Activity Report 2018

Project-Team FUN

self-organizing Future Ubiquitous Network

RESEARCH CENTER
Lille - Nord Europe

THEME
Networks and Telecommunications

Table of contents

Project-Team FUN

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Keywords:

Computer Science and Digital Science:

A1.2.1. - Dynamic reconfiguration
A1.2.3. - Routing
A1.2.4. - QoS, performance evaluation
A1.2.5. - Internet of things
A1.2.6. - Sensor networks
A1.2.7. - Cyber-physical systems
A1.4. - Ubiquitous Systems
A5.10.6. - Swarm robotics

Other Research Topics and Application Domains:

B5.1. - Factory of the future
B5.6. - Robotic systems
B5.9. - Industrial maintenance
B6.4. - Internet of things
B7. - Transport and logistics
B8. - Smart Cities and Territories

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2. Overall Objectives

2.1. Overall Objectives

Context.

The Internet of Things [52] is a large concept with multiple definitions. However, the main concepts are the same in every vision and could be summed up as follows: *Imagine a world where every object has the capacity to communicate with its environment. Everything can be both analogue and digitally approached - reformulates our relationship with objects - things - as well as the objects themselves. Any object relates not only to you, but also to other objects, relations or values in a database. In this world, you are no longer alone, anywhere.* (Internet of Things council).

Future Ubiquitous Networks (FUN) are part of the Internet of Things. They are composed of tens to thousands heterogeneous hardware-constrained devices that interact with our environment and the physical world. These devices have limited resources in terms of storage and computing capacities and energy. They communicate through unreliable and unpredictable short-range wireless links and run on batteries that are not envisaged to be changed in current systems since generally deployed in hostile environments. Providing FUNs with energy saving protocols is thus a key issue. Due to these specific features, any centralized control is not conceivable, the new generation of FUNs must be autonomous, be self-organized and dynamically adapt to their environment. The devices that compose CPNs can be sensors, small robots, RFID readers or tags.

Objects or things can now communicate with their environment through the use for instance of an RFID (Radio Frequency IDentification) tag that provides them a unique identifier (ID) and a way to communicate through radio waves.

In the case of a simple passive **RFID tag**, the thing only embeds a tag equipped with an antenna and some memory. To communicate, it needs to be powered by the electromagnetic field of an RFID reader. This reader may then broadcast the information read on tag over a network.

When this tag is equipped with a battery, it is now able to communicate with nearby things similar to itself that may relay its message. Tags can also be equipped with additional capacity and sensors (for light, temperature, etc.). The Internet of Things can thus now refer to a **wireless sensor** network in which each sensor sends the data it collects over its environment and then sends it to a sink, *i.e.* a special sensor node able to analyze those data. In every case, RFID tags or sensor nodes can **be moved unexpectedly** like hold by moving things or animals. We speak then about **'*undergone* mobility'**.

So far, things can thus communicate information about their environment. But when the capacity of sensors is extended even further, they can also act on their environment (for instance, the detection of an event (fire) may trigger an action like switching the light or fire hoses on). Sensor nodes become **actuators**. When this extended capacity is the faculty to move, actuators are also referred as actors or robots. In this latter case, the mobility is computed on purpose, we then speak about **'*controlled* mobility'**. Actuators are not moved but move by themselves.

The FUN research group aims to focus on self-organizing techniques for these heterogeneous Future Ubiquitous Networks (FUNs). FUNs need various self-organization techniques to work properly. Self-organization encompasses neighbor discovery (which what other devices a sensor/actuator can communicate directly?), communication, self-deployment, self-localization, activity scheduling (when to wake up, when to send data to save energy without being detrimental to the well behavior of the network, etc.)...

Solutions provided by FUN should facilitate the use of FUNs and rub away heterogeneity and difficulties. These techniques should be **scalable**, **energy-aware**, **standard-compliant**, should manage undergone **mobility** and take advantage of controlled mobility when available [61].

Solutions provided by FUN will consider vagaries of the realistic wireless environment by integrating cross-layer techniques in their design.

Motivation.

To date, many self-organizing techniques for wireless sensor networks and mobile ad hoc networks arise in the literature and also from the FUN research group. Some of them are very efficient for routing [54], [51], discovering neighborhood [59], [58], scheduling activity and coverage [56], localizing [62], [50], etc. Nevertheless, to the best of our knowledge, most of them **have not been validated by experimentation**, only by simulation and thus cannot consider the real impact of the wireless links and real **node mobility** in different environments. In addition, some of them rely on assumptions that are known not to be true in realistic networks such as the fact that the transmission range of a node is a perfect disk. Other may perform well only when nodes are static. None of them considers to **take advantage of controlled mobility** to enhance performances. Similarly, many propositions arise regarding self-organization in RFID networks, mainly at the middleware level [67], [55] and at the MAC layer level [60]. Although these latter propositions are generally experimented, they are validated only in static environments with very few tags and readers. To fit realistic features, such algorithms should also be evaluated with regards to scalability and mobility.

RFID and sensor/actor technologies **have not been merged**. Though, RFID readers may now be mobile and communicate in a wireless peer-to-peer manner either with other RFID readers or wireless sensor nodes and all belong to the same network. This implies a study of the standards to allow inter-dependencies in a transparent manner. Although such works have been initiated inside EPC Global working groups, research actions remain scarce.

FUN research group aims at **filling this scientific gap** by proposing self-stabilizing solutions, considering vagaries of wireless links, node mobility and heterogeneity of nodes in compliance with current standards. Validation by experimentation is mandatory to prove the effectiveness of proposed techniques in realistic environments.

FUN will investigate new protocols and communication paradigms that allow the **transparent merging** of technologies. Objects and events might interconnect while **respecting on-going standards** and building an autonomic and smart network while being compliant with hardware resources and environment. FUN expects to rub away the difficulty of use and programmability of such networks by unifying the different technologies. In addition, FUN does not only expect to validate the proposed solutions through experimentation but also to learn from these experiments and from the observation of the impact of the wireless environment to take these features into consideration in the design of future solutions.

3. Research Program

3.1. Introduction

We will focus on wireless ubiquitous networks that rely on constrained devices, i.e. with limited resources in terms of storage and computing capacities. They can be sensors, small robots, RFID readers or tags. A wireless sensor retrieves a physical measure such as light. A wireless robot is a wireless sensor that in addition has the ability to move by itself in a controlled way. A drone is a robot with the ability to manoeuvre in 3D (in the air or in the water). RFID tags are passive items that embed a unique identifier for a place or an object allowing accurate traceability. They can communicate only in the vicinity of an RFID reader. An RFID reader can be seen as a special kind of sensor in the network which data is the one read on tags. These devices may run on batteries that are not envisaged to be changed or recharged. These networks may be composed of ten to thousands of such heterogeneous devices for which energy is a key issue.

Today, most of these networks are homogeneous, i.e. composed of only one kind of devices. They have mainly been studied in application and technology silos. Because of this, they are approaching fundamental limitations especially in terms of topology deployment, management and communications, while exploiting the complementarity of heterogeneous devices and communication technologies would enlarge their capacities and the set of applications. Finally, these networks must work efficiently even in dynamic and realistic situations, i.e. they must consider by design the different dynamic parameters and automatically self-adapt to their variations.

Our overall goal is represented by Figure 1. We will investigate wireless ubiquitous IoT services for constrained devices by smartly combining **different frequency bands** and **different medium access and routing techniques**over **heterogeneous devices** in a **distributed** and **opportunistic** fashion. Our approach will always deal with **hardware constraints** and take care of **security** and **energy** issues to provide protocols that ride on **synergy** and **self-organization** between devices.

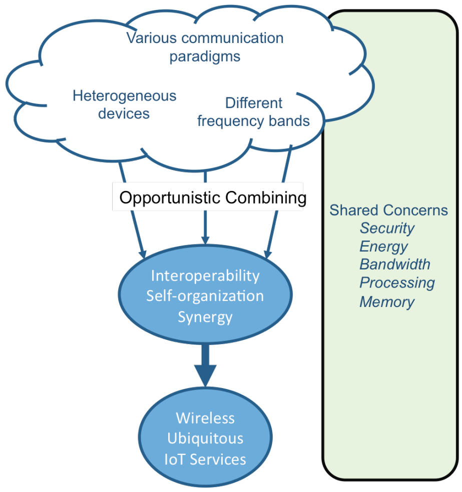

Figure 1. FUN's overal goal.

The goal of the FUN project team is to provide these next generation networks with a set of innovative and distributed self-organizing cooperative protocols to raise them to a new level of scalability, autonomy, adaptability, manageability and performance. We aim to break these silos to exploit the full synergy between devices, making them cooperate in a single holistic network. We will consider them as networks of heterogeneous devices rather than a collection of heterogeneous networks.

To realize the full potential of these ubiquitous networks, there is a need to provide them with a set of tools that allow them to *(i)* (self-)deploy, *(ii)* self-organize, *(iii)* discover and locate each other, resources and services and *(iv)* communicate. These tools will be the basics for enabling cooperation, co-existence and witnessing a global efficient behavior. The deployment of these mechanisms is challenging since it should be achieved in spite of several limitations. The main difficulties are to provide such protocols in a **secured** and **energy-efficient** fashion in spite of:

- dynamic topology changes due to various factors such as the unreliability of the wireless medium, the wireless interferences between devices, node mobility and energy saving mechanisms;
- hardware constraints in terms of CPU and memory capacities that limit the operations and data each node can perform/collect;
- lacks of interoperability between applicative, hardware and technological silos that may prevent from data exchange between different devices.

3.1.1. Objectives and methodology

To reach our overall goal, we will pursue the two following objectives, similar to the ones we set for the previous evaluation period. These two objectives are orthogonal and can be carried on jointly:

1. Providing realistic complete self-organizing tools *e.g. vertical perspective*.
2. Going to heterogeneous energy-efficient performing wireless networks *e.g. horizontal perspective*.

We give more details on these two objectives below. To achieve our main objectives, we will mainly apply the methodology depicted in Figure 2 combining both theoretical analysis and experimental validation. Mathematical tools will allow us to properly dimension a problem, formally define its limitations and needs to provide suitable protocols in response. Then, they will allow us to qualify the outcome solutions before we validate and stress them in real scenarios with regards to applications requirements. For this, we will realize proofs-of-concept with real scenarios and real devices. Differences between results and expectations will be analyzed in return in order to well understand them and integrate them by design for a better protocol self-adaptation capability.

3.2. Vertical Perspective

As mentioned, future ubiquitous networks evolve in dynamic and unpredictable environments. Also, they can be used in a large scope of applications that have several expectations in terms of performance and different contextual limitations. In this heterogeneous context, IoT devices must support multiple applications and relay traffic with non-deterministic pattern.

To make our solutions practical and efficient in real conditions, we will adopt the dual approach both *top-down* and *bottom-up*. The *top-down* approach will ensure that we consider the application (such as throughput, delay, energy consumption, etc.) and environmental limitations (such as deployment constraints, etc.). The *bottom-up* approach will ensure that we take account of the physical and hardware characteristics such as memory, CPU, energy capacities but also physical interferences and obstacles. With this integrated perpective, we will be in capacity to design **cross-layer** integrated protocols well adapted [68]. We will design jointly routing and MAC layers by taking dynamics occurring at the physical layer into account with a constant concern for energy and security. We will investigate new adaptive frequency hopping techniques combined with routing protocols [68], [25].

This vision will also allow us to integrate external factors by design in our protocols, in an opportunistic way. Yet, we will leverage on the occurrence of any of these phenomena rather than perceiving them as obstacles or limitations. As an example, we will rely on node undergone mobility to enhance routing performance as we have started to investigate in [63], [49]. On the same idea, when specific features are available like controlled mobility, we will exploit it to improve connectivity or coverage quality like in [57], [66].

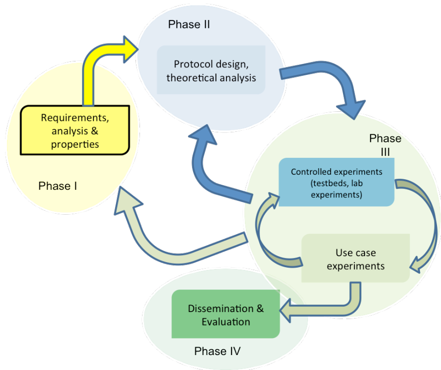

Figure 2. Methodology to be applied in FUN.

3.3. Horizontal perspective

We aim at designing efficient tools for a plethora of wireless devices supporting highly heterogeneous technologies. We will thus investigate these networks from a horizontal perspective, e.g. by considering heterogeneity in low level communications layers.

Given the spectrum scarcity, they will probably need to coexist in the same frequency bands and sometimes for different purposes (RFID tag reading may use the same frequency bands as the wireless sensors). One important aspect to consider in this setting is how these different access technologies will interact with each other and what are the mechanisms needed to be put in place to guarantee that all services obtain the required share of resources when needed. This problem appears in different application domains, ranging from traffic offloading to unlicensed bands by cellular networks and the need to coexist with WiFi and radars, from a scenario in which multiple-purpose IoT clouds coexist in a city [64]. We will thus explore the dynamics of these interactions and devise ways to ensure smooth coexistence while considering the heterogeneity of the devices involved, the access mechanisms used as well as the requirements of the services provided.

To face the spectrum scarcity, we will also investigate new alternative communication paradigms such as phonon-based or light-based communications as we have initiated in [39] and we will work on the coexistence of these technologies with traditional communication techniques, specifically by investigating efficient switching techniques from one communication technology to the other (they were most focused on the security aspects, to prevent jamming attacks). Resilience and reliability of the whole system will be the key factors to be taken into account [14], [23].

As a more prospective activity, we consider exploring software and communication security for IoT. This is challenging given that existing solutions do not address systems that are both constrained and networked [53]. Finally, in order to contribute to a better interoperability between all these technologies, we will continue to contribute to standardization bodies such as IETF and EPC Global.

4. Application Domains

4.1. Application Domains

The set of applications enabled through FUN and IoT is very large and can apply in every application area. We can thus not be exhaustive but among the most spread applications, we can name every area, event, environmental or animal monitoring, understanding and protection. To illustrate this, we may refer to the use cases addressed by our AgriNet project which goals is to monitor vineyards and potatoes fields with smart communicating devices to fight against water waste.

Other field of application is exploration of hostile and/or unknown environment by a fleet of self-organizing robots that cooperate with RFID and sensors to ensure a continue monitoring afterwards.

Also, IoT and FUN can play a key role in logistics and traceability by relying on the use of sensors or RFID technologies as implemented in our STORECONNECT project or our collaboration with the start up TRAXENS.

Finally, IoT and FUN leverage a lot of applications in Smart City concept , ranging from parking aid to a better energy consumption going through air quality monitoring, traffic fluidizing etc. (See our CityLab Inria).

5. Highlights of the Year

5.1. Highlights of the Year

- Valeria Loscrí has been elevated to the IEEE Senior Membership degree.

- Valeria Loscrí and Nathalie Mitton highlighted as Women in Computer Science 2018 by Elsevier https://www.elsevier.com/physical-sciences-and-engineering/computer-science/journals/women-in-computer-science.

5.1.1. Awards

Paper [65] has been awarded Top Paper from 2017 in Transactions on Emerging Telecommunications Technologies, as selected by the Editorial Board. See https://onlinelibrary.wiley.com/page/journal/21613915/homepage/ett_best_paper_awards.htm.

VITALOS, issued from the FP7 VITAL project from which the FUN team is one of the main contributors, has been awarded as one of the 50 most transformative smart projects: https://spring.smartcitiesconnect.org/Smart50Awards/.

6. New Software and Platforms

6.1. AspireRFID ALE

FUNCTIONAL DESCRIPTION: AspireRFID middleware is a modular OW2 open source RFID middleware. It is compliant with EPC Global standards. This new module integrates the modifications of the new standard release, including new RP and LLRP definitions and fixing bugs. This module has been implemented in the framework of the MIAOU project.

- Participants: Ibrahim Amadou, Julien Vandaële, Nathalie Mitton and Rim Driss
- Contact: Nathalie Mitton

6.2. ETINODE-CONTIKI-PORT

FUNCTIONAL DESCRIPTION: Contiki is an open source embedded OS for Internet of Things (IoT). It is light and portable to different hardware architectures. It embeds communication stacks for IoT Il embarque aussi des piles de communication pour l'internet des objets. This driver allows the running of Contiki OS over Etinode-MSP430. The code dalso allows the use of radio chip and embedded sensors. This module has been implemented in the framework of the ETIPOPS project.

- Participants: Nathalie Mitton, Roudy Dagher and Salvatore Guzzo Bonifacio
- Contact: Salvatore Guzzo Bonifacio

6.3. ETINODE-DRIVERS

FUNCTIONAL DESCRIPTION: These drivers for Etinode-MSP430 control the different embedded sensors and hardware components available on an Etinode-MSP430 node such as gyroscope, accelerometer and barometric sensor. This module has been implemented in the framework of the ETIPOPS project.

- Participants: Nathalie Mitton, Roudy Dagher and Salvatore Guzzo Bonifacio
- Contact: Salvatore Guzzo Bonifacio

6.4. EVe-TCF

Embedded Verifier for Transitive Control Flow
KEYWORDS: Control Flow - JavaCard - Embedded systems - Embedded - Security - Code analysis

FUNCTIONAL DESCRIPTION: Verification of transitive control flow policies on JavaCard 2.x bytecode. Control flow policies expressed using a DSL language are embedded in JavaCard packages (CAP files) using EVe-TCF convert tool. Control flow policies are then statically verified on-device at loading-time thanks to an embedded verifier (designed for smart cards in EVe-TCF). EVe-TCF (Embedded Verifier for Transitive Control Flow) also contains an off-device (i.e. PC tool) to simulate on-device loading process of JavaCard 2.x platforms with GlobalPlatform 2.x installed.

- Participants: Arnaud Fontaine and Isablle Simplot Ryl
- Contact: Nathalie Mitton

6.5. GOLIATH

Generic Optimized LIghtweight communication stack for Ambient TecHnologies
KEYWORDS: WSN - WSN430
FUNCTIONAL DESCRIPTION: GOLIATH (Generic Optimized LIghtweight communication stack for Ambient TecHnologies) is a full protocol stack for wireless sensor networks. This module has been implemented in the framework of the ETIPOPS project.

- Participants: David Simplot Ryl, Fadila Khadar, Nathalie Mitton and Salvatore Guzzo Bonifacio
- Contact: Nathalie Mitton
- URL: https://gforge.inria.fr/projects/goliath/

6.6. IoT-LAB robots

KEYWORDS: Internet of things - Robotics
FUNCTIONAL DESCRIPTION: IoT-LAB robots is an embedded robot controler on a Turtlebot2 providing the IoT-LAB node mobility functionnality

- Partner: Université de Strasbourg
- Contact: Julien Vandaële
- URL: https://github.com/iot-lab/

6.7. T-SCAN

KEYWORDS: Rfid - RFID Middleware
FUNCTIONAL DESCRIPTION: T-Scan is an interface ensuring the translation from a SGTIN tag format to an ONS hostname format according to the EPCGlobal standards. It allows the sending of a DNS request to look up the EPC-IS aides to which the product belongs in order to access the data relative to that product. This module has been implemented in the framework of the TRACAVERRE project.

- Participants: Gabriele Sabatino and Nathalie Mitton
- Contact: Gabriele Sabatino

6.8. FIT IoT-Lab

Participants: Nathalie Mitton [correspondant], Julien Vandaele, Matthieu Berthome.

FIT IoT-LAB is a very large scale open testbed that features over 2700 wireless sensor nodes and more than 200 robots spread across six different sites in France. Nodes are either fixed or mobile and can be allocated in various topologies throughout all sites. A variety of wireless sensors are available, with different processor architectures (MSP430, STM32 and Cortex-A8) and different wireless chips (802.15.4 PHY at 800 MHz or 2.4 GHz). In addition, "open nodes" can receive custom wireless sensors for inclusion in IoT-LAB testbed. This platform is completely open and can be used by any one wishing to run experiment on wireless sensors and robots.

The Lille site displays 3 subsets of the platforms:

- Euratechnologies: this site features 256 WSN430 sensor nodes operating in the 2.4GHz band. 64 nodes are mobile, embedded on mobile trains.
- Haute Borne: this site features 256 M3 sensor nodes operating in the 2.4GHz band and 64 mobile robots (32 turtlebots and 32 wifibots) completely remotely programmable.
- Opennodes: this site will feature (opening beginning 2015) 64 hardware open slots to allow any one to plug his own hardware and benefits from the platform debugging and monitoring tools.

7. New Results

7.1. Performance Evaluation, Security, Safety and Verification

Participants: Antoine Gallais, Nathalie Mitton, Allan Blanchard.

7.1.1. Performance Evaluation and validation methodology

Envisioned communication densities in Internet of Things applications are increasing continuously. Because these wireless devices are often battery powered, we need specific energy efficient (low-power) solutions. Moreover, these smart objects use low-cost hardware with possibly weak links, leading to a lossy network. Once deployed, these low-power lossy networks (LLNs) are intended to collect the expected measurements, handle transient faults, topology changes, etc. Consequently, validation and verification during the protocol development are a matter of prime importance. A large range of theoretical or practical tools are available for performance evaluation. A theoretical analysis may demonstrate that the performance guarantees are respected, while simulations or experiments aim on estimating the behavior of a set of protocols within real-world scenarios. In [16], we review the various parameters that should be taken into account during such a performance evaluation. Our primary purpose is to provide a tutorial that specifies guidelines for conducting performance evaluation campaigns of network protocols in LLNs. We detail the general approach adopted in order to evaluate the performance of layer 2 and 3 protocols in LLNs. Furthermore, we also specify the methodology that should be adopted during the performance evaluation, while reviewing the numerous models and tools that are available to the research community.

7.1.2. Correlated failures

Current practices of fault-tolerant network design ignore the fact that most network infrastructure faults are localized or spatially correlated (i.e., confined to geo-graphic regions). Network operators require new tools to mitigate the impact of such region-based faults on their infrastructures. Utilizing the support from the U.S. Department of Defense, and by consolidating a wide range of theories and solutions developed in the last few years, [14] designs RAPTOR, an advanced Network Planning and Management Tool that facilitates the design and provisioning of robust and resilient networks.The tool provides multi-faceted network design, evaluation, and simulation capabilities for network planners. Future extensions of the tool currently being worked upon not only expand the tool's capabilities, but also extend these capabilities to heterogeneous interdependent networks such as communication, power, water, and satellite networks.

7.1.3. Contiki verification

Internet of Things (IoT) applications are becoming increasingly critical and require formal verification. Our recent work presented formal verification of the linked list module of Contiki, an OS for IoT. It relies on a parallel view of a linked list via a companion ghost array and uses an inductive predicate to link both views. In this work, a few interactively proved lemmas allow for the automatic verification of the list functions specifications, expressed in the acsl specification language and proved with the Frama-C/Wp tool. In a broader verification context, especially as long as the whole system is not yet formally verified, it would be very useful to use runtime verification , in particular, to test client modules that use the list module. It is not possible with the current specifications, which include an inductive predicate and axiomatically defined functions. In

[27], an early-idea paper we show how to define a provably equivalent non-inductive predicate and a provably equivalent non-axiomatic function that belong to the executable subset e-acsl of acsl and can be transformed into executable C code. Finally, we propose an extension of Frama-C to handle both axiomatic specifications for deductive verification and executable specifications for runtime verification.

In [23], [47], we target Contiki, a widely used open-source OS for IoT, and present a verification case study of one of its most critical modules: that of linked lists. Its API and list representation differ from the classical linked list implementations, and are particularly challenging for deductive verification. The proposed verification technique relies on a parallel view of a list through a companion ghost array. This approach makes it possible to perform most proofs automatically using the Frama-C/WP tool, only a small number of auxiliary lemmas being proved interactively in the Coq proof assistant. We present an elegant segment-based reasoning over the companion array developed for the proof. Finally, we validate the proposed specification by proving a few functions manipulating lists.

With the wide expansion of multiprocessor architectures, the analysis and reasoning for programs under weak memory models has become an important concern. [13] presents MMFilter, an original constraint solver for generating program behaviors respecting a particular memory model. It is implemented in Prolog using CHR (Constraint Handling Rules). The CHR formalism provides a convenient generic solution for specifying memory models. It benefits from the existing optimized implementations of CHR and can be easily extended to new models. We present MMFilter design, illustrate the encoding of memory model constraints in CHR and discuss the benefits and limitations of the proposed technique.

7.2. Alternative communication paradigms

Participants: Antonio Costanzo, Valeria Loscri.

Nowadays, the always growing of connected objects and the strong demand to downsizing the devices in order to make the Internet of Things (IoT) paradigm more pervasive and ubiquitous, has motivated academic and industry people to investigate from one side mechanisms able to adapt quickly to the rapid external changes and to the quality of Services (QoS) parameters defined by the users and imposed by the adoption of new services and from another side, the investigation of portion of spectrum that have not been considered till this moment such as Terahertz band.

Nowadays, the always growing of connected objects and the strong demand to downsizing the devices in order to make the Internet of Things (IoT) paradigm more pervasive and ubiquitous, has motivated academic and industry people to investigate from one side mechanisms able to adapt quickly to the rapid external changes and to the quality of Services (QoS) parameters defined by the users and imposed by the adoption of new services and from another side, the investigation of portion of spectrum that have not been considered till this moment such as Terahertz band. In order to be able to realize a paradigm shift towards the Internet of Everything concept, a downsizing of devices is imposed allowing new applications as *in-vivo* diagnosis and monitoring. In order to be effective at this level it is imperative to analyze the new context, by highlighting the unique features to concretely realize the IoE paradigm. In this context, we have studied quantum particles called phonons, quasi-particles derived from vibrations of atoms in solids. Phonons have been envisaged as enabler of information transfer and their special characteristics have been exploited in [17]. Phonons have been also considered for a quantum channel in [26]. Another interesting approach for enabling the nano communication paradigm is represented by molecular communication. In particular, a main issue that is important to face is the coexistence between an artificial molecular communication and a biological system as explained in [40]. Alternative communication paradigms have attracted a lot of attention in the last a few years, not only by academic researchers but also by industry. Research on optical communication and in particular the possible exploitation of Visible Light communication with a twofold objective, to illuminate and to communicate has been object of an increasing interest. In this directions, we have proposed context-aware VLC systems in[39], [38] and [24]. The context is different in respect to the “traditional” wireless communication, since the external environment can change fastly and abruptly. Based on this primary observation, our main objective is to make theVLC system aware of the external noise and try to make it as robust as possible in respect of it.

7.3. Self-Organization

Participants: Antoine Gallais, Nathalie Mitton, Valeria Loscri, Farouk Mezghani, Anjalalaina Jean Cristanel Razafimandimby.

7.3.1. Stable parent selection

The Industrial Internet of Things consists in the use of low power lossy networks to enable next industrial applications. To work properly, the network has to provide strict guarantees concerning the delay and the reliability. IEEE 802.15.4-TSCH proposes time synchronized and slow channel hopping medium access control to cope with these requirements. It relies on a strict schedule of the transmissions, spread over orthogonal radio channels, to set up a resilient wireless infrastructure. A routing protocol (e.g. RPL) has then to construct energy-efficient routes on top of this link-layer topology (as investigated in the 6TiSCH IETF working group). Most of existing solutions rely on tree-based topologies, where each node has to select one or multiple parents to forward its traffic to the destination. Unfortunately, the links to the routing parents exhibit time-varying characteristics, due to e.g. obstacles, and external interference, thus leading to oscillations and increased required control of the routing topology. Moreover, the network has to provision enough resources (i.e., time, channel) to cope with those variations, while still being reactive to node/link failures. We investigated the stability of 6TiSCH networks, and especially the impact on routing parent selection. We identified moments of instability due to oscillations in the radio conditions caused by external interference and obstacles, in two indoor testbeds with different channel conditions. We identified the causes of instabilities, and proposed solutions for each of the layers in the 6TiSCH stack. First, at the MAC layer, we demonstrated that a rearrangement of shared cells in the slotframe reduces the probability of collisions for control packets, paving the way to a faster negotiation during topology reconfigurations. Next, we eased the schedule consistency management between two nodes (renegociated from scratch in the current standard, upon detection of a schedule inconsistency). Finally, at the routing layer, we exploited the existing correlation between the broadcast packet reception rate and the unicast link quality to create a two-step parent selection that favors stable parents. We finally obtained a network that converged faster and that reacted accurately during moments of instabilities. Results are available in [46], [42].

7.3.2. Bayesian communications

The amount of data that are generated in IoT devices is huge and the most of time data are highly correlated, by making useless the forwarding of all the raw data generated. Bearing that in mind, we have designated and implemented an effective mechanism to reduce the amount of data sent in the network in [45]. Results are encouraging since there is a size effect of less interfering in the communication system with an important impact on battery consumption for wireless devices that are energy constrained.

7.3.3. Multi-technology self-organization

Opportunistic communications present a promising solution for disaster network recovery in emergency situations such as hurricanes, earthquakes, and floods, where infrastructure might be destroyed. Some recent works in the literature have proposed opportunistic-based disaster recovery solutions, but they have omitted the consideration of mobile devices that come with different network technologies and various initial energy levels. [19], [30] present COPE, an energy-aware Cooperative OPportunistic alErt diffusion scheme for trapped survivors to use during disaster scenarios to report their position and ease their rescue operation. It aims to maintain mobile devices functional for as long as possible for maximum network coverage until reaching proximate rescuers. COPE deals with mobile devices that come with an assortment of networks and aims to perform systematic network interface selection. Furthermore, it considers mobile devices with various energy levels and allows low-energy nodes to hold their charge for longer time with the support of high-energy nodes. A proof-of-concept implementation has been performed to study the doability and efficiency of COPE, and to highlight the lessons learned. Following-up with these results, we performed several experimentations and could benchmark smartphone performances with regards to their multi-communications interfaces. Testing experiments have been carried out to measure the performance of smartphones in terms of energy consumption, clock synchronization and transmission range. We believe that such experimental results can support technological choices for rescue operations but also for many other applications relying on smartphone performances. Results are available in [30].

7.3.4. Heterogeneous Self-organizing (smart) Things

In the panorama of the Internet of Things, one main important issue is the management of heterogeneous objects, that need to communicate in order to exchange information and to interact in order to be able to synergically accomplish complex tasks and for providing services to final users. In this context, the thesis [10] has tried to face the main challenges related to complex heterogeneous systems, where objects are able to self-organize to each other and are equipped with some kind of intelligence in order to dynamically react to the environment changes. Several tools have been exploited ranging from artificial neural networks to genetic algorithms and different solutions have been proposed to make these systems dynamic and responding to the ∗self properties.

7.4. Smart Grids

Participants: Nathalie Mitton, Jad Nassar.

The Smart Grid (SG) aims to transform the current electric grid into a “smarter” network where the integration of renewable energy resources, energy efficiency and fault tolerance are the main benefits. This is done by interconnecting every energy source, storage point or central control point with connected devices, where heterogeneous SG applications and signaling messages will have different requirements in terms of reliability, latency and priority. Hence, data routing and prioritization are the main challenges in such networks.

So far, RPL (Routing Protocol for Low-Power and Lossy networks) protocol is widely used on Smart Grids for distributing commands over the grid. RPL assures traffic differentiation at the network layer in wireless sensor networks through the logical subdivision of the network in multiple instances, each one relying on a specific Objective Function. However, RPL is not optimized for Smart Grids, as its main objective functions and their associated metric does not allow Quality of Service differentiation.

In order to overcome this, we propose $OFQS$ an objective function [20] with a multi-objective metric that considers the delay and the remaining energy in the battery nodes alongside with the dynamic quality of the communication links. Our function automatically adapts to the number of instances (traffic classes) providing a Quality of Service differentiation based on the different Smart Grid applications requirements. We tested our approach on a real sensor testbed. The experimental results show that our proposal provides a lower packet delivery latency and a higher packet delivery ratio while extending the lifetime of the network compared to solutions in the literature.

The management of communication is an issue in WSN-based Smart Grid: billions of messages with different sizes and priorities are sent across the network. Data aggregation is a potential solution to reduce loads on the communication links, thus achieving a better utilization of the wireless channel and reducing energy consumption. On the other hand, SG applications require different Quality of Service (QoS) priorities. Delays caused by data aggregation must then be controlled in order to achieve a proper communication. In [33], [34], we propose a work in progress, that consists of a QoS efficient data aggregation algorithm with two aggregation functions for the different traffics in a SG network. We expect to reduce the energy consumption while respecting the data delivery delays for the different SG applications.

In order to reduce the amount of data sent over the network, and thus reduce energy consumption, data prediction is another potent solution of data reduction. It consists on predicting the values sensed by sensor nodes within certain error threshold, and resides both at the sensors and at the sink. The raw data is sent only if the desired accuracy is not satisfied, thereby reducing data transmission. We focus on time series estimation with Least Mean Square (LMS) for data prediction in WSN, in a Smart Grid context, where several applications with different data types and Quality of Service (QoS) requirements will exist on the same network. LMS proved its simplicity and robustness for a wide variety of applications, but the parameters selection (step size and filter length) can directly affect its global performance, choosing the right ones is then crucial. Having no clear and robust method on how to optimize these parameters for a variety of applications, we propose in [44] a modification of the original LMS that consists of training the filter for a certain time with the data itself in order to customize the aforementioned parameters. We consider different types of real data traces for the photo voltaic cells monitoring. Our simulation results provide a better data prediction while minimizing the mean square error compared to an existing solution in literature.

All these solutions have also been detailed in [12].

7.5. Connected Cars

Participants: Nathalie Mitton, Valeria Loscri, Joao Batista Pinto Neto.

7.5.1. Geolocalisation

Connected car technology promises to drastically reduce the number of accidents involving vehicles. Nevertheless, this technology requires the vehicle precise location to work. The adoption of Global Positioning System (GPS) as a navigation device imposes limitations to geolocation information under non-line-of-sight conditions. [22] introduces the Time Series Dead Reckoning System (TedriS) as a solution for dead reckoning navigation when the GPS fails. TedriS uses Time Series Regression Models (TSRM) and the data from the rear wheel speed sensor of the vehicle to estimate the absolute position. The process to estimate the position is carried out in two phases: training and predicting. In the training phase, a novel technique applies TSRM and stores the relationship between the GPS and the rear wheel speed data; then in the predicting phase, this relationship is used. We analyze TedriS using traces collected at the campus of Federal University of Rio de Janeiro (UFRJ), Brazil, and with indoor experiments with a robot. Results show an accuracy compatible with dead-reckoning navigation state-of-art systems.

7.5.2. Data forwarding

Intelligent inter-vehicle communication is a key research field in the context of vehicular networks that applies in real-life applications (e.g., management of accidents, intelligent fuel consumption, smart traffic jams, etc.). Considering different roles of nodes based on their “social aptitude” to relay information could provide a social component in the vehicular structure that can be useful in getting a clear prediction of the topological evolution in time and space proving to be very effective in managing intelligent data forwarding. In [36], we characterize a vehicular network as a graph using the link layer connectivity level and we classify nodes on the basis of specific attributes characterizing their “social aptitude” to forward data. Two forwarding approaches are presented, based on different socialites that allow to (i) select the most social node (i.e., a social hub) or (ii) choose among various social nodes.

7.5.3. Internet of vehicles

Internet, in its most recent evolution, is going to be the playground where a multitude of heterogeneous interconnected “things” autonomously exchange information to accomplish some tasks or to provide a service. Recently, the idea of giving to those smart devices the capability to organize themselves according to a social structure, gave birth to the so-called paradigm of the Social Internet of Things. The expected benefits of SIoT range from the enhanced effectiveness, scalability and speed of the navigability of the network of interconnected objects, to the provision of a level of trustworthiness that can be established by averaging the social relationships among things that are “friends”. Bearing in mind the beneficial effects of social components in IoT, we consider a social structure in a vehicular context i.e., Social Internet of Vehicles (SIoV). In SIoV, smart vehicles build social relationships with other social objects they might come into contact, with the intent of creating an overlay social network to be exploited for information search and dissemination for vehicular applications. In [43], we aim to investigate the social behavior of vehicles in SIoV and how it is affected by mobility patterns. Specifically, through the analysis of simulated traffic traces, we distinguish friendly and acquaintance vehicles based on the encounter time and connection maintenance.

7.6. Robots and drones

Participants: Nathalie Mitton, Valeria Loscri, Farouk Mezghani, Anjalalaina Jean Cristanel Razafimandimby.

Internet of Robotic Things (IoRT) is a new concept introduced for the first time by ABI Research. Unlike the Internet of Things (IoT), IoRT provides an active sensorization and is considered as the new evolution of IoT. In this context, we propose a Neuro-Dominating Set algorithm (NDS) [21] to efficiently deploy a team of mobile wireless robots in an IoRT scenario, in order to reach a desired inter-robot distance, while maintaining global connectivity in the whole network. We use the term Neuro-Dominating Set to describe our approach, since it is inspired by both neural network and dominating set principles. With NDS algorithm, a robot adopts different behaviors according whether it is a dominating or a dominated robot. Our main goal is to show and demonstrate the beneficial effect of using different behaviors in the IoRT concept. The obtained results show that the proposed method outperforms an existing related technique (i.e., the Virtual Angular Force approach) and the neural network based approach presented in our previous work. As an objective, we aim to decrease the overall traveled distance and keep a low energy consumption level, while maintaining network connectivity and an acceptable convergence time.

Routing a fleet of robots in a known surface is a complex problem. It consists in the determination of the exact trajectory each robot has to follow to collect information. This is what we propose in [32] with the objective is to maximize the exploration of the given surface. To ensure that the robots can execute the mission in a collaborative manner, connectivity constraints are considered. These constraints guarantee that robots can communicate among each other and share the collected information. Moreover, the trajectories of the robots need to respect autonomy constraints.

When a disaster strikes, the telecommunications infrastructure gets damaged making rescue operations more challenging. Connecting first responders through flying base stations (i.e. drone mounted LTE (Long-Term Evolution) femtocell base station) presents a promising alternative to support infrastructure failure during disasters. The drone can travel the area and communicate with ground mobile devices, such as smartphones, and serves as flying data link to share information between survivors and rescuers. Problem statement. We would like to submit the following open problem to the community. Given the position of the ground mobile devices to serve, the problem presented here is about the dynamic drone path planning. As the drone autonomy is very limited and due to the high cost of drone mounted base station, the goal of this problem is to determine the best energy-efficient and minimum-time path to travel the area as fast as possible while still remaining in range of each survivor long enough to assure full servicing. This is the problem stated in [31].

7.7. MAC mechanisms

Participant: Nathalie Mitton.

In the era of the Internet of Things (IoT), the number of connected devices is growing dramatically. Often, connected objects use Industrial, Scientific and Medical (ISM) radio bands for communication. These kinds of bands are available without license, which facilitates development and implementation of new connected objects. However, it also leads to an increased level of interference in these bands. Interferences not only negatively affect the Quality of Service, but also cause energy losses, which is especially unfavorable for the energy constrained Wireless Sensor Networks (WSN). In [25], we develop an explicit formula of outage probability in a distributed wireless sensor network (WSN), assuming the MAC layer protocol being a slotted-ALOHA. And adopting a Markovian approach, we develop a model that analyses the performance of the slotted-ALOHA in order to improve these performances, in particular, by adding a preliminary stage of channel reservation, we show that this modification is important to have a high performance distributed wireless sensor network.

Several wild animal species are endangered by poaching. As a solution, deploying wireless sensors on animals able to send regular messages and also alert messages has been envisaged recently by several authorities and foundations. In that context, we have proposed WildMAC [35], a multichannel, multihop wireless communication protocol for these specific wireless sensor networks that have to collect data from unknown large areas with different QoS requirements. WildMAC is a TDMA based MAC protocol that leverages long range communication properties to propose an efficient data collection mean. Its performance evaluation shows it meets QoS requirements. To size the different parameters of WildMAC, we relied on the results of the study of [25].

7.8. RFID

Participants: Nathalie Mitton, Abdoul Aziz Mbacke, Ibrahim Amadou.

While RFID technology is gaining increased attention from industrial community deploying different RFID-based applications, it still suffers from reading collisions. As such, many proposals were made by the scientific community to try and alleviate that issue using different techniques either centralized or distributed, monochannel or multichannels, TDMA or CSMA. However, the wide range of solutions and their diversity make it hard to have a clear and fair overview of the different works. [18] surveys the most relevant and recent known state-of-the-art anti-collision for RFID protocols. It provides a classification and performance evaluation taking into consideration different criteria as well as a guide to choose the best protocol for given applications depending on their constraints or requirements but also in regard to their deployment environments.

Among all these approaches, [29], [28] propose new reader anti-collision schemes and data-priority aware data collection in a multi-hop RFID data collection protocol. [28] examines the implementation of two applications: for industrial IoT and for smart cities, respectively. Both applications, in regards to their requirements and configuration, challenge the operation of a RFID sensing solution combined with a dynamic wireless data gathering over multihops. They require the use of both mobile and fixed readers to cover the extent of deployment area and a quick retrieval of tag information. We propose a distributed crosslayer solution for improving the efficiency of the RFID system in terms of collision and throughput but also its proficiency in terms of tag information routing towards one or multiple sinks. Simulation results show that we can achieve high level of throughput while maintaining a low level of collision and a fairness of reader medium access above 95% in situations where readers can be fix and mobile, while tag information is routed with a data rate of 97% at worst and reliable delays for considered applications. [29] proposes cross-layer solutions meant for both scheduling of readers' activity to avoid collisions, and a multihop routing towards base stations, to gather read tag data. This routing is performed with a data priority aware mechanism allowing end-to-end delay reduction of urgent data packets delivery up to 13% faster compared to standard ones. Using fuzzy logic, we combine several observed metrics to reduce the load of forwarding nodes and improve latency as well as data rate. We validate our proposal running simulations on industrial and urban scenarios.

All these solutions have also been detailed in [11].

7.9. Smart Cities

Smart cities are a key factor in the consumption of materials and resources. As populations grow and resources become scarcer, the efficient usage of these limited goods becomes more important. Building on and integrating with a huge amount of data, the cities of the future are becoming a realization today. There are millions of sensors in place already, monitoring various things in metropolises. In the near future, these sensors will multiply until they can monitor everything from streetlights and trashcans to road conditions and energy consumption. In this context, effective strategies or solutions for refining data sets can play a key role. In [37], we propose a scheme in which passive RFID is shown as an interesting alternative and complement to WSN to alleviate the cost of some Smart City applications.

Also, in Smart Cities, crowd sensing may help to identify the current speed for each street, the congested areas, etc. In this context, map matching techniques are required to map a sequence of GPS waypoints into a set of streets on a common map. Unfortunately, most map matching approaches are probabilistic. In [41], we propose rather an unambiguous algorithm, able to identify all the possible paths that match a given sequence of waypoints. We need an unambiguous identification for each waypoints set. For instance, the actual speed should be assigned to the correct set of streets, without error. To identify all the possible streets, we construct the set of candidates iteratively. We identify all the edge candidates around each waypoint, and reconstruct all the possible sub-routes that connect them. We then verify a set of constraints, to eliminate impossible routes. The road segments common to all computed routes form an unambiguous match. We evaluate the matching ratio of our technique on real city maps (London, Paris and Luxembourg). We also validate our approach with a real GPS trace in Seattle.

In parallel, we proposed a MOOC in the framework of the IPL CityLab project (See Section 9.2.1), whose working documents are available online [48].

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

- Sencrop
  Participants: Brandon Foubert, Nathalie Mitton [correspondant].
  This collaboration aims to develop a complete multi-technology bilateral wireless communication stack for agriculture sensor networks.
- Enedis and NooliTic
  Participants: Ibrahim Amadou, Nathalie Mitton [correspondant].
  This collaboration aims to investigate a novel localization approach based on wireless propagations. It is a tri-partite contract between our Inria team, the SME NooliTic and Enedis.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. StoreConnect

Participants: Nathalie Mitton, Valeria Loscri [correspondant], Antonio Costanzo, Ibrahim Amadou.

Title: StoreConnect

Type: FUI

Duration: September 2016 - October 2018

Coordinator: NEOSENSYS

Others partners: Inria FUN, SPIRALS and STARS, TeVolys, Ubudu, Smile, STIME, Leroy Merlin

The aim of StoreConnect is to provide French large retailers with efficient and powerful tools in the in-store customer interaction. This project has yielded to several publications in 2018: [39], [38], [24], [40].

9.1.2. PIPA

Participants: Nathalie Mitton [correspondant], Farouk Mezghani.

Title: Partager de l'Info PArtout à bas coût

Type: Chercheur citoyen

Duration: Dec 2015 - Aug 2018

Coordinator: Inria FUN

Others partners: SpotTrotter

PIPA project aims to provide an innovative low cost solution to share information in places where communication infrastructure are lacking, insuffisant or not adapted, going beyond technical, economical or political limitations. This project has yield to several publications in 2018: [31], [19], [30].

9.2. National Initiatives

9.2.1. Inria Project Lab

9.2.1.1. CityLab@Inria

Participants: Valeria Loscri, Abdoul Aziz Mbacke, Nathalie Mitton [correspondant].

- Title: CityLab@Inria
- Type: IPL
- Duration: 2015 - 2019
- Coordinator: Valerie Issarny
- CityLab@Inria studies ICT solutions toward smart cities that promote both social and environmental sustainability. A strong emphasis of the Lab is on the undertaking of a multi-disciplinary research program through the integration of relevant scientific and technology studies, from sensing up to analytics and advanced applications, so as to actually enact the foreseen smart city Systems of Systems. Obviously, running urban-scale experiments is a central concern of the Lab, so that we are able to confront proposed approaches to actual settings. The Lab's research leverages relevant effort within Inria project-teams that is further revisited as well as integrated to meet the challenges of smart cities. Research themes span: energy-efficient wireless communication protocols, urban-scale social and physical sensing, privacy by design, cloud-based urban data management, data assimilation, visual analysis, and urban system software engineering. In addition, CityLab Inria research builds upon collaborative effort at the International level, and especially collaboration in the context of the Inria SiliconValley program. This project has yield to the set up of a full course on Smart Cities via a MOOC [48] and a set of publications [18], [29], [28], [37], [11].

9.2.2. ADT

9.2.2.1. Catimex

Participants: Matthieu Berthome, Nathalie Mitton [correspondant], Julien Vandaele.

Duration: September 2017 -June 2019

Coordinator: Inria FUN

The purpose of this project is to foster research transfer in IoT from ADT members to their industrial partners by widening experimental features and PoC realization. It is lead in closed partnership with Inria Chile and Université of Strasbourg.

9.2.3. Equipements d'Excellence

9.2.3.1. FIT

Participants: Nathalie Mitton [correspondant], Julien Vandaele, Matthieu Berthome.

Title: Future Internet of Things

Type: EquipEx

Duration: March 2010 - December 2019

Coordinator: UPMC

See also: http://fit-equipex.fr/

Abstract: FIT (Future Internet of Things) aims to develop an experimental facility, a federated and competitive infrastructure with international visibility and a broad panel of customers. It will provide this facility with a set of complementary components that enable experimentation on innovative services for academic and industrial users. The project will give French Internet stakeholders a means to experiment on mobile wireless communications at the network and application layers thereby accelerating the design of advanced networking technologies for the Future Internet. FIT is one of 52 winning projects from the first wave of the French Ministry of Higher Education and Research's "Equipements d'Excellence" (Equipex) research grant program. Coordinated by Professor Serge Fdida of UPMC Sorbonne Universités and running over a nine-year period, the project will benefit from a 5.8 million euro grant from the French government.

9.3. European Initiatives

9.3.1. H2020 Projects

9.3.1.1. VESSEDIA

Participants: Rehan Malak, Nathalie Mitton, Allan Blanchard [correspondant].

- Title: VERIFICATION ENGINEERING OF SAFETY AND SECURITY CRITICAL DYNAMIC INDUSTRIAL APPLICATIONS
- Program: H2020
- Duration: January 2017 - Dec. 2019
- TECHNIKON FORSCHUNGS UND PLANUNGSGESELLSCHAFT MBH (TEC)

The VESSEDIA project will bring safety and security to many new software applications and devices. In the fast evolving world we live in, the Internet has brought many benefits to individuals, organizations and industries. With the capabilities offered now (such as IPv6) to connect billions of devices and therefore humans together, the Internet brings new threats to the software developers and VESSEDIA will allow connected applications to be safe and secure. VESSEDIA proposes to enhance and scale up modern software analysis tools, namely the mostly open-source Frama-C Analysis platform, to allow developers to benefit rapidly from them when developing connected applications. At the forefront of connected applications is the IoT, whose growth is exponential and whose security risks are real (for instance in hacked smart phones). VESSEDIA will take this domain as a target for demonstrating the benefits of using our tools on connected applications. VESSEDIA will tackle this challenge by 1) developing a methodology that allows to adopt and use source code analysis tools efficiently and produce similar benefits than already achieved for highly-critical applications (i.e. an exhaustive analysis and extraction of faults), 2) enhancing the Frama-C toolbox to enable efficient and fast implementation, 3) demonstrating the new toolbox capabilities on typical IoT (Internet of Things) applications including an IoT Operating System (Contiki), 4) developing a standardization plan for generalizing the use of the toolbox, 5) contributing to the Common Criteria certification process, and 6) defining a label "Verified in Europe" for validating software products with European technologies such as Frama-C. This project yields to set of publications in 2018: [23], [47], [27].

9.4. International Initiatives

9.4.1. Inria International Labs

9.4.1.1. Agrinet

Participants: Abdoul Aziz Mbacke, Brandon Foubert, Valeria Loscri, Anjalalaina Jean Cristanel Razafimandimby, Nathalie Mitton [correspondant].

Agrinet

Title: Agrinet

International Partner (Institution - Laboratory - Researcher):

Type: LIRIMA Associate team

Duration: 2017-2020

See also: https://team.inria.fr/agrinet/

The current drought and limited water resources in many parts of Southern Africa and beyond, already have a significant impact on agriculture and hence, food production. Sustainable food security depends upon proper plant and crop management respectful of soils and natural re- sources, such as water. This includes very important South African farming areas, such as the Western Cape and Northern Cape. In France, agriculture is also hugely important. Not just nationally, but also in Europe. The system proposed can be applied to a variety of crops. The economic- and social consequences are profound and any contribution towards more efficient farming within increasingly onerous natural constraints, should be a priority. To address these constraints, we propose to develop a flexible, rapidly deployable, biological/agricultural data acquisition platform and associated machine learning algorithms to create advanced agricultural monitoring and management techniques, to improve crop management and use of natural resources. The project also addresses an industry with very high socioeconomic impact.

Publications issued from that project in 2018 are: [25], [45], [35].

9.4.2. Inria International Partners

9.4.2.1. Declared Inria International Partners

Université Mediterranea di Reggio Calabria (UNIC) (Italy) Objective of this collaboration is the design of an innovative architecture that enables autonomic and decentralized fruition of the services offered by the network of smart objects in many heterogeneous and dynamic environments, in a way that is independent of the network topology, reliable and flexible. The result is an 'ecosystem' of objects, self-organized and self-sustained, capable of making data and services available to the users wherever and whenever required, thus supporting the fruition of an 'augmented' reality thanks to a new environmental and social awareness.

9.4.2.2. Informal International Partners

Southern University, China

The purpose of this collaboration is to study the green (or energy-efficient) communication problem in vehicular ad hoc networks (VANETs) and the application of vehicular network communication in green transportation. In this framework, Nathalie Mitton visited the Nanjing University. It gave birth to joint project submission, joint conference organization and joint publications.

Arun Sen from Arizona State University, USA

The purpose of this collaboration is to study the joint scheduling and trajectory of RFID readers in a mobile environment. In this framework, Arun Sen visited the FUN team for 6 months in 2015 and in July 2016. It gave birth to joint project submission, joint conference submission and joint publications, among them in 2018 [14].

Anna-Maria Vegni from Roma Tre University, Italy

The purpose of this collaboration is to study alternative communication paradigms and investigate their limitations and different effects on performances. In this framework, joint publications have been obtained, among them in 2018 [17], [21], [26], [36], [43], [45].

9.4.3. Participation in Other International Programs

9.4.3.1. CROMO

Participants: Valeria Loscri, Joao Batista Pinto Neto, Nathalie Mitton [correspondant].

Title: Crowd Data In the mobile cloud

Duration: January 2015 - December 2019

CroMo (Crowd Data In the mobile cloud) is a submission to the CAPES-COFECUB project call lead by Inria from the French side and University of Rio de Janeiro from Brazilian Side. Other partner institutions are Université Pierre et Marie Curie and Université de la Rochelle.

Mobile cloud computing is an emerging paradigm to improve the quality of mobile applications by transferring part of the computational tasks to the resource-rich cloud. The multitude data sources combined with the known difficulties of wireless communications represent an important issue for mobile cloud computing. Therefore, the additional computational power added by the cloud has to deal with the constraints of the wireless medium. One could imagine a situation where different sensors collect data and require intensive computation. This data must be transmitted at high rates before becoming stale. In this case, the network becomes the main bottleneck, not the processing power or storage size. To circumvent this issue, different strategies can be envisioned. As usual alternatives, wireless data rates must be increased or the amount of data sent to the cloud must be reduced. CROMO tackles challenges from all these three components of the mobile clouds (data generation, collect and processing) to then integrate them as a whole enhanced mobile cloud with improved network performances in terms of delay, energy consumption, availability, and reliability. In this context, joint exchanges and crossed visits have been done (Aziz went to Rio, Dianne went to Lille). The project yield to several publications such as [22].

9.5. International Research Visitors

9.5.1. Visits of International Scientists

Several researchers have visited our group in 2018, mainly from our partner universities but not only:

- Gentian, Jakllari, ENSEEITH, France, January 2018
- Georgios Papadopoulos, IMT Atlantique, France, January 2018
- Bruno Quoitin, University of Mons, Belgium, January and March 2018
- Sebastien Bindel, Université de Haute Alsace, France, June 2018
- Karen Miranda Campos, Metropolitan Autonomous University Lerma Campus, Mexico, October 2018
- Zied Chtourou, University of Sfax, Tunisia, October 2018
- Fabrice Théoleyre, University of Strasbourg, October 2018
- Fabrice Valois, INSA Lyon, October 2018
- Miguel Elias Campista, Federal University of Rio de Janeiro (UFRJ), Brazil, December 2018
- Pranvera Kortoci, Aalto University, from Mar 2018 until Apr 2018
- Noura Mares Univ. Sfax, from Apr 2018 until Jul 2018
- Morgan O Kennedy, Stellenbosch University, from Jul 2018 until Sep 2018

9.5.1.1. Research Stays Abroad

- Jad Nassar visited Metropolitan Autonomous University Cuajimalpa Campus, Mexico in January-February 2018

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. General Chair, Scientific Chair

- Nathalie Mitton is a member of the Steering committee of CIoT
- Nathalie Mitton is demo/poster chair of infocom 2019
- Valeria Loscri is general co-chair of City-Wide Pervasive Environment CoWPER, in conjunction with IEEE SECON 2018, and of a Special Session on Mobile Social Networks in PIMRC 2018
- Antoine Gallais was the co-chair of IIoT day 2018

10.1.2. Scientific Events Selection

10.1.2.1. Chair of Conference Program Committees

- Antoine Gallais is TPC co-chair of CoRes 2019
- Valeria Loscri is TPC co-chair of IEEE ACM Nanocom 2019 and of IEEE ACM SmartComp in conjunction with Mobihoc 2018
- Nathalie Mitton is TPC co-chair of ICC 2019 and 2018

10.1.2.2. Member of the Conference Program Committees

- Valeria loscri is/was member in the Technical Program Committee (TPC) in IFIP/IEEE NTMS 2018, Globecom 2018-2019, CORES 2018, VTC 2018-2019, GIoTS 2018-2019, WiMob 2018, CCNC 2018-2019, ICC 2019

- Nathalie Mitton is/was in the Technical Program Committee (TPC) of Percom 2019, WCNC 2019, DCOSS 2019, CORES 2018, Infocom workshop 2018, VTC 2018, globecom 2019&2018, GIIS 2018, CSCN2018, ICC 2018, coconet 2018, adhocnow 2018
- Antoine Gallais was/is in the Technical Program Committee (TPC) of IEEE Globecom'19 and 2018, IEEE ICNC'19 and 2018, IEEE GIIS'18, IARIA INNOV'18, IEEE COMNETSAT'18, IARIA EMERGING'18, ADHOC-NOW'18, ICST Adhocnets'18
- Allan Blanchard was/is in the Technical Program Committee (TPC) of 4PAD 2018

10.1.3. Journal

10.1.3.1. Guest editorial activities

- Nathalie Mitton was (co-)editor of Sensor Special Issues of MDPI Sensors on QoS in WSN and of MDPI Future Internet WSN in Smart Agriculture
- Valeria Loscri was editor of IEEE Access Special Section on Protocols for Nanocommunication Networks, of IEEE Access Special Section on Body Area Networks and of a Special Issue on IEEE Internet of Things Journal on Recent Advances on Social Internet of Vehicles

10.1.3.2. Member of the Editorial Boards

- Nathalie Mitton is editorial board members of AHSWN since 2011
- Nathalie Mitton is editorial board member of Adhoc Networks since 2012
- Nathalie Mitton is editorial board member of IET-WSS since 2013
- Nathalie Mitton is editorial board member of ComSoc MMTC e-letter since 2014
- Nathalie Mitton is editorial board member of Wiley Transactions Emerging Telecommunications Technologies since 2016
- Nathalie Mitton is editorial board member of Wireless Communications and Mobile Computing since 2016
- Nathalie Mitton is editorial board member of MDPI Future Internet since 2018
- Valeria Loscri is editorial board member of IEEE Transactions on Nanobioscience journal since 2017
- Valeria Loscri is editorial board member of Elsevier Computer Networks journal since 2016
- Valeria Loscri is editorial board member of Robotics Software Design and Engineering of the International Journal of Advanced Robotic Systems since 2016
- Valeria Loscri is editorial board member of Elsevier Journal of Networks and Computer Applications (JNCA) journal since 2016

10.1.4. Invited Talks

- Nathalie Mitton was invited speaker at Workshop “Digital Agriculture in Africa”, in Montpellier, in April 2018
- Nathalie Mitton was invited speaker at CORES conference in Roscoff, France, in May 2018
- Nathalie Mitton was invited speaker at WFCS conference in Imperia, Italy, in June 2018
- Nathalie Mitton was invited speaker at Nantes University, France, in October 2018
- Antoine Gallais was invited speaker at Innov'School Network of Things (ISNOT), Gammarth, Tunisia in April 2018
- Allan Blanchard gave an invited tutorial at ZINC 2018, Novi Sad, Serbia in June 2018
- Allan Blanchard gave an invited tutorial at HPCS 2018, Orleans, France, in July 2018
- Valeria Loscri was invited as panelist in the panel “Inspirations from wireless networks to biology” in the 3rd EU FET CIRCLE Workshop, Ghent April 2018

- Valeria Loscri was invited as panelist in the Panel New Trends in Communication and at the Doctoral Colloquium at ACM/IEEE NanoCom 2018
- Valeria Loscri has been appointed as Faculty Mentor in N2 Women meeting at ACM Mobihoc 2018
- Valeria Loscri was invited to attend the Seed meeting on Dynamical Modeling and Simulation for Molecular Communication that was held at the Embassy of France in London
- Valeria Loscri was invited speaker at the LiFi seminar in Vélizy, September 2018

10.1.5. Leadership within the Scientific Community

- Nathalie Mitton is a member of the Steering Committee of the GDR Rescom
- Valeria Loscri is a member of Social Network Technical Committee
- Valeria Loscri is a member of Emerging Technologies Initiatives for Molecular, Biological and Multi-Scale Communications (ETI-MBMC)
- Valeria Loscri is a member of the Quantum Communications & Information Technology Emerging Technical Subcommittee (QCIT)
- Valeria Loscri is a member of the "Research Group on IoT Communications and Networking Infrastructure" at ComSoc Communities

10.1.6. Scientific Expertise

- Nathalie Mitton is an elected member of the evaluation community of Inria. She has acted as a reviewer for ANRT and ANR project submissions and as an evaluator for Chilean National Science and Technology Commission (CONICYT - Chile) FONDECYT Initiation into Research 2018 projects. She is also member of the scientific committees of the competitiveness cluster of MATIKEN and for CITC (International Contactless Technologies Center). Finally, Nathalie Mitton is a member of the HCERES visiting committee for the LISIS laboratory.
- Valeria Loscri is Scientific European Responsible for Inria Lille - Nord Europe. She is reviewer in the context of ERC Consolidator Grant. She is reviewer for Equipes Associées. She has been scientific reviewer of TOP grant for senior researchers in the context of Netherlands Organisation for Scientific Research (NWO) program.
- Valeria Loscri has been external expert reviewer of proposal for grant competition at the Center for Excellence in Applied Computational Science and Engineering (CEACSE), UTC (USA).

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

E-learning

Mooc, Nathalie Mitton, "Villes intelligentes : défis technologiques et sociétaux" , 5-week mooc by the IPL CityLab@Inria team, FUN, Inria, in November 2018

SPOC, Nathalie Mitton,EIT Digital "Technological challenges of participatory Smart cities", 5-week by the IPL CityLab@Inria team in November 2018

Remote curse, Nathalie Mitton, Internet of things, 5-week + face to face week in May 2018

Master: Valeria Loscri, Objets Communicants, 24h (Mineure Habitat Intelligent), Ecole des Mines de Douai, France

Master: Nathalie Mitton, Wireless sensor networks, 16h eqTD (Master MINT), Université Lille 1 and Telecom Lille 1, France

Master: Nathalie Mitton, Introduction to Internet of Things, 8h CM Ecole Centrale de Lille, France

Master: Ibrahim Amadou, Introduction to Internet of Things, 8h TP Ecole Centrale de Lille, France

Master: Ibrahim Amadou and Abdoul Aziz Mbacke, Introduction to RFID, 16h IMT Rennes, France

Master: Ibrahim Amadou, Wireless sensor networks, 16h eqTD (Master ROC), IMT, France

Bsc: Farouk Mezghani, Contactless technologies, 20h eqTD, Université de Valenciennes, France

Licence: Jean Razafimandimby, Algorithms and Programming, 30h eqTD, Université Lille 1, France

10.2.2. Supervision

PhD defended on October 18th 2018: Aziz Mbacke, Smart Deployment of heterogeneous sensors and RFID in a Smart City, Université Lille 1, 2015-2018, Nathalie Mitton and Hervé Rivano (Urbanet)

PhD defended on October 12th 2018: Jad Nassar, Ubiquitous networks for smart grids, Université Lille 1, 2015-2018, Nathalie Mitton and Nicolas Gouvy (HEI)

PhD in progress: Brandon Foubert, Communication sans fil Polymorphe pour l'Agriculture Connectée, Université Lille 1, 2018-2021, Nathalie Mitton

PhD in progress: Rodrigo Teles, Virtualizing Heterogeneous Wireless Networks with SDN for the 5G, Université Strasbourg, 2016-2019, Antoine Gallais and Fabrice Théoleyre

PhD in progress: M. Amine Falek, Optimization algorithms for personalized and dynamic multimodal itinerary planning, Université Strasbourg, 2016-2029, Antoine Gallais, Cristel Pelsser and Fabrice Theoleyre

PhD in progress: Loïc Miller, Secure work-flow access control, Université Strasbourg, 2018-2021, Antoine Gallais, Pascal Merindol and Cristel Pelsser

10.2.3. Juries

- PhD/HDR committees:
  - Antoine Gallais is/was members of the following PhD thesis committees:
    - François Lemercier, IMT Atlantique, Rennes, France, November 2018
    - Solomon Petrus le Roux, Stellenbosch University, South Africa, December 2018
    - Hugo Chelle, Universite´ de Toulouse, France, December 2018
  - Valeria Loscri is/was members of the following PhD thesis committees:
    - Alexis Duque, INSA Lyon, France, October 2018
    - Óscar Alvear, Universidade Politecnica Valencia, Spain, July 2018
    - Sabrine Aroua, Université de La Rochelle, France, July 2018
    - Mohamed Abdelkrim, Université Paris Est Créteil, December 2018
  - Nathalie Mitton is/was member of the following PhD thesis committees:
    - Patrick Olivier Kamgueu, Univ. de Yaounde - Univ. de Lorraine, January 2018
    - Hermes Pimenta de Moraes Junior, UTC (présidente), May 2018
    - Hamadoun Tall, Clermont Auvergne, (reviewer) May 2018
    - Marwan Ghanem, UPMC, September 2018
    - Wafa Badreddine, UPMC, (reviewer) November 2018
    - Yosra Zguira, INSA Lyon (reviewer), November 2018
    - Solomon Petrus le Roux (reviewer), Stellenbosch University, December 2018
    - Fadhlallah Baklouti, Université Bretagne Sud (reviewer), February 2019
    - M Naas, Université de Bretagne Occidentale (reviewer), February 2019
  - Nathalie Mitton was a member of the HDR defense committees
    - Valeria Loscri, Université Lille 1, March. 2018
    - Fen Zhou, Université d'Avignon, Sept. 2018
- Researcher selection committees:

- Nathalie Mitton was a member of the Professor competition selection committee at Ecole des Mines Nancy, Université Nice-Sophia Antipolis and Clermont-Ferrand
- Nathalie Mitton was a member of the Inria chaire committee for Supelec Rennes
- Nathalie Mitton was a member of the Assistant Professor (MdC) at Valenciennes

- Nathalie Mitton is/was reviewer of the following PhD follow-up committees:
  - Rodrigue Domgua Rodriguez, INSA Lyon
  - Yosra Zguira, INSA Lyon
  - Vaseileios Kotsiou, Université de Strasbourg
- Antoine Gallais is/was reviewer of the following PhD follow-up committees:
  - Tomas Lagos Jenschke, IMT Atlantique

10.3. Popularization

- Matthieu Berthome, Jad Nassar, Ibrahim Amadou, Antonio Costanzo and Antoine Gallais gave some talks in high schools for the "Fête de la Science" in October 2018
- Nathalie gave an interview for France Info on connected objects

11. Bibliography

Major publications by the team in recent years

[1] R. T. HERMETO, A. GALLAIS, F. THEOLEYRE. *On the (over)-Reactions and the Stability of a 6TiSCH Network in an Indoor Environment*, in "21st ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWIM '18)", Montreal, Canada, October 2018 [*DOI :* 10.1145/3242102.3242104], https://hal.archives-ouvertes.fr/hal-01886716

[2] K. KRITSIS, G. PAPADOPOULOS, A. GALLAIS, P. CHATZIMISIOS, F. THEOLEYRE. *A Tutorial on Performance Evaluation and Validation Methodology for Low-Power and Lossy Networks*, in "Communications Surveys and Tutorials, IEEE Communications Society", July 2018, vol. 20, n^o 3, pp. 1799 - 1825 [*DOI :* 10.1109/COMST.2018.2820810], https://hal.archives-ouvertes.fr/hal-01886690

[3] V. LOSCRI, B. D. UNLUTURK, A. MARIA VEGNI. *A Molecular Optical Channel Model based on Phonon-Assisted Energy Transfer Phenomenon*, in "IEEE Transactions on Communications", August 2018, https://hal.inria.fr/hal-01864323

[4] A. A. MBACKÉ, N. MITTON, H. RIVANO. *A survey of RFID readers anticollision protocols*, in "IEEE Journal of Radio Frequency Identification", March 2018, vol. 2, n^o 1, 11 p. [*DOI :* 10.1109/JRFID.2018.2828094], https://hal.inria.fr/hal-01767311

[5] J. NASSAR, M. BERTHOMÉ, J. DUBRULLE, N. GOUVY, N. MITTON, B. QUOITIN. *Multiple Instances QoS Routing In RPL: Application To Smart Grids*, in "Sensors", August 2018, vol. 18, n^o 8 [*DOI :* 10.3390/s18082472], https://hal.inria.fr/hal-01851713

[6] J. B. PINTO NETO, N. MITTON, M. E. M. CAMPISTA, L. H. M. K. COSTA. *Dead Reckoning Using Time Series Regression Models*, in "MobiHoc 2018 - 4th ACM MobiHoc Workshop on Experiences with the Design and Implementation of Smart Objects", Los Angeles, United States, June 2018, vol. 18 [*DOI :* 10.1145/3213299.3213305], https://hal.inria.fr/hal-01798550

[7] C. RAZAFIMANDIMBY, V. LOSCRI, A. M. VEGNI, A. BENSLIMANE. *Neuro-Dominating Set Scheme for a Fast and Efficient Robot Deployment in Internet of Robotic Things*, in "Ad Hoc Networks", August 2018, https://hal.inria.fr/hal-01864325

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[9] A. M. VEGNI, V. LOSCRI, P. MANZONI. *Data Forwarding Techniques Based on Graph Theory Metrics in Vehicular Social Networks*, in "IEEE PIMRC 2018 - 29th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications", Bologna, Italy, September 2018, https://hal.inria.fr/hal-01826237

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Doctoral Dissertations and Habilitation Theses

[10] V. LOSCRI. *Toward Interoperability of Heterogeneous Self-organizing (smart) Things*, University of Lille 1, March 2018, Habilitation à diriger des recherches, https://hal.inria.fr/tel-01743527

[11] A. A. MBACKÉ. *Collection and multi-hop forwarding of RFID data for the monitoring of urban infrastructures*, Université de Lille, October 2018, https://hal.inria.fr/tel-01901740

[12] J. NASSAR. *Ubiquitous Networks for Smart Grids*, Universite des Sciences et Technologies de Lille, October 2018, https://hal.inria.fr/tel-01908825

Articles in International Peer-Reviewed Journals

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[23] A. BLANCHARD, N. KOSMATOV, F. LOULERGUE. *Ghosts for Lists: A Critical Module of Contiki Verified in Frama-C*, in "Tenth NASA Formal Methods Symposium - NFM 2018", Newport News, United States, April 2018, https://hal.inria.fr/hal-01720401

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[34] J. NASSAR, K. MIRANDA, N. GOUVY, N. MITTON. *Prédiction de données différenciée pour les Smart Grids* , in "Rencontres Francophones sur la Conception de Protocoles, l'Évaluation de Performance et l'Expérimentation des Réseaux de Communication", Roscoff, France, May 2018, https://hal.archives-ouvertes.fr/hal-01785425

[35] V. TOLDOV, L. CLAVIER, N. MITTON. *Multi-channel Distributed MAC protocol for WSN-based wildlife monitoring*, in "WiMob 2018 - 14th International Conference on Wireless and Mobile Computing, Networking and Communications", Limassol, Cyprus, October 2018, https://hal.inria.fr/hal-01866809

[36] A. M. VEGNI, V. LOSCRI, P. MANZONI. *Data Forwarding Techniques Based on Graph Theory Metrics in Vehicular Social Networks*, in "IEEE PIMRC 2018 - 29th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications", Bologna, Italy, September 2018, https://hal.inria.fr/hal-01826237

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[40] M. EGAN, T. Q. DUONG, M. DI RENZO, J.-M. GORCE, I. NEVAT, V. LOSCRI. *Cognitive Molecular Communication*, in "2018 -3rd Workshop on Molecular Communications", Ghent, Belgium, April 2018, pp. 1-2, https://hal.archives-ouvertes.fr/hal-01728766

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