RESEARCH CENTRE

Lille - Nord Europe

2020
ACTIVITY REPORT

Project-Team
FUN

self-organizing Future Ubiquitous Network

DOMAIN

Networks, Systems and Services, Distributed Computing

THEME

Networks and Telecommunications

Contents

Project-Team FUN

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

Keywords

Computer sciences and digital sciences

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

A1.2.8. – Network security

A1.4. – Ubiquitous Systems

A5.10.6. – Swarm robotics

Other research topics and application domains

B2.3. – Epidemiology

B2.8. – Sports, performance, motor skills

B3.5. – Agronomy

B5.1. – Factory of the future

B5.6. – Robotic systems

B5.9. – Industrial maintenance

B6.4. – Internet of things

B7. – Transport and logistics

B7.2. – Smart travel

B7.2.1. – Smart vehicles

B7.2.2. – Smart road

B8. – Smart Cities and Territories

B8.1. – Smart building/home

B8.1.2. – Sensor networks for smart buildings

B8.2. – Connected city

1 Team members, visitors, external collaborators

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- Nathalie Mitton [Team leader, Inria, Senior Researcher, HDR]
- Valeria Loscri [Inria, Researcher, HDR]

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- Antonio Costanzo [Inria]
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- Yasir Saleem Shaikh [Inria, from Feb 2020]

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- Nina Santi [Inria, from Oct 2020]
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2 Overall objectives

2.1 Context

The Internet of Things is a large concept with multiple definitions. However, the main definitions 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, self-organized and dynamically adapting to their environment. The devices that compose CPNs can be sensors, small robots, RFID (Radio Frequency IDentification) readers or tags.

Objects or things can now communicate with their environment through the use for instance of an RFID 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 (with 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 [60].

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

2.2 Motivation

To date, many self-organizing techniques for wireless sensor networks and mobile ad hoc networks are proposed in the literature and also by the FUN research group. Some of them are very efficient for routing [48], discovering neighborhood [52, 53], scheduling activity and coverage [50], localization [39, 42, 62] 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 [49, 70] and at the MAC layer level [57]. 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 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.

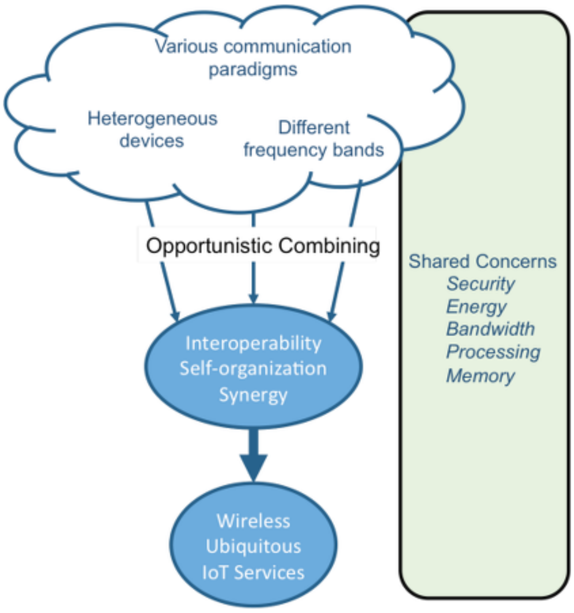

Figure 1: FUN's overal goal.

> ***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.

Objectives and methodology

To reach our overall goal, we will pursue the two following objectives. 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.

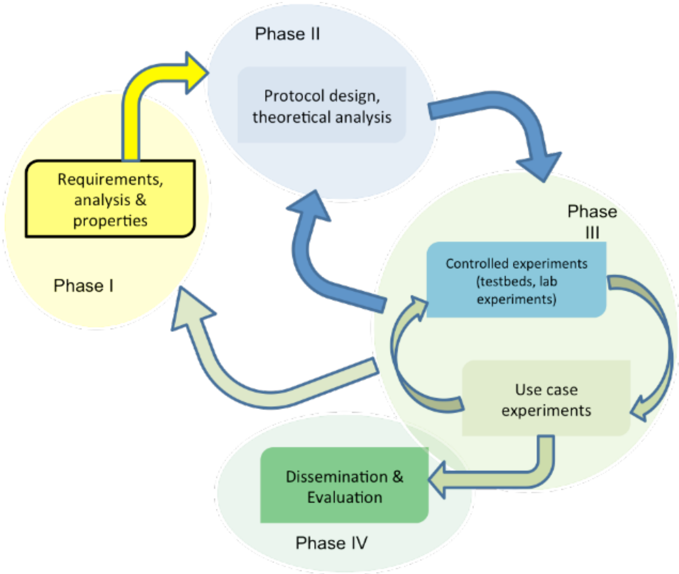

Figure 2: Methodology to be applied in FUN.

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 well adapted **cross-layer** integrated protocols [72]. 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 [47, 72].

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 [38, 63]. On the same idea, when specific features are available like controlled mobility, we will exploit it to improve connectivity or coverage quality like in [51, 59, 58].

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 [67]. 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 [44] 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 [40, 41, 45].

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 [46]. 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

The FUN research can be applied in various applications. We only cite here the ones on which we currently focus.

- Smart Cities: IoT devices are more and more deployed in smart cities to make it more environment and citizen compliant. We have been active in the IPL CityLab project and H2020 VITAL project. Examples of our contributions are: [7] and [64, 65, 66, 68].
- Smart Agriculture: Wireless sensors are more and more deployed in remote fields and livestock for an accurate monitoring. This generates new challenges in terms of reliability, energy consumption and range. Examples of our contributions are [10, 14, 15, 20, 27, 30, 31, 32, 35].
- Vehicular networks: vehicules become smarter and smarter, providing new useful services. But communications between vehicles and between vehicles and road infrastructures raise a lot of challenges. Examples of our contributions in this field are: [2, 8] and [43, 54, 71, 73, 74].
- Smart infrastructures: FUN research can also apply to different urban and civil infrastructure like road monitoring (as discussions started with CEREMA) or Smart Grids. Examples of our contributions in this field are [61, 69].
- Logistic and traceability: RFID and IoT are the key technologies to enable large scale traceability. Examples of our contributions in this field are [55, 56, 57].

5 Highlights of the year

5.1 Awards

Nathalie Mitton has been nominated as one of the 10 2020 N^{2}Women: Stars in Computer Networking and Communications.

6 New results

6.1 Security

Participants Emilie Bout, Valeria Loscri, Nathalie Mitton, Edward Staddon.

The inherent openness of the wireless transmission medium has made wireless communication systems particularly vulnerable to a multitude of attacks. Furthermore, with the incorporation of IoT into Critical Infrastructure (CI) hardware and applications, the protection of not only the systems but the citizens themselves has become paramount. One of the biggest threats to these communication systems is the jamming attack, in part by its ease of implementation. This kind of attack consists in intentionally interfering with the communication medium to keep it occupied or to corrupt data in transit to cause a denial of service (DoS). The effectiveness of a jamming attack is based on many parameters such as the transmission properties (e.g., modulation, power), the characteristics of the network (e.g., routing), or also the strategy of the jammer along with its position. The last point has been the subject of a few studies in recent years under the name of jammer placement problem. The goal of this problem is to find the optimal position of the jammer to minimize the throughput of the network. Studying this dilemma would make it possible to improve detection methods, such as the location of jamming nodes. In [21], we have studied the impact of the specific position of a jammer and the effectiveness of different attacks, namely constant, reactive and random based on the specific distance of the jamming attacker. Results have shown that the performance of the type of attacks are influenced by the distance between the attacker and the transmitter node under attack.

6.2 Visible Light Communication

Participants Antonio Costanzo, Valeria Loscri, Meysam Mayahi.

The dual use of light for illumination and for wireless information has recently raised a greater attention from the wireless networks community. Visible Light Communication (VLC) is recognized as a green communication technology solution and as a safe technology to human people in comparison of Radio Frequency (RF) based technology. The growing research interest in optical wireless spectrum relies on the need to find a complementary technology to the conventional one based on RF in order to overcome the spectrum scarcity and to meet the high data rates required. Among the positive characteristics associated to VLC, are a wider bandwidth, an inherent security and no RF electromagnetic frequency interference. It is wellknown that VLC is vulnerable to the optical interference noise, but no works have been done for characterizing the interference of VLC with Radio Frequency (RF) waves. In [22], by the means of extensive experimental resutls, we demonstrated that there is interefrence at certain specific RF frequencies and we evaluated the impact. In particular, we considered a completely controlled suite of experiments in an anechoic chamber, with and without external interference as an antenna transmitting a signal at different frequencies up to 1 GHz and at different powers. Results are surprising, since at certain frequencies, we detect very high interference. In order to evaluate the impact of the interference from a communication point of view, we have implemented different modulation schemes, m-Pulse Position Modulation (mPPM, with $m = 2, 4, 8, 16$) and we have considered different scenarios to identify the specific conditions impacting on the communication system.

6.3 Emerging Communication Technologies

Participants Valeria Loscri, Mohammad Ojaroudi, Carola Rizza.

In the very recent years, research community is devoting a lot of attention on emerging communication paradigms based on the exploitation of metamaterial and the interaction of the signals with this specific material. In particular, metamaterial are characterized with features not existing in nature, that can be efficacely exploited for controlling and manipulating the wavefront. Metasurfaces are a specific type of metamaterial and the integration of metasurface in a wireless communication system allows the implementation of a revolutionary communication paradigm, by integrating the environment by design instead of consiering it as a passive and often negative element to suffer. The great point is that this concept can be applied to various contexts and applications ranging from biological contexts [33] to outdoor wireless communications systems [18, 28]. Specific types of structures can be designed for responding to the specific needs as has been shown in [33], where a new ultrathin metasurface structure based on an inverted T-shaped strip surrounded by SRR for using in biosensing applications in THz-TDS has been proposed. By inserting the inverted T-shaped strip inside the SRR structure, the coupling between the inverted T-shaped strip and the SRR is enhanced, with an improved transmission impact at resonance frequency of 0.6 THz. Thorugh simulation results, it has been shown that is possibile to achieve a 65 GHz/RIU sensitivity factor, which proves that the proposed metasurface structure is a good candidate for biosensing applications in THz-TDS. The great versatility of RIM-based paradigm allows the characterization of specific features of the system in order to “translate” them in specific design characteristic of the metasurfaces. This approach has been followed in [28, 33].

6.4 On the use of LoRa

Participants Brandon Foubert, Nathalie Mitton.

Recently, new technologies that enable low-power and long-range communications have emerged. These technologies, in opposition to more traditional communication technologies rather defined as “short range”, allow kilometer-wide wireless communications. Long-range technologies are used to form Low-Power Wide-Area Networks (LPWAN). Many LPWAN technologies are available, and they offer different performances, business models etc., answering different applications’ needs. This makes it hard to find the right tool for a specific use case. In [15], we present a survey about the long-range technologies available presently as well as the technical characteristics they offer. Then we propose a discussion about the energy consumption of each alternative and which one may be most adapted depending on the use case requirements and expectations, as well as guidelines to choose the best suited technology.

Among these technologies is LoRa. LoRa (Long Range) is a low-power wide-area network (LPWAN) protocol developed by Semtech and is gaining more and more attention these last years.

We consider in [27] the technique of carrier sensing for application in a LoRa mesh network aimed at wildlife monitoring. A key challenge in this application is to limit collisions in order to increase the channel capacity. Since CSMA is very rarely applied in LoRa-based networks, our goal is to determine its practical viability. We evaluate the LoRa Channel Activity Detection (CAD) mechanism under laboratory and field conditions. Our results show that both preamble and payload symbols are detectable even at distances exceeding 4 km. Detecting LoRa preamble symbols had a SNR advantage of between 1 and 2 dB over payload symbols. Furthermore, we find that by taking at least eight consecutive CAD measurements, a clear channel assessment (CCA) comparable to the LoRa frame reception rate can be achieved between two nodes.

In the context of covering areas based on reduced infrastructure and with a low energy consumption, LPWAN plays an important role. In [14], we investigate LoRa, a low-power technology offering large coverage, but low transmission rates. Radio range and data rate are tunable by using different spreading factors and coding rates, which are configuration parameters of the LoRa physical layer. LoRa can cover large areas but variations in the environment affect link quality. This work studies the propagation of LoRa signals in forest, urban, and suburban vehicular environments. Besides being environments with variable propagation conditions, we evaluate scenarios with node mobility. To characterize the communication link, we mainly use the Received Signal Strength Indicator (RSSI), Signal to Noise Ratio (SNR), and Packet Delivery Ratio (PDR). As for node mobility, speeds are chosen according to prospective applications. Our results show that the link reaches up to 250 m in the forest scenario, while in the vehicular scenario it reaches up to 2 km. In contrast, in scenarios with high-density buildings and human activity, the maximum range of the link reaches up to 200 m in the urban scenario.

6.5 Mobile Edge computing

Participants Nathalie Mitton, Nina Santi.

The potential offered by the abundance of sensors, actuators, and communications in the IoT era is hindered by the limited computational capacity of local nodes. Several key challenges should be addressed to optimally and jointly exploit the network, computing, and storage resources, guaranteeing at the same time feasibility for time-critical and mission-critical tasks. We propose the DRUID-NET framework to take upon these challenges by dynamically distributing resources when the demand is rapidly varying. It includes analytic dynamical modeling of the resources, offered workload, and networking environment, incorporating phenomena typically met in wireless communications and mobile edge computing, together with new estimators of time-varying profiles. Building on this framework [3], we aim to develop novel resource allocation mechanisms that explicitly include service differentiation and context-awareness, being capable of guaranteeing well-defined Quality of Service (QoS) metrics. DRUID-NET goes beyond the state of the art in the design of control algorithms by incorporating resource allocation mechanisms to the decision strategy itself. To achieve these breakthroughs, we combine tools from Automata and Graph theory, Machine Learning, Modern Control Theory, and Network Theory. DRUID-NET constitutes the first truly holistic, multidisciplinary approach that extends recent, albeit fragmented results from all aforementioned fields, thus bridging the gap between efforts of different communities. We also presented the different challenges raised by such a framework though a set of tutorials [37] including self-deployment adaptive MEC resources.

6.6 Vehicular networks and applications

Participants Valeria Loscri, Nathalie Mitton, Mohammad Ojaroudi Parchin, Carola Rizza, Yasir Saleem Shaikh.

Vehicular communications networks (VCNs) are created by vehicles equipped with short and medium range wireless communication technology. Vehicular networks may include vehicle-to-infrastructure and vehicle-to-vehicle communications. The research interest on VCNs is always very high and is incresing in the latest years by considering the plethora of important applications and services, ranging from active safety or safety of life applications to traffic information, music/maps download and multi-hop internet connection that can be realized by the means of this paradigm. Recently, the promises of wireless communications to support vehicular safety applications have led to several national/international projects around the world. Among the safety applications, high accuracy of position is a fundamental requirement in order to effectively accomplish safety applications. For that, in [8] a GNSS positioning system that uses Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications to cooperatively determine absolute and relative position of the ego-vehicle with enough precision was developed. On the other hand, the increasing requirement of higher bandwidth and data rate require the adoption of new emerging communication technology to be developed as in [28], where the high potentiality of inclusion of a mteasurface in the vehicular wireless network is demonstrated. In order to make the new communication technology effective, efficient forwarding mechanisms have to be designed, by accouting specific features of trace duration such as in [16]. In particular, we study the impact that contact duration has on the broadcast of messages, showing that splitting a large message into smaller parts can improve its diffusion. Based on this idea, we propose an extension of the epidemic protocol called Xpread. The efficiency of this protocol mainly depends on how the original message is partitioned. Thus, in order to evaluate the impact and the efficiency of the partition scheme, we have developed an analytical model based on Population Processes, showing that a fixed size partition is the best option, while also providing a simple expression to obtain the optimal size.

6.7 Data Prediction

Participants Nathalie Mitton, Christian Salim.

Nowadays, climate change is one of the numerous factors affecting the agricultural sector. Optimising the usage of natural resources is one of the challenges this sector faces. For this reason, it could be necessary to locally monitor weather data and soil conditions to make faster and better decisions locally adapted to the crop. Wireless sensor networks (WSNs) can serve as a monitoring system for these types of parameters. However, in WSNs, sensor nodes suffer from limited energy resources. The process of sending a large amount of data from the nodes to the sink results in high energy consumption at the sensor node and significant use of network bandwidth, which reduces the lifetime of the overall network and increases the number of costly interference. Data reduction is one of the solutions for this kind of challenges. In [20], data correlation is investigated and combined with a data prediction technique in order to avoid sending data that could be retrieved mathematically in the objective to reduce the energy consumed by sensor nodes and the bandwidth occupation. The data correlation and prediction technique [35] is proposed both at the sensor node level and at the sink level based on a Pearson algorithm. The aim of this approach is to reduce the amount of transmitted data to the sink, depending on the degree of correlation between different parameters. This data reduction maintains the accuracy of the information while reducing the amount of data sent from the nodes to the sink. It is then combined with a machine learning based technique [30] to reduce the amount of data to send even more. This approach is validated through simulations on MATLAB using real meteorological data-sets from Weather-Underground sensor network. The results show the validity of our approach which reduces the amount of data by a percentage up to eighty eight percent for a maximum losse in accuracy of seven percent.

6.8 On the use of multi technologies

Participants Brandon Foubert, Nathalie Mitton.

Leveraging multi technologies allow to extend the network coverage and efficiency. We investigate this research direction in two main use cases: rescue operations in which multitechnologies allow to extend the network lifetime and smart agriculture in which it allows to extend coverage and reliability.

Rescue operation: Disaster scenarios have caused crisis situations that have threatened human life. Particularly, during such events, public communication infrastructure get damaged which impedes rescue operations and it took a considerable time and effort (days to weeks) before a reliable communication infrastructure could be restored. Therefore, there is a tremendous need to quickly deploy communication networks to assist rescue operations for sharing emergency data (e.g. alert message, rescue instruction). The work in [17] evaluates the performances of smartphones and leverages the ubiquitous presence of mobile devices during disaster scenarios to assist and speed up rescue operations. It proposes a cooperative communication scheme that exploits available network technologies and takes various energy levels into account. A multi-tiers network architecture is proposed targeting a balanced energy consumption in the whole network. Moreover, it introduces a lifetime efficient data collection scheme that employs drones to scan the disaster area and to visit mobile devices and relay their data. Extensive simulations have been conducted and results show that the proposed scheme allows to keep mobile devices alive as long as possible by saving a considerable energy and guarantees a short drone-path for data relaying.

Smart agriculture: Wireless sensor networks (WSN) are composed of hardware constrained and battery-powered devices that communicate wirelessly. WSN find more and more applications, but their deployment is limited among others by the range and the throughput of the communication technology used. Several technologies are available nowadays, with various performances, cost and coverage. One solution to overcome the deployment limitations and in some cases extend the coverage would be to dynamically select the technology based on the data requirements, environment, geographic location, etc. Thus we need multi-technologies WSN devices and efficient algorithms to select the best available technology in an autonomous and local way. This issue is known as Network Interface Selection (NIS). Multi-Attribute Decision Making (MADM) methods are an efficient tool to tackle NIS. Among MADM methods is Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). However, TOPSIS suffers from a rank reversal issue, which may alter the ranking quality. Furthermore, TOPSIS method is computation heavy, which might increase the energy consumption of the constrained devices and the latency of the network. In [32], we introduce a lightweight TOPSIS-based method tailored for NIS in WSN, allowing more reliable communications.

7 Bilateral contracts and grants with industry

7.1 Bilateral contracts with industry

Sencrop

Participants Brandon Foubert, Nathalie Mitton *(contact person)*.

This collaboration aims to develop a complete multi-technology bilateral wireless communication stack for agriculture sensor networks.

8 Partnerships and cooperations

8.1 International initiatives

8.1.1 Inria International Labs

AGRINET

Title: *AGRINET - Smart Agriculture*

Duration: 2020 - 2022

Coordinator: Nathalie Mitton

Participants Brandon Foubert, Christian Salim.

Partners:

- Stellenbosch University (South Africa)

Inria contact: Nathalie Mitton

Summary: The proposed research entails the development of a flexible, rapidly deployable, biological data acquisition platform to create advanced agricultural monitoring and management techniques for better natural resource management and smart farming decision making. This platform will involve a wireless sensor network and a machine-learning based decision making tools. Sensors will be spread over the fields to sense information on soil water and nitrate concentration, temperature etc, and remotely communicate this data in a wireless way to the server which will provide decision making tools according to the kind of culture. A first objective is to create an advanced, flexible wireless sensor network for wide area agricultural data measurement, with an adaptable dynamic routing strategy including the considerations of various factors such as network availability, node positioning, message priority and resource availability (typically battery capacity) in order to optimize data transmission reliability and utilize communication resources optimally. This particular topology is proposed to enhance the total network coverage and to compensate for propagation problems that are certain to occur due to the variable crop-, climatic- and vineyard topography. A second objective to be achieved in parallel is to adapt current machine learning and pat- tern recognition algorithms to obtain an area wide and in depth view of crop and soil conditions to identify and enable optimal crop management and harvest conditions. In AgriNet, multiple inputs from multiple nodes will be integrated into a machine learning based classification framework. Complementary and inter-dependent data input will enable and enhance the detection of converging patterns, providing a completely new level of confidence in terms of early warning strategies and sensing accuracy. This could be of enormous value in presenting early warning signs of disease and other unwanted conditions for cost efficiency and increase in crop yield and quality. A third objective is the integration of the final system (wireless sensor network and machine learning based system) in a complete agriculture-oriented prototype. Pilot projects will be deployed during the last year in both France and South Africa focusing on two main cultures: potato crops and vineyards in order to stress and evaluate the AgriNet prototype. Publications issued from that project in 2020 are: [14, 15, 20, 27, 30, 31, 32, 35].

DC4SCM

Title: *DC4SCM - Data Collection for Smart Crop Management*

Duration: 2020 - 2022

Coordinator: Philippe Preux (SCOOL team)

Participants Brandon Foubert, Nathalie Mitton, Christian Salim.

Partners:
- Bihar Agricultural University (India)

Inria contact: Philippe Preux

Summary: Beyond DC4SCM our goal is to investigate the use of reinforcement learning to make recommendation of practices to farmers. To reach this goal, we need relevant data: DC4SCM is precisely about investigating the features that are relevant and may actually be collected *in situ*: in a nutshell, the goal of DC4SCM is to investigate the following question: what is the ideal, yet within reach, dataset for our longer term goal?

8.1.2 Informal international partners

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 2020 [1, 16].

8.2 International research visitors

8.2.1 Visits of international scientists

Remy Grunblatt from Université de Lyon visited us in September 2020. All other visits have been cancelled because of the sanitary situation.

8.2.2 Visits to international teams

Following the sanitary situation, all visits have been cancelled in 2020 and hopefully postponed in 2021.

Research stays abroad Following the sanitary situation, all stays abroad have been cancelled in 2020 and postponed in 2021.

8.3 European initiatives

8.3.1 FP7 & H2020 Projects

CyberSANE

Participants Valeria Loscri, Nathalie Mitton *(contact person)*, Edward Staddon.

- Title: Cyber Security Incident Handling, Warning and Response System for the European Critical Infrastructures
- Program: H2020
- Duration: September 2019 - September 2022

CyberSANE aims to enhance the security and resilience of Critical Information Infrastructures (CIIs) by providing a dynamic collaborative, warning and response system supporting and guiding security officers and operators (e.g., Incident Response professionals) to recognize, identify, dynamically analyze, forecast, treat and respond to advanced persistent threats (APTs) and handle their daily cyber incidents utilizing and combining both structured data (e.g., logs and network traffic) and unstructured data (e.g., data coming from social networks and dark web).

In achieving that aim, CyberSANE will introduce a holistic and privacy-aware approach in handling security incidents, addressing the complexity of these nets consisting of cyber assets hosted in cross-border, heterogeneous Critical Information Infrastructures (CIs). Moreover, CyberSANE is fully in-line with relevant regulations (such as the GDPR and NIS directive), which require organizations to increase their preparedness, improve their cooperation with each other, and adopt appropriate steps to manage security risks, report and handle security incidents.

8.3.2 Collaborations in European programs, except FP7 and H2020

DRUIDNET

Participants Nathalie Mitton *(contact person)*, Nina Santi.

- Title: eDge computing ResoUrce allocatIon for Dynamic NETworks
- Program: CHIST ERA
- Duration: May 2020 - September 2023

Following the NFV/SDN paradigm, DRUID-NET separates the flow of information into control and data plane. At the lowest layer, the IoT-enabled applications are deployed, and the generated workload (data flow) can be offloaded for further processing at the above EC layer, which provides essential virtualized services. The DRUID-NET framework collects information (control flow) about the status of the computing and network infrastructure at the EC level in order to create workload-resource profiles, update the performance model for every application, and realize the feedback control mechanism for the resource allocation and simultaneously implements a resource-aware control strategy for the CPS to be controlled (control flow). This holistic approach allows the application's dynamical modelling taking into account various contextual information. Furthermore, the controller co-design treats the resource allocation algorithms as application components in the virtualized services.

Publications in 2020 are [3, 37].

ELASMA

Participants Nathalie Mitton *(contact person)*.

- Title: Exploiting LoRa for smart metering applications
- Program: PHC ULYSSES
- Duration: January 2020 - December 2021

Current metering operations are labor intensive and may require a lot of time since the meters are often located at inaccessible places such as indoors or underground. This implies additional labor costs and due to this increased cost, water or electricity providers often schedule the operations every months, which leads to inaccurate measurements. A solution to this problem is to use smart meters that continuously capture data and transmit them in regular time intervals using a wireless communication protocol. Due to the distant location of the meters only a long range protocol such as LoRa could achieve remote data collection in such dense urban environment. However, current LoRa solutions such as the LoRaWAN, suffer from poor performance when the traffic increases due to the unregulated access to the medium and the presence of external interference. The purpose of the current project is to: 1) extend network coverage taking into account more network characteristics and develop multi-hop approaches, 2) develop algorithms to compute optimal (mobile) gateway positions and routes for a given network topology for efficient data collection and 3) exploit machine learning techniques to tackle external interference.

8.4 National initiatives

8.4.1 Exploratory Action

Ethicam

Participants Valeria Loscri *(contact person)*, Mohammad Ojaroudi Parchin, Carola Rizza.

- Duration: October 2019 - October 2022

The evolution of IoT towards the Internet of Everything (IoE) paradigm represents an important and emerging research direction, capable to connect and interconnect massive number of heterogeneous nodes, both inanimate and living entities, encompassing molecules, nanosensors, vehicles and people. This new paradigm demands new engineering communication solutions to overcome miniaturization and spectrum scarcity. Novel pervasive communication paradigms will be conceived by the means of a cutting edge multidisciplinary research approach integrating (quasi) particles (e.g. phonons) and specific features of the (meta)material (e.g. chirality) in the design of the communication mechanisms. In particular, by the means of the meta-materials, it would be possible to control the propagation environment. More specifically, through this paradigm it will be possible to manipulate not only the desired signals, but also the interfering signals.

Publications in 2020 are [18, 28, 33, 34].

8.4.2 Equipements d'Excellence

FIT

Participants Nathalie Mitton *(contact person)*, Julien Vandaele.

- Title: Future Internet of Things
- Type: EquipEx
- Duration: March 2010 - December 2020
- 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. FIT will continue under the bannier of SILECS to offer larger services and facilities, being connected with the Grid5k research instrument.

8.5 Regional initiatives

LumiCAR

Participants Antonio Costanzo, Valeria Loscri *(contact person)*, Meysam Mayahi.

- Title: LumiCAR
- Type: ISITE STIMULE
- Duration: October 2019 - October 2021
- Vehicle-to-Vehicle and Vehicle-RSU (Roadside Units) communication (V2X) has become a very active topic of research in recent years as it appears to be a means of improving road safety and make effective and timely intervention of road safety actors. To date, most research activities are based on the use of conventional RF technology. However, faced with multiple constraints, these vehicular communications are not always effective. In the LumiCar project we will base the V2X communication mainly on the VLC technology and we will focus on the coexistence of the VLC with other technologies. VLC has already started to work in other indoor applications such as connected stores for geolocation of customers. The properties offered by light (speed, directional, controlled containment etc.) suggest that VLC technology is more suitable for vehicular communications and can effectively meet the needs of a reliable, robust and with increasing flow to consider new applications such as virtual reality in future cars. In addition, VLC technology can be recognized as a "green" technology because it is based on the exploitation of LEDs and lamps already used for lighting and visibility. It is therefore a question of optimizing the use (by the transmission of information) of an energy already consumed. Publication in 2020 is [22].

GloCAT

Participants Valeria Loscri *(contact person)*, Nathalie Mitton.

- Title: GloCAT

- Type: STIMULE
- Duration: December 2020 - December 2021
- The goal of this project is to detect cyber attack such as Man in The Middle to counterbalance and localize the attacker.

9 Dissemination

9.1 Promoting scientific activities

- Nathalie Mitton is the referent researcher for the creation of the MATH Laboratory in Nord and participates to the official inauguration March 2020.
- Valeria Loscri and Nathalie Mitton are in the GIS CybCOMM, Scientific Interest Group in the Cyber Security for wireless networks.

9.1.1 Scientific events: organisation

General chair, scientific chair

- Valeria Loscri was General co-Chair of ACM NanoCom 2020. She is publicity co-chair of IEEE ICCCN 2021.
- Nathalie Mitton was/is EWSN 2020 competition co-chair, MDM 2020 keynote co-chair, ISCC 2020 publicity co-chair and workshop co-chair of ISCC 2021.

Member of the organizing committees

- Valeria Loscri was co-Organizer and TPC-chair of Workshop on Pervasive Systems in the IoT era (PERSIST-IoT) in conjunction with Infocom 2020.
  She is Co-organizer of the Feature Topic on Networking Technologies to Combat the COVID-19 Pandemic in IEEE Communications Magazine.

9.1.2 Scientific events: selection

Chair of conference program committees

- Valeria Loscri is Symposium Co-chair of Mobile and Wireless Networking Symposium in Globecom 2021. She was TPC co-chair of CORES 2020 and of Special Workshop on Communications and Networking Technologies for Responding to COVID-19 in conjunction with Globecom 2020
  She was/is TPC-chair of Short Papers and Demo Session in WiMob 2020 and 2021
- Nathalie Mitton is co-track chair IEEE ICCCN 2021.

Member of the conference program committees

- Valeria Loscri was TPC member of ICC 2021, 2020, Globecom 2021 and 2020, WCNC 2021 and 2020, WINSYS 2021, CITS 2021 and 2020, VTC 2020.
- Nathalie Mitton was TPC member of ISCC 2020, Infocom 2021 and 2020, VTC 2020, DCOSS 2020 and 2021, CORES 2020, Percom 2020, Globecom 2020, ICC 2021 and 2020, Adhocnow 2020 and WCNC 2021 and 2020.

9.1.3 Journal

Member of the editorial boards

- Nathalie Mitton is an editorial board member of Adhoc Networks since 2012, of IET-WSS since 2013, of Wireless Communications and Mobile Computing since 2016, of MDPI Future Internet since 2018, of Networks as Review Editor for Frontiers in Communications and Networks since 2020.
- Nathalie Mitton is co-editor of Special Issues in MDPI Sensors "Optimization and Communication in UAV Networks" and "Multi sensor fusion for indoor localization"
- Valeria Loscri is Associate Editor of IEEE Communications Survey and Tutorials (COMST, since 2020), Frontiers in Communications and Networks, ITU-FET Journal, IEEE Transactions on Nanobioscience journal since 2017, of Elsevier Computer Networks journal since 2016, of Robotics Software Design and Engineering of the International Journal of Advanced Robotic Systems since 2016, of Elsevier Journal of Networks and Computer Applications (JNCA) journal since 2016, of Wiley Transactions Emerging Telecommunications Technologies since 2019.
- Valeria Loscri is Co-organizer and Guest Editor of the Special Issue: Smart Vehicles 2021: Special Issue on Revolutionary Paradigms for Smart Connected Vehicles Elsevier Vehicular Communications in Elsevier Vehicular Communications.

9.1.4 Invited talks

- Nathalie Mitton gave a talk to the IoT4Maintenance ITrans club.
- Christian Salim gave a talk at Journées Cloud.

9.1.5 Scientific expertise

- Nathalie Mitton has been appointed as scientific expert to evaluate projects submitted to ANR, FWO-Research-Project (Germany), South Africa's National Research Foundation (NRF), AmSTic Sud.
- Nathalie Mitton was a member of the GDR's PhD award, of the IoT Student Challenge and a NGI Pointer advisory board member.
- Valeria Loscri was evaluator of projects submitted to ANR.

9.2 Teaching - Supervision - Juries

9.2.1 Teaching

- **E-learning**
  - Mooc, Nathalie Mitton, "Internet of Things with Microcontrollers: a hands-on course", 5-week mooc by the FIT IoT LAB team, FUN, Inria, in February 2020
  - Remote curse, Nathalie Mitton, Internet of things, 5-week + virtual face to face week in May 2020
- Master: Valeria Loscri, Objets Communicants, 24h (Mineure Habitat Intelligent), Ecole des Mines de Douai, France
- Master: Nathalie Mitton, Wireless networks, 16h eqTD (Master TiiR), Université Lille 1, France
- Master: Nathalie Mitton, Wireless sensor networks, 16h eqTD (Master MINT), Université Lille 1 and Telecom Lille 1, France
- Master: Nathalie Mitton, Smart objects, 10h CM + 12h TP, Ecole centrale de Lille, France
- Master: Nathalie Mitton, Industrial Internet of Things, 10h CM Ecole centrale de Lille, France

- Master: Brandon Foubert, Industrial to Internet of Things, 12h TP Ecole centrale de Lille, France
- Master: Nathalie Mitton, Introduction to Internet of Things, 4h CM Ecole centrale de Lille, France
- Master: Brandon Foubert, Introduction to Internet of Things, 8h TP Ecole centrale de Lille, France
- Master: Christian Salim, Wireless sensor networks, 12h eqTD (Master ROC), IMT, France
- Master 1: Christian Salim, Introduction to iot, 21h eqTD (Ingénieurs généralistes, Option Smart Cities 'English'), HEI, France.
- Master 2: Christian Salim, Web Scraping, 10h eqTD (Ingenieurs généralistes, Option Informatique et technologie de l'information), HEI, France.
- L3 INFO: Edward Staddon, Introduction aux Réseaux, 19.5 HTD, Université de Lille, France.
- L3 INFO: Emilie Bout, Introduction aux Réseaux, 19.5 HTD, Université de Lille, France.

9.2.2 Supervision

- PhD in progress: Nina Santi, Adaptive and dynamic edge gateways IoT-oriented deployments, Université Lille 1, 2020-2023, Nathalie Mitton
- PhD in progress: Brandon Foubert, Communication sans fil Polymorphe pour l'Agriculture Connectée, Université Lille 1, 2018-2021, Nathalie Mitton
- PhD in progress: Edward Staddon, Threat detection, identification and quarantine in wireless IoT based Critical Infrastructures, Université Lille 1, 2019-2022, Nathalie Mitton & Valeria Loscri
- PhD in progress: Carola Rizza, Nouveaux paradigmes de communication basés sur les technologies émergentes, Université Lille 1, 2019-2022, Valeria Loscri
- PhD in progress: Emilie Bout, Denial-of-sleep over IoT networks, Université Lille 1, 2019-2022, Valeria Loscri & Antoine Gallais
- PhD in progress: Meysam Mayahi, Communication Protocols based on alternative paradigm for wireless mobile devices, Université Lille 1, 2019-2022, Valeria Loscri

9.2.3 Juries

- PhD and HDR committees:
  - Valeria Loscri is/was member of the following PhD thesis committees:
    - Pengfei Lu, University of Oslo (Norway), March 2021 (reviewer and opponent)
    - Randa M. Abdelmonem Aboelfotoh, Université d'Avignon, Februrary 2021
    - Steve Joumessi Demeffo, Université de Limoges, December 2020 (reviewer)
    - Xuewen Qian, Université Paris Saclay, December 2020 (reviewer)
  - Nathalie Mitton is/was member of the following PhD thesis committees:
    - Domga Rodrigue Komguem, INSA Lyon / University of Yaoundé (Cameroon), April 2020 (reviewer)
    - Gaby Bou Tayeh, Université de Bourgogne Franche Comté, July 2020 (reviewer)
    - Vasileios Kotsiou, Université de Strasbourg, September 2020 (reviewer)
    - Illyyne Saffar, Nokia Bell Labs / Université de Rennes, November 2020 (opponent)
    - Nicolas Gonzalez, Université de Toulouse, October 2020 (opponent)
    - Bruno Donassolo, Université Grenoble Alpes, November 2020 (opponent)
    - Juliette Garcia, Ecole Nationale de l'Aviation Civile, December 2020 (reviewer)
    - Tomas Lagos, IMT Atlantique, December 2020 (reviewer)

    - Remy Grunblatt, Université de Lyon, January 2021 (reviewer)
    - Cedric Berenger, Université Aix-Marseille January 2021 (reviewer)
  - Nathalie Mitton was a member of the HDR defense committees
    - Patrick Sondi, Université du Littoral Côte d'Opale, October 2020 (reviewer)
    - Francoise Sailhan, CNAM, January 2021 (reviewer)

- Researcher selection committees:
  - Nathalie Mitton was a member of the Full Professor competition selection committee at Clermont Ferrand and Toulouse
  - Nathalie Mitton was a member of the Assistant Professor (MdC) committee for INSA Lyon and Clermont Ferrand.
  - Nathalie Mitton was a member of the Inria SRP for ERC selection committee.
  - Nathalie Mitton was a member of the Inria junior researcher (CRCN) competition committee for Grenoble and Nancy.
  - Nathalie Mitton was a member of the Inria senior researcher (DR) competition committee.
  - Valeria Loscri was a member of the Assistant Professor (MdC) committee for Université de Valenciennes.

- PhD progress committees:
  - Nathalie Mitton is/was reviewer of the following PhD progress committees:
    - Alexis Bitaillou, Université de Nantes
    - Razanne Abu-Aisheh, Sorbonne Université
    - Diego Madriaga, Sorbonne Université
    - Mayssa Khalil, Université de Technologie de Troyes
  - Valeria Loscri is/was reviewer of the following PhD progress committees:
    - Emmanuel Plascencia, Université de Versailles

9.3 Popularization

9.3.1 Internal or external Inria responsibilities

- Nathalie Mitton is
  - member of the Bureau des Comités de Projets of the Inria Lille center
  - elected member of the Inria evaluation committee
  - member of the Administration Board of CITC
  - nominated member of the Scientific Commitee of MathNum Department of INRAE
- Valeria Loscri is
  - responsible for Scientific International Relations of the Inria Lille center.

10 Scientific production

10.1 Major publications

[1] L. Chancay-García, E. Hernández-Orallo, P. Manzoni, A. M. Vegni, V. Loscri, J. C. Cano and C. T. Calafate. 'Optimising Message Broadcasting in Opportunistic Networks'. In: *Computer Communications* 157 (Apr. 2020), pp. 162–178. DOI: 10.1016/j.comcom.2020.04.031. URL: https://hal.archives-ouvertes.fr/hal-02544184.

[2] A. Costanzo and V. Loscri. 'Error Compensation in Indoor Positioning Systems based on Software Defined Visible Light Communication'. In: *Physical Communication* (2019). URL: https://hal.archives-ouvertes.fr/hal-02087506.

[3] D. Dechouniotis, N. Athanasopoulos, A. Leivadeas, N. Mitton, R. Jungers and S. Papavassiliou. 'Edge Computing Resource Allocation for Dynamic Networks: The DRUID-NET Vision and Perspective'. In: *Sensors* 20.8 (Apr. 2020), p. 2191. DOI: 10.3390/s20082191. URL: https://hal.inria.fr/hal-02541335.

[4] M. Egan, V. Loscri, T. Q. Duong and M. D. Renzo. 'Strategies for Coexistence in Molecular Communication'. In: *IEEE Transactions on NanoBioscience* 18.1 (Jan. 2019), pp. 51–60. DOI: 10.1109/tnb.2018.2884999. URL: https://hal.archives-ouvertes.fr/hal-01928205.

[5] F. Guerriero, V. Loscri, P. Pace and 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. URL: https://hal.inria.fr/hal-01386749.

[6] F. Mezghani and N. Mitton. 'Alternative opportunistic alert diffusion to support infrastructure failure during disasters'. In: *Sensors* (Oct. 2017). DOI: 10.3390/s17102370. URL: https://hal.inria.fr/hal-01614744.

[7] R. Morabito, R. Petrolo, V. Loscri and N. Mitton. 'LEGIoT: a Lightweight Edge Gateway for the Internet of Things'. In: *Future Generation Computer Systems* (2017). URL: https://hal.inria.fr/hal-01614714.

[8] J. B. Pinto Neto, L. C. Gomes, F. C. Ortiz, T. T. Almeida, M. E. M. Campista, L. H. Maciel Kosmalski Costa and N. Mitton. 'An Accurate Cooperative Positioning System for Vehicular Safety Applications'. In: *Computers and Electrical Engineering (COMPELECENG)* (2020). URL: https://hal.inria.fr/hal-02364355.

[9] V. Toldov, L. Clavier, V. Loscri and 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, Sept. 2016. URL: https://hal.inria.fr/hal-01355002.

[10] V. Toldov, L. Clavier and 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, Oct. 2018. URL: https://hal.inria.fr/hal-01866809.

10.2 Publications of the year

International journals

[11] L. Chancay-García, E. Hernández-Orallo, P. Manzoni, A. M. Vegni, V. Loscrì, J. C. Cano and C. T. Calafate. 'Optimising Message Broadcasting in Opportunistic Networks'. In: *Computer Communications* 157 (Apr. 2020), pp. 162–178. DOI: 10.1016/j.comcom.2020.04.031. URL: https://hal.archives-ouvertes.fr/hal-02544184.

[12] A. Costanzo, V. Loscrì and M. Biagi. 'Adaptive Modulation Control for Visible Light Communication Systems'. In: *Journal of Lightwave Technology* (2021). URL: https://hal.archives-ouvertes.fr/hal-03134465.

[13] D. Dechouniotis, N. Athanasopoulos, A. Leivadeas, N. Mitton, R. Jungers and S. Papavassiliou. 'Edge Computing Resource Allocation for Dynamic Networks: The DRUID-NET Vision and Perspective'. In: *Sensors* 20.8 (13th Apr. 2020), p. 2191. DOI: 10.3390/s20082191. URL: https://hal.inria.fr/hal-02541335.

[14] A. E. Ferreira, F. C. Ortiz, L. H. Maciel Kosmalski Costa, B. Foubert, I. Amadou and N. Mitton. 'A study of the LoRa signal propagation in forest, urban, and suburban environments'. In: *Annals of Telecommunications - annales des télécommunications* (23rd July 2020). DOI: 10.1007/s12243-020-00789-w. URL: https://hal.inria.fr/hal-02907283.

[15] B. Foubert and N. Mitton. 'Long-Range Wireless Radio Technologies: A Survey'. In: *Future internet* 12.1 (14th Jan. 2020), p. 13. DOI: 10.3390/fi12010013. URL: https://hal.inria.fr/hal-02440409.

[16] A. Maria Vegni, C. Souza, V. Loscrì, E. Hernández-Orallo and P. Manzoni. 'Data Transmissions using Hub Nodes in Vehicular Social Networks'. In: *IEEE Transactions on Mobile Computing*. IEEE Transactions on Mobile Computing 19.7 (2020), pp. 1570–1585. DOI: 10.1109/TMC.2019.2928803. URL: https://hal.archives-ouvertes.fr/hal-02180932.

[17] F. Mezghani and N. Mitton. 'Opportunistic multi-technology cooperative scheme and UAV relaying for network disaster recovery'. In: *Information* 11.1 (Jan. 2020). DOI: 10.3390/info11010037. URL: https://hal.inria.fr/hal-02431659.

[18] M. Ojaroudi, V. Loscrì and A. M. Vegni. 'Design and analysis of a reconfigurable intelligent meta-surface for vehicular networks'. In: *ITU Journal on Future and Evolving Technologies* (Dec. 2020). URL: https://hal.archives-ouvertes.fr/hal-03082231.

[19] J. Pinto Neto, L. Gomes, F. Ortiz, T. Almeida, M. E. M. Campista, L. H. Maciel Kosmalski Costa and N. Mitton. 'An Accurate Cooperative Positioning System for Vehicular Safety Applications'. In: *Computers and Electrical Engineering* 83 (2020). DOI: 10.1016/j.compeleceng.2020.106591. URL: https://hal.inria.fr/hal-02364355.

[20] C. Salim and N. Mitton. 'K-Predictions Based Data Reduction Approach in WSN for Smart Agriculture'. In: *Computing* (30th Oct. 2020). DOI: 10.1007/s00607-020-00864-z. URL: https://hal.archives-ouvertes.fr/hal-02975997.

International peer-reviewed conferences

[21] E. Bout, V. Loscrì and A. Gallais. 'Energy and Distance evaluation for Jamming Attacks in wireless networks'. In: IEEE/ACM DS-RT 2020. Prague, Czech Republic, 14th Sept. 2020. URL: https://hal.archives-ouvertes.fr/hal-02933418.

[22] A. Costanzo, V. Loscrì, V. Deniau and J. Rioult. 'On the Interference Immunity of Visible Light Communication (VLC)'. In: GLOBECOM 2020 - IEEE Global Communications Conference. Tapei, Taiwan: https://globecom2020.ieee-globecom.org/, 8th Dec. 2020. URL: https://hal.archives-ouvertes.fr/hal-02935606.

[23] R. Dagher, F.-X. Molina, A. Abadie, N. Mitton and E. Baccelli. 'An Open Experimental Platform for Ranging, Proximity and Contact Event Tracking using Ultra-Wide-Band and Bluetooth Low-Energy'. In: CNERT 2021 - IEEE INFOCOM Workshop on Computer and Networking Experimental Research using Testbeds. Virtual, France: https://infocom2021.ieee-infocom.org/, 10th May 2021. URL: https://hal.inria.fr/hal-03140370.

[24] B. Foubert. 'Routing in Multi-Technologies Wireless Sensor Networks'. In: EWSN 2021 (PhD Forum) - 18th International Conference on Embedded Wireless Systems and Networks. Delft, Netherlands, 17th Feb. 2021. URL: https://hal.inria.fr/hal-03080085.

[25] B. Foubert and N. Mitton. 'Lightweight network interface selection for reliable communications in multi-technologies wireless sensor networks'. In: DRCN 2021 - 17th International Conference on the Design of Reliable Communication Networks. Milan, Italy, 19th Apr. 2021. URL: https://hal.inria.fr/hal-03141833.

[26] B. Foubert and N. Mitton. 'Routing Over Multiple Technologies with RODENT'. In: Percom 2021 (Demo) - 19th International Conference on Pervasive Computing and Communications. Kassel, Germany, 22nd Mar. 2021. URL: https://hal.inria.fr/hal-03106247.

[27] M. O'Kennedy, T. Niesler, R. Wolhuter and N. Mitton. 'Practical evaluation of carrier sensing for a LoRa wildlife monitoring network'. In: IFIP Networking. Paris, France, 22nd June 2020. URL: https://hal.inria.fr/hal-02538121.

[28] C. Rizza, V. Loscrì and M. O. Parchin. 'A Millimeter-Wave Reconfigurable Intelligent Metasurface Design for Vehicular Networks Applications'. In: 2020 IEEE Vehicular Technology Conference. Victoria, Canada, 4th Oct. 2020. URL: https://hal.inria.fr/hal-02894947.

[29] C. Salim and N. Mitton. 'Image Similarity based Data Reduction Technique in Wireless Video Sensor Networks for Smart Agriculture'. In: AINA-2021 - 35th International Conference on Advanced Information Networking and Applications. Toronto, Canada, 12th May 2021. URL: https://hal.inria.fr/hal-03145329.

[30] C. Salim and N. Mitton. 'Machine Learning Based Data Reduction in WSN for Smart Agriculture'. In: AINA 2020 - 34th International Conference on Advanced Information Networking and Applications. Caserta, Italy, 15th Apr. 2020. URL: https://hal.inria.fr/hal-02463167.

Conferences without proceedings

[31] V. Bellon-Maurel, L. Brossard, F. Garcia, N. Mitton, E. Prados and A. Termier. 'Livre blanc INRIA / INRAE sur le numérique en Agriculture'. In: PFIA 2020 - (Plateforme de l'Intelligence Artificielle) - Journée Agronomie et IA. Virtual, France: http://pfia2020.fr/, 29th June 2020, pp. 1–26. URL: https://hal.inrae.fr/hal-02887646.

[32] B. Foubert and N. Mitton. 'Sélection d'interface de communication dans les réseaux de capteurs multi-technologies'. In: CoRes 2020 - 5èmes Rencontres Francophones sur la Conception de Protocoles, l'Evaluation de Performance et l'Expérimentation des Réseaux de Communication. Lyon, France, 28th Sept. 2020. URL: https://hal.inria.fr/hal-02570838.

[33] M. Ojaroudi and V. Loscrì. 'A Novel Design of Ultrathin Metasurface Structure for Terahertz Time-Domain Spectroscopy (THz-TDS) Applications'. In: 15th European Conference on Antennas and Propagation. Düsseldorf, Germany, 22nd Mar. 2021. URL: https://hal.archives-ouvertes.fr/hal-03082170.

[34] M. Ojaroudi and V. Loscrì. 'Graphene-Based Reconfigurable Intelligent Metasurface Structure for THz Communications'. In: 15th European Conference on Antennas and Propagation. Düsseldorf, Germany, 22nd Mar. 2021. URL: https://hal.archives-ouvertes.fr/hal-03082069.

[35] C. Salim and N. Mitton. 'On-Node Correlation Based Data Reduction in WSN for Smart Agriculture'. In: IEEE International Conference on Advanced Networks and Telecommunications Systems 2020 (ANTS'20). New Delhi, India, 14th Dec. 2020. URL: https://hal.archives-ouvertes.fr/hal-03016015.

Edition (books, proceedings, special issue of a journal)

[36] C. Caillouet and N. Mitton. *Optimization and Communication in UAV Networks*. Vol. 20. 18. Sept. 2020, p. 5036. DOI: 10.3390/s20185036. URL: https://hal.inria.fr/hal-03142038.

Other scientific publications

[37] N. Athanasopoulos, D. Dechouniotis, R. Jungers, A. Leivadeas, N. Mitton and S. Papavassiliou. *Control co-design and resource allocation in edge computing and dynamic networks (Tutorial Session Proposal)*. 15th May 2020. URL: https://hal.inria.fr/hal-02538160.

10.3 Cited publications

[38] N. Anciaux, L. Bouganim, T. Delot, S. Ilarri, L. Kloul, N. Mitton and P. Pucheral. 'Opportunistic Data Services in Least Developed Countries: Benefits, Challenges and Feasibility Issues'. In: *ACM SIGMOD Record* (Mar. 2014). URL: https://hal.inria.fr/hal-00971805.

[39] J. Bachrach and C. Taylor. 'Localization in sensor networks'. In: *Artificial Intelligence* (2004), pp. 227–310.

[40] A. Blanchard, N. Kosmatov and 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, Apr. 2018. URL: https://hal.inria.fr/hal-01720401.

[41] A. Blanchard, F. Loulergue and N. Kosmatov. 'Towards Full Proof Automation in Frama-C Using Auto-active Verification'. In: *NASA Formal Methods*. Houston, TX, United States: Springer, May 2019, pp. 88–105. DOI: 10.1007/978-3-030-20652-9_6. URL: https://hal.inria.fr/hal-02317055.

[42] A. Costanzo and V. Loscri. 'Système de localisation à Lumière Visible avec compensation du bruit environnemental'. In: *CORES 2019*. Narbonne, France, June 2019. URL: https://hal.archives-ouvertes.fr/hal-02119952.

[43] A. Costanzo and V. Loscri. 'Visible Light Indoor Positioning in a Noise-aware Environment'. In: *WCNC 2019 - IEEE Wireless Communications and Networking Conference*. Marrakesh, Morocco, Apr. 2019. URL: https://hal.archives-ouvertes.fr/hal-02022610.

[44] A. Costanzo, V. Loscri and S. Costanzo. 'Adaptive Dual Color Visible Light Communication (VLC) System'. In: *6th World Conference on Information Systems and Technologies*. Napoli, Italy, Mar. 2018. URL: https://hal.inria.fr/hal-01687543.

[45] A. Das, A. Sen, C. Qiao, N. Ghani and N. Mitton. 'RAPTOR: a network tool for mitigating the impactof spatially correlated failures in infrastructure networks'. In: *Annals of Telecommunications - annales des télécommunications* 73.1 (Feb. 2018), pp. 153–164. URL: https://hal.inria.fr/hal-01584867.

[46] S. Duquennoy, B. Al Nahas, O. Landsiedel and T. Watteyne. 'Orchestra: Robust Mesh Networks Through Autonomously Scheduled TSCH'. In: *Proceedings of the International Conference on Embedded Networked Sensor Systems (ACM SenSys)*. 2015.

[47] M. El Amine Seddik, V. Toldov, L. Clavier and N. Mitton. 'From Outage Probability to ALOHA MAC Layer Performance Analysis in Distributed WSNs'. In: *WCNC 2018 - IEEE Wireless Communications and Networking Conference*. Barcelona, Spain, Apr. 2018. URL: https://hal.inria.fr/hal-01677687.

[48] E. Elhafsi, N. Mitton, B. Pavkovic and D. Simplot-Ryl. 'Energy-aware Georouting with Guaranteed Delivery in Wireless Sensor Networks with Obstacles'. en. In: *International Journal of Wireless Information Networks* 16.3 (2009), pp. 142–153.

[49] B. Fabian and O. Günther. 'Distributed ONS and its Impact on Privacy'. In: *IEEE International Conference on Communications*. 2007, pp. 1223–1228.

[50] A. Gallais, J. Carle, D. Simplot-Ryl and I. Stojmenovic. 'Localized Sensor Area Coverage with Low Communication Overhead'. In: *IEEE Transactions on Mobile Computing (TMC)* 5.7 (May 2008), pp. 661–672.

[51] N. Gouvy, N. Mitton and J. Zheng. 'Greedy Routing Recovery Using Controlled Mobility in Wireless Sensor Networks'. In: *ADHOC-NOW - The 12th International Conference on Ad Hoc Networks and Wireless - 2013*. Wroclaw, Poland, July 2013. URL: http://hal.inria.fr/hal-00830374.

[52] F. Ingelrest, N. Mitton and D. Simplot-Ryl. 'A Turnover based Adaptive HELLO Protocol for Mobile Ad Hoc and Sensor Networks'. In: *Proc. of the 15th IEEE International Symposium on Modeling, Analysis, and Simulation of Computer and Telecommunication Systems (MASCOTS'07)*. Bogazici University, Istanbul, Turkey, Oct. 2007.

[53] X. Li, N. Mitton and D. Simplot-Ryl. 'Mobility Prediction Based Neighborhood Discovery in Mobile Ad Hoc Networks'. en. In: *Proc. of the IFIP/TC6 NETWORKING 2011*. Valencia, Spain, 2011.

[54] V. Loscri, G. Ruggeri, A. M. Vegni and I. Cricelli. 'Social Structure Analysis in Internet of Vehicles'. In: *CoWPER Workshop in conjunction with IEEE International Conference on Sensing, Communication and Networking*. Hong-Kong, China, June 2018. URL: https://hal.archives-ouvertes.fr/hal-01798609.

[55] A. A. Mbacke, N. Mitton and H. Rivano. 'Using Fuzzy Logic for data priority aware collection in RFID sensing wireless networks'. In: *PIMRC 2018 - IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*. Bologne, Italy, Sept. 2018. URL: https://hal.inria.fr/hal-01830721.

[56] A. A. Mbacké, N. Mitton and H. Rivano. 'DACAR: Distributed & Adaptable Crosslayer Anticollision and Routing protocol for RFID'. In: *AdHoc-Now 2018 - 17th International Conference on Ad Hoc Networks and Wireless*. St Malo, France, Sept. 2018. URL: https://hal.inria.fr/hal-01819767.

[57] A. A. Mbacké, N. Mitton and H. Rivano. 'RFID Anticollision in Dense Mobile Environments'. In: *WCNC 2017 - IEEE Wireless Communications and Networking Conference*. San Francisco, United States, Mar. 2017. URL: https://hal.inria.fr/hal-01418170.

[58] F. Mezghani, P. Kortoçi, N. Mitton and M. Di Francesco. 'A Multi-tier Communication Schemefor Drone-assisted Disaster Recovery Scenarios'. In: *PIMRC 2019 - IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*. Istanbul, Turkey, Sept. 2019. URL: https://hal.inria.fr/hal-02152133.

[59] F. Mezghani and N. Mitton. 'Drone assisted multi-technology rescue operations'. In: *CORES 2019 - Rencontres Francophones sur la Conception de Protocoles, l'Évaluation de Performance et l'Expérimentation des Réseaux de Communication*. Saint Laurent de la Cabrerisse, France, June 2019. URL: https://hal.archives-ouvertes.fr/hal-02122806.

[60] N. Mitton and D. Simplot-Ryl. *Wireless Sensor and Robot Networks From Topology Control to Communication Aspects*. WorldScientific, Feb. 2014, p. 284. URL: https://hal.inria.fr/hal-00927526.

[61] J. Nassar, K. Miranda, N. Gouvy and N. Mitton. 'Heterogeneous data reduction in WSN: Application to Smart Grids'. In: *SMARTOBJECTS 2018 - 4th Workshop on Experiences with the Design and Implementation of Smart Objects*. Los Angeles, California, United States, June 2018. URL: https://hal.archives-ouvertes.fr/hal-01773861.

[62] A. Pal. 'Localization Algorithms in Wireless Sensor Networks: Current Approaches and Future Challenges'. In: *Network Protocols and Algorithms* 2.1 (2010).

[63] R. Petrolo, T. Delot, N. Mitton, A. Molinaro and C. Campolo. 'O-SPIN: an Opportunistic Data Dissemination Protocol for Folk-enabled Information System in Least Developed Countries'. In: *ADHOC-NOW - 13th International Conference on Ad-Hoc Networks and Wireless*. Benidorm, Spain, June 2014. URL: https://hal.inria.fr/hal-00960023.

[64] R. Petrolo, S. Guzzo Bonifacio, V. Loscri and N. Mitton. 'The discovery of "relevant" data-sources in a Smart City environment'. In: *Proceedings of SSC - 2nd International IEEE SMARTCOMP Workshop on Sensors and Smart Cities*. St. Louis, Missouri, United States, May 2016. URL: https://hal.inria.fr/hal-01300335.

[65] R. Petrolo, V. Loscri and N. Mitton. 'Confident-based Adaptable Connected objects discovery to HArmonize smart City Applications'. In: *Proceedings of WD - IFIP Wireless Days*. Toulouse, France, Mar. 2016. URL: https://hal.inria.fr/hal-01269633.

[66] R. Petrolo, V. Loscri and N. Mitton. 'Cyber-Physical Objects as key elements for a Smart Cyber-City'. In: *Management of Cyber Physical Objects in the Future Internet of Things*. Feb. 2016. URL: https://hal.inria.fr/hal-01257162.

[67] R. Petrolo, V. Loscri, N. Mitton and E. Herrmann. 'Adaptive Filtering as a Service for Smart City Applications'. In: *14th IEEE International Conference on Networking, Sensing and Control (ICNSC)*. Cosenza, Italy, May 2017. URL: https://hal.inria.fr/hal-01482715.

[68] R. Petrolo, A. Roukounaki, V. Loscri, N. Mitton and J. Soldatos. 'Connecting physical things to a SmartCity-OS'. In: *Proceedings of CoWPER - International IEEE SECON Workshop on Toward a city-wide pervasive environment*. London, United Kingdom, June 2016. URL: https://hal.inria.fr/hal-01309638.

[69] M. Rekik, Z. Chtourou, N. Mitton and A. atieh. 'Geographic routing protocol for the deployment of virtual power plant within the smart grid'. In: *Sustainable Cities and Society* (2016). DOI: 10.1016/j.scs.2015.12.003. URL: https://hal.inria.fr/hal-01252686.

[70] L. Schmidt, N. Mitton, D. Simplot-Ryl, R. Dagher and R. Quilez. 'DHT-based distributed ALE engine in RFID Middleware'. In: *IEEE International Conference on RFID-Technologies and Applications (RFID-TA 2011)*. Barcelona, Spain, Sept. 2011. URL: http://hal.inria.fr/inria-00599128/en.

[71] G. Smart, N. Deligiannis, R. Surace, V. Loscri, G. Fortino and Y. Andreopoulos. 'Decentralized Time-Synchronized Channel Swapping for Ad Hoc Wireless Networks'. In: *IEEE Transactions on Vehicular Technology* (2016). URL: https://hal.archives-ouvertes.fr/hal-01241833.

[72] V. Toldov. 'Adaptive MAC layer for interference limited WSN'. Theses. Université Lille 1 Sciences et technologies, Jan. 2017. URL: https://hal.inria.fr/tel-01493094.

[73] A. M. Vegni, V. Loscri and 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, Sept. 2018. URL: https://hal.inria.fr/hal-01826237.

[74] Y. Wang, J. Zheng and N. Mitton. 'Delivery Delay Analysis for Roadside Unit Deployment in Vehicular Ad Hoc Networks with Intermittent Connectivity'. In: *IEEE Transactions on Vehicular Technology* (Jan. 2016). URL: https://hal.inria.fr/hal-01233732.