Activity Report 2017

Project-Team EVA

Wireless Networking for Evolving & Adaptive Applications

RESEARCH CENTER
Paris

THEME
Networks and Telecommunications

Table of contents

1. Personnel **2**
2. Overall Objectives **2**
3. Research Program **3**
3.1. Generalities 3
3.2. Physical Layer 3
3.3. Wireless Access 3
3.4. Coexistence of Wireless Technologies 3
3.5. Energy-Efficiency and Determinism 4
3.6. Network Deployment 4
3.7. Data Gathering and Dissemination 4
3.8. Self-Learning Networks 5
3.9. Security Trade-off in Constrained Wireless Networks 5
4. Application Domains **5**
4.1. Industrial Process Automation 5
4.2. Environmental Monitoring 6
4.3. The Internet of Things 6
4.4. Military, Energy and Aerospace 6
4.5. Emergency Applications 6
4.6. Types of Wireless Networks 7
4.6.1. Wireless Sensor and Mesh Networks 7
4.6.2. Deterministic Low-Power Networks 7
4.6.3. MANETs and VANETs 8
4.6.4. Cellular and Device-to-Device Networks 8
5. Highlights of the Year **8**
5.1.1. Awards 8
5.1.2. 6TiSCH Standardization Virtually Completed 8
5.1.3. Over 1,000 Sensors Deployed on 3 Continents 9
6. New Software and Platforms **9**
6.1. OpenWSN 9
6.2. 6TiSCH Simulator 9
6.3. Argus 9
6.4. SolSystem 10
6.5. 6TiSCH Wireshark Dissector 10
6.6. F-Interop 10
6.7. Mercator 10
6.8. Platforms 10
6.8.1. SolSystem 10
6.8.2. OpenMote B 10
7. New Results **12**
7.1. 6TiSCH Standardization and Benchmarking 12
7.1.1. Minimal Security Solution 12
7.1.2. OpenWSN Fresh with full 6TiSCH Support 12
7.1.3. First F-Interop 6TiSCH Interop Event 12
7.1.4. Agile Networking 12
7.2. SolSystem Deployments 13
7.2.1. SmartMarina 13
7.2.2. SaveThePeaches 13
7.2.3. SnowHow 14
7.3. IoT and Wireless Sensor Networks 14

7.3.1. Deployment of autonomous and mobile wireless sensor nodes 14
7.3.2. Collision avoidance on shared slots in wireless slotted networks 15
7.3.3. Security in the OCARI wireless sensor network 15
7.3.4. Security in Wireless Sensor Networks 16
7.3.5. Massive MIMO Cooperative Communications for Wireless Sensor Networks 16
7.4. Industry 4.0 and Wireless Sensor Networks 16
7.4.1. Building an IEEE 802.15.4e TSCH network 17
7.4.2. Increasing the reliability of an IEEE 802.15.4e TSCH network 17
7.4.3. Scheduling transmissions in an IEEE 802.15.4e TSCH network 18
7.5. Machine Learning for an efficient and dynamic management of network resources and services 18
7.5.1. Machine Learning in Networks 18
7.5.2. Prediction of video content popularity 19
7.5.3. Clustering of video contents 19
7.6. Protocols and Models for Wireless Networks - Application to VANETs 20
7.6.1. Protocols for VANETs 20
7.6.1.1. TRPM: a TDMA-aware routing protocol for multi-hop communications in VANETs 20
7.6.1.2. Trust-CTMAC: A Trust Based Scheduling Algorithm 21
7.6.1.3. A Flooding-Based Location Service in VANETs 22
7.6.2. Models for Wireless Networks and VANETs 23
7.6.2.1. Performance analysis of IEEE 802.11 broadcast schemes with different inter-frame spacings 23
7.6.2.2. Model and optimization of CSMA 23
7.6.2.3. Adaptive CSMA 24
7.6.2.4. Optimizing spatial throughput in device-to-device networks 24
7.6.2.5. Model and analysis of Coded Slotted Aloha (CSA) with capture 24
7.6.2.6. Mobility Prediction in Vehicular Networks : An Approach through Hybrid Neural Networks under Uncertainty 24
7.6.3. Reliable routing architecture 25
8. Bilateral Contracts and Grants with Industry **25**
9. Partnerships and Cooperations **26**
9.1. National Initiatives 26
9.2. European Initiatives 26
9.2.1. FP7 & H2020 Projects 26
9.2.2. Collaborations in European Programs, Except FP7 & H2020 26
9.3. International Initiatives 26
9.3.1. Inria International Labs 26
9.3.2. Inria Associate Teams Not Involved in an Inria International Labs 26
9.3.2.1. REALMS 26
9.3.2.2. DIVERSITY 27
9.3.3. Inria International Partners 27
9.3.3.1. Declared Inria International Partners 27
9.3.3.2. Informal International Partners 27
9.3.4. Participation in Other International Programs 28
9.4. International Research Visitors 29
9.4.1. Visits of International Scientists 29
9.4.2. Internships 29
9.4.3. Visits to International Teams 29
10. Dissemination **30**
10.1. Promoting Scientific Activities 30

10.1.1. Scientific Events Organization 30
10.1.1.1. General Chair, Scientific Chair 30
10.1.1.2. Member of the Organizing Committees 30
10.1.2. Scientific Events Selection 30
10.1.2.1. Chair of Conference Program Committees 30
10.1.2.2. Member of the Conference Program Committees 31
10.1.2.3. Member of the Editorial Boards 32
10.1.2.4. Reviewer (Journals) 32
10.1.2.5. Reviewer (Book proposals) 32
10.1.3. Invited Talks 33
10.1.4. Leadership within the Scientific Community 33
10.1.5. Scientific Expertise 33
10.1.6. Research Administration 33
10.2. Teaching - Supervision - Juries 33
10.2.1. Teaching 33
10.2.2. Supervision 33
10.2.3. Juries 34
10.3. Popularization 34
10.3.1. Web presence 35
10.3.2. Tradeshows 35
10.3.3. In The News 35
10.3.4. Miscellaneous Activities 35
11. Bibliography **36**

Project-Team EVA

Creation of the Team: 2015 April 01, updated into Project-Team: 2016 May 01

Keywords:

Computer Science and Digital Science:

A1. - Architectures, systems and networks
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
A1.2.8. - Network security
A1.2.9. - Social Networks
A1.4. - Ubiquitous Systems
A1.6. - Green Computing
A2.3. - Embedded and cyber-physical systems
A3.4. - Machine learning and statistics
A3.5. - Social networks
A4.1. - Threat analysis
A4.4. - Security of equipment and software
A4.6. - Authentication
A4.7. - Access control
A6.1. - Mathematical Modeling
A6.1.2. - Stochastic Modeling (SPDE, SDE)
A8.2. - Optimization
A8.8. - Network science
A8.9. - Performance evaluation
A8.11. - Game Theory
A9.2. - Machine learning
A9.6. - Decision support

Other Research Topics and Application Domains:

B4.2. - Nuclear Energy Production
B4.3. - Renewable energy production
B5.1. - Factory of the future
B5.9. - Industrial maintenance
B6.3.2. - Network protocols
B6.3.3. - Network Management
B6.4. - Internet of things
B7.2. - Smart travel
B7.2.1. - Smart vehicles
B7.2.2. - Smart road
B8.1.2. - Sensor networks for smart buildings

1. Personnel

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2. Overall Objectives

2.1. Overall Objectives

It is forecast that the vast majority of Internet connections will be wireless. The EVA project grasps this opportunity and focus on wireless communication. EVA tackles challenges related to providing efficient communication in wireless networks and, more generally, in all networks that are not already organized when set up, and consequently need to evolve and spontaneously find a match between application requirements and the environment. These networks can use opportunistic and/or collaborative communication schemes. They can evolve through optimization and self-learning techniques. Every effort is made to ensure that the results provided by EVA have the greatest possible impact through standardization. The miniaturization and ubiquitous nature of computing devices has opened the way to the deployment of a new generation of wireless (sensor) networks. These networks are central to the work in EVA, as EVA focuses on such crucial issues as power conservation, connectivity, determinism, reliability and latency. Wireless Sensor Network (WSN) deployments are also be a new key subject, especially for emergency situations (e.g. after a disaster). Industrial process automation and environmental monitoring are considered in greater depth.

3. Research Program

3.1. Generalities

EVA inherits its expertise in designing algorithms and protocols from HiPERCOM2 (e.g. OLSR). EVA also inherit know-how in modeling, simulation, experimentation and standardization. Through this know-how and experience, the results obtained are both far-reaching and useful.

3.2. Physical Layer

We plan to study how advanced physical layers can be used in low-power wireless networks. For instance, collaborative techniques such as multiple antennas (e.g. the Massive MIMO technology) can improve communication efficiency. The idea is to use a massive network densification by drastically increasing the number of sensors in a given area in a Time Division Duplex (TDD) mode with time reversal. The first period allows the sensors to estimate the channel state and, after time reversal, the second period is to transmit the data sensed. Other techniques, such as interference cancellation, are also possible.

3.3. Wireless Access

Medium sharing in wireless systems has received substantial attention throughout the last decade. HiPERCOM2 has provided models to compare TDMA and CSMA. HiPERCOM2 has also studied how network nodes must be positioned to optimize the global throughput.

EVA will pursue modeling tasks to compare access protocols, including multi-carrier access, adaptive CSMA (particularly in VANETs), as well as directional and multiple antennas. There is a strong need for determinism in industrial networks. The EVA team will focus particularly on scheduled medium access in the context of deterministic industrial networks; this will involve optimizing the joint time slot and channel assignment. Distributed approaches will be considered, and the EVA team will determine their limits in terms of reliability, latency and throughput. Furthermore, adaptivity to application or environment changes will be taken into account.

3.4. Coexistence of Wireless Technologies

Wireless technologies such as cellular, low-power mesh networks, (Low-Power) WiFi, and Bluetooth (low-energy) can reasonably claim to fit the requirements of the IoT. Each, however, uses different trade-offs between reliability, energy consumption and throughput. The EVA team will study the limits of each technology, and will develop clear criteria to evaluate which technology is best suited to a particular set of constraints.

Coexistence between these different technologies (or different deployments of the same technology in a common radio space) is a valid point of concern.

The EVA team aims at studying such coexistence, and, where necessary, propose techniques to improve it. Where applicable, the techniques will be put forward for standardization. Multiple technologies can also function in a symbiotic way.

For example, to improve the quality of experience provided to end users, a wireless mesh network can transport sensor and actuator data in place of a cellular network, when and where cellular connectivity is poor.

The EVA team will study how and when different technologies can complement one another. A specific example of a collaborative approach is Cognitive Radio Sensor Networks (CRSN).

3.5. Energy-Efficiency and Determinism

Reducing the energy consumption of low-power wireless devices remains a challenging task. The overall energy budget of a system can be reduced by using less power-hungry chips, and significant research is being done in that direction. That being said, power consumption is mostly influenced by the algorithms and protocols used in low-power wireless devices, since they influence the duty-cycle of the radio.

EVA will search for energy-efficient mechanisms in low-power wireless networks. One new requirement concerns the ability to predict energy consumption with a high degree of accuracy. Scheduled communication, such as the one used in the IEEE802.15.4 TSCH (Time Slotted CHannel Hopping) standard, and by IETF 6TiSCH, allows for a very accurate prediction of the energy consumption of a chip. Power conservation will be a key issue in EVA.

To tackle this issue and match link-layer resources to application needs, EVA's 5-year research program around Energy-Efficiency and Determinism centers around 3 studies:

- Performance Bounds of a TSCH network. We propose to study a low-power wireless TSCH network as a Networked Control System (NCS), and use results from the NCS literature. A large number of publications on NCS, although dealing with wireless systems, consider wireless links to have perfect reliability, and do not consider packet loss. Results from these papers can not therefore be applied directly to TSCH networks. Instead of following a purely mathematical approach to model the network, we propose to use a non-conventional approach and build an empirical model of a TSCH network.
- Distributed Scheduling in TSCH networks. Distributed scheduling is attractive due to its scalability and reactivity, but might result in a sub-optimal schedule. We continue this research by designing a distributed solution based on control theory, and verify how this solution can satisfy service level agreements in a dynamic environment.

3.6. Network Deployment

Since sensor networks are very often built to monitor geographical areas, sensor deployment is a key issue. The deployment of the network must ensure full/partial, permanent/intermittent coverage and connectivity. This technical issue leads to geometrical problems which are unusual in the networking domain.

We can identify two scenarios. In the first one, sensors are deployed over a given area to guarantee full coverage and connectivity, while minimizing the number of sensor nodes. In the second one, a network is re-deployed to improve its performance, possibly by increasing the number of points of interest covered, and by ensuring connectivity. EVA will investigate these two scenarios, as well as centralized and distributed approaches. The work starts with simple 2D models and will be enriched to take into account more realistic environment: obstacles, walls, 3D, fading.

3.7. Data Gathering and Dissemination

A large number of WSN applications mostly do data gathering (a.k.a "convergecast"). These applications usually require small delays for the data to reach the gateway node, requiring time consistency across gathered data. This time consistency is usually achieved by a short gathering period.

In many real WSN deployments, the channel used by the WSN usually encounters perturbations such as jamming, external interferences or noise caused by external sources (e.g. a polluting source such as a radar) or other coexisting wireless networks (e.g. WiFi, Bluetooth). Commercial sensor nodes can communicate on multiple frequencies as specified in the IEEE 802.15.4 standard. This reality has given birth to the multichannel communication paradigm in WSNs.

Multichannel WSNs significantly expand the capability of single-channel WSNs by allowing parallel transmissions, and avoiding congestion on channels or performance degradation caused by interfering devices.

In EVA, we will focus on raw data convergecast in multichannel low-power wireless networks. In this context, we are interested in centralized/distributed algorithms that jointly optimize the channel and time slot assignment used in a data gathering frame. The limits in terms of reliability, latency and bandwidth will be evaluated. Adaptivity to additional traffic demands will be improved.

3.8. Self-Learning Networks

To adapt to varying conditions in the environment and application requirements, the EVA team will investigate self-learning networks. Machine learning approaches, based on experts and forecasters, will be investigated to predict the quality of the wireless links in a WSN. This allows the routing protocol to avoid using links exhibiting poor quality and to change the route before a link failure. Additional applications include where to place the aggregation function in data gathering. In a content delivery network (CDN), it is very useful to predict the popularity, expressed by the number of solicitations per day, of a multimedia content. The most popular contents are cached near the end-users to maximize the hit ratio of end-users' requests. Thus the satisfaction degree of end-users is maximized and the network overhead is minimized.

3.9. Security Trade-off in Constrained Wireless Networks

Ensuring security is a sine qua non condition for the widespread acceptance and adoption of the IoT, in particular in industrial and military applications. While the Public-Key Infrastructure (PKI) approach is ubiquitous on the traditional Internet, constraints in terms of embedded memory, communication bandwidth and computational power make translating PKI to constrained networks non-trivial.

In the IETF 6TiSCH working group, and through the work on Malisa Vucinic as part of the H2020 ARMOUR project, we have started to work on a "Minimal Security" solution at the IETF. This solution is based on pre-shared keying material, and offers mutual authentication between each node in the network and central security authority, replay protection and key rotation.

4. Application Domains

4.1. Industrial Process Automation

Wireless networks have become ubiquitous and are an integral part of our daily lives. These networks are present in many application domains; the most important are detailed in this section.

Networks in industrial process automation typically perform **monitoring and control** tasks. Wired industrial communication networks, such as HART [1], have been around for decades and, being wired, are highly reliable. Network administrators tempted to "go wireless" expect the same reliability. Reliable process automation networks – especially when used for control – often impose stringent latency requirements. Deterministic wireless networks can be used in critical systems such as control loops, however, the unreliable nature of the wireless medium, coupled with their large scale and "ad-hoc" nature raise some of the most important challenges for low-power wireless research over the next 5-10 years.

Through the involvement of team members in standardization activities, the protocols and techniques will be proposed for the standardization process with a view to becoming the *de-facto* standard for wireless industrial process automation. Besides producing top level research publications and standardization activities, EVA intends this activity to foster further collaborations with industrial partners.

[1] Highway Addressable Remote Transducer

4.2. Environmental Monitoring

Today, outdoor WSNs are used to monitor vast rural or semi-rural areas and may be used to detect fires. Another example is detecting fires in outdoor fuel depots, where the delivery of alarm messages to a monitoring station in an upper-bounded time is of prime importance. Other applications consist in monitoring the snow melting process in mountains, tracking the quality of water in cities, registering the height of water in pipes to foresee flooding, etc. These applications lead to a vast number of technical issues: deployment strategies to ensure suitable coverage and good network connectivity, energy efficiency, reliability and latency, etc.

We work on such applications in an associate team ”REALMS” comprising members from EVA, the university of Berkeley and the university of Michigan.

4.3. The Internet of Things

The general agreement is that the Internet of Things (IoT) is composed of small, often battery-powered objects which measure and interact with the physical world, and encompasses smart home applications, wearables, smart city and smart plant applications.

It is absolutely essential to (1) clearly understand the limits and capabilities of the IoT, and (2) develop technologies which enable user expectation to be met.

The EVA team is dedicated to understanding and contributing to the IoT. In particular, the team will maintain a good understanding of the different technologies at play (Bluetooth, IEEE 802.15.4, WiFi, cellular), and their trade-offs. Through scientific publications and other contributions, EVA will help establishing which technology best fits which application.

4.4. Military, Energy and Aerospace

Through the HIPERCOM project, EVA has developed cutting-edge expertise in using wireless networks for military, energy and aerospace applications. Wireless networks are a key enabling technology in the application domains, as they allow physical processes to be instrumented (e.g. the structural health of an airplane) at a granularity not achievable by its wired counterpart. Using wireless technology in these domains does however raise many technical challenges, including end-to-end latency, energy-efficiency, reliability and Quality of Service (QoS). Mobility is often an additional constraint in energy and military applications. Achieving scalability is of paramount importance for tactical military networks, and, albeit to a lesser degree, for power plants. EVA will work in this domain.

Smart cities share the constraint of mobility (both pedestrian and vehicular) with tactical military networks. Vehicular Ad-hoc NETworks (VANETs) will play an important role in the development of smarter cities.

The coexistence of different networks operating in the same radio spectrum can cause interference that should be avoided. Cognitive radio provides secondary users with the frequency channels that are temporarily unused (or unassigned) by primary users. Such opportunistic behavior can also be applied to urban wireless sensor networks. Smart cities raise the problem of transmitting, gathering, processing and storing big data. Another issue is to provide the right information at the place where it is most needed.

4.5. Emergency Applications

In an “emergency” application, heterogeneous nodes of a wireless network cooperate to recover from a disruptive event in a timely fashion, thereby possibly saving human lives. These wireless networks can be rapidly deployed and are useful to assess damage and take initial decisions. Their primary goal is to maintain connectivity with the humans or mobile robots (possibly in a hostile environment) in charge of network deployment. The deployment should ensure the coverage of particular points or areas of interest. The wireless network has to cope with pedestrian mobility and robot/vehicle mobility. The environment, initially unknown, is progressively discovered and may contain numerous obstacles that should be avoided. The nodes of the wireless network are usually battery-powered. Since they are placed by a robot or a human, their weight is very limited. The protocols supported by these nodes should be energy-efficient to maximize network lifetime. In such a challenging environment, sensor nodes should be replaced before their batteries are depleted. It is therefore important to be able to accurately determine the battery lifetime of these nodes, enabling predictive maintenance.

4.6. Types of Wireless Networks

The EVA team will distinguish between opportunistic communication (which takes advantage of a favorable state) and = collaborative communication (several entities collaborate to reach a common objective). Furthermore, determinism can be required to schedule medium access and node activity, and to predict energy consumption.

In the EVA project, we will propose **self-adaptive wireless networks** whose evolution is based on:

- optimization to minimize a single or multiple objective functions under some constraints (e.g. interference, or energy consumption in the routing process).
- machine learning to be able to predict a future state based on past states (e.g. link quality in a wireless sensor network) and to identify tendencies.

The types of wireless networks encountered in the application domains can be classified in the following categories.

4.6.1. Wireless Sensor and Mesh Networks

Standardization activities at the IETF have defined an “upper stack” allowing low-power mesh networks to be seamlessly integrated in the Internet (6LoWPAN), form multi-hop topologies (RPL), and interact with other devices like regular web servers (CoAP).

Major research challenges in sensor networks are mostly related to (predictable) power conservation and efficient multi-hop routing. Applications such as monitoring of mobile targets, and the generalization of smart phone devices and wearables, have introduced the need for WSN communication protocols to cope with node mobility and intermittent connectivity.

Extending WSN technology to new application spaces (e.g. security, sports, hostile environments) could also assist communication by seamless exchanges of information between individuals, between individuals and machines, or between machines, leading to the Internet of Things.

4.6.2. Deterministic Low-Power Networks

Wired sensor networks have been used for decades to automate production processes in industrial applications, through standards such as HART. Because of the unreliable nature of the wireless medium, a wireless version of such industrial networks was long considered infeasible.

In 2012, the publication of the IEEE 802.15.4e standard triggered a revolutionary trend in low-power mesh networking: merging the performance of industrial networks, with the ease-of-integration of IP-enabled networks. This integration process is spearheaded by the IETF 6TiSCH working group, created in 2013. A 6TiSCH network implements the IEEE 802.15.4e TSCH protocol, as well as IETF standards such as 6LoWPAN, RPL and CoAP. A 6TiSCH network is synchronized, and a communication schedule orchestrates all communication in the network. Deployments of pre-6TiSCH networks have shown that they can achieve over 99.999% end-to-end reliability, and a decade of battery lifetime.

The communication schedule of a 6TiSCH network can be built and maintained using a centralized, distributed, or hybrid scheduling approach. While the mechanisms for managing that schedule are being standardized by the IETF, which scheduling approach to use, and the associated limits in terms of reliability, throughput and power consumption remains entirely open research questions. Contributing to answering these questions is an important research direction for the EVA team.

4.6.3. MANETs and VANETs

In contrast to routing, other domains in MANETs such as medium access, multi-carrier transmission, quality of service, and quality of experience have received less attention. The establishment of research contracts for EVA in the field of MANETs is expected to remain substantial. MANETs will remain a key application domain for EVA with users such as the military, firefighters, emergency services and NGOs.

Vehicular Ad hoc Networks (VANETs) are arguably one of the most promising applications for MANETs. These networks primarily aim at improving road safety. Radio spectrum has been ring-fenced for VANETs worldwide, especially for safety applications. International standardization bodies are working on building efficient standards to govern vehicle-to-vehicle or vehicle-to-infrastructure communication.

4.6.4. Cellular and Device-to-Device Networks

We propose to initially focus this activity on spectrum sensing. For efficient spectrum sensing, the first step is to discover the links (subcarriers) on which nodes may initiate communications.= In Device-to-Device (D2D) networks, one difficulty is scalability.

For link sensing, we will study and design new random access schemes for D2D networks, starting from active signaling. This will assume the availability of a control channel devoted to D2D neighbor discovery. It is therefore naturally coupled with cognitive radio algorithms (allocating such resources): coordination of link discovery through eNode-B information exchanges can yield further spectrum usage optimization.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

1. **Pascale Minet**, **Paul Muhlethaler** and Ines Khoufi received the best paper award for their paper "Coded Slotted Avoidance in a Wireless Network: Models and Simulations" at PEMWN 2017.
2. SolSystem selected as one of the 10 testbeds at the IoT Solutions World Congress, Barcelona, Spain, 3-5 October 2017.
3. SmartMesh IP awarded "Internet of Things Product of the Year" at the Annual Creativity in Electronics (ACE) Awards, 6 December 2017. (Note: this is not a personal award)

5.1.2. 6TiSCH Standardization Virtually Completed

Time Synchronized Channel Hopping (TSCH) is a Medium-Access Control (MAC) technique in which nodes synchronize, and a schedule orchestrates all communication in the network. Inria-EVA created the IETF 6TiSCH Working Group in 2013. The goal of 6TiSCH is to get the best of both world by combining TSCH ("industrial" performance) and the ease of use of IPv6 through the IETF upper stack (6LoWPAN, RPL, CoAP). Since the creation of 6TiSCH in October 2013, **Thomas Watteyne** co-chairs the working group, helps drive its technical developments, and coaches authors and authors technical documents. 6TiSCH also encompasses and important security aspect, where we look how to enable nodes to join a network efficiently, which includes mutual authentication between node and network. The 6TiSCH security solution if based on PSK, and relies on AES-128 CCM*.

421 people now follow the 6TiSCH activities through its mailing-list, with a healthy mix of industrial and academic contributors. In 2017, 6TiSCH has produced 2 RFCs, 6 working group document in the process of being published, and various individual submissions. The working group has met 3 times in person during 2017, tens of times through Webex. Inria-EVA co-organized a 6TiSCH interop event (attended by 15 entities) in July 2017. 6TiSCH is now supported by all major open-source implementations (OpenWSN , Contiki , RIOT, TinyOS), and several companies are building commercial product lines with it. 6TiSCH has been playing a real role of catalyst for the academic low-power wireless community, which has now mostly moved towards TSCH/6TiSCH.

5.1.3. Over 1,000 Sensors Deployed on 3 Continents

Inria-EVA uses SmartMesh IP as a low-power wireless building block for building end-to-end solutions. Deploying real networks allows Inria-EVA to do system-level cross-disciplinary research. Inria-EVA oversees over 1,000 sensors deployed on 3 continents:

- http://snowhow.io/. Monitoring the snowmelt process in the California Sierra Nevada. 945 sensors deployed in 21 networks. Collaboration with UC Berkeley Prof. Steven Glaser.
- http://www.savethepeaches.com/. Predicting frost events in peach orchards. 120 sensors deployed in Mendoza, Argentina. Collaboration with local agronomy/networking teams
- http://smartmarina.org/. Monitoring the occupancy and per-boat water/electricity consumption of the 3rd largest marina in Europe (Cap d'Agde, 4300 boats). Inria-EVA is working on turning this activity into a startup company.

6. New Software and Platforms

6.1. OpenWSN

KEYWORDS: Internet of things - 6TiSCH - 6LoWPAN - CoAP
FUNCTIONAL DESCRIPTION: OpenWSN is an open-source implementation of a fully standards-based protocol stack for the Internet of Things. It has become the de-facto implementation of the IEEE802.15.4e TSCH standard, has a vibrant community of academic and industrial users, and is the reference implementation of the work we do in the IETF 6TiSCH standardization working group.

- Partner: University of California Berkeley
- Contact: Thomas Watteyne
- URL: http://www.openwsn.org/

6.2. 6TiSCH Simulator

High-level simulator of a 6TiSCH network
KEYWORDS: Network simulator - 6TiSCH
FUNCTIONAL DESCRIPTION: The simulator is written in Python. While it doesn't provide a cycle-accurate emulation, it does implement the functional behavior of a node running the full 6TiSCH protocol stack. This includes RPL, 6LoWPAN, CoAP and 6P. The implementation work tracks the progress of the standardization process at the IETF.

- Contact: Malisa Vucinic

6.3. Argus

KEYWORDS: Cloud - Low-Power WIreless - Sniffer
FUNCTIONAL DESCRIPTION: There are three piece to the Argus:

The Argus Probe is the program which attaches to your low-power wireless sniffer and forwards its traffic to the Argus Broker.

The Argus Broker sits somewhere in the cloud. Based on MQTT, it connect Argus Probes with Argus Clients based on a pub-sub architecture.

Several Argus Clients can the started at the same time. It is a program which subscribes to the Argus Broker and displays the frames in Wireshark.

- Contact: Rémy Leone

6.4. SolSystem

Sensor Object Library System
KEYWORDS: Low-Power WIreless - Back-End System - SmartMesh IP
FUNCTIONAL DESCRIPTION: The source code is composed of the definition of the SOL structure (https://github.com/realms-team/sol), the code that runs on the manager (https://github.com/realms-team/solmanager, written in Python) and the code that runs on the server receiving the data (https://github.com/realms-team/solserver, written in Python)

- Contact: Keoma Brun-Laguna
- URL: http://www.solsystem.io/

6.5. 6TiSCH Wireshark Dissector

KEYWORDS: 6TiSCH - Wireshark
FUNCTIONAL DESCRIPTION: Implementation on the dissectors is done through an open-source repository, stable code is regularly contributed back to the main Wireshark code base.

- Contact: Jonathan Munoz

6.6. F-Interop

Remote Conformance and Interoperability Tests for the Internet of Thing
KEYWORDS: Interoperability - Iot - Conformance testing - Standardization

- Partners: UPMC - IMEC - ETSI - EANTC - Mandat International - Digital Catapult - University of Luxembourg - Device Gateway
- Contact: Rémy Leone

6.7. Mercator

KEYWORDS: Deployment - Low-Power WIreless - Testbeds - Connectivity
FUNCTIONAL DESCRIPTION: The firmware is written as part of the OpenWSN project. Scripts and analysis tools are written in Python.

- Contact: Keoma Brun-Laguna

6.8. Platforms

6.8.1. SolSystem

In collaboration with University College London and IBM, we have designed a cloud-based low-power network management solution called SolSystem. It serves as a “control tower” for the networks we deploy, allowing us to manage both the network and data produced by those networks. It is architected following the micro-service principle, and we are in the process of switching all of our deployments to that interface. Fig. 1 gives an example of the visualization the SolSystem web interface gives us.

6.8.2. OpenMote B

In collaboration with OpenMote (http://www.openmote.com/), we have designed the OpenMote B platform. This board contains both a CC2538 IEEE802.15.4 radio, and an AT86RF215 IEEE802.15.4g radio, offering communication on both 2.4 GHz and sub-GHz frequency bands, 4 modulations schemes, and data rates from 50 kbps to 800 kbps. The first prototypes (shown in Fig. 2) started being tested in December 2017.

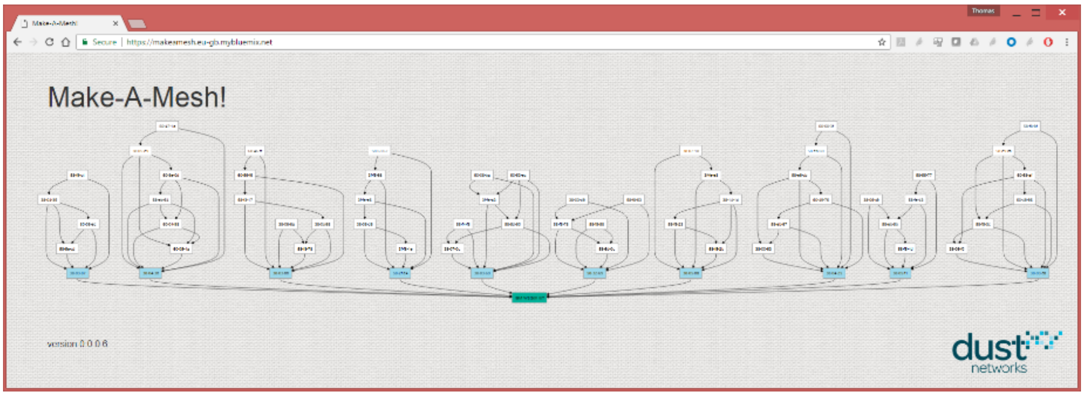

Figure 1. Topological view of the canopy network deployed across the Robert's building at University College London from February to April 2017, using SolSystem.

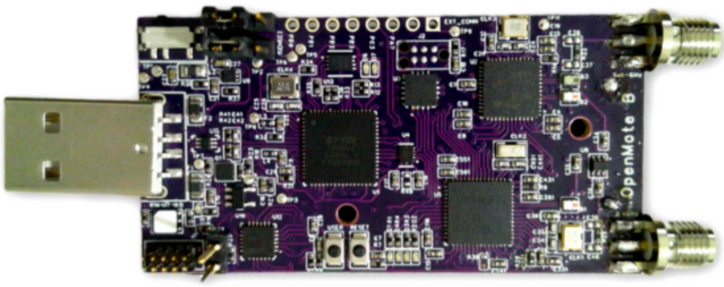

Figure 2. The OpenMote B. sub-GHz radio (and antenna connector) on top, 2.4 GHz radio on the bottom.

7. New Results

7.1. 6TiSCH Standardization and Benchmarking

7.1.1. *Minimal Security Solution*

Participants: Malisa Vucinic, Thomas Watteyne.

The 6TiSCH standardization effort had, until 2017, a big gap: security. Thanks to the work of Malisa Vucinic, this gap is now filled, with the publication of the Minimal Security solution (draft-ietf-6tisch-minimal-security). Here is a summary of what has been implemented and tested:

- Two implementations of the OSCORE protocol, formerly known as OSCOAP, specified in draft-ietf-core-object-security-03, in C and in Python, supporting both client and server roles, as part of the OpenWSN stack. Updated the test suite of the Python implementation with OSCOAP functional tests.
- Two implementations of Simple Join Protocol for 6TiSCH, specified in draft-ietf-6tisch-minimal-security-03, in C supporting the role of a pledge and in Python, supporting the role of JRC. Written unit tests for the implemented CBOR decoder in C.
- Simulation of the join process in 6TiSCH simulator. Extended the simulator to support shared cells, downwards RPL routing and join traffic. Tested the two implementations of Simple Join Protocol/OSCOAP using the F-Interop tools.

7.1.2. *OpenWSN Fresh with full 6TiSCH Support*

Participants: Tengfei Chang, Thomas Watteyne.

Thanks to the incredible work of Tengfei Chang, the OpenWSN project was refocused on being the lead reference 6TiSCH implementation. “OpenWSN Fresh” was a 2017 program to separate the protocol stack implementation from the rest of the OpenWSN code, and to have full standards-compliance.

7.1.3. *First F-Interop 6TiSCH Interop Event*

Participants: Remy Leone, Tengfei Chang, Malisa Vucinic, Thomas Watteyne.

The 6TiSCH WG organized an interoperability event co-located with the IETF meeting in Prague in July 2017. The interop tests focused on the minimal security framework and the 6top protocol. OpenWSN was used as the reference implementation, and F-Interop tools were demonstrated.

7.1.4. *Agile Networking*

Participants: Jonathan Munoz, Thomas Watteyne.

Today’s low-power wireless devices typically consist of a micro-controller and a radio. The most commonly used radios are IEEE802.15.4 2.4GHz, IEEE802.15.4g sub-GHz and LoRA (SemTech) compliant. Radios offer a different trade-off between range and data-rate, given some energy budget. To make things more complex, standards such IEEE802.15.4g include different modulations schemes (2-FSK, 4-FSK, O-QPSK, OFDM), further expanding the number of options.

The main idea behind agile networking is to redefine a low-power wireless device as having multiple radios, which it can possibly use at the same time. That is, in a TSCH context, for each frame a node sends, it can change the radio it is using, and its setting. If the next hop is close, it sends the frame with a fast data rate thereby reducing the radio on-time and the energy consumption. If the next hop is far, it uses a slower data rate.

We recently design the OpenMote B within the OpenMote company. This board contains both a CC2538 IEEE802.15.4 radio, and an AT86RF215 IEEE802.15.4g radio, offering communication on both 2.4GHz and sub-GHz frequency bands, 4 modulations schemes, and data rates from 50 kbps to 800 kbps. The first prototypes started being tested in December 2017.

The second challenge is to redesign the protocol stack in a standards-compliant way. We are working with Jonathan Munoz on a 6TiSCH design in which neighbor discovery happens independently on each radio, and the same neighbor node can appear as many times in the neighbor table as it has radios. The goal is to standardize an “Agile 6TiSCH” profile, without having to touch the core specifications. This is been implemented in OpenWSN. The next step is to evaluate the performance of the solution on an 80-node OpenMote B testbed we are putting together. We hope to show that a single device running the same stack can satisfy both building-size and campus-size deployment, with the same industrial requirements.

7.2. SolSystem Deployments

SolSystem (http://solsystem.io/) is a complete sensor-to-cloud solution, which the Inria-EVA team uses to federate the different real-world deployments it is conducting.

7.2.1. SmartMarina

Participants: Ziran Zhang, Keoma Brun-Laguna, Thomas Watteyne.

Marinas are quickly evolving from sailing spots to floating neighborhoods. It is now common for people to live on their boat year-round, and for boats to be rented for just a week-end through online platforms. Today, living or staying on a boat is often cheaper that buying or renting an apartment. Similarly, in coastal areas, the marina is often the center of the city, so an ideal location for lodging. As a result, the trend is not going to end any time soon. Today’s marinas are tomorrow’s smart cities.

And as the marina is evolving, so are its needs.

- From a marina management point of view, automatic mooring management and electricity/water monitoring allows personnel to free up to welcome visitors and focus entirely on their well-being.
- Year-road boat owners and occasional marina visitors now can enjoy new services, from increased mooring availability to remote monitoring and alerts about the state of their boat.

The combination of embedded micro-controllers, low-power wireless communication and sensors/actuators offers tremendous opportunities for marinas. Off-the-shelf “Internet of Things” technology can now be used to detect the presence of boats in moorings, track usage of water and electricity on a per-boat basis, track a boat in real-time as it enters the marina, etc. Because no wires need to be installed – neither for power, nor communication – installation can be done in a matter of hours in a peal-and-stick fashion. Pontoons can be moved, rearranged or removed, without having to worry about the smart devices mounted on it.

The goal of the SmartMarina project (http://smartmarina.org/) is to build a system composed of sensors deployed all over the marina, and advanced software to monitor the occupation of moorings, and the electricity and water consumption on each spot. The result is a system that allows more efficient management and new services. The first sensor was installed in April 2017, and the Inria-EVA team is looking at turning this activity into a startup company.

7.2.2. SaveThePeaches

Participants: Keoma Brun-Laguna, Thomas Watteyne.

In 2013, 85% of the peach production in the Mendoza region (Argentina) was lost because of frost. Because less fruit was produced in the region, 600.000 less work days were needed to process the harvest between November 2013 and March 2014, a reduction in work force of 10.600 people. Across the Mendoza region, frost has caused a loss of revenue of 950 million Argentine pesos roughly 100 million USD in the peach business alone.

A frost event happens when the temperature is so low that the crops cannot recover their tissue or internal structure from the effects of water freezing inside or outside the plant. For the peach production, a critical period is when the trees are in bloom and fruit set (Aug./Sept. in Mendoza), during which the temperature needs to be kept above 3 C. Even a few hours below that temperature causes flowers to fall, preventing fruits to grow.

Because of the huge economic impact, countermeasures exist and are used extensively. Today, virtually all industrial peach orchards are equipped with a small number of meteorological stations which monitor temperature and humidity. If the temperature drops dangerously low, the most effective countermeasures is to install a number of furnaces in the orchard (typically coalfueled) and fly helicopters above the orchard to distribute the heat and avoid cold spots. This countermeasure is effective, but suffers from false positives (the helicopters are called in, but there is no frost event) and false negatives (the meteorological stations don't pick up a frost event happening in some part of the orchard).

What the SaveThePeaches project (http://www.savethepeaches.com/) has developed in 2016-2017 is a dense 120-sensor real-time monitoring solution deployed in the orchard, and feeding a frost prediction model. A node is the size of a deck of cards, is self-contained and battery-operated. When switched on, nodes form a multi-hop low-power wireless network, automatically. Rather than being installed at a fixed location, these nodes can be hung directly in the trees. A network is deployed in an orchard in a matter of hours, and if needed, sensing points can be moved to improve the accuracy of the prediction model in minutes. We use machine learning and pattern recognition to build an micro-climate predictive model by continuously analyzing the gathered sensor data in real time. This model generates early frost warnings. Ones demonstrated, the solution can be extended to other crops, and other regions.

7.2.3. SnowHow

Participants: Keoma Brun-Laguna, Thomas Watteyne.

Between 2012 and 2015, California suffered from the highest water drought since recordings started in this state. Up to 2/3 of its water resources are coming from the Sierra Nevada snowpack. Understanding the effect of the droughts on the mountain snowpack is crucial.

Historically, the study of mountain hydrology and the water cycle has been largely observational, with variables extrapolated from a few infrequent manual measurements. Low-power wireless mesh networking technology has evolved significantly over recent years. With this technology, a node is the size of a deck of cards, is self-contained and battery-operated. When switched on, nodes form a multi-hop low-power wireless network, automatically. Next-generation hydrologic science and monitoring requires real-time, spatially distributed measurements of key variables including: soil moisture, air/soil temperature, snow depth, and air relative humidity.

The SnowHow project (http://snowhow.io/) provides these measurements by deploying low-power mesh networks across the California Sierra Nevada. Off-the-shelf commercial solutions are available today which offer >99.999% end-to-end data reliability and a decade of battery lifetime. A new wireless network can be deployed in a couple of hours and report sensor data minutes after it was measured.

7.3. IoT and Wireless Sensor Networks

More than 50 billions of devices will be connected in 2020. This huge infrastructure of devices, which is managed by highly developed technologies, is called Internet of Things (IoT). The latter provides advanced services, and brings economical and societal benefits. This is the reason why engineers and researchers of both industry and scientific communities are interested in this area. The Internet of Things enables the interconnection of smart physical and virtual objects, managed by highly developed technologies. WSN (Wireless Sensor Network), is an essential part of this paradigm. The WSN uses smart, autonomous and usually limited capacity devices in order to sense and monitor their environment.

7.3.1. Deployment of autonomous and mobile wireless sensor nodes

Participants: Ines Khoufi, Pascale Minet.

This work was done in collaboration with Nadia Boufares (ENSI, University of Manouba, Tunisia) and Leila Saidane (ENSI, University of Manouba, Tunisia).

Wireless Sensor Networks (WSNs) are used in a wide range of applications due to their monitoring and tracking abilities. Depending on the applications goals, sensor nodes are deployed either in a two-dimensional (2D) area or in a three-dimensional (3D) area. In addition, WSN deployment can be either in a distributed or a centralized manner. In 2017, we were interested in a fully distributed deployment of WSN in several 3D-flat-surface configurations using autonomous and mobile nodes. Our goal was to ensure full 3D flat surfaces coverage and maintain network connectivity for these surfaces. To reach our goal we proposed 3D-DVFA-FSC, a distributed deployment algorithm based on virtual forces strategy to move sensor nodes over different 3D-flat-surface shapes. Initially, nodes were randomly deployed. Full coverage was reached in the given configurations and maintained up to the end of simulation. We also evaluated the total distance traveled by nodes. Simulation results show that sensor nodes still move even when full 3D-surface coverage is reached. This is due to the node oscillations problem. This problem will be tackled in our future work. We will also focus on how to stop nodes when full coverage is reached and consider 3D surface complex shapes where the challenges of coverage and connectivity are more complicated. This work was presented at the IWCMC 2017 conference, see [15].

7.3.2. Collision avoidance on shared slots in wireless slotted networks

Participants: Ines Khoufi, Pascale Minet, Paul Muhlethaler.

We propose an analysis of slotted based protocols designed for devices of the Internet of Thing (IoT). In contrast to other TDMA-based protocols this scheme uses a random technique to access shared slots which presents similarities with CSMA protocols. In practice the transmissions are scheduled in a given back-off window of slots whose duration allows the transmission of a packet and its acknowledgment. Therefore this protocol can be analyzed according to the methodology introduced by Bianchi for the IEEE 802.11 protocol even if the protocol studied differs in many aspects. The model we use is also particular because we succeed in obtaining a Markov model even if the scheme used to send a packet (in a node) may depend on the transmission of the previous packet(s). We distinguish two protocols. In the first one, at the initial stage or after a successful transmission, the packets are transmitted without any back-off, whereas in the second protocol each transmission is always preceded by the count down of a random back-off. Extensive simulations show a very good match between the model and the simulation results, see [22]. For moderate medium load, the protocol performing a backoff before each transmission outperforms the TSCH protocol, when the number of neighboring nodes is greater than or equal to 8. For a smaller number of neighboring nodes, the TSCH protocol provides a higher throughput. For high medium load, the TSCH protocol provides the highest normalized throughput at the cost of some unfairness in the transmission opportunities.

7.3.3. Security in the OCARI wireless sensor network

Participant: Pascale Minet.

Wireless Sensor Networks and Industrial Internet of Things use smart, autonomous and usually limited capacity devices in order to sense and monitor industrial environments. The devices in a wireless sensor network are managed by a controller, also called CPAN, which should authenticate them before they join the network. OCARI is a promising wireless sensor network technology providing optimized protocols in order to reduce the energy consumption and support pedestrian mobility. However, it needs to be secured against the different threats, especially those that concern confidentiality, data integrity, and entities authentication. This challenge was addressed in a joint work with Mohammed Tahar Hammi (Telecom ParisTech), Erwan Livolant (AFNet, Boost technologies), Patrick Bellot (Telecom ParisTech), Ahmed Serhouchni (Telecom ParisTech) and **Pascale Minet** (Inria). The main results have been published in two papers.

A robust mutual authentication is the challenge addressed in the paper presented at the ICMWT 2017 conference [28]. We proposed a lightweight, robust, and energy efficient WSN mutual authentication protocol. This protocol is especially designed to be implemented on devices with low storage and computing capacities. It has been implemented on OCARI. All nodes wanting to access the network should be authenticated at the MAC sub-layer of OCARI. This solution provides a protection against "replay attacks", because the exchanged OTPs are based on random numbers, therefore, they are valid only for one transaction. Using the blacklisting mechanism we can secure our systems against "some DoS" attacks. Finally it is flexible and does not decrease the scalability of the system, and can be deployed in different WSNs technologies, while keeping the same level of robustness. In our future work we aim to ensure the confidentiality of the transmitted messages exchanged after the MAC sub-layer association and authentication procedure. And thus we will have a secure system which ensures the “Confidentiality”, “Integrity, and “Authentication” services.

In the paper presented at CSNet 2017 ([27] , we designed a security protocol that enables to secure most of the WSNs thanks to its lightness and energy efficiency. It ensures a mutual authentication of the communicating entities and a protection of both the integrity and the confidentiality of the exchanged data. The “personalization” mechanism solves the problem of the internal identity usurpation. The proposed key management allows a safe and secure keys exchange between the concerned entities. Furthermore, this protocol provides a very fast establishment of a secure channel based on a robust, fast, and lightweight symmetric encryption algorithm (AES GCM/CCM). Finally, this solution is resilient against the cryptanalysis and the replay attacks. In our future works, we aim to create a secure communicating system between different CPANs and to facilitate a secure migration of devices from a network managed by a CPAN to a network managed by another CPAN.

7.3.4. Security in Wireless Sensor Networks

Participants: Selma Boumerdassi, Paul Muhlethaler.

Sensor networks are often used to collect data from the environment where they are located. These data can then be transmitted regularly to a special node called a *sink*, which can be fixed or mobile. For critical data (like military or medical data), it is important that sinks and simple sensors can mutually authenticate so as to avoid data to be collected and/or accessed by fake nodes. For some applications, the collection frequency can be very high. As a result, the authentication mechanism used between a node and a sink must be fast and efficient both in terms of calculation time and energy consumption. This is especially important for nodes which computing capabilities and battery lifetime are very low. Moreover, an extra effort has been done to develop alternative solutions to secure, authenticate, and ensure the confidentiality of sensors, and the distribution of keys in the sensor network. Specific researches have also been conducted for large-scale sensors. At present, we work on an exchange protocol between sensors and sinks based on low-cost shifts and xor operations. After this publication, we have been working on the performance evaluation of the solution to determine the memory overhead together with both computing and communication latencies.

7.3.5. Massive MIMO Cooperative Communications for Wireless Sensor Networks

Participants: Nadjib Achir, Paul Muhlethaler.

This work is done in collaboration with Mérouane Debbah (Supelec, France).

The objective of this work is to propose a framework for massive MIMO cooperative communications for Wireless Sensor Networks. Our main objective is to analyze the performances of the deployment of a large number of sensors. This deployment should cope with a high demand for real time monitoring and should also take into account energy consumption. We have assumed a communication protocol with two phases: an initial training period followed by a second transmit period. The first period allows the sensors to estimate the channel state and the objective of the second period is to transmit the data sensed. We start analyzing the impact of the time devoted to each period. We study the throughput obtained with respect to the number of sensors when there is one sink. We also compute the optimal number of sinks with respect to the energy spent for different values of sensors. This work is a first step to establish a complete framework to study energy efficient Wireless Sensor Networks where the sensors collaborate to send information to a sink. Currently, we are exploring the multi-hop case.

7.4. Industry 4.0 and Wireless Sensor Networks

By the year 2020, it is expected that the number of connected objects will exceed several billions devices. These objects will be present in everyday life for a smarter home and city as well as in future smart factories that will revolutionize the industry organization. This is actually the expected fourth industrial revolution, more known as Industry 4.0. In which, the Internet of Things (IoT) is considered as a key enabler for this major transformation. IoT will allow more intelligent monitoring and self-organizing capabilities than traditional factories. As a consequence, the production process will be more efficient and flexible with products of higher quality.

Several standards have been designed for industrial wireless sensor (IoT) networks such as WirelessHart and ISA100. Both of them are based on the IEEE 802.15.4 standard for the lower layers. More recently, Time Slotted Channel Hopping (TSCH) which is specified in amendment e of the IEEE 802.15.4 standard, uses a time slotted medium access operating on several channels simultaneously. In addition, radio perturbations are mitigated by frequency hopping. TSCH supports star and mesh topologies, as well as multi-hop communication. It has been designed for process automation, process control, equipment monitoring and more generally the Internet of Things. It is a candidate technology for the Industry 4.0. In fact, Industry 4.0 will use more and more the on-demand manufacturing in a highly fexible and widespread environment. Different supply chains located in various regions need to coordinate their actions in a real-time basis with high fidelity. The IoT communicating in a wireless manner will play a major role to achieve this target. Time Slotted Channel Hopping (TSCH) networks are emerging as a promising technology for the Internet of Things and the Industry 4.0 where ease of deployment, reliability, short latency, flexibility and adaptivity are required. However, the strong requirements in terms of short latency and high reliability of such applications are obstacles to its penetration in the Industry 4.0. That is why in 2017 we made three contributions dealing with:

- how to quickly build a TSCH network;
- how to increase the reliability of end-to-end communications;
- how to efficiently schedule the transmissions made for data gathering.

7.4.1. Building an IEEE 802.15.4e TSCH network

Participants: Ines Khoufi, Pascale Minet.

The IEEE 802.15.4e amendment has been designed to meet the requirements of industrial applications with regard to the wireless sensor networks supporting them. Because of its scheduled medium access and multichannel transmissions, the TSCH mode has received much attention. In this study, we focus on the time needed by a node to detect a beacon sent by a TSCH network, as well as on the time needed to build a TSCH network. These times are important for industrial applications where new nodes are inserted progressively, or when failed nodes are replaced. Both times highly depend on the beacon advertisement policy, policy that is not specified in the standard and is under the responsibility of a layer upper than the MAC one. Since beacons are broadcast, they are lost in case of collisions: the vital information they carry is lost. The main problem is how to avoid collisions between two devices that are not neighbors. That is why we propose DBA, a Deterministic Beacon Advertisement algorithm that ensures a regular transmission of beacons without collisions. The goal of DBA is to ensure that beacons are transmitted on all frequencies used by the TSCH network, regularly and without collision. With DBA, the exact value for the maximum time for a joining node to detect a beacon can be computed easily. We use the NS3 Simulator to evaluate this time as well as the the number of message losses, considering different network topologies (star or multihop). Simulation results show that DBA clearly outperforms existing solutions such as Random Vertical and Random Horizontal, two algorithms existing in the state of the art. In addition, DBA is able to provide the exact value of the maximum joining time.These results have been presented at the EUCASS 2017 conference, see [31].

7.4.2. Increasing the reliability of an IEEE 802.15.4e TSCH network

Participants: Ines Khoufi, Pascale Minet.

Our goal is to improve reliability of data gathering in such wireless sensor networks. We present three redundancy patterns to build a reliable path from a source to a destination. The first one is the well-known two node-Disjoint paths. The second one is based on a Triangular pattern, and the third one on a Braided pattern. The reliability provided by each pattern, the delivery time and the overhead in terms of the number of transmissions generated by each pattern as well as the amount of energy consumed by an end-to-end transmission allows us to conclude that the Braided pattern provides the highest reliability but with an overhead approximately twice the overhead of the Disjoint-path pattern and 4/3 the overhead of the Triangular pattern. These performance results are corroborated by simulations performed with NS3 for various configurations. This result has been presented at the NCA 2017 conference ([21]).

7.4.3. Scheduling transmissions in an IEEE 802.15.4e TSCH network

Participants: Ines Khoufi, Pascale Minet.

TSCH provides a multichannel slotted medium access ruled by a periodic schedule and supports multihop communications. This schedule is repeated every slotframe. A slotframe consists of a set of cells, each cell is identified by a (time slot offset, channel offset) pair. The size of a timeslot (e.g. 10 ms by default) allows the transmission of a point-to-point frame and its immediate acknowledgment. The schedule defines for each cell the nodes allowed to transmit and those that should receive. The channel offset is translated into a physical channel depending on the channel hopping sequence of the TSCH network. Channel hopping allows the TSCH to increase its robustness against external perturbations of the radio signal.

In the paper presented at VTC-Fall 2017 [20], we study how applications with data delivery constraints can be supported by a TSCH network. We first propose a framework based on a multislotframe that allows the coexistence of Data Slotframes and Control Slotframes. We then determine a lower bound on the minimum number of slots required to perform data gathering, taking into account the number of channels, the number of interfaces of the sink, the number of packets generated by each sensor node as well as the number of children of the sink. These feasibility conditions are established for two cases: with spatial reuse and without. We propose a debt-based scheduler that for simple topologies, provides a schedule minimizing the slotframe size. We determine the conditions for which an increase in the number of channels or sink's interfaces leads to a shorter data delivery delay. We compare the number of slots needed by data gathering with and without spatial reuse for small configurations. Finally, we consider a network configuration representative of an industrial application and evaluate the performance of the TSCH network in terms of data delivery delay and queue size for each sensor node, using the NS-3 simulator, where the multislotframe has been integrated. Simulation results Simulation results showed that the maximum theoretical delivery delay is never exceeded and the number of messages in the Transmit queue of each sensor node remains small. In addition, the debt-based scheduler builds a valid schedule with the minimum number of slots for the industrial application considered. we can conclude that TSCH with its time-slotted and multichannel medium access provides an efficient support for data gathering.

7.5. Machine Learning for an efficient and dynamic management of network resources and services

7.5.1. Machine Learning in Networks

Participants: Nesrine Ben Hassine, Dana Marinca, Pascale Minet.

This work was done in collaboration with Dominique Barth (UVSQ) .

Content Delivery Networks (CDNs) are faced with an increasing and time varying demand of video contents. Their ability to promptly react to this demand is a success factor. Caching helps, but the question is: which contents to cache? We need to know which resources are needed before they are requested. This anticipation is made possible by using prediction computed by learning techniques.

Machine learning techniques can be used to improve the quality of experience for the end users of Content Delivery Networks (CDNs). In a CDN, the most popular video contents are cached near the end-users in order to minimize the contents delivery latency. Classically, machine learning techniques are classified as supervised or unsupervised. In 2017, we addressed two challenges:

- as a supervised learning, the use of prediction techniques based on regression to evaluate the future popularity of video contents in order to decide which ones should be cached. The popularity of a video content is evaluated by the number of daily requests for this content.
- as an unsupervised learning, the use of clustering techniques to put together videos with similar features. This clustering will reduce the number of prediction methods, called experts, used to provide an accurate prediction.

7.5.2. *Prediction of video content popularity*

Participants: Nesrine Ben Hassine, Dana Marinca, Pascale Minet.

This work was done in collaboration with Dominique Barth (UVSQ).

We consider various experts, coming from different fields (e.g. statistics, control theory). To evaluate the accuracy of the experts' popularity predictions, we assess these experts according to three criteria: cumulated loss, maximum instantaneous loss and best ranking. The loss function expresses the discrepancy between the prediction value and the real number of requests. We use real traces extracted from YouTube to compare different prediction methods and determine the best tuning of their parameters. The goal is to find the best trade-off between complexity and accuracy of the prediction methods used.
We also show the importance of a decision maker, called forecaster, that predicts the popularity based on the predictions of a selection of several experts. The forecaster based on the best K experts outperforms in terms of cumulated loss the individual experts' predictions and those of the forecaster based on only one expert, even if this expert varies over time.
The paper presented at the Wireless days 2017 conference ([29] is the result of a joint work done in collaboration with Ruben Milocco (Universidad Nacional Comahue, Buenos Aires, Argentina) and Selma Boumerdassi (CNAM, Paris). We focused on predicting the popularity of video contents using Auto-Regressive Moving Average (ARMA) methods applied on a sliding window. These predictions are used to put the most popular video contents into caches. After having identified the parameters of ARMA experts, we compare them with an expert predicting the same number of requests as the previous day. Results show that ARMA experts improve the accuracy of the predictions. Nevertheless, there is no ARMA model that provides the best prediction for all the video contents over all their lifetime. We combine these statistical experts with a higher level of experts, called forecasters. By combining the experts prediction, some forecasters succeed in predicting more accurate values which helped to increase the hit ratio while keeping a correct update ratio. Hence, improving the accuracy of the predictions succeeds in improving the hit ratio. To summarize, we proposed an original solution combining the predictions of several ARMA models. This solution achieves a better Hit Ratio and a smaller Update Ratio than the classical Least Frequently Used (LFU) caching technique.

7.5.3. *Clustering of video contents*

Participants: Nesrine Ben Hassine, Pascale Minet.

With regard to video content clustering, we proposed an original solution based on game theory that was presented at the CCNC 2017 conference ([30]. This is a joint work with Mohammed-Amine Koulali (Mohammed I University Oujda, Morocco), Mohammed Erradi (Mohammed I University Rabat, Morocco), Dana Marinca (University of Versailles Saint-Quentin) and Dominique Barth (University of Versailles Saint-Quentin). Game theory is a powerful tool that has recently been used in networks to improve the end users' quality of experience (e.g. decreased response time, higher delivery rate). In this paper, the original idea consists in using game theory in the context of Content Delivery Networks (CDNs) to organize video contents into clusters having similar request profiles. The popularity of each content in the cluster can be determined from the popularity of the representative of the cluster and used to store the most popular contents close to end users. A group of experts and a decision-maker predict the popularity of the representative of the cluster. This considerably reduces the number of experts used. More precisely, we model the clustering problem as a hedonic coalition formation game where the players are the video contents. We proved that this game always converges to a stable partition consisting of different clusters. We determined the best size of the observation window and showed that the play order minimizing the maximum distance to the representative of the cluster is the Rich-to-Poor order, whatever the number of video contents in the interval [20; 200]. The complexity of the coalition game remains very light. Convergence is obtained in a small number of rounds (i.e. less than 35 rounds for 200 video contents). We compare the results of this approach with the clustering obtained by the K-means algorithm, using real traces extracted from YouTube. We also evaluate the complexity of the proposed algorithm. The coalition game outperforms K-means in terms of the average and maximum distances to the representative of the cluster. The execution time is also in favor of the coalition game when the number of contents is higher than or equal to 50. Furthermore, the coalition game can be used to quickly determine the best value of K that is required as an input parameter of the K-means algorithm. Simulation results show that the coalition game provides very good performances.

7.6. Protocols and Models for Wireless Networks - Application to VANETs

7.6.1. Protocols for VANETs

7.6.1.1. TRPM: a TDMA-aware routing protocol for multi-hop communications in VANETs

Participants: Mohamed Elhadad Or Hadded, Paul Muhlethaler, Anis Laouiti.

The main idea of TRPM is to select the next hop using the vehicle position and the time slot information from the TDMA scheduling. Like the GPSR protocol, we assume that each transmitting vehicle knows the position of the packet's destination. In TRPM, the TDMA scheduling information and the position of a packet's destination are sufficient to make correct forwarding decisions at each transmitting vehicle. Specifically, if a source vehicle is moving in area x_i, the locally optimal choice of next hop is the neighbor geographically located in area x_{i+1} or x_{i-1} according to the position of the packet's destination. As a result, the TDMA slot scheduling obtained by DTMAC can be used to determine the set of next hops that are geographically closer to the destination. In fact, each vehicle that is moving in the area x_i can know the locally optimal set of next hops that are located in adjacent areas x_{i+1} or x_{i-1} by observing the set of time slots $S_{(i+3)\%3}$ or $S_{(i+1)\%3}$, respectively. We consider the same example presented above when vehicle G as the destination vehicle that will broadcast a message received from vehicle A. As shown in Figure 3, only two relay vehicles are needed to ensure a multi-hop path between vehicle A and G (one relay node in the area x_2 and another one in the area x_3).

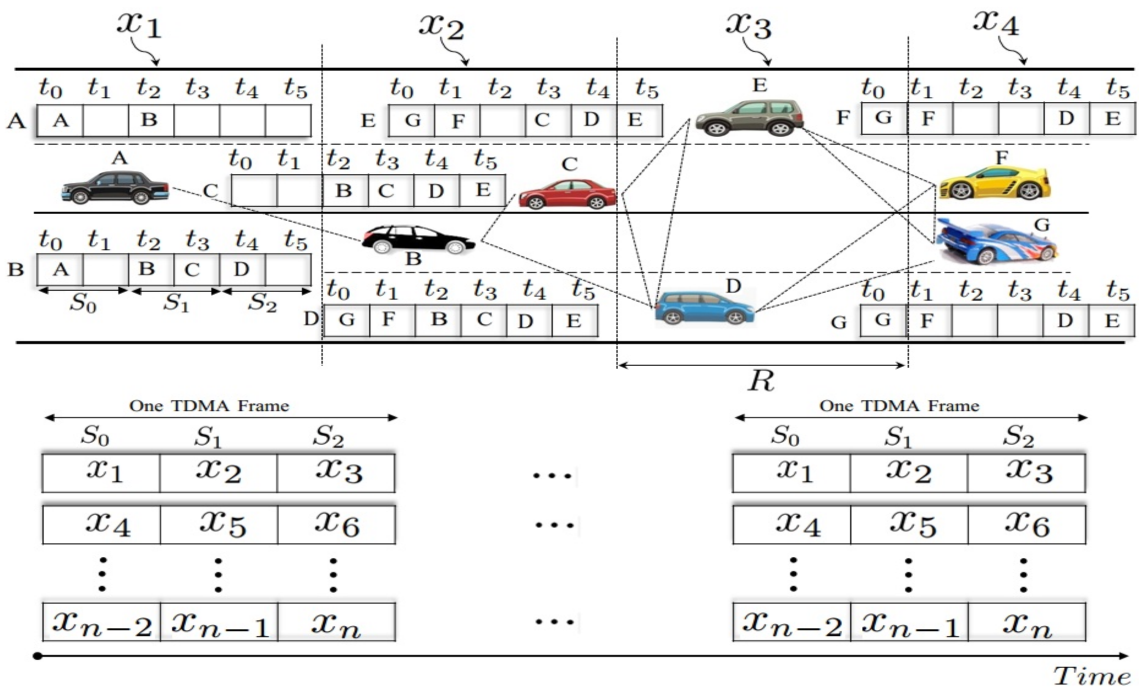

Figure 3. VANET network using DTMAC scheduling scheme.

In the following, the DTMAC protocol has been used by the vehicles to organize the channel access. The TDMA slot scheduling obtained by DTMAC is illustrated in Figure 3. Firstly, vehicle A forwards a packet to B, as vehicle A uses its frame information to choose a vehicle that is accessing the channel during the set S_1. Upon receiving the packet for forwarding, vehicle B will choose by using its frame information a vehicle that's accessing the channel during the set of time slots S_2 (say vehicle D). Then, vehicle D will forward the packet to G, as G is moving in area x_4 (accessing the channel during the set S_0) and it is the direct neighbor of vehicle D. By using DTMAC as the MAC layer, we can note that the path A-B-D-G is the shortest, in terms of the number of hops as well as the end-to-end delay which is equal to 6 time slots (2 time slots between t_0 and t_2 as t_2 is the transmission slot for vehicle B, then 2 time slots between t_2 and t_4 as t_4 is the transmission slot for vehicle D and finally 2 time slots between t_4 and t_0 as t_0 is the transmission slot in which vehicle G will broadcast the message received from vehicle A).

The idea of TRPM [16] is the following . Whenever a vehicle i accessing the channel during the set S_k wants to send/forward an event-driven safety message, it constructs two sets of candidate forwarders based on its frame information FI as follows, where $TS(j)$ indicates the time slot reserved by vehicle j.

- $A_i = \{j \in N(i) \mid TS(j) \in S_{(k+1)\%3}\}$ *// The set of vehicles that are moving in the adjacent right-hand area.*
- $B_i = \{j \in N(i) \mid TS(j) \in S_{(k+2)\%3}\}$ *// The set of vehicles that are moving in the adjacent left-hand area.*

Each source vehicle uses the position of a packet's destination and the TDMA scheduling information to make packet forwarding decisions. In fact, when a source vehicle i is moving behind the destination vehicle, it will select a next hop relay that belongs to set B_i; when the transmitter is moving in front of the destination vehicle, it will select a forwarder vehicle from those in set A_i. For each vehicle i that will send or forward a message, we define the normalized weight function WHS (Weighted next-Hop Selection) which depends on the delay and the distance between each neighboring vehicle j. WHS is calculated as follows:

$$WHS_{i,j} = \alpha * \frac{\Delta t_{i,j}}{\tau} - (1-\alpha) * \frac{d_{i,j}}{R} \qquad (1)$$

Where:

- τ is the length of the TDMA frame (in number of time slots).
- j is one of the neighbors of vehicle i, which represents the potential next hop that will relay the message received from vehicle i.
- $\Delta t_{i,j}$ is the gap between the sending slot of vehicle i and the sending slot of vehicle j.
- $d_{i,j}$ is the distance between the two vehicles i and j, and R is the communication range.
- α is a weighted value in the interval $[0,1]$ that gives more weight to either distance or delay. When α is high, more weight is given to the delay. Otherwise, when α is small, more weight is given to the distance.

We note that the two weight factors $\frac{\Delta t_{i,j}}{\tau}$ and $\frac{d_{i,j}}{R}$ are in conflict. For simplicity, we assume that all the factors should be minimized. In fact, the multiplication of the second weight factor by (-1) allows us to transform a maximization to a minimization. Therefore, the forwarding vehicle for i is the vehicle j that is moving in an adjacent area for which $WHS_{i,j}$ is the lowest value.

The simulation results reveal that our routing protocol significantly outperforms other protocols in terms of average end-to-end delay, average number of relay vehicles and the average delivery ratio.

We have developed an analytical model to evaluate the packet loss rate and the end-to-end delay for safety messages transmitted in vehicular networks over long distances when TRPM is used as a routing protocol, see refhadded:hal-01617924. Comparisons of realistic simulation results, carried out using ns-2 and MOVE/SUMO, and analytical results show that the analytical model proposed provides close approximations for the end-to-end delay and packet loss rate for the different scenarios considered.

7.6.1.2. Trust-CTMAC: A Trust Based Scheduling Algorithm

Participants: Mohamed Elhadad Or Hadded, Paul Muhlethaler, Anis Laouiti.

In Vehicular Ad hoc NETworks, communication is possible both between the vehicles themselves and between the vehicles and the infrastructure. These applications need a reliable and secure broadcast system that takes into consideration the security issues in VANETs, the high speed of nodes and the strict QoS requirements. For these reasons, we propose a trust-based and centralized TDMA-based MAC protocol. Our solution will permit Road Side Units (RSUs) to manage time slot assignment by avoiding malicious nodes and by minimizing message collision. The experiments carried out and the results obtained prove the effectiveness of our approach.

We present a trust based centralized TDMA scheduling mechanism which aims to isolate and prevent malicious vehicles from accessing the channel. This is accomplished by serving only the slot reservation requests of vehicles that have trust values greater than a trust threshold. In Trust-CTMAC, each RSU maintains additional data structure called Trust Counters Table (TCT) and Malicious Vehicles Table (MVT) for all vehicles within its communication range based on the list of properties shown in Table 1. The TCT and the FI information are periodically broadcasted by the RSU for ecah time interval of $100ms$. So each vehicle can identify and isolate malicious vehicles among all neighboring nodes based on the TCT information received from its RSU, which can protect the radio channel from any potential damage caused by the malicious vehicles. An RSU declares a vehicle as a malicious node if the corresponding trust value falls below a trust threshold.

Table 1. Threat lists that are checked in our trust platform

Threat Name	Description	Level
Message Saturation	A huge number of a vehicle packets do not include any form of identification information	3 (high)
False GNSS (Global Navigation Satellite System) Signals	A vehicle is sending messages with false geographic information	3 (high)
Slot reservation attack	A vehicle requests different slots during the same frame	3 (high)
Malicious MAC behavior	A vehicle is sending data in another slot different to its reserved one	4 (Critical)
Malicious isolation	Some vehicle functionalities are disabled (create, process, receive and send messages) caused by the installation of a malware	3 (high)
Denial of access to incoming messages	A vehicle may be unlinked if it receives a huge number of messages.	4 (Critical)
Frame information poisoning	The frame information is falsified by a vehicle	3 (high)
Identity spoofing	A vehicle is using a wrong node type in order to act as an RSU	3 (high)

7.6.1.3. A Flooding-Based Location Service in VANETs

Participants: Selma Boumerdassi, Paul Muhlethaler.

This work has been done in collaboration with Eric Renault, Telecom Sud Paris.

We have designed and analyzed a location service for VANETs; such a service can be used in Location-based routing protocols for VANETs. Our protocol is a proactive flooding-based location service that drastically reduces the number of update packets sent over the network as compared to traditional flooding-based location services. This goal is achieved by partially forwarding location information at each node. A mathematical model and some simulations are proposed to show the effectiveness of this solution. Cases for 1D, 2D and 3D spaces are studied for both deterministic and probabilistic forwarding decisions. We compare our protocol with the Multi-Point Relay (MPR) technique which is used in the OLSR protocol and determine the best technique according to the network conditions.

7.6.2. Models for Wireless Networks and VANETs

7.6.2.1. Performance analysis of IEEE 802.11 broadcast schemes with different inter-frame spacings

Participants: Younes Bouchaala, Paul Muhlethaler, Nadjib Achir.

This work has been done in collaboration with Oyunchimeg Shagdar (Vedecom).

We have started to build a model which analyzes the performance of IEEE 802.11p managing different classes of priorities. The differentiation of traffic streams is obtained with different inter-frame spacings: AIFSs (for Arbitration Inter Frame Spacings) and with different back-off windows: CWs (for Collision Windows). This model is based on a Markov model where the state is the remaining number of idle slots that a packet of a given class has to wait before transmission. However, in addition to this Markov model for which we compute a steady state we also consider the Markov chain which counts the number of idle slots after the smallest AIFS. As a matter of fact the probability these states are not evenly distributed since with different AIFSs the arrival rate is not constant when the number of idle slots experienced after the smallest AIFS varies. The resolution of the steady state of these two inter-mixed Markov chains lead to non linear and intertwined equations that can be easily solved with a software such as Maple. With the model we have obtained, we can compute the delivery rate of packets of different classes and show the influence of system parameters: AIFSs and CWs. The preliminary results show a a very strong influence of different AIFSs on the performance for each traffic streams, see [13].

7.6.2.2. Model and optimization of CSMA

Participants: Younes Bouchaala, Paul Muhlethaler, Nadjib Achir.

This work has been done in collaboration with Oyunchimeg Shagdar (Vedecom).

We have studied the maximum throughput of CSMA in scenarios with spatial reuse. The nodes of our network form a Poisson Point Process (PPP) of a one- or two-dimensional space. The one-dimensional PPP well represents VANETs. To model the effect of Carrier Sense Multiple Access (CSMA), we give random marks to our nodes and to elect transmitting nodes in the PPP we choose the nodes with the smallest marks in their neighborhood, this is the Matern hardcore selection process. To describe the signal propagation, we use a signal with power-law decay and we add a random Rayleigh fading. To decide whether or not a transmission is successful, we adopt the Signal-over-Interference Ratio (SIR) model in which a packet is correctly received if its transmission power divided by the interference power is above a capture threshold. We assume that each node in our PPP has a random receiver at a typical distance. We choose the average distance to its closest neighbor. We also assume that all the network nodes always have a pending packet. With these assumptions, we analytically study the density of throughput of successful transmissions and we show that it can be optimized with the carrier-sense threshold. The model makes it possible to analytically compute the performance of a CSMA system and gives interesting results on the network performance such as the capture probability when the throughput is optimized, and the effect on a non-optimization of the carrier sense threshold on the throughput. We can also study the influence of the parameters and see their effects on the overall performance. We observe a significant difference between 2D an 1D networks.

We have built two models to compare the spatial density of successful transmissions of CSMA and Aloha. To carry out a fair comparison, we optimize both schemes by adjusting their parameters. For spatial Aloha, we can adapt the transmission probability, whereas for spatial CSMA we have to find the suitable carrier sense threshold. The results obtained show that CSMA, when optimized, outperforms Aloha for nearly all the parameters of the network model values and we evaluate the gain of CSMA over Aloha. We also find interesting results concerning the effect of the model parameters on the performance of both Aloha and CSMA. The closed formulas we have obtained provide immediate evaluation of performance, whereas simulations may take minutes to give their results, see [14]. Even if Aloha and CSMA are not recent protocols, this comparison of spatial performance is new and provides interesting and useful results.

For Aloha networks, when we study transmissions over the average distance to the closest neighbor, the optimization does not depend on the density of nodes, which is a very interesting property. Thus in Aloha networks, the density of successful transmissions easily scales linearly in λ when we vary λ whereas in CSMA networks the protocol must be carefully tuned to obtain this scaling.

With CSMA, we have also shown that this density of throughput (when optimized) scales with the density of nodes if we study the throughput is measured between the nodes to their closest neighbors. We have mathematically justified this property.

7.6.2.3. Adaptive CSMA

Participants: Nadjib Achir, Younes Bouchaala, Paul Muhlethaler.

This work has been done in collaboration with Oyunchimeg Shagdar (Vedecom).

Using the model we have built for CSMA, we have shown that when optimized with the carrier sense detection threshold P_{cs}, the probability p^* of transmission for a node in the CSMA network does not depend on the density of nodes λ. In other words when the CSMA is optimized to obtain the largest density of successful transmissions (communication from nodes to their neighbors), p^* is constant. We have verified this statement on several examples and we think that a formal proof of this remark is possible using scaling arguments. The average access delay is a direct function of the probability of transmission p. Thus the average delay when the carrier sense detection threshold is optimized is a constant D_{target} which does not depend on λ. A stabilization algorithm which adapts P_{cs} to reach the D_{target} can thus be envisioned. Another stabilization algorithm adapts P_{cs} so that the mean number of neighbors of a node is N_{target} a given number of nodes which only depends on the network parameters and not on the network density. A third stabilization algorithm adapts P_{cs} so that the channel busy ratio (CBR) is near a given target.

We have justified theoretically all these algorithms and simulated their behavior. The simulations well justify the theoretical analysis.

7.6.2.4. Optimizing spatial throughput in device-to-device networks

Participants: Bartek Blaszczyszyn, Paul Keeler, Paul Muhlethaler.

Results are presented for optimizing device-to-device communications in cellular networks, while maintaining spectral efficiency of the base-station-to-device downlink channel. We build upon established and tested stochastic geometry models of signal-to-interference ratio in wireless networks based on the Poisson point process, which incorporate random propagation effects such as fading and shadowing. A key result is a simple formula, allowing one to optimize the device-to-device spatial throughput by suitably adjusting the proportion of active devices, see [19]. These results can lead to further investigation as they can be immediately applied to more sophisticated models such as studying multi-tier network models to address coverage in closed access networks.

7.6.2.5. Model and analysis of Coded Slotted Aloha (CSA) with capture

Participants: Ebrahimi Khaleghi, Cedric Adjih, Paul Muhlethaler.

This work has been done in collaboration with Amira Alloum, Nokia Bell Labs.

Motivated by scenario requirements for 5G cellular networks, we have studied one among the protocols candidate to the massive random access: the family of random access methods known as Coded Slotted ALOHA (CSA). Recent body of research has explored aspects of such methods in various contexts, but one aspect has not been fully taken into account: the impact of the path loss, which is a major design constraint in long-range wireless networks. We have explored the behavior of CSA, by focusing on the path loss component correlated to the distance to the base station. Path loss provides opportunities for capture, improving the performance of CSA. We have revised methods for estimating CSA behavior. We have provided bounds of performance and derived the achievable throughput. We have extensively explore the key parameters, and their associated gain (experimentally). Our results has shed light on the open question of the optimal distribution of repetitions in actual wireless networks.

7.6.2.6. Mobility Prediction in Vehicular Networks : An Approach through Hybrid Neural Networks under Uncertainty

Participants: Soumya Banerjee, Samia Bouzefrane, Paul Muhlethaler.

Conventionally, the exposure regarding knowledge of the inter vehicle link duration is a significant parameter in *Vehicular Networks* to estimate the delay during the failure of a specific link during the transmission. However, the mobility and dynamics of the nodes is considerably higher in a smart city than on highways and thus could emerge a complex random pattern for the investigation of the link duration, referring all sorts of uncertain conditions. There are existing link duration estimation models, which perform linear operations under linear relationships without imprecise conditions. Anticipating, the requirement to tackle the uncertain conditions in *Vehicular Network*s, this paper presents a hybrid neural network-driven mobility prediction model. The proposed hybrid neural network comprises a *Fuzzy Constrained Boltzmann machine (FCBM*), which allows the random patterns of several vehicles in a single time stamp to be learned. The several dynamic parameters, which may make the contexts of *Vehicular Networks* uncertain, could be vehicle speed at the moment of prediction, the number of leading vehicles, the average speed of the leading vehicle, the distance to the subsequent intersection of traffic roadways and the number of lanes in a road segment. In this paper, a novel method of hybrid intelligence is initiated to tackle such uncertainty. Here, *the Fuzzy Constrained Boltzmann Machine (FCBM)* is a stochastic graph model that can learn joint probability distribution over its visible units (say n) and hidden feature units (say m). It is evident that there must be a prime driving parameter of the holistic network, which will monitor the interconnection of weights and biases of *the Vehicular Network* for all these features. The highlight of this paper is that the prime driving parameter to control the learning process should be a fuzzy number, as fuzzy logic is used to represent the vague and and uncertain parameters. Therefore, if uncertainty exists due to the random patterns caused by vehicle mobility, the proposed Fuzzy Constrained Boltzmann Machine could remove the noise from the data representation. Thus, the proposed model will be able to predict robustly the mobility in VANET, referring any instance of link failure under *Vehicular Network* paradigm.

7.6.3. Reliable routing architecture

Participants: Mohamed Hadded, Anis Laouiti, Paul Muhlethaler.

Flooding scheme represents one of the fundamental operation in wireless mesh networks. It plays an important role in the design of network and application protocols. Many existing flooding solutions have been studied to address the flooding issues in mesh networks. However, most of them are not able to operate efficiently where there are network equipment failures. In this work, we consider nodes failures and we build the flooding tree the maximum expectation of the throughput (taking into account the potential unavailability of certain nodes). After a formal stochastic definition of the problem, we show how to use a tabu search algorithm, to solve this optimization problem.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. CNES contract

Participants: Pascale Minet, Ines Khoufi.

Inria and CNES co-funded a study of one year in the framework of the CNES Launchers Research and Technology program. This study deals with the improvement and performance evaluation of a solution of wireless sensor networks in a spatial environment, based on the IEEE 802.15.4e standard of TSCH (Time Slotted Channel Hopping).
In space launch vehicles, a NASA study shows that the mass per channel of 0.45 kg for a wiring approach can be reduced to 0.09 kg for a wireless approach.8 A question arises: which wireless technology is able to meet the requirements of space launch vehicles in terms of latency, throughput and robustness. The IEEE 802.15.4e amendment has been designed to meet such requirements. More specifically, the Time Slotted Channel Hopping (TSCH) mode of the IEEE 802.15.4e standard that has been designed for industrial automation, process control and equipment monitoring, appears very promising for space launch vehicles. More precisely, the study for CNES deals with:

- Avoiding collisions on shared slots: see the PEMWN 2017 conference.
- Building an IEEE 802.15.4e TSCH network: see the EUCASS 2017 publication.
- Increasing the reliability of an IEEE 802.15.4e TSCH network: see the NCA 2017 publication.
- Scheduling transmissions in an IEEE 802.15.4e TSCH network: see the VTC-Fall 2017 publication.

9. Partnerships and Cooperations

9.1. National Initiatives

- EVA has a collaboration with Vedecom. **Paul Muhlethaler** supervises Younes Bouchaala's PhD funded by Vedecom. This PhD aims at studying vehicle-to-vehicle communication to improve roads safety.
- EVA has an ongoing collaboration with SODEAL company, which exploits the Cap d'Agde marina, as part of the SmartMarina project.

9.2. European Initiatives

9.2.1. FP7 & H2020 Projects

The H2020 following projects are ongoing:

- H2020 F-Interop, http://f-interop.eu/, Nov 2015 – Oct 2018.
- H2020 ARMOUR, https://www.armour-project.eu/, Feb 2016 – Jan 2018.

9.2.2. Collaborations in European Programs, Except FP7 & H2020

9.2.2.1. Collaborations with Major European Organizations

Inria-EVA has collaboration in 2017 with ETSI (the European Telecommunications Standards Institute) to organize the F-Interop 6TiSCH Interop Event in July 2017 in Prague.

9.3. International Initiatives

9.3.1. Inria International Labs

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

9.3.2.1. REALMS

- Title: Real-Time Real-World Monitoring Systems
- International Partner (Institution - Laboratory - Researcher):
  - University of California Berkeley (United States) - Civil and Environmental Engineering - Steven Glaser
  - University of Michigan (United States) - Civil and Environmental Engineering - Branko Kerkez
- Start year: 2015
- See also: http://glaser.berkeley.edu et http://www-personal.umich.edu/~bkerkez/

- The Internet of Things revolution prompted the development of new products and standards; The IEEE802.15.4e (2012) standard introduced the Time Synchronized Channel Hoping (TSCH) which can provide end-to-end reliability of 99.999 % and an energy autonomy of many years. This exceptional performance prompted the IETF to create the 6TISCH working group to standardize the integration of TSCH networks in the Internet. While the first experimental data have highlighted the great robustness of these networks, there is no data of a real network, accessible in real time, on a large scale and over a long period. Such data is needed to better model network performance and produce better products and standards. Teams of Professors Glaser and Kerkez are successfully deploying such networks to study mountain hydrology, monitor water quality and manage rainwater in urban environments. A model is missing to assist in the deployment and operation of these networks, as well as to monitor an operational network.

9.3.2.2. DIVERSITY

- Title: Measuring and Exploiting Diversity in Low-Power Wireless Networks
- International Partner (Institution - Laboratory - Researcher):
  - University of Southern California (United States) - Autonomous Networks Research Group (ANRG) - Bhaskar Krishnamachari
- Start year: 2016
- The goal of the DIVERSITY associate team is to develop the networking technology for tomorrow's Smart Factory. The two teams comes with a perfectly complementary background on standardization and experimentation (Inria-EVA) and scheduling techniques (USC-ANRG). The key topic addressed by the joint team will be networking solutions for the Industrial Internet of Things (IIoT), with a particular focus on reliability and determinism.

9.3.3. Inria International Partners

9.3.3.1. Declared Inria International Partners

Inria-EVA has a long-standing Memorandum of Understanding with the OpenMote company (http://www.openmote.com/), which runs until 2020. OpenMote emerged as a spin-off of the OpenWSN project, co-lead by **Thomas Watteyne** and Prof. Xavier Vilajosana, Professor at the Open University of Catalonia and Chief Technical Officer at OpenMote.

The collaboration has been ongoing since 2012 and at the time of writing has resulted in:

- Joint academic publications, including 7 journal articles, 1 letter, 1 book chapter, 5 conference papers, 2 tutorials and invited talks.
- Joint standardization activities, in particular in the IETF 6TiSCH working group, co-chaired by **Thomas Watteyne** and for which Prof. Xavier Vilajosana is a key contributor. This activity has resulted in the joint participation in 12 IETF face-to-face meetings, joint participation in over 100 audioconferences, co-authorship of 3 Internet-Drafts and joint organization of 2 interop events.
- Joint software development, as both institutions closely collaborate in the maintenance, development, promotion and research along the OpenWSN project, including the development of the protocol stack, the integration of novel hardware technologies, the support to the community and the participation in standardization activities and interoperability events.

This MOU is NOT a commitment of funds by any part.

9.3.3.2. Informal International Partners

The Inria-EVA collaborates extensively with Prof. Pister's group at UC Berkeley on the OpenWSN and Smart Dust projects. This activity translated into several members of the Pister team visiting Inria-EVA and vice-versa in 2017.

9.3.4. Participation in Other International Programs

9.3.4.1. International Initiatives

- **PEACH**
- Title: PrEcision Agriculture through Climate researcH
- International Partners (Institution - Laboratory - Researcher):
  - Universidad Diego Portales (Chile) - Diego Dujovne
  - Universidad Tecnológica de Mendoza (Argentina) - Gustavo Mercado
- Duration: 2016 - 2017
- In 2013, 85% of the peach production in the Mendoza region (Argentina) was lost because of frost. Because less fruit was produced in the region, 600.000 less work days were needed to process the harvest between November 2013 and March 2014, a reduction in work force of 10.600 people. Across the Mendoza region, frost has caused a loss of revenue of 950 million Argentine pesos - roughly 100 million USD - in the peach business alone. A frost event happens when the temperature is so low that the crops cannot recover their tissue or internal structure from the effects of water freezing inside or outside the plant. For the peach production, a critical period is when the trees are in bloom and fruit set (Aug./Sept. in Mendoza), during which the temperature needs to be kept above -3 C. Even a few hours below that temperature causes flowers to fall, preventing fruits to grow. Because of the huge economic impact, countermeasures exist and are used extensively. Today, virtually all industrial peach orchards are equipped with a small number of meteorological stations which monitor temperature and humidity. If the temperature drops dangerously low, the most effective countermeasures is to install a number of furnaces in the orchard (typically coal-fueled) and fly helicopters above the orchard to distribute the heat and avoid cold spots. This countermeasure is effective, but suffers from false negatives (the helicopters are called in, but there is no frost event) and false positives (the meteorological stations don't pick up a frost event happening in some part of the orchard). What is missing is a dense real-time monitoring solution deployed in the orchard, and feeding a frost prediction model. For this, having a couple of meteorological stations doesn't provide the measurement density needed. Frost events are micro-climatic: cold and hot air have a different density, wind blows irregularly between the trees, so different parts of an orchard are affected very differently by frost. What is needed are a large number of sensing points (humidity, temperature, wind speed), at different elevations, throughout the orchard. Low-power wireless mesh networking technology has evolved significantly over recent years. With this technology, a node is the size of a deck of cards, is self-contained and battery-operated. When switched on, nodes form a multi-hop low-power wireless network, automatically. Off-the-shelf commercial solutions are available today which offer >99.999% end-to-end data reliability and a decade of battery lifetime. Rather than being installed at a fixed location, these nodes can be hung directly in the trees. A network is deployed in an orchard in a matter of hours, and if needed, sensing points can be moved to improve the accuracy of the prediction model in minutes. And this solution is cheap, too: for the price one meteorological station, one can build 10 low-power wireless mesh sensing nodes. We use machine learning and pattern recognition to build an micro-climate predictive model by continuously analyzing the gathered sensor data in real time. This model generates early frost warnings. If successful, the solution can be extended to other crops, and other regions. The goal of this project is to dramatically increase the predictability of frost events in peach orchards by using dense monitoring using low-power wireless mesh networking technology. The project is designed to be completed in 24-month, and involves: (1) building a dense sensing solution based on off-the-shelf networking and sensing products, (2) developing accurate frost prediction models based on the sensing data gathered, (3) conducting real-world deployments on peach orchards in the Mendoza region. This project brings together world experts in agronomic and networking fields in a symbiotic manner. Perfectly in line with the philosophy of STIC-AmSud, the teams are already conducting cutting-edge research in their respective fields the funding we are applying for would enable the teams to collaborate together in a cross-disciplinary manner.

9.4. International Research Visitors

9.4.1. Visits of International Scientists

1. *David Burnett* (*UC Berkeley*), Micro-Motes, collaboration with **Thomas Watteyne**, 30 November 2017.
2. *Prof. Xavi Vilajosana* (*UOC/OpenMote*), OpenMote B, 6TiSCH, collaboration with **Thomas Watteyne** and Tengfei Chang, 20 November – 19 December 2017.
3. *Pablo Modernell* (*UOC*), F-Interop, collaboration with Remy Leone and **Thomas Watteyne**, 20–27 November 2017.
4. *Malisa Vucinic* (*U Montenegro*), 6TiSCH Security, collaboration with **Thomas Watteyne**, 06-24 November 2017.
5. *Carlos Oroza* (*UC Berkeley*), Machine-Learning Based Placement Strategy, collaboration with **Thomas Watteyne**, 18 October – 06 November 2017.
6. *Prof. Xavi Vilajosana* (*UOC/OpenMote*), OpenMote B, the greatest thing since sliced bread, collaboration with **Thomas Watteyne** and Tengfei Chang, 19–20 September 2017.
7. *Felipe Lallane* (*Inria Chile*), Exploiring collaboration opportunities with Inria-Chile around IoT, collaboration with **Thomas Watteyne**, 19–20 June 2017.
8. *Cristina Cano* (*UOC, Barcelona*), Wireless Coexistence, collaboration with **Thomas Watteyne**, 16 May 2017.
9. *Ryan Grammenos* (*Univ. College London*), Machine Learning for 6TiSCH networks, collaboration with Keoma Brun-Laguna and **Thomas Watteyne**, 15–19 May 2017.
10. *Craig Schindler* (*UC Berkeley*), Industrial Process Control with 6TiSCH, collaboration with Tengfei Chang and **Thomas Watteyne**, 9–19 May 2017.
11. *Pedro Henrique Gomez* (*USC*), Exploiting Diversity in 6TiSCH Networks, collaboration with Tengfei Chang and **Thomas Watteyne**, 5 June – 9 July 2017.
12. *Prof. Diego Dujovne* (*UDP, Chile*), Advanced Scheduling in 6TiSCH networks, collaboration with **Thomas Watteyne**, 5–22 July 2017.
13. *Prof. Steven Glaser* (*UC Berkeley*), Real-time real-world remote sensing, collaboration with Ziran Zhang, Keoma Brun-Laguna, **Thomas Watteyne**, 27 May – 3 June 2017.
14. *Prof. Xavi Vilajosana* (*UOC/OpenMote*), OpenWSN core-team meet-up, collaboration with **Thomas Watteyne** and Tengfei Chang, 3–7 April 2017.

9.4.2. Internships

1. **Felipe Moran Correa Meyer**, sub-100 μs synchronization and sub-m RTLS with SmartMesh IP (ENSTA), September 2017 – August 2018.
2. **Fatima Adda**, simulation of active signaling in TDMA networks (Paris VI), March-August 2017.
3. **Nasr Khouaja Mohamed Hassine**, positioning with wireless networks (ENSTA), April-June 2017.

9.4.3. Visits to International Teams

9.4.3.1. Research Stays Abroad

- **Thomas Watteyne** spent the month of August 2017 at UC Berkeley, working with Prof. Glaser on the SnowHow project, and with Prof. Pister on Smart Dust and OpenWSN.
- Keoma Brun-Laguna spent summer 2017 with the Dust Networks product team at Analog Devices in Silicon Valley as part of an internship.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organization

10.1.1.1. General Chair, Scientific Chair

- **Thomas Watteyne** co-chaired the IOT2SUSTAIN invited workshop (https://tinyurl.com/iot2sustain), which brought together 22 researcher (half UCL, half Inria) to brainstorm on the state of IoT research today, and identify research directions. This event was organized on the UCL campus in London, 6-7 July 2017.
- **Thomas Watteyne** co-chaired the IETF98 (Chicago, remotely), IETF99 (Prague) and IETF100 (Singapore) 6TiSCH Working group meetings.
- **Pascale Minet** was general co-chair with Leila Saidane from ENSI (Tunisia) of the PEMWN 2017 conference, the 6th IFIP international conference on Performance Evaluation and Modeling of Wired and Wireless Networks, technically co-sponsored by IFIP WG6.2 and IEEE ComSoc (see https://sites.google.com/site/pemwn2017/). This conference was held at CNAM in Paris, the 28th, 29th and 30th of November 2017. It was sponsored by Inria, CNAM and ENSI. The organization co-chairs were Samia Bouzefrane and Selma Boumerdassi. Three tutorials were given:
  - *Dynamic Resource Allocation and Network Optimization in C-RAN* by Rami Langar, University of Paris-Est Marne-la vallée, (UPEM), France.
  - *Getting your Hands Dirty With the Industrial IoT!* by Thomas Watteyne, Inria, France.
  - *Machine learning: From supervised to unsupervised* by Francis Bach, Inria, France.

  Twenty papers have been selected by the technical program committee and presented during the three days of the PEMWN 2017 conference.
- **Samia Bouzefrane** was general co-chair with Mehammed Daoui (University of Tizi-Ouzou, Algeria) and Damien Sauveron (Univesity of Limoges, France) of the MSPN 2017 conference, the 3rd IFIP international conference on Mobile and Secure Programming Networks, technically co-sponsored by IFIP WG 11.2 (see http://cedric.cnam.fr/workshops/mspn2017/). This conference was held at CNAM in Paris, the 29th and 30th of June 2017. It was sponsored by CNAM, University of Limoges and SAFRAN. Two tutorials were given:
  - *Enabling emergent mobile systems in the IoT: Functional and QoS interoperability aspects at the middleware layer* by Nikolaos Georgantas, MIMOVE team (Inria, Paris), France.
  - *Identity Management for Internet connected objects* by Hanene Maupas, SAFRAN, France.

  Seventeen papers have been selected by the technical program committee and presented during the two days of the MSPN 2017 conference

10.1.1.2. Member of the Organizing Committees

- **Paul Muhlethaler** organized the DGA Inria workshop on Telecommunication and networking "Cloud, cloudlet & MANET" in May 2017. The EVA team presented its activities: Remy Leone the results of the project F-Interop, Malisa Vucinic the results of the project ARMOUR, **Pascale Minet** the model and simulation results on collision avoidance on shared slots in TSCH, **Thomas Watteyne** presented the standardization issues in 6TiSCH, **Paul Muhlethaler** presented results on adaptive CSMA techniques.
- **Kevin Bonny** was member of the organizing committee of the international conference PEMWN 2017.

10.1.2. Scientific Events Selection

10.1.2.1. Chair of Conference Program Committees

- **Paul Muhlethaler** was in Steering committee member of MobileHealth Workshop 2017.
- **Samia Bouzefrane** was track chair of ANT, The 8th International Conference on Ambient Systems, Networks and Technologies, May 2017.
- **Anis Louiti** was in Steering committee member of MobileHealth Workshop 2017.

10.1.2.2. Member of the Conference Program Committees

- **Paul Muhlethaler**:
  - ITST 2017,
  - Mownet 2017, International Conference on Selected Topics in Mobile & Wireless Networking, May 2017.
  - PEMWN 2017, 6th International Conference on Performance Evaluation and Modeling in Wired and Wireless Networks, November 2017.
  - Wireless Days, IFIP/IEEE Wireless Days 2017, 29 - 31 March 2017 Porto, Portugal.
  - WiOpt 2017, Paris, France, 15th - 19th May, 2017.
- **Pascale Minet**:
  - CoRes 2017, May 2017.
  - ETFA 2017, 22th IEEE International Conference on Emerging Technologies & Factory Automation, September 2017.
  - IINTEC 2017, the IEEE International Conference on Internet of Things, Embedded Systems and Communications, October 2017.
  - IUCC 2017, the 16th IEEE International Conference on Ubiquitous Computing and Communications, December 2017.
  - MoWNet 2017, International Conference on Selected Topics in Mobile & Wireless Networking, May 2017.
  - PEMWN 2017, 6th International Conference on Performance Evaluation and Modeling in Wired and Wireless Networks, November 2017.
  - PECCS 2017, 7th International conference on Pervasive and Embedded Computing and Communication Systems, July 2017.
  - WINCOM 2017, 3rd International Conference on Wireless Networks and Mobile Communications, October 2015.
  - Wireless Days, IFIP/IEEE Wireless Days 2017, 29 - 31 March 2017 Porto, Portugal.
  - WiSEE 2017, 5th IEEE International Conference on Wireless for Space and Extreme Environments, October 2017.
- **Thomas Watteyne**:
  - IFIP/IEEE International Symposium on Integrated Network Management, workshop on Future Networks for Secure Smart Cities (FNSSC), 2017.
  - IEEE International Conference on Communications (ICC), Selected Areas in Communications (SAC), 2015, 2016, 2017.
- **Samia Bouzefrane**:
  - PEMWN, 6th International Conference on Performance Evaluation and Modeling in Wired and Wireless Networks, November 2017.
  - VECoS, 11th International Conference on Verification and Evaluation of Computer and Communication Systems, August 2017.
  - MobiSecServ, the third International Conference On Mobile And Secure Services, February 2017.

  - EUSPN, The 8th International Conference on Emerging Ubiquitous Systems and Pervasive Networks, September 2017.
- **Anis Louiti**:
  - AIST 2017,
  - ITST 2017,
  - Mownet 2017,
  - PEMWN 2017,
  - SMARTCOMP 2017
  - Aintec 2017

10.1.2.3. Member of the Editorial Boards

Nadjib Achir was guest editor of the special issue “Planning and Deployment of Wireless Sensor Networks”, of the International Journal of Distributed Sensor Networks.

10.1.2.4. Reviewer (Journals)

- **Paul Muhlethaler**
  - Reviewer Annals of telecommunications
  - Reviewer IEEE Transactions on Wireless Communications
  - Reviewer IEEE Transactions on Vehicular Technology
  - Reviewer IEEE Transactions on Information Theory
  - Reviewer International Journal of Distributed Sensor Networks. Hindawi.
- **Pascale Minet**
  - Annals of Telecommunications,
  - Ad Hoc Networks,
  - Computer Communications,
  - Computer Networks,
- **Thomas Watteyne**
  - ACM Transactions on Sensor Networks, 2017.
- Nadjib Achir
  - Reviewer Sensor Networks (MDPI)
  - Reviewer Wireless Communications and Mobile Computing (Wiley)
  - Reviewer Internet of Things Journal (IEEE)
  - Reviewer Ad Hoc Networks Journal (Elsevier)
- Selma Boumerdassi
  - Reviewer Ad Hoc Networks Journal (Elsevier);
  - Reviewer The journal of Future Generation Computer Systems (Elsevier).
- Samia Bouzefrane
  - The International Journal of Computer and Telecommunications Networking (Elsevier),
  - The IEEE Transactions on Mobile Computing,
  - The Information and Software Technology Journal (Elsevier)
  - The Springer Multimedia Tools and Application Journal
  - The ACM Transaction on Internet Technology
  - The Concurrency and Computation Practice and Experience Journal
  - the Journal of Systems and Software (Elsevier)

10.1.2.5. Reviewer (Book proposals)

Samia Bouzefrane was reviewer for the two book proposals in the CRC Press Taylor and Francis.

10.1.3. Invited Talks

- *(tutorial)* **Thomas Watteyne**. Getting your Hands Dirty With the Industrial IoT! International Conference on Performance Evaluation and Modeling in Wired and Wireless Networks (PEMWN), Paris, France, 28 November 2017.
- *(talk)* **Thomas Watteyne**. Construire son Reseau IoT en 10min. Inria-Paris, 12 March 2018.
- *(talk)* **Thomas Watteyne**. Exciting Developments in Industrial IoT, and its Potential Applications to Smart Agriculture. INRA-Inria Workshop, Rennes, France, 19 December 2017
- *(talk)* **Thomas Watteyne**. Low Power Wireless Solutions for Industry 4.0: Products, Standardization, Research and Example Deployments. Industry 4.0 Predictive Analytics and Forecasting: Research and Applications. Siemens Corporate Technology, Munich, Germany, 14-15 September 2017.
- *(tutorial)* **Thomas Watteyne** and Sami Malek. Wireless Bootcamp with NoeMote and SolSystem. UC Berkeley, 22-23 August 2017.
- *(talk)* **Thomas Watteyne**. OpenWSN Fresh: the 6TiSCH Reference Protocol Stack. Journees Scientifiques Inria, Sofia Antipolis, 15 June 2017.
- *(panel)* **Thomas Watteyne**. "Enough with the visions, Industrial IoT is here Today!", on the panel "the path to successful IoT: from need of standards to security threads". IEEE ICC, Paris, France, 22 May 2017.
- *(talk)* **Thomas Watteyne**. Building the Internet of (Important) Things, Universidad Diego Portales, Santiago, Chile, 5 May 2017.
- *(talk)* **Thomas Watteyne**. Researching and Deploying 6TiSCH Networks, Inria-Chile, 5 May 2017.
- *(talk)* **Thomas Watteyne**. Deploying 6TiSCH Networks. RIOT seminar, 13 April 2017.

10.1.4. Leadership within the Scientific Community

Thomas Watteyne co-chairs the IETF 6TiSCH standardization group.

10.1.5. Scientific Expertise

Thomas Watteyne regularly consults with major player in the (Industrial) IoT space.

10.1.6. Research Administration

Thomas Watteyne is of the Inria-Paris "Comite de Centre", since 2016, where we work on making sure Inria-Paris will always remain one of the greatest places to work at!

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

- Intensive 1-week course on IoT, with associated hands-on labs. ENSTA ParisTech. Graduate level. **Thomas Watteyne** and Ziran Zhang. 9-12 October 2017.
- 1/2-day crash course on the Industrial IoT. Telecom ParisTech. Graduate level. **Thomas Watteyne**. 28 September 2017..
- 6-week course on IoT, with associated hands-on labs. ENSTA ParisTech. Undergraduate level. **Thomas Watteyne**, Keoma Brun-Laguna and Dominique Barthel. Spring 2017.

10.2.2. Supervision

- PhD : Nesrine Ben Hassine : Machine learning techniques for network resource allocation. University of Paris Saclay. **Pascale Minet** and Dana Marinca.
- PhD : Younes Bouchaala : Handling Safety Messages in Vehicular Ad-hoc NETworks. University of Paris Saclay. **Paul Muhlethaler**.

- PhD (in progress) : Keoma Brun-Laguna : Deterministic networking for the Industrial Internet of Things. Sorbonne University. **Thomas Watteyne** and **Pascale Minet**.
- PhD (in progress) : Jonathan Munoz. Time slotted systems for long range communications. Sorbonne University. **Thomas Watteyne** and **Paul Muhlethaler**.
- PhD (in progress) : Amar Abane : Name Data Networks in the Internet of Things. CNAM. Samia Bouzefrane and **Paul Muhlethaler**.
- PhD (in progress) : Abdallah Soheby : Etude et évaluation de la dissémination des informations dans la 5G. Eric Renault and **Paul Muhlethaler**.

10.2.3. Juries

- HdR:
  - Riadh Dhaou, "IoT composé de réseaux terrestres et par satellite au service des Smart Cities : mobilité et hétérogénéité", Institut National Polytechnique de Toulouse, November 2017, **Pascale Minet** reviewer.
  - Hanen Hidoudi, "Contributions à l'amélioration des communications dans les réseaux sans fil multi-sauts", University of Toulouse, November 2017, **Pascale Minet** examiner.
- PhD:
  - Alexandre Laubé, "Agrégation de trafic pour réduire la consommation énergétique globale dans les réseaux sans fil multi-sauts", University of Paris Saclay, September 2017, Anis Laouiti examiner.
  - Bilal M. Maaz, "Allocation des ressources radio dans les réseaux sans-fil de la 5G", University of Paris-Saclay, prepared at the University of Versailles-Saint Quentin, March 2017, **Pascale Minet** examiner.
  - Laurent Reynaud, "Stratégie de mobilité optimisée s pour la tolérance aux perturbations dans les r'eseaux sans fil", University of Lyon, March 2017, **Pascale Minet** examiner.
  - Ahmed Amari, "Specification and analysis of AeroRing - a full duplex Ethernet ring network for new generation avionics systems", University of Toulouse - ISAE, September 2017, **Pascale Minet** reviewer.
  - Florian Grandhomme, "Etudes de protocoles de routage dynamique externe de type BGP dans un environnement réseaux tactiques ad hoc mobiles : faisabilité et performances", University of Rennes 1, November 2017, **Pascale Minet** reviewer.
  - Moussa Déthié Sarr, "Spécification d'un mécanisme de construction automatique de topologies et d'adressage permettant la gestion dynamique de réseaux de capteurs sans fil lineéaires", University of Clermont, December 2017, **Pascale Minet** reviewer.
  - Aravinthan Gopalasingham, " SDN Based Service Oriented Control Approach For Future Radio Access Networks", Télécom Sud-Paris, June 2017, **Paul Muhlethaler** examiner,
  - Boutheina Dab, "Optimization of Routing and Wireless Resource Allocation in Hybrid Data Center Networks", Paris VI, July 2017, **Paul Muhlethaler** examiner.
  - David Alvarez Corrales, "Cooperative Communications in very large cellular Networks", Télécom ParisTech, November 2017, **Paul Muhlethaler** examiner.
  - Younes Bouchaala, "Handling Safety Messages in Vehicular Ad-hoc NETworks", UVSQ, December 2017, **Paul Muhlethaler** examiner.

10.3. Popularization

Outreach is very important for Inria-EVA, and it brings enormous visibility to the research done in the team. We use it to target a audience different that the one targetted through purely scientific publications.

10.3.1. Web presence

Within the Inria-EVA team, we are regular Twitter contributor through a dozen Twitter accounts, promoting the activities of Inria and Inria-Paris.

Inria-EVA also maintains the following Inria websites:

- https://team.inria.fr/eva/
- http://www.openwsn.org/
- http://smartmarina.org/
- http://www.savethepeaches.com/
- http://www.snowhow.io/
- http://www.solsystem.io/
- http://www.headsup.tech/

10.3.2. Tradeshows

- **Thomas Watteyne**, Ziran Zhang, Felipe Moran. IoT Solutions World Congress 2017, Barcelona, presenting SolSystem.
- **Thomas Watteyne**, Ziran Zhang. VIVATech 2017, Paris, Inria booth, presenting SolSystem.

10.3.3. In The News

- *(French)* SolSystem : une solution "sensor-to-cloud" clés en main, InriaInnovation, 10 November 2017 (**Thomas Watteyne**).
- Interview by L'Esprit Sorcier about SmartMarina, Fete de la Science, 8 October 2017 (**Thomas Watteyne**).
- Presenting the Smart Marina project at the VIVA Tech trade-show, Inria@Silicon Valley Newsletter, 19 September 2017 (**Thomas Watteyne**).
- *(French, TV)* Cap d'Agde : Une puce innovante pour gérer le port de plaisance, TV Sud, aired 20 June 2017 (**Thomas Watteyne**).
- *(French)* 1ère mondiale au Cap d'Agde, des capteurs détectent les entrées les sorties de bateaux, Atout Nautic, 20 June 2017 (**Thomas Watteyne**).
- *(French)* Le port du Cap d'Agde connecté, une première mondiale, France Bleu, 20 June 2017 (**Thomas Watteyne**).
- Interview with Thomas Watteyne "The new use of marinas requires rethinking their operation and imagining a new offer of services", Marine & Oceans, June 2017 (**Thomas Watteyne**).
- *(Spanish)* Experto en IoT de Inria visita Inria Chile, Inria Chile, 9 May 2017 (**Thomas Watteyne**).
- *(Spanish)* Proyecto SmartMarina reinventa los puertos utilizando IoT, Inria Chile, 5 May 2017 (**Thomas Watteyne**).
- The EVA team reinvents the Smart Marina, Inria.fr, 26 April 2017 (**Thomas Watteyne**).
- FBF supports SmartMarina project in Cap d'Agde, France. France Berkeley Fund new, 21 April 2017 (**Thomas Watteyne**).
- *(French)* Le Cap d'Agde – le Port en Passe d'Etre Connecte ! Herault Tribune, 19 April 2017 (**Thomas Watteyne**).
- *(French, video)* Objets connectés : des capteurs intelligents pour mesurer l'environnement, YouTube InriaChannel, March 2017 (**Thomas Watteyne**).
- *(French)* Le numérique peut-il sauver l'agriculture? Inriality, February 2017 (**Thomas Watteyne**).

10.3.4. Miscellaneous Activities

The Inria-EVA team is running a permanent demo in the Inria-Paris demo showroom.

We worked together with the A/V team on the following videos:

- SmartMarina [English] https://www.youtube.com/watch?v=LUcLE8D0RbM
- SmartMarina [French] https://www.youtube.com/watch?v=CwgyCmJvyuw
- interview [French] https://www.youtube.com/watch?v=zsbS310YVe0
- SolSystem [French] https://www.youtube.com/watch?v=juQGnGX5OGs
- SaveThePeaches [English] https://www.youtube.com/watch?v=_qGSH8l0Vkk
- SaveThePeaches [French] https://www.youtube.com/watch?v=cZvGw7DyIzI
- HeadsUp! [English] https://www.youtube.com/watch?v=51mIibi-tDs

The Inria-EVA team very regularly hosts visiting companies interested in using the technologu developed.

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Publications of the year

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[2] T. CHANG, T. WATTEYNE, X. VILAJOSANA, Q. WANG. *CCR: Cost-Aware Cell Relocation in 6TiSCH Networks*, in "Transactions on Emerging Telecommunications Technologies", October 2017, https://hal.inria.fr/hal-01533174

[3] P. H. GOMES, T. WATTEYNE, B. KRISHNAMACHARI. *MABO-TSCH: Multi-hop And Blacklist-based Optimized Time Synchronized Channel Hopping*, in "Transactions on emerging telecommunications technologies", October 2017, https://hal.inria.fr/hal-01555429

[4] K. M. JOSEPH, T. WATTEYNE, B. KERKEZ. *Awa: Using Water Distribution Systems to Transmit Data*, in "Transactions on emerging telecommunications technologies", October 2017, https://hal.inria.fr/hal-01548381

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[8] X. VILAJOSANA, K. PISTER, T. WATTEYNE. *Minimal IPv6 over the TSCH Mode of IEEE 802.15.4e (6TiSCH) Configuration*, in "Internet Engineering Task Force RFC series", May 2017, n^o^ RFC8180, https://hal.inria.fr/hal-01531205

[9] M. VUCINIC, T. WATTEYNE, X. VILAJOSANA. *Broadcasting Strategies in 6TiSCH Networks*, in "Internet Technology Letters", December 2017, https://hal.inria.fr/hal-01630316

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[14] Y. BOUCHAALA, P. MUHLETHALER, O. SHAGDAR, N. ACHIR. *Optimized Spatial CSMA for VANETs: A Comparative Study using a Simple Stochastic Model and Simulation Results*, in "CCNC 2017. 8-11 january 2017. Las Vegas", Las Vegas, United States, Proceedings of CCNC 2017, January 2017, https://hal.archives-ouvertes.fr/hal-01379978

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for Wireless Networks", Paris, France, IEEE, May 2017, 5 p. , https://arxiv.org/abs/1612.09198 - 6 pages, 4 figures. Submitted, https://hal.inria.fr/hal-01505044

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