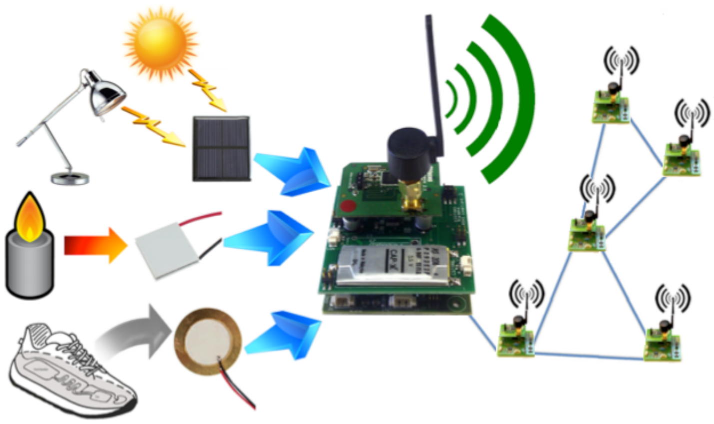

Figure 5: PowWow WSN Platform with Energy Harvesting

PowWow platform for WSNs We have proposed and developed PowWow (Power Optimized Hardware and Software FrameWork 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. 5. 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.

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. 6, 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. 6).

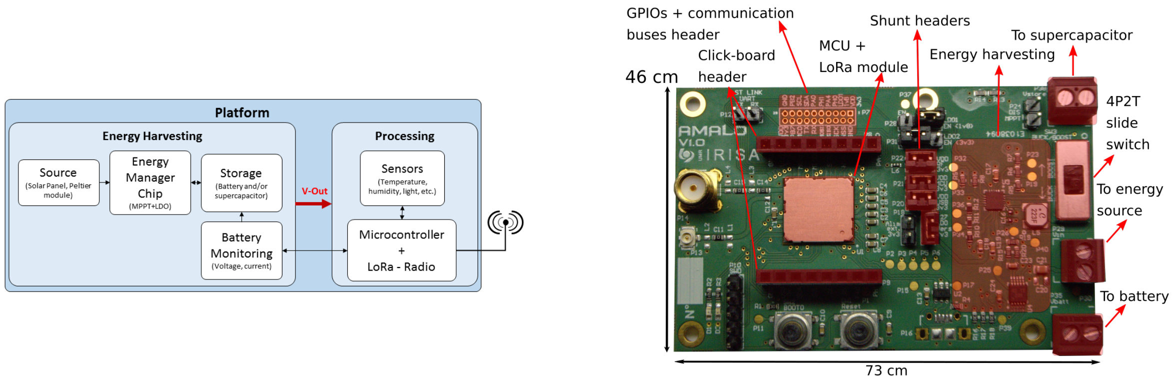

Figure 6: AMALO Block diagram (left) and described board picture (right)

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.

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. 7. 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. 8. 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.

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

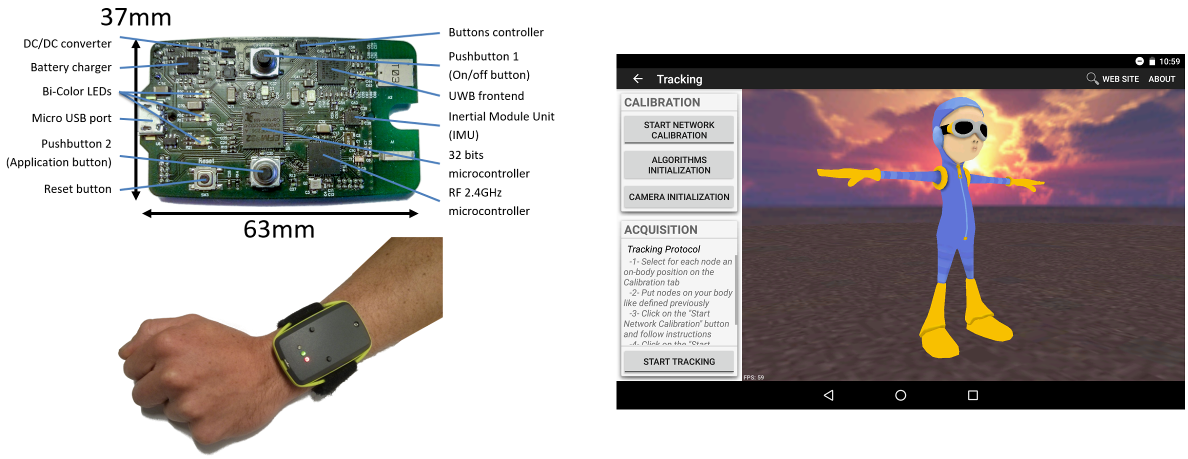

Figure 7: Zyggie V2 and avatar application

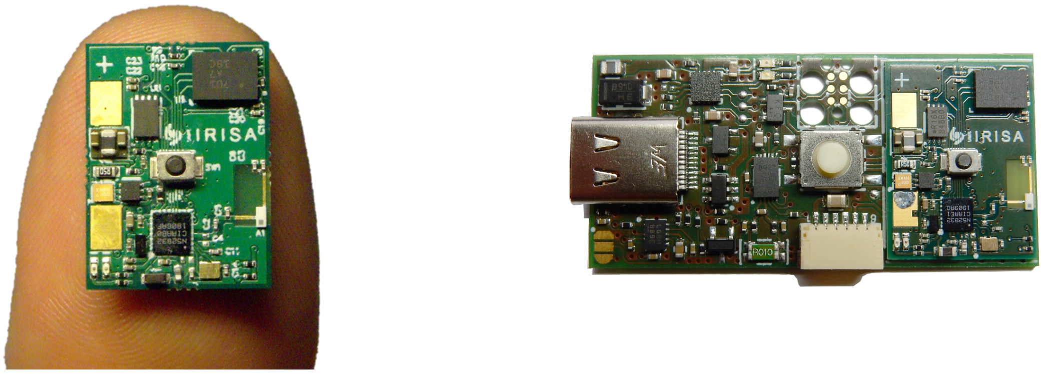

Figure 8: Zyggie Light and its motherboard

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 **Io**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, the Côtes d'Armor Department Council (CD22) and the University of Rennes.

SmartSense With 150 nodes deployed in the buildings of IRISA's laboratories (Lannion and Rennes), the SmartSense platform makes it possible to collect a large amount of data on energy consumption and usage in buildings. This data allows a large number of applications, notably in data mining, disaggregation of electrical loads or processing of sensor data.

SmartSense consists in power measurements and sensor nodes (Fig. 9) :

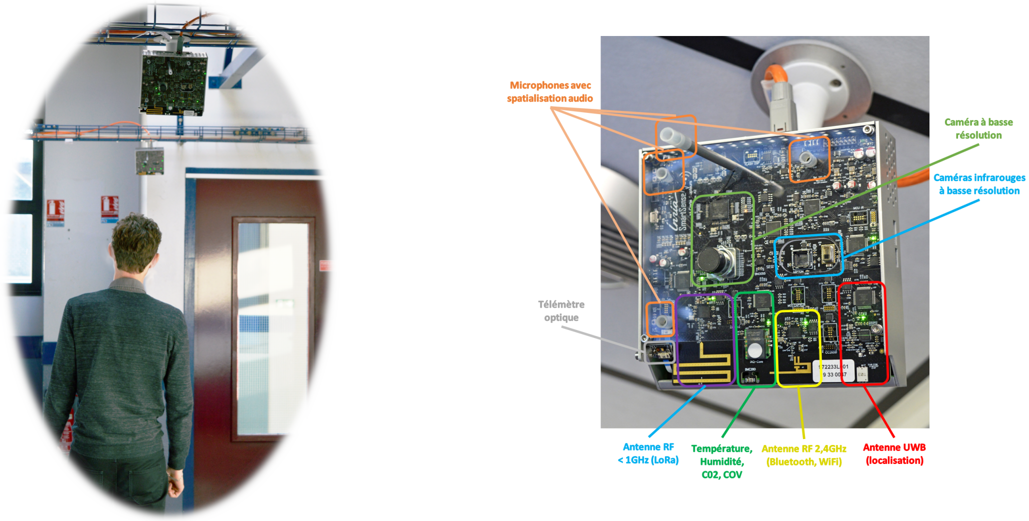

Figure 9: SmartSense network

- The power consumption can be obtained at different levels (individual, a room or whole stage) or on the types (light or plug sectors).

- Each node includes about twenty sensors: image, infrared, audio, radio spectrum, inertial unit, humidity, pressure, temperature, light (red, green, blue, white, UVA, UVB), distance radar with centimeter accuracy, CO2 and VOC (Volatile Organic Compound). A room may host several nodes for spatial diversity.

This project was funded by CPER SmartSense and currently takes place in the Equipex+ TERRA FORMA to monitor anthropized natural systems.

4.2 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.

5 New Results

5.1 Highlights

- Emmanuel Casseau, Full Professor at ENSSAT Lannion (Université de Rennes) has joined GRANIT team from January 2025. Emmanuel was previously part of Taran research Team (also in IRISA D3 department), and his reasearch interests on algorithm architecture adequation and sustainable electronics perfectly match GRANIT research topics.

- Robin Gerzaguet successfully defended his Habilitation á Diriger les Recherches (HDR) at Université de Rennes (ENSSAT), Lannion, June 18 2025 [4].

- 8 new PhD thesis have started in 2026 in the Granit Team.

- Granit team members are currrently involved in 7 ANR projects, and 2 of them are international (LightSwift and MIoT, with Japan and Switzerland, respectively).

5.2 Energy optimization of wireless networks

Participants: Olivier Berder, Marie-Anne Lacroix, Pascal Scalart, Baptiste Vrigneau, Jules Courjault.

The rise of IoT in the past few years has led to the massive deployment of connected devices making IoT networks denser. To optimize transmission arising from congestion in dense networks, adaptive data-rate algorithms have been implemented such as the one used in the LoRaWAN protocol. Utilization of algorithms based on reinforcement learning, especially multi-armed bandit, have been investigated, but the duty-cycle limitation decreases the performance of these algorithms in dense networks up to 15%. [22] and [21] aim at giving a solution to resolve the issue caused by duty-cycle limitation, using the LoRa technology as a study case. An effort was done on energy consumption and the reward is modified in order to save energy according to the quality of service. Performances are evaluated thanks to our new simulator J-LoRaNeS based on the Julia language.

Focusing on IoT constraints, we investigate in [9] the trade-off between throughput, QoS, and energy consumption over Rayleigh fading channels, as well as the impact of audio feature transmission on detection performance. Key parameters affecting spectral and energy efficiency are identified, providing insights into reducing node energy consumption and balancing energy and spectral efficiency in advanced use cases.

5.3 Indoor Localization

Participants: Olivier Berder, Antoine Courtay, Mickaël Le Gentil, Taha Moussa.

Accurate indoor localization remains challenging due to frequent Non-Line-of-Sight (NLOS) conditions, which degrade the performance of Ultra-Wideband (UWB)-based positioning systems. Traditional filters like the Extended Kalman Filter (EKF) and its variants assume ideal Line-of-Sight (LOS) scenarios and struggle in complex indoor environments. To address this, we propose in [27] the NLOS-Aware Adaptive Extended Kalman Filter (NA-AEKF), designed to improve robustness and accuracy under dynamic conditions. NA-AEKF uses machine learning to classify real-time measurements as LOS or NLOS, adjusting filter parameters accordingly. This integration improves adaptability to changing conditions and mitigates NLOS-related errors. Simulations show that NA-AEKF outperforms EKF, the Unscented Kalman Filter (UKF), the Adaptive EKF (AEKF) and the Improved adaptive EKF (I-AEKF), achieving higher precision in complex indoor settings.

5.4 Wireless security

Participants: Olivier Berder, Robin Gerzaguet, Matthieu Gautier, Alice Chillet, Emma Bothereau.

Radio-Frequency Fingerprint Identification (RFFI) has emerged as a promising method for enhancing physical layer security by leveraging the unique imperfections inherent in hardware emitters. These imperfections, though not impeding data transmission, act as unique identifiers due to their dis- tinctive characteristics. The development of Machine Learning (ML) has revitalized RFFI in the last few years, offering more robust and flexible recognition capabilities than traditional approaches.
In a first step, we have investigated RFF identification complexity. Indeed, these new methods, which primarily relies on deep learning, faces challenges for a real-time deployment on edge devices. Both memory and computational resources are indeed presented as the major obstacle of such deployment. To address these issues, we have proposed to investigate the behavior of compressed convolutional neural networks when using unstructured pruning in a data-free scenario, on several public datasets [12]. In [6][14][13], we revisit Fully Connected Neural Networks (FCNNs) and show that a simple one-hidden-layer FCNN can achieve competitive performance, requiring at least 5xfewer FLOPs and inference time than state-of-the-art architectures, with only a marginal drop in F1-score (0.02% to 0.21% depending on the dataset, for 16 transmitters or fewer).
In [19][20], we proposed to change the paradigm of diversity to avoid over-fitting the propagation channel environment: instead of adding diversity to the channel, we choose to add diversity to the data.
Another contribution related the RF security concerns telecom side-channels on frequency-hopping signals, that are harsh to eavesdrop due to their sporadic nature in both time and frequency domains. A wideband interception system has been proposed in [10], able to intercept frequency-hopping signals in real time and to extract sensitive red data from it. The proposed architecture is capable of detecting jumps on the order of 20 μs and can therefore track 50,000 jumps per second across 1,024 channels. The criticality of telecom side-channels in Bluetooth communications has been demonstrated through real interception on several microcontroller chips.

5.5 High-level synthesis

Participants: Robin Gerzaguet, Matthieu Gautier, Gaetan Lounes.

The increasing usage of Field Programmable Gate Arrays has enabled a large range of applications in hardware acceleration. The introduction of High Level Synthesis (HLS) has significantly simplified development and exploration of complex applications. To ease the design burden new HLS toolchains have been introduced using more expressive compiler framework such as Multi Level Intermediate Representation (MLIR). In this context, we aim to use the Julia programming language as a flexible front-end for HLS framework using MLIR, taking advantage of Julia type system, modular infrastructure and rich libraries.
In [24][25], we introduced a new compiler that leverages Julia compiler infrastructure in order to generate MLIR code, facilitating hardware acceleration. The interest of this approach has been demonstrated in the context of rapid prototyping and exploration of type spaces for numerical algorithms.
This first contribution falls into the category of static MLIR generation (such as DSLs or generic front-ends like Polygeist) and cannot address certain kinds of programs, such as data-dependent control flow and runtime type specialization. In contrast, dynamic approaches (such as JAX and Reactant) capture runtime behavior but miss compile-time details. In [23], we proposed enhancing the Reactant tracing system by integrating the Julia compiler's static analysis. This hybrid approach improves the expressiveness and precision of tracing. The effectiveness of our approach is demonstrated on the Polybench benchmark suite.

5.6 Sensor-aided Energy Disaggregation

Participants: Baptiste Vrigneau, Pascal Scalart, Nidhal Balti.

NILM, for Non intrusive Load Monitoring, aims to disaggregate individual electrical power consumption from a global measurement. Nidhal Balti defensed his PhD on March 2025. The goal of this thesis is to improve the performance and applicability of Non-Intrusive Load Monitoring (NILM) systems by addressing key challenges related to accuracy. This work explores the innovative integration of environmental sensors data with NILM frameworks and leverages deep learning models to overcome limitations of traditional approaches. By focusing on both residential and laboratory environments, this research aims to provide a comprehensive solution adaptable to various energy monitoring scenarios. The thesis [1] was structured around three main contributions:

1. Integration of Environmental Sensors for NILM through a dedicated framework
2. Development of a novel Deep Learning Architecture based on rotation operations that we call "Spiral layer".
3. Creation of a novel NILM dataset from the SmartSense platform, including environmental sensors data and high-resolution energy consumption measurements.

5.7 Physical activity monitoring

Participants: Olivier Berder, Souébou Bouro, Antoine Courtay, Mickaël Le Gentil.

In the field of sports, including kayaking, developing technical skills and optimizing performance are essential. Given the constraints on equipment design (paddles, footrests, seats, and boats), the use of portable on-water measurement systems is crucial for elite kayakers and coaches to study equipment usage and athletes movements in real-world conditions. Among the technologies employed, force sensors and inertial measurement units (IMUs) are commonly used for on the water dynamic and kinematic analysis, respectively. However, finding a portable system for kayaking that allows comprehensive evaluation while being suitable for on-water analysis has proven extremely challenging. Existing systems primarily focus on paddle data collection and analysis, with limited attention to data transmission and the energy efficiency of wireless sensor nodes. Moreover, the body of literature in this area remains relatively fragmented and limited, with contributions dispersed across disciplines including biomechanics, embedded systems, and sports science. The study [7] reviews essential systems for real-time, comprehensive analysis of professional kayakers performance. It examines both commercial systems and academic research, focusing on dynamic and kinematic measurements, with an emphasis on inertial and force sensors, particularly strain gauges, which play a central role in this emerging trend in kayaking. These technologies enable detailed analysis, paving the way for future developments to enhance kayakers training programs significantly.

Stroke rate is one of the key indicators for analyzing kayaking performance, yet its real-time estimation is rarely addressed by current embedded systems. The contribution [15] presents a robust method to estimate stroke rate from force signals measured directly on the paddle. The approach is based on an adapted autocorrelation function (ACF), applied to preprocessed and fused data, and offers a balance between accuracy, energy efficiency, and robustness to individual variability. Validated on an ergometer, the lightweight and user-friendly system shows strong correlation with reference measurements, confirming its potential for real-world performance analysis [2].

5.8 Frugal AI

Participants: Olivier Berder, Emmanuel Casseau, Matthieu Gautier, Robin Gerzaguet, Nada Kouddane, Pascal Scalart.

The Industrial Internet of Things (IIoT) is transforming modern industries by enabling intelligent, data-driven operations at the edge of networks. As these systems grow in scale and complexity, optimizing the energy consumption of Machine Learning (ML) techniques becomes essential for sustainable and reliable performance. To pave the way to frugal AI mechanisms for IIoT, our survey[11] examines the architectural foundations of IIoT systems and offers a structured classification of methods for reducing the energy use of ML. A real-world case study, the Energy Efficient Internet of Emergency Services, illustrates the practical deployment of energy-optimized IIoT infrastructures in demanding operational contexts. The article concludes with a discussion of current challenges and future directions focused on ultra-low-power architectures, scalable deployment strategies, and robust security for next-generation industrial intelligence.

6 Contracts and Grants with Industry

6.1 CIFRE PhD Grant Prolann/seismowave

Participants: Olivier Berder, Antoine Courtay, Quentin Lamotte.

This is a Cifre contract with Prolann/SeismoWave company that includes the supervision of Quentin Lamotte.

During the last few years, infrasound sensors have been getting an increased interest, due to their ability to provide a near real-time and continuous monitoring of natural hazards (e.g. climate-related phenomena, detection of seismic event like earthquakes or unusual volcano activity), but also the potential to survey and control comprehensive nuclear Test Ban Treaty over long time periods.

Prolann/SeismoWave is one of the major companies in this field and offers a wide range of infrasound and seismic sensors, some of them based on common patents with CEA. However, energy consumption of current infrasound systems is very high and their deployment and maintenance very heavy.

This thesis purposes the development of an energy-aware infrasound detection array, contributing through the development of a real-time embedded detection chain, and based on previous works on the energy autonomy of radio-connected infrasound sensors or infrasound nodes. The goal of this thesis is twofold: achieving accurate on-site detection bulletins towards a more integrated solution and providing feedback to the nodes for them to reach Energy Neutral Operations. First, a native centralized approach of processing has to be addressed while in a second approach, a distributed implementation of the detection algorithms will be investigated.

6.2 CIFRE PhD Grant Orange Innovation - Audio Coding

Participants: Pascal Scalart, Thomas Muller, Nour Meriem Bouayed.

This concerns two Cifre contracts with Orange Innovation company (located in Lannion for the first contract, and in Rennes for the second contract) that include the supervision of the PhD of Thomas Muller (2022-25) and Nour Meriem Bouayed (2025-28).

In recent years the field of audio coding has been shaken up by deep learning technologies. The use of neural networks enables much lower data rates in a variety of applications, such as voice/video calling, music storage. More recently, neural audio coding has been essential to "tokenize" audio to interface with large language models, for instance in speech-to-speech translation or music generation applications. Autoencoder architectures with Generative Adversarial Network (GAN) training (using discriminators) have shown great results. One fundamental building block of such neural audio coding is the quantization of latent space and Residual Vector Quantization (RVQ) - which is revisiting the well-known multi-stage VQ- is a popular method enabling multi-rate operation.

Alternative methods have been proposed, such as Finite Scalar Quantization or Lookup Free Quantization. Many quantization techniques have been available in the literature for many years. Among them, algebraic vector quantization, in particular spherical lattice VQ, has been successfully applied to "traditional" speech and audio coding. During the PhD of Thomas Muller [26], we propose to study the use of such algebraic VQ within the state-of-the-art neural audio codec Descript Audio Codec (DAC) and we replace RVQ in the DAC neural audio codec by spherical algebraic VQ. We show that the performance obtained with spherical lattice VQ seems very promising [5].

In the same field of neuronal audio coding, the PhD thesis of Nour Meriem Bouayed (2025-28) is dedicated to the multichannel case that can be produced using "spatial parametric" approaches or using "High Order Ambisonics" (HOA) representation formats.

6.3 CIFRE PhD Grant Orange Innovation - Optical Communications

Participants: Pascal Scalart, Dylan Chevalier, Brendan Torillec.

This concerns two Cifre contracts with Orange Innovation company (Lannion) that include the supervision of the PhD of Dylan Chevalier (2022-25) and Brendan Torillec (2025-28).

The 50 Gigabit capable Passive Optical Network (50G-PON) is the last technology proposed by the International Telecommunication Union (ITU-T). On the operator's side, an Optical Line Termination (OLT) connects up to 128 Optical Network Units (ONUs) over distances typically below 20 km. Due to the point-to-multipoint nature of the network, an Non-Return-to-Zero On-Off-Keying (NRZ-OOK) signal is broadcasted to all ONUs at a bitrate of 50 Gbit/s at 1342 nm in the Downstream (DS) and burst mode is required in the Upstream (US) for bitrates between 12.5 and 50 Gbit/s at a wavelength of 1286 nm. However, the 50G-PON is considerably challenged by the restricted bandwidths of low-cost commercially available transmitters and receivers often utilized from the datacenter market which cause severe InterSymbol Interference (ISI). To address these issues, equalization techniques have been integrated into PON specifications for the first time.

Whereas most of the community focused on Digital Signal Processing (DSP), our work considers a cost-effective 50G ONU solution employing analog Analog FeedForward Equalization (AFFE) [8] [17] and Soft Input (SI) or Hard-Input (HI) Forward Error Coding (FEC), enabling high-performance transmission and reducing complexity and costs for the DS ONU. We compare [16] [18] two solutions: one considering ASP with SI-FEC, corresponding to a reference ONU, and one considering ASP with HI-FEC, which is considered as a cost-effective ONU. By simplifying the architecture of the ONU, i.e. by choosing to use an HI-FEC, we get performance that are good enough to be compliant with the standard. In this way, we have shown that it is possible to reduce ONU costs and energy consumption for 50G-PON by adding ASP with HI-FEC, making it more efficient than a SI-FEC alone, and thus avoiding the complexity and cost of the DSP [3].

In the same field of Optical communications, the PhD thesis of Brendan Torillec (2025-28) is dedicated to technological challenges of future passive optical networks (PONs) for 200Gb/s/Î», and beyond. The use of coherent technology in access networks provides a great solution based on concepts from mature technologies to achieve the speeds needed for very-high-speed PON (VHSP).

6.4 European Space Agency (ESA)

Participants: Robin Gerzaguet, Paul Bazerque.

The European Space Agency (ESA) is an intergovernmental organization dedicated to the exploration and utilization of space. Established in 1975, it coordinates the space activities of 22 member states, fostering advancements in science, technology, and satellite applications. ESA's mission is to shape the development of space exploration and innovation. The IRIS^2 (Infrastructure for Resilience, Interconnectivity, and Security by Satellite) program by ESA aims to develop a secure, space-based communication system for Europe. It focuses on enhancing connectivity, resilience, and cybersecurity through advanced satellite technologies.

The aims of the contract is the development of a Julia-based software simulator capable of implementing end-to-end physical layer satellite communications and supporting key waveforms such as 5G NR, DVB-S2X, and DVB-RCS2, alongside a variety of channel and receiver impairment conditions.

7 Other Grants and Activities

7.1 National Collaborations

- **ANR PRC SPINNACH (2025-2029)**
  Participants: Olivier Berder, Matthieu Gautier
  The SpiNNAch project takes place in the context of energy-autonomous nodes for the IoT addressing a cross-cutting problem of energy efficiency, quality of service (QoS) adaptation and security. With the adoption of AI algorithms in all areas of our society, proposing an adaptive AI algorithm where QoS and energy consumption can be adapted accordingly to guarantee node autonomy dependent on a hard-to-predict energy harvesting is challenging. Moreover, the ease of physical access to an IoT node by a malicious person is a major security concern for system designers, service providers and end users. However, the physical protection of these nodes is also constrained by area and energy cost limitations. SpiNNAch we aim to propose the methods and techniques required for the design of secured and adaptive-QoS Spiking Neural Networks for energy-autonomous nodes. These methods will enable SNN nodes to adapt the produced QoS level based on user needs and, more importantly, on the amount of harvested and predicted energy. Furthermore, security explorations will help defining the set of countermeasures to ensure the security of the SNN nodes according to the context of application criticality, while considering limited energy and area constraints. SPINNACH consortium is composed of IRISA (Granit team), Laboratoire Hubert Curien (SESAM team) and LEAT (Edge team).

- **ANR PRC OWL (2024-2028)**
  Participants: Robin Gerzaguet, Olivier Berder, Matthieu Gautier, Mickaël Le Gentil
  Project OWL (Operating Within Limits) proposes a new model of computation for more frugal intelligent autonomous sensors: circadian artificial intelligence (AI). The targeted applications are in the field of environmental monitoring, especially bioacoustics. This

model is particularly well suited for intermittent systems, i.e., sensors without batteries that are powered by ambient energy. Circadian AI is interested in observing phenomena that have a period of one day. It exploits the fact that this period is shared with the availability of solar energy, which is used to power the sensors. This correlation allows the sensors to temporally shift the costly computations required to perform the AI functions to times when the observed phenomenon is at rest and energy is abundant. The project proposes two main contributions. The first is to propose a new structure for circadian AI algorithms that allows for this temporal shift in computation. The second is to provide the software and hardware infrastructure necessary to run these algorithms on an intermittent sensor. OWL consortium is composed of IRISA (Granit team), INRIA (PACAP team) and LS2N (SRC and SIMS teams).

- **ANR PRC PERENNE (2024-2028)**
  Participants: Robin Gerzaguet, Olivier Berder, Matthieu Gautier, Baptiste Vrigneau
  In PERENNE, we propose to develop a fully programmable communication stack for wireless networks by leveraging the software-defined paradigm (namely, Software Defined Networking - SDN, and Software Defined Radio - SDR). We target the ultimate flexibility, from the reconfiguration of the protocol suite at runtime to the deployment of any future wireless technologies on the same infrastructure. The ultimate goal is to sustain the deployed infrastructure in the very long term, fighting against premature obsolescence without endangering innovation. We will transform each element of the communication stack into a computer program, i.e. a set of instructions in a specific language, that will be transmitted and executed by the end devices. Such an approach raises major scientific challenges such as securing the control plane, optimizing the system efficiency (in terms of energy consumption for example), or guaranteeing system convergence. PERENNE consortium is composed of IRISA (Granit and OCIF teams), ICube (Network research group) and ANFR.

- **ANR JCJC RedInBLack (2023-2026)**
  Participants: Robin Gerzaguet, Olivier Berder, Matthieu Gautier, Paul Bazerque
  TEMPEST attacks target device that unintentionally emits sensible data through an electromagnetic channel. This kind of compromising are due to coupling, hardware impairments or physical proximity between components. Sensitive information emitted by these devices may be recovered passively by any radio component and more particularly by software defined radio, now capable to sample very large bandwidths. The objectives of RedInBlack are many-folds i) Assess new radio fingerprint based methods to identify devices through learning methods fed by large bandwidths features ii) propose coherent and non-coherent decoding methods to recover the sensitive data emitted by the device iii)develop effective methods able to cope with large bandwidths to identify TEMPEST channel and recover sensitive data in real time with the use of a new hardware/software methodology based on Julia langage.

- **ANR Labex CominLabs - NOP and NOPAL (2021-2025)**
  Participants: Matthieu Gautier, Olivier Berder, Robin Gerzaguet, Mickaël Le Gentil
  Intermittent computing is an emerging paradigm for batteryless IoT nodes powered by

harvesting ambient energy. It intends to provide transparent support for power losses so that complex computations can be distributed over several power cycles. NOP aims at improving the efficiency and usability of intermittent computing, based on consolidated theoretical foundations and a detailed understanding of energy flows within systems. For this, it brings together specialists in system architecture, energy-harvesting IoT systems, compilation, and real-time computing. NOP consortium is composed of IRISA (Granit team), IETR (SysCom) team, INRIA (PACAP team) and LS2N (SRC team). Within this project, our GRANIT team will develop both hardware and software parts of the platform.

- **RAPID DGA RECSANet (2024-2026)**
  Participants: Olivier Berder, Matthieu Gautier, Robin Gerzaguet, Mickaël Le Gentil
  The RECSANet project addresses resilience issues in long-range, low-power wireless communication networks. Many applications in constrained and disturbed environments require high resilience to interference, obstacles and mobility. In response to this use case, we need to design a multi-radio opportunistic communications node with power management mechanisms. Various algorithms need to be developed to select the frequency bands to be used while minimizing the node's power consumption. The consortium allows for complementarity between the different parts of the project: the hardware (CG-Wireless), the communication protocol (INZU - IRISA) and the radio and energy management algorithms (Granit - IRISA).

7.2 International Collaborations

- **France-Swiss ANR/SNF Call : MIOT Massive IoT Project (2025-2029)**
  Participants: Matthieu Gautier, Olivier Berder, Robin Gerzaguet, Baptiste Vrigneau, Bertrand Le Gal (Taran)
  The Internet-of-Things (IoT) has become integral to modern life, with wireless sensors and devices serving as essential components. These technologies utilize short-range wireless links like Bluetooth and Zigbee, or long-range Low-power Wide Area Networks (LPWANs) tailored to IoT device requirements. However, Unlicensed-LPWAN systems, like LoRa, face challenges due to the burgeoning number of IoT devices, causing network congestion and hindering scalability. These technologies are approaching their scaling limits, necessitating upgrades.
  The MIOT research proposal aims to address the fundamental challenges of unlicensed-LPWAN communication, facilitating IoT network scaling and supporting energy-efficient nodes. Key practical constraints include scaling existing standards without significant changes and exploring new technologies for long-term evolution. Three research centers in France (IRISA and Lab-STICC) and Switzerland (EPFL) collaborate on three main innovations: improving receivers, developing an advanced radio-access infrastructure, and exploring new waveforms and channel codes. The research involves theoretical analysis, simulations, and multi-site measurements to validate these innovations. Extensions are benchmarked against current systems, with the developed code made available as OpenSource for wider collaboration and experimentation.

MIOT project aims to enhance spectral efficiency through: associating q-ary modulations with q-ary non-binary codes to design an efficient waveform, using advanced multi-user detection algorithms, that goes behind the classical SIC decoder, leveraging a global Cloud-RAN architecture to perform a global MU receiver, and Optimizing waveform parameters at the Cloud-RAN level.

- **France-Japan ANR/JST Call on EDGE IA : Light-Swift Project (2023-2027)**
  Participants: Olivier Berder, Robin Gerzaguet, Pascal Scalart
  Artificial intelligence (AI) brings without any doubt huge opportunities to optimize efficiency of every industrial application and is a key point of Industry 4.0. The deployment of various sensors in factories, also called Industrial Internet of Things (IIoT) can either help workers in charge of machine maintenance by detecting abnormal behaviours, thus preventing machine breakdown, or help to localize objects or persons in such complex environments. AI algorithms probably represent the best solution to cope with the huge amount of data provided by sensors, but their complexity is also a severe drawback and the processing is mainly centralized.

  Energy is crucial for IIoT, since the more sensors are deployed, the more difficult it becomes to ensure sufficient energy, as batteries would need to be recharged more frequently. Moving the processing closest as possible to the sensors would avoid energy hungry transmissions of data. Most of the latter is indeed useless, since AI algorithms need to be fed with descriptors more than raw data. To further enhance energy efficiency of Edge AI, LIGHT-SWIFT aims at proposing a new methodology to reduce the complexity of AI algorithms, paving the way for sustainable smart sensors in Industry 4.0. This methodology will be applied to sound sensor nodes able to detect unusual situations, either in machine behaviour but also in the general context of the factory. In case of emergency, the system may have to cope with massive amounts of additional data, entailing a crucial need for extremely reliable high data rate transmissions, despite the limited spectrum resources. The methodology of LIGHT-SWIFT project will therefore be applied to the wireless transmissions themselves, to optimize the radio resource access, while achieving the best possible energy efficiency. To reach this goal, our project will leverage a well-balanced consortium composed of two academic partners, IRISA and NII, that work respectively on energy efficient wireless sensor networks and edge AI for wireless communications, the Small and Medium-sized Enterprise (SME) Wavely specialized in sound event detection for IIoT, and one of the largest telecommunications operating companies in the world, NTT, with applications in Industry 4.0.

- **France-Tunisie PHC Utique : frugal AI applied to NILM (2024-2026)**
  Participants: Pascal Scalart, Baptiste Vrigneau
  The Non Intrusive Load Monitoring challenge is to determine states of electrical devices and their electrical consumptions by using a global measurement. The problem is to separate several signals, directly linked to the state of the device, from the sum of all electrical consumptions. The unknown values are the consumption in a first step and the state device in a second step. Thanks to the platform SmartSense, part of EEWOK, we are able to collect all individual consumptions but also the aggregated power a several

levels (rooms and global) of the laboratory IRISA at Lannion and Rennes. However, the challenge is still difficult and not still tackled. Indeed, in some cases classical NILM algorithms provide good result but some other device combination activations still mislead them. Our works introduce sensors in order to help the NILM and may be called semi-intrusif load monitoring (SILM), hybrid NILM or sensor-aided NILM. New solutions based on deep learning was proposed but AI requires huge hardware resources. The aim of the collaboration is to explore solutions of pruning, quantization, binarization of RNN in order to run efficient NILM algorithms.

8 Dissemination

8.1 Scientific Responsibilities

- O. Berder, M Gautier and B. Vrigneau are members of Scientific Committee of IUT Lannion.
- R. Gerzaguet is member of the Scientific Committee of ENSSAT (since 2020).
- R. Gerzaguet is a member of the IRISA Laboratory Council (since 2021).
- R. Gerzaguet is a member of Collége numérique France 2030 (since 2023)
- O. Berder is a member of the Scientific Committee of EUR Digisport (since 2021)
- O. Berder is a member of Labelling Committee (CSV) of Images & Networks cluster (since 2018)
- O. Berder is the coordinator of Wireless Devices for Transitions topic at CNRS GDR SoC2 (since 2023).
- M. Gautier is a coordinator of Architecture and algorithms Topic at GDR IASIS (since 2023).
- M. Gautier is the head of the D3 "Computer Architecture" Department of IRISA Lab since September 2024.
- M. Gautier has been a member of the 2024 jury for the PhD price conjointly delivered by GRETSI, Club EEA and GDR IASIS.
- M. Lacroix is a coordinator of Tools and Methods for Eco-design and Sobriety topic at CNRS GDR DEFIE (since 2025)

8.2 Involvement in the Scientific Community

Scientific events:

- M. Gautier organized a one-day inter-GDR IASIS/SoC2/Secu seminar "Screaming Channels et empreintes Radio-fréquence : Exploiter et sécuriser les signaux invisibles des communications sans fils", Paris, November 20 2025

Scientific presentations:

- O. Berder gave the invited talk "Near Sensor Computing : Towards smart and energy autonomous sensors", for the colloquium *Les défis des transitions énergétique et numérique* at CentraleSupelec, Paris, October 2, 2025
- O. Berder gave the invited talk "Edge AI : Towards smart and energy autonomous sensors", for the *Blue Day on Edge Computing* of Sea Competitivity Cluster and Images and Networks Cluster, IMT Atlantique, Brest, October 9, 2025
- O. Berder gave the invited talk "Real-time architecture for intercepting compromising Bluetooth signals" for the joint research day of GDR Security and GDR SoC2 on *Security and Forensics in IoT*, Paris, October 10, 2025
- O. Berder gave the invited talk "Edge AI : l'intelligence au plus près des capteurs" for the colloquium *Assises de la Recherche sur l'IA*, Conseil Départemental des Côtes d'Armor, Saint-Brieuc, November 5, 2025
- O. Berder gave the invited talk "Edge AI : l'intelligence au plus près des capteurs" for the colloquium *Assises de la Recherche sur l'IA*, Conseil Départemental des Côtes d'Armor, Saint-Brieuc, November 5, 2025
- O. Berder gave the invited talk "Near Sensor Computing : Vers des capteurs environnementaux intelligents et autonomes en énergie" for the research day *Journée sur les capteurs en environnement et leurs impacts environnementaux*, jointly organized by GDRS EcoInfo and GDR IASIS, IRISA, Rennes, November 25, 2025
- M. Lacroix was an invited speaker at Impact'Day on November 28, 2025, in Lannion, France, in the session " Digital lifecycle: measuring and reducing environmental footprint"

PhD and HDR committees:

- O. Berder served as a reviewer for the PhD of Abir Hannachi, *Block Turbo Codes For Next Generation Optical Communications*, defended at Orange Labs, Rennes, March 11, 2025
- O. Berder served as a member of Defence Committee for the PhD of Timothée Presles, *Evaluation of the applicability of quantum computing for problems in the airborne radar domain*, defended at Université de Bretagne Occidentale, March 28, 2025
- O. Berder served as a reviewer for the PhD of Zeinab Kteish, *Next-Gen Communication System for Directional Transmitters and Receivers Based on Localization and Positioning of Users*, defended at Université de Bretagne Occidentale, May 12, 2025
- O. Berder served as a member of Defence Committee for the HDR of Robin Gerzaguet, *Adéquation algorithme-architecture pour les systèmes embarqués communicants*, defended at Université de Rennes (ENSSAT), Lannion, June 18, 2025

- O. Berder served as a reviewer for the PhD of Lyna Touileb, *Apprentissage Automatique pour les Communications Sans Fil à Ressources Limitées sur le EDGE : Détection d'anomalies Réseau*, defended at Université de Poitiers, October 15, 2025
- O. Berder served as a reviewer for the PhD of Sylvain Nérondat, *Apprentissage par renforcement profond pour l'optimisation conjointe de l'allocation de ressource et de l'ordonnancement pour les réseaux ad hoc*, defended at Telecom ParisTech, December 11, 2025
- O. Berder served as a reviewer for the PhD of Adrien Deverin, *Les Primitive Neural Networks (PrNNs) : un paradigme biomimétique pour l'IA embarqué à ultra basse consommation*, defended at Université de Toulon, December 12, 2025
- M. Gautier served as the reviewer of Defence Committee for the PhD of Julien Schrive, *Vers des processus de ranging robustes à la non-ligne de vue dans les réseaux sans fil Ultra-Wideband*, defended at Université de Toulouse, June 13, 2025
- M. Gautier served as the president of Defence Committee for the PhD of Shanglin Yang, *Spatio-temporal Synchronization and Signal Processing for Zero-Energy Digital Twins in Ambient Backscatter Communication Systems*, defended at INSA de Lyon, November 28, 2025
- M. Gautier served as a member of Defence Committee for the HDR of Robin Gerzaguet, *Adéquation algorithme-architecture pour les systèmes embarqués communicants*, defended at Université de Rennes (ENSSAT), Lannion, June 18, 2025
- R. Gerzaguet served as a member of Defence Committee for the PhD of Paul Miqueu, *High speed serial links: performance studies and digital signal processing algorithms*, defended at Université de Grenoble, November 14, 2025

Editorial and reviewing activities:

- 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
- E. Casseau was a member of the technical program committee of SWC25.
- M. Gautier was a member of technical program committee of IEEE ICM, IEEE WCNC, IEEE PIMRC and IEEE Globecom.

- B. Vrigneau served as a reviewer for IEEE Communications Letters, PIMRC, ISTC, WCMC, MDPI Sensors, IEEE Trans. on Vehicular Technology.
- Robin Gerzaguet served as a reviewer for IEEE EUCNC, IEEE WCNC, IEEE Access, IEEE Transaction on Wireless Communications and IEEE Transactions on Aerospace and Electronic Systems.

8.3 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.

- O. Berder is Deputy Director of IUT Lannion.
- O. Berder and M. Gautier are in charge of the CUPGE (Cycle Universitaire Préparatoire aux Grandes Ecoles) ENSSAT, respectively for the Physics and Cybersecurity grants at IUT Lannion.
- E. Casseau is in charge of the Digital Systems Department at ENSSAT.
- A. Courtay is supervising the first year students of the Electronics Engineering department of ENSSAT.
- R. Gerzaguet is supervising the third year students of the Electronics Engineering department of ENSSAT.
- R. Rocher is the Head of the Network and Telecommunications Department at IUT Lannion.
- M. Gautier is supervising the second year students of the Network and Telecommunications Department at IUT Lannion and is in charge of Studies Pursuit.
- B. Vrigneau is the Head of the department Multimedia and Internet at IUT Lannion.
- B. Vrigneau is jury member of DNMADe Graphism of High school Savina in Tréguier.
- B. Vrigneau is board member of AMI project NUMEAC.

8.4 Teaching

Main courses:

- O. Berder: signal processing, 60h, IUT Lannion (L2)
- O. Berder: sensors and control, 70h, IUT Lannion (L2)
- O. Berder: digital systems, 60h, IUT Lannion (L1)
- O. Berder: Energy Harvesting, 30h, IUT Lannion (L3)

- O. Berder: IoT and connected objects, 14h, ENSSAT (M2)
- E. Casseau: Digital electronics, 52h, ENSSAT (L3)
- E. Casseau: Real time design methodology, 56h, ENSSAT (M1)
- E. Casseau: Computer architecture, 16h, ENSSAT (M1)
- E. Casseau: VHDL design, 32h, ENSSAT (M1)
- E. Casseau: Life cycle analysis of electronic devices, 10h, ENSSAT (M1)
- E. Casseau: SoC and high-level synthesis, 24h, ENSSAT (M2)
- A. Courtay: digital electronics, 116h, ENSSAT (L3)
- A. Courtay: PCB conception, 14h, ENSSAT (L3)
- A. Courtay: PCB conception, 20h, ENSSAT (M1)
- A. Courtay: PCB conception, 16h, IUT Lannion (L3)
- A. Courtay: digital electronics communication interfaces, 68h, ENSSAT (M1)
- A. Courtay: digital electronics: Laser diode driver, 40h, 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: Embedded systems and connected objects, 90h, IUT Lannion (L3)
- M. Gautier: IoT and connected objects, 10h, ENSSAT (M2)
- M. Lacroix: sustainable digital, 4h, ENSSAT (L3)
- M. Lacroix: introduction to signal processing, 26h, ENSSAT (L3)
- M. Lacroix: random signals and systems, 18h, ENSSAT (M1)
- M. Lacroix: artificial intelligence, 30h, ENSSAT (M2)
- M. Lacroix: sustainable digital, 14h, UBS (M2)
- 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, 16h, ENSSAT (M2)
- R. Gerzaguet: GIT & Test Driven Development, 8h, ENSSAT (L3)
- R. Gerzaguet: System On Chips, 22h, ENSSAT (M2)
- R. Gerzaguet: Hardware security, 18h, ENSSAT (M2)
- B. Vrigneau: digital datas for multimedia, 50h, IUT Lannion (L1, L2)
- B. Vrigneau: dataviz with JS/HTML/CSS, 24h, IUT Lannion (L2)
- B. Vrigneau: wireless sensor data collect and visualization (LoRaWAN), 31.5h, IUT Lannion (L3)
- B. Vrigneau: preparation for the oral exams of the agrǵation, 6h, ENS Rennes (M2)

9 Bibliography

Doctoral dissertations and "Habilitation" theses

[1] N. Balti, *NILM assisté par capteurs à l' aide d'algorithmes d'apprentissage profond*, Theses, Université de Rennes, March 2025, https://theses.hal.science/tel-05264612.

[2] S. Bouro, *Multi-Sensor System for In-Situ Motion Analysis of Kayaker*, Theses, Université de Rennes, December 2025.

[3] D. Chevalier, *Amélioration des réseaux d'accès optique par égalisation analogique*, Theses, Université de Rennes, November 2025, https://hal.science/tel-05405697.

[4] R. Gerzaguet, *Adéquation algorithme-architecture pour les systèmes embarqués communicants*, Accreditation to supervise research, Université de Rennes, June 2025, https://theses.hal.science/tel-05216501.

[5] T. Muller, *Single-channel audio compression using deep learning*, Theses, Université de Rennes, December 2025.

Articles in referred journals and book chapters

[6] E. Bothereau, R. Gerzaguet, M. Gautier, A. Chillet, O. Berder, "Why RF Fingerprinting Needs Better Data, Not Bigger Models", *IEEE Access 13*, 2025, p. 171348–171355, https://hal.science/hal-05304180.

[7] S. Bouro, A. Courtay, G. Nicolas, N. Bideau, M. Le Gentil, O. Berder, "Sensors and Measurement Systems for Comprehensive On-water Performance Analysis of Kayakers: A Review", *IEEE Sensors Journal*, 2025, p. 1–1, https://hal.science/hal-05241448.

[8] D. Chevalier, P. Scalart, G. Simon, J. Potet, L. Bramerie, M. Joindot, M. Gay, P. Chanclou, M. Thual, "Analog feedforward equalizer optimization in the context of 50G-PON", *Journal of Optical Communications and Networking 17*, 5, April 2025, p. 401, https://univ-rennes.hal.science/hal-05042324.

[9] M.-A. Lacroix, R. Rocher, N. Bertin, P. Scalart, "Advanced hardware-dependent spectral efficiency analysis for energy-efficient wireless communications", *EURASIP Journal on Wireless Communications and Networking 2025*, November 2025, p. 99, https://hal.science/hal-05456444.

[10] C. Lavaud, R. Gerzaguet, M. Gautier, O. Berder, E. Nogues, S. Molton, "A real-time interception system for compromised frequency-hopping signal eavesdropping", *Microprocessors and Microsystems: Embedded Hardware Design 113*, February 2025, https://inria.hal.science/hal-04979209.

[11] Y. Shnaiwer, J. Weber, J. Roland, M. Kaneko, R. Gerzaguet, K. Kawamura, O. Berder, S. Berra, P. Scalart, K. Wakao, Y. Takatori, "Energy Efficiency Improvement Methods for Edge AI IIoT Networks: An Overview", *IEEE Internet of Things Magazine*, November 2025, p. 1–9, https://inria.hal.science/hal-05393718.

Publications in Conferences and Workshops

[12] E. Bothereau, A. Chillet, R. Gerzaguet, M. Gautier, O. Berder, "Élagage Non Structuré pour l'Identification des Empreintes Radio-fréquences", *in: 30ème colloque du Groupement de Recherche en Traitement du Signal et des Images (GRETSI'25)*, Strasbourg, France, August 2025, https://hal.science/hal-05269850.

[13] E. Bothereau, R. Gerzaguet, M. Gautier, A. Chillet, O. Berder, "Lightweight RF Fingerprint Identification: the Revenge of the Fully Connected Neural Networks?", *in: Second Workshop on Physical Layer Security for Wireless Communications at IEEE PIMRC*, Istanbul, Turkey, September 2025, https://hal.science/hal-05395705.

[14] E. Bothereau, R. Gerzaguet, M. Gautier, A. Chillet, O. Berder, "Réseaux de Neurones Denses pour l'Identification des Empreintes Radio Fréquences", *in: Sécurisation de la couche Physique des Télécommunications Militaires*, Rennes, France, November 2025, https://hal.science/hal-05398815.

[15] S. Bouro, A. Courtay, O. Berder, M. Le Gentil, N. Bideau, G. Nicolas, "Estimation temps réel de la cadence de pagayage par autocorrélation glissante de signaux de force", *in: Actes du GRETSI*, Strasbourg, France, August 2025, https://hal.science/hal-05393674.

[16] D. Chevalier, L. Anet Neto, G. Simon, P. Scalart, L. Ingles, J. Potet, P. Chanclou, L. Bramerie, M. Joindot, M. Gay, M. Thual, "Digital vs Analog Equalization in FEC Supported 50G-PON", *in: 2025 European Conference on Optical Communications (ECOC)*, IEEE, p. 1–4, Copenhagen, France, September 2025, https://hal.science/hal-05405699.

[17] D. Chevalier, L. A. Neto, P. Scalart, G. Simon, L. Inglés, J. Potet, G. Gaillard, P. Chanclou, L. Bramerie, M. Joindot, M. Gay, M. Thual, "Performances of Cost-Effective 50G ONU with Analog FFE and HI-FEC", *in: Optical Fiber Communication Conference*, Optica Publishing Group, p. W1F.5, San Francisco, France, 2025, https://univ-rennes.hal.science/hal-05122216.

[18] D. Chevalier, P. Scalart, G. Simon, L. Bramerie, M. Joindot, J. Potet, M. Gay, P. Chanclou, M. Thual, "Impact of Analog FeedForward Equalizer Cells Initialization and Optimization in 50G-PON", *in: Advanced Photonics Congress (IPR, Networks, NOMA, SOLITH, SPPCom) (2025)*, Optica Publishing Group, Marseille, France, July 2025, https://hal.science/hal-05266882.

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[20] A. Chillet, R. Gerzaguet, K. Desnos, P. Bazerque, E. Nogues, M. Gautier, "Diversification des Données pour l'Identification d'Empreinte RF", *in: 30ème colloque du Groupement de Recherche en Traitement du Signal et des Images (GRETSI'25)*, Strasbourg, France, August 2025, https://hal.science/hal-05269847.

[21] J. Courjault, B. Vrigneau, O. Berder, C. Guichaoua, A. L. Murphy, "Le retour groupé des bandits multi-bras pour aider les réseaux LoRaWAN", *in: Actes du GRETSI 2025*, Strasbourg, France, August 2025, https://hal.science/hal-05393561.

[22] J. Courjault, B. Vrigneau, C. Guichaoua, O. Berder, A. Murphy, "Bypassing Duty-Cycle Limitations for RL-Enhanced LoRaWAN Communications", *in: IEEE International Conference on Communications (ICC)*, IEEE, p. 3509–3514, Montreal, Canada, June 2025, https://inria.hal.science/hal-05393746.

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[24] G. Lounes, R. Gerzaguet, M. Gautier, "Flexible front-end for high level synthesis leveraging heterogeneous compilation", *in: Workshop on Rapid Simulation and Performance Evaluation for Design Optimization: Methods and Tools (RAPIDO)*, Barcelona (ES), Spain, January 2025, https://inria.hal.science/hal-04979196.

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