Activity Report 2017

Project-Team FUN

self-organizing Future Ubiquitous Network

RESEARCH CENTER
Lille - Nord Europe

THEME
Networks and Telecommunications

Table of contents

Project-Team FUN

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

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

1. Personnel

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2. Overall Objectives

2.1. Overall Objectives

Context.

The Internet of Things [60] 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 [68].

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 [62], [59], discovering neighborhood [67], [66], scheduling activity and coverage [64], localizing [69], [58], 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 [72], [63] and at the MAC layer level [25]. 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.

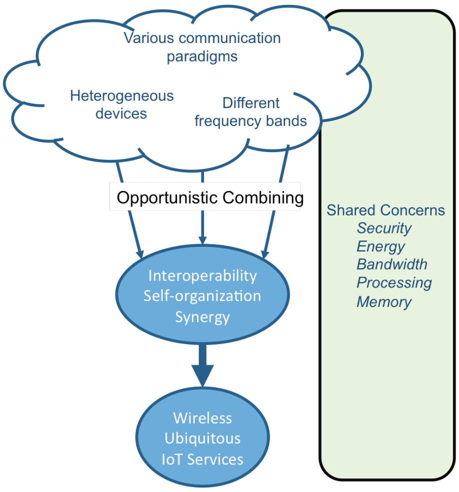

Figure 1. FUN's overal goal.

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 [11]. 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 [11]. Also, we will work on new scheduling techniques for TSCH (a MAC layer of IEEE 802.15.4e) that are able work under the above-mentioned assumptions and bring the robustness of TSCH to IoT scenarios. We will investigate the performance boundaries of TSCH in particular in terms of energy-efficiency of time synchronization [42], and will propose alternative approaches such as capture effect-based time synchronization in TSCH or opportunistic routing. Another technology we will consider is IEEE 802.15.4g, which provides communication ranges in the order of tens of kilometers. We will propose

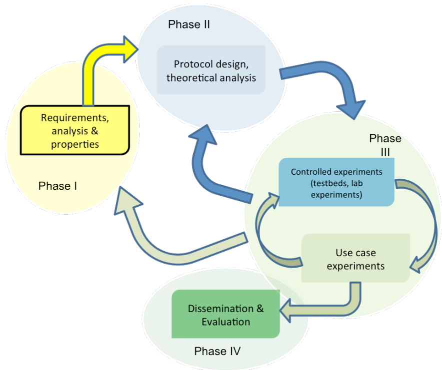

Figure 2. Methodology to be applied in FUN.

mechanisms to support scaling up to networks with a density of hundreds of nodes, at the MAC layer and above. We will also consider dual-technology networks where both long and short-range communication cooperate for increased robustness.

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 [70], [57]. On the same idea, when specific features are available like controlled mobility, we will exploit it to improve connectivity or coverage quality like in [65], [71].

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 [32]. 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 [50] 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 [37], [12].

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 [61]. 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 or animal monitoring, understanding and protection. To illustrate this, we may refer to the use cases addressed by our PREDNET project which goals is to equip rhinoceros with smart communicating devices to fight against poaching.

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 ca play a key role in logistics and traceability by relying on the use of sensors or RFID technologies as implemented in our TRACAVERRE 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 and VITAL projects).

5. Highlights of the Year

5.1. Highlights of the Year

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

5.1.1. Awards

BEST PAPER AWARD:

[26]
P. MERLE, C. GOURDIN, N. MITTON. *Mobile Cloud Robotics as a Service with OCCIware*, in "2nd IEEE International Congress on Internet of Things, IEEE ICIOT 2017", Honolulu, Hawaii, United States, Proceedings of the 2nd IEEE International Congress on Internet of Things, IEEE ICIOT 2017, June 2017, pp. 50 - 57 [*DOI :* 10.1109/IEEE.ICIOT.2017.15], https://hal.archives-ouvertes.fr/hal-01522684

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: Security - Embedded - Embedded systems - JavaCard - Control Flow - 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. Routing

Participants: Nathalie Mitton, Julien Vandaele.

Wireless sensor and actuator/robot networks need some routing mechanisms to ensure that data travel the network to the sink with some guarantees. The FUN research group has investigated different routing paradigms.

Geographic routing has gained much attention as a basic routing primitive in wireless sensor networks due to its memory-less, scalability, efficiency and low overhead features. Greedy forwarding is the simplest geographic routing scheme, it uses the distance as a forwarding criterion. Nevertheless, it may suffer from communication holes, where no next hop candidate is closer to the destination than the node currently holding the packet. For this purpose, a void handling technique is needed to recover from the void problem and successfully deliver data packets if a path does exist between source and destination nodes. Many approaches have been reported to solve this issue at the expense of extra processing and or overhead. [19] proposes GRACO, an efficient geographic routing protocol with a novel void recovery strategy based on ant colony optimization (ACO). GRACO is able to adaptively adjust the forwarding mechanism to avoid the blocking situation and effectively deliver data packets. Compared to GFG, one of the best performing geographic routing protocols, simulation results demonstrate that GRACO can successfully find shorter routing paths with higher delivery rate, less control packet overhead and shorter end-to-end delay.

Betweenness centrality metrics usually underestimate the importance of nodes that are close to shortest paths but do not exactly fall on them. In [16], [41], we reevaluate the importance of such nodes and propose the ρ-geodesic betweenness centrality, a novel metric that assigns weights to paths (and, consequently, to nodes on these paths) according to how close they are to shortest paths. The paths that are just slightly longer than the shortest one are defined as quasi-shortest paths, and they are able to increase or to decrease the importance of a node according to how often the node falls on them. We compare the proposed metric with the traditional, distance-scaled, and random walk betweenness centralities using four network datasets with distinct characteristics. The results show that the proposed metric, besides better assessing the topological role of a node, is also able to maintain the rank position of nodes overtime compared to the other metrics; this means that network dynamics affect less our metric than others. Such a property could help avoid, for instance, the waste of resources caused when data follow only the shortest paths and reduce associated costs.

To illustrate the data routing over a real demo, in [39], we show a webcam view of the testbed with remotely controlled lighting (ceiling LEDs and a mobile robot carrying a torch). A tight grid of 256 sensors will be used to collect light information. We display live updates of the resulting heatmap, live energy profiles and other performance metrics.

7.2. Security, Safety and Verification

Participants: Nathalie Mitton, Allan Blanchard, Simon Duquennoy.

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, [12] 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.

IoT applications often utilize the cloud to store and provide ubiquitous access to collected data. This naturally facilitates data sharing with third-party services and other users, but bears privacy risks, due to data breaches or unauthorized trades with user data. To address these concerns, we present Pilatus, a data protection platform where the cloud stores only encrypted data, yet is still able to process certain queries (e.g., range, sum). More importantly, Pilatus features a novel encrypted data sharing scheme based on re-encryption, with revocation capabilities and in situ key-update. The solution proposed in [37], [56] includes a suite of novel techniques that enable efficient partially homomorphic encryption, decryption, and sharing. We present performance optimizations that render these cryptographic tools practical for mobile platforms. We implement a prototype of Pilatus and evaluate it thoroughly. Our optimizations achieve a performance gain within one order of magnitude compared to state-of-the-art realizations; mobile devices can decrypt hundreds of data points in a few hundred milliseconds. Moreover, we discuss practical considerations through two example mobile applications (Fitbit and Ava) that run Pilatus on real-world data.

7.3. 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.

Bearing that in mind, we envisaged the possibility to leverage in a synergic way the Software Defined Radio (SDR) paradigm and the controlled mobility of mobiles wireless devices in order to adopt the most suitable modulation scheme and the best position with the objective to improve the network connectivity and coverage area [13].

On the other hand, spectrum scarcity and growing demand of nanocommunication systems have motivated researchers to investigation novel channel models in different portions of spectrum, namely in the THz band.

The fervent research activity in this direction is also motivated by the recent technological advances in new types of materials (e.g. graphene, novel metamaterials) presenting specific features suitable for this frequency spectrum and for the growing demand of downsizing antenna dimension.

In [15], we have investigated the chirality effect and Giant Optical Activity (GOA) and their impact when assuming different power allocation techniques.

On the other hand, when the nature of the matter and the interactions of specific particles and (quasi)particles such as phonons and photons are considered, there is a growing interest to investigate alternative communication paradigms based on these specific phenomena. In [14] we have performed an information theory analysis based on the generation of phonons elements when a source power as a cellphone is applied on biological tissue. The lesson learnt in this works is based on the consideration that where is heat transport it is possible to associate a communication paradigm. Follow this reasoning, in [50] we have revised the most recent advancement in terms of Visible Light Communication (VLC). Specifically, we have investigated Software Defined paradigm for VLC, in order to sketch out the main research directions for this new research domain.

7.4. Self-Organization

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

7.4.1. Bayesian communications

In the last few years, Internet has become a very important vector of information sharing. Beyond the interconnection of computers and devices, there is still an important expansion capability, thanks to the capacity to interconnect heterogeneous devices. This extension of Internet known as Internet of Things (IoT) leads to (inter)connection of billions of objects. Nevertheless, IoT paradigm raises many challenges, such as the need to manage a massive amount of data generated by sensing devices. It was observed that, with the increase of sensors density, the redundancy of data increases. Thus, uploading raw data to the cloud can become extremely inefficient.

In order to address this issue, we proposed a Bayesian Inference Approach (BIA), able to remove a great amount of spatio-temporal correlated data [46], [10], [35].

In order to validate these approaches it was considered that experiments in real-world scenarios were needed. More specifically, we considered indoor tests in [46] and agricultural/outdoor experiments in [47]

7.4.2. Alert diffusion

Opportunistic communications present a promising solution as a disaster network recovery in emergency situations such as hurricanes, earthquakes and floods where infrastructure might be damaged. Recent works have proposed opportunistic-based alert diffusion approaches useful for trapped survivors. However, two main features were left behind. On the one hand, these works do not consider the assortment of networks integrated in mobile devices (e.g. WiFi-Direct, WiFi ad-hoc, cellular, bluetooth) and the choice of the network interface is left to the user who has no idea what is best or might be in a physical or psychological distress that impede the efficient selection. On the other hand, most of these works are based on selfish diffusion which might drain quickly the battery power. Moreover, they do not consider various energy level, which obviously influences the alert diffusion scheme. [17], [27], [28], [44] propose COPE and its demo, a cooperative opportunistic alert diffusion approach for disaster scenario that considers mobile devices that come with multiple network interfaces and with various battery power level. In order to maintain mobile devices alive longer, survivors form cliques and zones in which they diffuse alternately and periodically alert messages until reaching a potential rescuers team. Simulation results show that COPE largely outperforms the selfish diffusion scheme in terms of energy consumption while guaranteeing an important alert delivery success.

7.4.3. Consensus-based Leader election

In low-power wireless networking, new applications such as cooperative robots or industrial closed-loop control demand for network-wide consensus at low-latency and high reliability. Distributed consensus protocols is a mature eld of research in a wired context, but has received little attention in low-power wireless settings. In [21], [55], we present A^2: Agreement in the Air, a system that brings distributed consensus to low-power multi-hop networks. A^2 introduces Synchrotron, a synchronous transmissions kernel that builds a robust mesh by exploiting the capture effect, frequency hopping with parallel channels, and link-layer security. A^2 builds on top of this reliable base layer and enables the two-and three-phase commit protocols, as well as network services such as group membership, hopping sequence distribution and re-keying. We evaluate A^2 on four public testbeds with different deployment densities and sizes. A^2 requires only 475 ms to complete a two-phase commit over 180 nodes. The resulting duty cycle is 0.5% for 1-minute intervals. We show that A^2 achieves zero losses end-to-end over long experiments, representing millions of data points. When adding controlled failures, we show that two-phase commit ensures transaction consistency in A^2 while three-phase commit provides liveness at the expense of inconsistency under specific failure scenarios.

7.5. Smart Cities

Participants: Nathalie Mitton, Valeria Loscri, Abdoul Aziz Mbacke.

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. Based on these premises, we propose in [32] intelligent and adaptive filtering mechanisms as a service (FIlAAS) integrated in the VITAL-OS middleware and will show their feasibility and their effectiveness in the smart city context.

Connecting all these devices to a cloud encompasses the execution of many network tasks at the *edge* and in particular on constrained gateways by low computational resources capabilities. Moreover, these gateways have to deal with the plethora of disparate technologies available in the IoT landscape. To cope with these issues, we introduce a Lightweight Edge Gateway for the Internet of Things (LEGIoT) architecture [18]. It relies on the modular characteristic of microservices and the flexibility of lightweight virtualization technologies to guarantee an extensible and flexible solution. In particular, by combining the implementation of specific frameworks and the benefits of container-based virtualization, our proposal enhances the suitability of edge gateways towards a wide variety of IoT protocols/applications (for both downlink and uplink) enabling an optimized resource management and taking into account requirements such as energy efficiency, multi-tenancy, and interoperability. LEGIoT is designed to be hardware agnostic and its implementation has been tested within a real sensor network. Achieved results demonstrate its scalability and suitability to host different applications meant to provide a wide range of IoT services.

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 [51], [52], [53], [54].

7.6. Smart Grids

Participants: Nathalie Mitton, Jad Nassar.

The Internet of Thing is a on going revolution which promises to interconnect most of our world with billions of connected devices. Hence, data routing and prioritization in IoT is a main challenge in this gigantic network. This is all the more true for the Smart Grids data management where heterogeneous applications and signaling messages have different requirements in terms of reliability, latency and priority. So far, standards on Smart Grid have recommended the use of RPL (Routing Protocol for Low-Power and Lossy networks) protocol for distributing commands over the grid. RPL assures Quality of Service (QoS) 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 function and its associated metric does not allow for QoS differentiation. In order to overcome this, in [31], [45] we propose *OFQS* an objective function with a multi-objective metric that considers the delay and the remaining energy in the battery nodes alongside with the quality of the links. Our function automatically adapts to the number of instances (traffic classes) providing a QoS differentiation based on the different Smart Grid applications requirements. Simulations show that our proposal provides a low packet delivery latency and a higher packet delivery ratio while extending the lifetime of the network compared to literature solutions.

In the same spirit, we have proposed QoSGRACO [36], a routing protocol which takes account of the Quality of Service (QoS) of NAN's traffic by using colored pheromones ant colonies. We show, through simulations, that QoS-GRACO is able to satisfy NAN's requirements, especially in terms of delay and reliability.

7.7. Vehicular networks and smart car platforms

Participants: Nathalie Mitton, Valeria Loscri.

Roadside Units (RSUs) are an important component of vehicular ad hoc networks (VANETs). In a VANET, RSUs are deployed at intersections or some points along a road to help improve network connectivity, data delivery, and thus network services to vehicles. Therefore, RSU deployment has a big impact on the network performance and becomes an important issue in the design of a VANET. In general, RSU deployment is costly. To achieve a good tradeoff between deployment cost and network performance, it is expected to optimize the deployment of RSUs in a VANET. To address this challenge, considerable research work has been conducted on the optimization of RSU deployment for VANET.

To optimize the RSU deployment, the notion of centrality in a social network to RSU deployment has been introduced [40], and use it to measure the importance of an RSU position candidate in RSU deployment. Based on the notion of centrality, we propose a centrality-based RSU deployment approach and formulate the RSU deployment problem as a linear programing problem with the objective to maximize the total centrality of all position candidates selected for RSU deployment under the constraint of a given deployment budget.

Nowadays, many vehicular applications are emerging, arising from entertainment and road safety. The paradigm of Internet of Vehicles (IOV) is proliferating and it is an inevitable convergence of the existing mobile Internet and the concept of Internet-of-Things (IoT). In IoV, Internet of applications go on "wheels", then converting the existing vehicles into "digital cars" equipped with several technologies and sensors. The meeting of mobility with social interactions rises to a particular class of social networks, Vehicular Social Networks [20]. Vehicular social networks are online social networks where the social interactions are built *on-the-fly*, due to the opportunistic links in vehicular networks. In this context, the reliability of message dissemination becomes very important and the adding of social components allows the definition of trust parameter to be directly included in the forwarding technique.

On the other hand, the huge amount of sensors deployed in a car, are arising new types of applications and services, even if data are "confined" in the car.

However, with the increasing number of functionalities, computing and communication resources, that have to be handled by the On Board Unit (OBU), is constantly growing. OBUs are embedded systems with limited hardware resources and a critical software design that makes also a simple update procedure a not trivial operation. These constraints are combined with the typical software lifetime, which is much shorter than the lifetime of mechanical and technological components. Bearing all these points in mind, we have identified in the use of lightweight virtualization technologies a suitable mechanism, which allows to design an OBU that can satisfy several requirements in terms of efficient software and hard- ware resources management [29], [30].

7.8. Robots

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

With the advent of the Internet of Things (IoT) and robotics on one hand and of Cloud Computing on the other hand, people have witnessed a shift in the way they can interact and communicate with their things and their environment. Together with these main concepts, the vision of Robot as a Service can be considered and applied to different contexts and domains. Unfortunately, Remote programming and control of heterogeneous robots are not always possible, which ends up as difficult tasks requiring advanced skills. in order to face these challenges, Open Mobile Cloud Robotics Interface (OMCRI) has been proposed in [26]. It represents an extension of OCCI platform based on the Robot-as-Service paradigm. OMCRI presents interesting features such as modularity and extensibility.

Another interesting concept recently introduced by ABY Research, is the Internet of Robotic Things (IoRT), representing a dynamic actuation. In [48], to realize an efficient deployment and an effective coverage by also keeping a good communication quality, we have proposed an IoT- based and neural network control scheme. The neural network controller, in turn, is completely distributed and mimics perfectly the IoT-based approach. Results show that our approaches are efficient, in terms of convergence time, connectivity, and energy consumption.

7.9. MAC mechanisms

Participants: Nathalie Mitton, Simon Duquennoy, Viktor Toldov.

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. Interference not only negatively affect the Quality of Service, but also causes energy losses, which is especially unfavorable for the energy constrained Wireless Sensor Networks (WSN). In [11], the impact of the interference on the energy consumption of the WSN nodes is studied experimentally. The experimental results were used to estimate the lifetime of WSN nodes under conditions of different levels of interference. Then, a Thompson sampling based Cognitive Radio adaptive solution is proposed and evaluated via both, simulation and hardware implementation. Results show that this approach finds the best channel quicker than other state of the art solutions. Based on a set of experimentations, an adaptive WildMAC MAC layer protocol is proposed and evaluated experimentally.

In parallel, synchronized communication has recently emerged as a prime option for low-power critical applications. Solutions such as Glossy or Time Slotted Channel Hopping (TSCH) have demonstrated end-to-end reliability upwards of 99.9%. In this context, the IETF Working Group 6TiSCH is currently standardizing the mechanisms to use TSCH in low-power IPv6 scenarios [42] identifies a number of challenges when it comes to implementing the 6TiSCH stack [43]. It shows how these challenges can be addressed with practical solutions for locking, queuing, scheduling and other aspects. With this implementation as an enabler, we present an experimental validation and comparison with state-of-the-art MAC protocols. We conduct fine-grained energy profiling, showing the impact of link-layer security on packet transmission. We evaluate distributed time synchronization in a 340-node testbed, and demonstrate that tight synchronization (hundreds of microseconds) can be achieved at very low cost (0.3% duty cycle, 0.008% channel utilization). We finally compare TSCH against traditional MAC layers: low-power listening (LPL) and CSMA, in terms of reliability, latency and energy. We show that with proper scheduling, TSCH achieves by far the highest reliability, and outperforms LPL in both energy and latency.

7.10. RFID

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

The advent of RFID (Radio Frequency Identification) has allowed the development of numerous applications. Indeed, solutions such as tracking of goods in large areas or sensing in smart cities are now made possible. However, such solutions encounter two main issues, first is inherent to the technology itself which is readers collisions, the second one being the gathering of read data up to a base station, potentially in a multihop fashion. While the first one has been a main research subject in the late years, the next one has not been investigated for the sole purpose of RFID, but rather for wireless adhoc networks. This multihop tag information collection must be done in regards of the application requirements but it should also care for the deployment strategy of readers to take advantage of their relative positions, coverage, reading activity and deployment density to avoid interfering between tag reading and data forwarding. To the best of our knowledge, the issue for a joint scheduling between tag reading and forwarding has never been investigated so far in the literature, although important. [24] addresses the anti-collision issue in mobile environments. In [23], we propose two new distributed, crosslayer solutions meant for the reduction of collisions and better efficiency of the RFID system but also serve as a routing solution towards a base station. Simulations show high levels of throughput while not lowering on the fairness on medium access staying above 85% in the highest deployment density with up to 500 readers, also providing a 90% data rate. In [25], we propose two distributed and efficient solutions for dense mobile deployments of RFID systems. mDEFAR is an adaptation of a previous work highly performing in terms of collisions reduction, efficiency and fairness in dense static deployments. CORA is more of a locally mutual solution where each reader relies on its neighborhood to enable itself or not. Using a beaconing mechanism, each reader is able to identify potential (non-)colliding neighbors in a running frame and as such chooses to read or not. Performance evaluation shows high performance in terms of coverage delay for both proposals quickly achieving 100% coverage depending on the considered use case while always maintaining consistent efficiency levels above 70%. Compared to GDRA, our solutions proved to be better suited for highly dense and mobile environments, offering both higher throughput and efficiency. The results reveal that depending on the application considered, choosing either mDEFAR or CORA helps improve efficiency and coverage delay.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

- Evolution
  Participants: Gabriele Sabatino, Nathalie Mitton [correspondant].

  This collaboration aims to set up a full RFID system on the basis of AspireRFID middleware and pre-existing RFID modules issued from FUN research in the Evolution company facility and to integrate them with their IS.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. StoreConnect

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

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 yield to several publications in 2017: [50], [23], [24].

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 - Dec 2017

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 2017: [27], [28], [44].

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 [51], [52], [53], [54] and a set of publications [23], [24], [32].

9.2.2. ADT

9.2.2.1. RFunID

Participants: Ibrahim Amadou, Nathalie Mitton [correspondant], Julien Vandaele.

Duration: September 2015 - December 2017

Coordinator: Inria FUN

The purpose of this project is to deploy a large scale experimental RFID platform that enables remote programmation of RFID scenario on heterogeneous devices.

9.2.2.2. 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.

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. This project has yield to [39].

9.3. European Initiatives

9.3.1. H2020 Projects

9.3.1.1. VESSEDIA

Participants: Simon Duquennoy, Nathalie Mitton [correspondant], Allan Blanchard.

- Title: VERIFICATION ENGINEERING OF SAFETY AND SECURITY CRITICAL DYNAMIC INDUSTRIAL APPLICATIONS
- Program: H2020
- Duration: January 2017 - Dec. 202019
- 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.

9.4. International Initiatives

9.4.1. Inria International Labs

9.4.1.1. Agrinet

Participants: Abdoul Aziz Mbacke, 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.

9.4.2. Inria Associate Teams Not Involved in an Inria International Labs

9.4.2.1. DepIoT

Participants: Simon Duquennoy [correspondant], Nathalie Mitton.

Title: DepIoT: Coexistence and Security for Dependable Internet of Things

Type: North-European Inria Associate Team with SICS, Sweden

Duration: Sept 2016 - August 2018

Abstract: In order to foster the adoption of IoT technologies, dependability must be guaranteed. We will tackle this challenge by ensuring operation even in the presence of other networks sharing the same frequency band (coexistence) and by enabling a secure communication.

9.4.3. Inria International Partners

9.4.3.1. 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. This collaboration has allowed students and researchers exchanges and joint publications, among them for 2017: [30].

9.4.3.2. 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 (WCSP 2017) and joint publications, among them, in 2017 [40].

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 2017 [12].

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 2017 [14], [15], [20], [35], [47], [48].

9.4.4. Participation in Other International Programs

9.4.4.1. CROMO

Participants: Valeria Loscri, 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 [16], [41].

9.5. International Research Visitors

9.5.1. Visits of International Scientists

Several researchers have visited our group in 2017, mainly from our partner universities but not only:

- Luis Henrique Costa, Brazil, December 2017
- Milan Erdejl, UTC, France, December 2017
- Pedro Braconnot Velloso, UFRJ, Brasil, July 2017
- Essia Hamouda, Riverside University, USA, May 2017
- Felipe Lalanne, Inria Chile, June 2017
- Nicola Accettura, CNRS, March 2017
- Jacques Tiberghien, ULB, Brussels, May 2017
- Jens Gerlach, Frauhnofer FOKUS, March 2017
- Virgile Prevosto, CEA, March 2017

9.5.2. Visits to International Teams

9.5.2.1. Research Stays Abroad

- Abdoul Aziz Mbacke visited Stellenbosch university from October to December 2017
- Jad Nassar visited Metropolitan Autonomous University Cuajimalpa Campus, Mexico in September 2017

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 symposium chair of Wireless Ad hoc and Sensor Networks symposium ICNC 2017
- Farouk Mezghani was publicity chair for Pe-wasun 2017

10.1.2. Scientific Events Selection

10.1.2.1. Chair of Conference Program Committees

- Valeria Loscri is/was (co)-program chair for IoT and SmartCities MMSys 2017 and 2018, CITS 2018, Globecom 2017, NDIDO 2017 (Nouveaux Defis de l'Internet des Objets - 2017)
- Valeria Loscri is a Member of the Scientific Committee for the Conference Challenges of IoT in Digital Tools & Uses Congress
- Nathalie Mitton is/was (co)-program chair for WSCP 2017, TENCOn 2017, VTC2017, SWC 2017, Globecom 2017, IINTEC 2017, WiMob 2017 and Pe-Wasun 2017. She will be (co-)program chair for CCNC 2018, ICT 2018, CIoT 2018, ICC 2018

10.1.2.2. Member of the Conference Program Committees

- Valeria loscri is/was member in the Technical Program Committee (TPC) CoRES 2018, IoT Global Innovation Forum 2017, ICNSC 2017, NTMS 2017 and 2018, GIoTS 2017 and 2018, WF-5G'18 (2018 IEEE 1st 5G World Forum 2018), CSCN 2017, MoWNet 2017, VTC 2017, VTC 2018 - Spring, WPMC 2017, NEW2AN WSMART 2017, WiMob 2017, WPMC 2017, IoTGIF 2017
- Nathalie Mitton is/was in the Technical Program Committee (TPC) ICC 2017, VTC 2017, CSCN 2017, Cores 2017, Algotel 2017, Globecom 2017, CIoT 2017, ICT2018, ICNC 2018
- Farouk Mezghani was in the TPC of ISNCC 2017
- Antoine Gallais was/is in the TPC of ICNC 2017, GIIS 2017 and ICNC 2018

10.1.3. Journal

10.1.3.1. Guest editorial activities

- Valeria Loscri and Nathalie Mitton were co-editor of MMTC COM-SOC letter of issue on Visible Light Communications
- Nathalie Mitton was co-editor of MMTC COM-SOC letter of November issue on Industrial Wireless Sensor Networks
- Valeria Loscri is a member of the 'Research Group on IoT Communications and Networking Infrastructure' at ComSoc Communities
- Valeria Loscri was co-editor of IEEE Access journal special issue on Body Area Networks
- Valeria Loscri edited the book "Vehicular Social Networks", Taylor and Francis Group, 2017
- Valeria Loscri participated to the revue "Internet des Objets" iSTE OpenScience

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
- 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

- Valeria Loscri was invited speaker at Smart City Communication day in Sophia-Antipolis on January 2017
- Valeria Loscri was invited speaker at FET-European CIRCLE Workshop, Dublin - May 2017
- Valeria Loscri was invited speaker at Workshop on Retrofitting London and Paris via the Internet of Things - London, July 2017
- Valeria Loscri was invited speaker at IoT Week on December 2017
- Julien Vandaele was invited speaker at JDEV 2017 in Marseille in July 2017
- Antoine Gallais was invited speaker at the "Workshop sur l'IoT" in Sfax, Tunisia, in November 2017
- Nathalie Mitton was invited speaker at SOSI at INSA Rouen in September 2017
- Nathalie Mitton was invited speaker at Chile delegation in Lille in September 2017
- Nathalie Mitton was invited speaker at Journees Logistiques in Lille, September 2017
- Nathalie Mitton was invited speaker at Inria Chile - Universidad Católica Seminar in Santiago de Chile, November 2017

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 Social Network Technical Committee

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. She is also member of the scientific committees of the competitiveness cluster of MATIKEN and for CITC (International Contactless Technologies Center).

Valeria Loscri is Scientific European Responsible for Inria Lille - Nord Europe. She has been reviewer in the context of 2017 Air Force Young Investigator Research Program. She is reviewer in the context of ERC Consolidator Grant. She is reviewer for Equipes Associées. She has been involved as digital communication expert in the activities of "Convergences du Droit et du Numérique" - Bordeaux, February and September 2017.

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 March and November 2017

SPOC, EIT Digital "Technological challenges of participatory Smart cities", 5-week by the IPL CityLab@Inria team in November 2017

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

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 January 24th 2017: Viktor Toldov, Interférence et consommation dans les réseaux de capteurs, Université Lille 1, 2013-2016, Nathalie Mitton and Laurent Clavier

PhD defended on October 18th 2017: Jean Razafimandimby, Distributed Cooperation and Communication among Heterogeneous Devices, Université Lille 1, 2014-2017, Nathalie Mitton and Valeria Loscri

PhD in progress: 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 in progress: Jad Nassar, Ubiquitous networks for smart grids, Université Lille 1, 2015-2018, Nathalie Mitton and Nicolas Gouvy (HEI)

10.2.3. Juries

- PhD/HDR committees:
  - Valeria Loscri is/was reviewer of the PhD thesis of Jorge Herrera, Universidade Politecnica Valencia, Spain May 2017.
  - Nathalie Mitton is/was reviewer of the following PhD thesis:
    * Patrick Olivier Kamgueu, Univ. de Yaounde - Univ. de Lorraine, January 2018
    * Carlos Gonzales, Université de Reims, December 2017
    * Dareen Shehadeh, Telecom Bretagne, December 2017
    * Arbia Sfar, UTC, November 2017
    * Faycal Ait Aoudia, Université de Rennes 1, September 2017
    * Laurent Reynaud, Univ. Lyon 1, March 2017
    * Jean-Gabriel Krieg, EINSEITH, February 2017
  - Nathalie Mitton was a member of the HDR defense committee
    * Antoine Gallais, Université de Strasbourg, November 2017
    * Gentian Jakllari, EINSEEIHT, November 2017
- Researcher selection committees:
  - Nathalie Mitton was member of the Inria CR2 Lille competition selection committee
  - Nathalie Mitton was member of the Professor competition selection committee at UPMC and ENSEITH
  - Nathalie Mitton was member of the Assistant Professor (MdC) at Universités de Marseille, Valenciennes and Strasbourg and INSA Lyon
- Nathalie Mitton is a member of the scientific committee of "Convergences du Droit et du Numérique"

10.3. Popularization

- Simon Duquennoy and Nathalie Mitton gave a talk at "30 min de Sciences" in June and December 2017 resp.
- Valeria Loscri, Antonio Costanzo and Nathalie Mitton gave a talk in the context of Nuneriqu'elle - Euratechnologies, November 2017

- Matthieu Berthome, Jad Nassar, Ibrahim Amadou, Antonio Costanzo, Antoine Gallais, Nathalie Mitton, Farouk Mezghani and Julien Vandaele gave some talks in high schools for the "Fête de la Science" in October 2017
- Nathalie Mitton gave an interview for France Info on connected objects

11. Bibliography

Major publications by the team in recent years

[1] F. GUERRIERO, V. LOSCRÍ, P. PACE, R. SURACE. *Neural Networks and SDR Modulation schemes for wireless mobile nodes: a synergic approach*, in "Ad Hoc Networks", 2017 [*DOI :* 10.1016/J.ADHOC.2016.09.016], https://hal.inria.fr/hal-01386749

[2] A. MARIA VEGNI, V. LOSCRÍ. *Analysis of the Chirality Effects on the Capacity of Wireless Communication Systems in the THz band*, in "IEEE Transactions on Wireless Communications", 2017, vol. 1, https://hal.archives-ouvertes.fr/hal-01589268

[3] A. A. MBACKÉ, N. MITTON, H. RIVANO. *RFID Anticollision in Dense Mobile Environments*, in "WCNC 2017 - IEEE Wireless Communications and Networking Conference", San Francisco, United States, March 2017, https://hal.inria.fr/hal-01418170

[4] D. S. V. MEDEIROS, M. ELIAS MITRE CAMPISTA, N. MITTON, M. DIAS DE AMORIM, G. PUJOLLE. *The Power of Quasi-Shortest Paths: ρ-Geodesic Betweenness Centrality*, in "IEEE Transactions on Network Science and Engineering", December 2017 [*DOI :* 10.1109/TNSE.2017.2708705], https://hal.archives-ouvertes.fr/hal-01524360

[5] F. MEZGHANI, N. MITTON. *Alternative opportunistic alert diffusion to support infrastructure failure during disasters*, in "Sensors", October 2017 [*DOI :* 10.3390/S17102370], https://hal.inria.fr/hal-01614744

[6] R. MORABITO, R. PETROLO, V. LOSCRÍ, N. MITTON, G. RUGGERI, A. MOLINARO. *Lightweight Virtualization as Enabling Technology for Future Smart Cars*, in "International Symposium on Integrated Network Management (IM)", Lisbonne, Portugal, May 2017, https://hal.inria.fr/hal-01482721

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[8] H. SHAFAGH, A. HITHNAWI, L. BURKHALTER, P. FISCHLI, S. DUQUENNOY. *Secure Sharing of Partially Homomorphic Encrypted IoT Data*, in "ACM SenSys 2017 - 15th ACM Conference on Embedded Networked Sensor Systems", Delft, Netherlands, November 2017 [*DOI :* 10.1145/3131672.3131697], https://hal.inria.fr/hal-01581495

[9] V. TOLDOV, L. CLAVIER, V. LOSCRÍ, N. MITTON. *A Thompson Sampling Approach to Channel Exploration-Exploitation Problem in Multihop Cognitive Radio Networks*, in "27th annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)", Valencia, Spain, September 2016, https://hal.inria.fr/hal-01355002

Publications of the year

Doctoral Dissertations and Habilitation Theses

[10] C. RAZAFIMANDIMBY. *Toward Internet of Heterogeneous Things : Wireless communication maintenance and efficient data sharing among devices*, Université Lille 1 - Sciences et Technologies, October 2017, https://hal.archives-ouvertes.fr/tel-01622920

[11] V. TOLDOV. *Adaptive MAC layer for interference limited WSN*, Université Lille 1 Sciences et technologies, January 2017, https://hal.inria.fr/tel-01493094

Articles in International Peer-Reviewed Journals

[12] A. DAS, A. SEN, C. QIAO, N. GHANI, N. MITTON. *RAPTOR: a network tool for mitigating the impactof spatially correlated failures in infrastructure networks*, in "Annals of Telecommunications - annales des télécommunications", August 2017, pp. 1-12, https://hal.inria.fr/hal-01584867

[13] F. GUERRIERO, V. LOSCRÍ, P. PACE, R. SURACE. *Neural Networks and SDR Modulation schemes for wireless mobile nodes: a synergic approach*, in "Ad Hoc Networks", 2017 [*DOI :* 10.1016/J.ADHOC.2016.09.016], https://hal.inria.fr/hal-01386749

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[24] A. A. MBACKÉ, N. MITTON, H. RIVANO. *Protocoles d'anticollision de lecteurs RFID pour des déploiements denses et mobiles*, in "CoRes 2017- 2ème Rencontres Francophones sur la Conception de Protocoles, l'Évaluation de Performance et l'Expérimentation des Réseaux de Communication", Quiberon, France, May 2017, https://hal.inria.fr/hal-01515418

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