Activity Report 2016

Project-Team EVA

Wireless Networking for Evolving & Adaptive Applications

RESEARCH CENTER
Paris

THEME
Networks and Telecommunications

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

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1. Members

Research Scientists

Pascale Minet [Inria, Research Scientist, HDR]
Paul Muhlethaler [Inria, Team leader, Research Scientist, HDR]
Thomas Watteyne [Inria, Research Scientist]

Engineers

Tengfei Chang [Inria, Postdoctoral Research Engineer]
Ines Khoufi [Inria, Postdoctoral Research Engineer]
Remy Leone [Inria, Postdoctoral Research Engineer, started Feb 2016]
Erwan Livolant [Inria, until Nov 2016]
Malisa Vucinic [Inria, Postdoctoral Research Lead, started Sep 2016]

PhD Students

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Fatma Marzouk [Ensi]
Jonathan Muñoz [Gridbe, CIFRE]

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Visiting Scientists

Felipe Lalanne [Reseacher, Inria Chile, Chile, visit 19–26 Octobre 2016]
Mario Gerla [Professor, UCLA, USA, visit 31 August - 23 September 10-20 December 2016]
Travis Massey [PhD Student, UC Berkeley, USA, visit 22 July 2016]
Diego Dujovne [Professor, Universidad Diego Portales, Chile, visit 22-31 July 2016]
Carlos Oroza [PhD Student, UC Berkeley, USA, visit 23-29 July 2016]
David Burnett [PhD Student, UC Berkeley, USA, visit 13-15 June 2016]
Branko Kerkez [Professor, U. Michigan, USA, visit 17-22 June 2016]
Steven Glaser [Professor, UC Berkeley, USA, visit 21-25 March 2016]
Filip Barac [PhD Student, Mid Sweden University, Sweden, visit 8-19 February 2016]
Xavi Vilajosana [Professor, UOC/OpenMote, Spain, visit 2-4 February 2016]

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Samia Bouzefrane [CNAM, Associate Professor]
Philippe Jacquet [Bell Labs (Alcatel), Division Leader, HDR]
Anis Laouiti [France Telecom, Associate Professor, HDR]
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Jiangnan Yang [Inria, Internship, Apr-Aug 2016]

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. Nevertheless, 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 IEEE 802.15.4e 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.

Two related standardization working groups were created in 2013 to address this issue. DICE (DTLS In Constrained Environments) is defining a DTLS (Datagram Transport Layer Security) profile that is suitable for IoT applications, using the (Constrained Application Protocol) CoAP protocol. ACE is standardizing authentication and authorization mechanisms for constrained environments.

The issue is to find the best trade-off between a communication and computation overhead compatible with the limited capacity of sensor nodes and the level of protection required by the application.

4. Application Domains

4.1. Generalities

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.

4.2. Industrial Process Automation

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.

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[1] Highway Addressable Remote Transducer, http://en.hartcomm.org/.

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.

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

4.4. 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.

The Internet of Things (IoT) has received continuous attention since 2013, and has been a marketing tool for industry giants such as IBM and Cisco, and the focal point of major events such the Consumer Electronics Show and the IETF. The danger of such exposure is that any under-performance may ultimately disappoint early adopters.

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.

With the general public becoming increasingly familiar with the term “Internet of Things”, its definition is broadening to include all devices which can be interacted with from a network, and which do not fall under the generic term of “computer”.

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 establish which technology best fits which application.

4.5. 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.

4.6. Smart Cities

It has been estimated that by 2030, 60% of the world’s population will live in cities. On the one hand, smart cities aim at making everyday life more attractive and pleasant for citizens; on the other hand, they facilitate how those citizens can participate in the life of the city.

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.

4.7. 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.

5. Highlights of the Year

5.1. Highlights of the Year

Awards

- Prof. Steven Glaser (UC Berkeley) and **Thomas Watteyne** recipients of the France-Berkeley Fund award for the project "SHRIMP: Smart Harbor Implementation", August 2016.
- Keoma Brun-Laguna and **Thomas Watteyne**, together with Ana Laura Diedrichs, Javier Emilio Chaar, Diego Dujovne, Juan Carlos Taffernaberry, Gustavo Mercado. Runner up IEEE SECON 2016 Best Demo Award with "A Demo of the PEACH IoT-based Frost Event Prediction System for Precision Agriculture", London, UK, 28 June 2016.
- Remy Leone and **Thomas Watteyne**. Recipient Google IoT Technology Research Award on "6TiSCH and WiFi coexistence with OpenWSN", March 2016.
- Tengfei Chang and **Thomas Watteyne**, together with Pedro Henrique Gomes, Pradipta Gosh, Bhaskar Krishnamachari. EWSN dependability competition 4th place with project "Reliability through Time-Slotted Channel Hopping and Flooding-based Routing", 16 February 2016.

Meeting & Seminars

Organization of Workshops and Conferences

- ***PEMWN 2016*** international conference on Performance Evaluation and modeling in Wired and wireless Networks, co-chaired by Leila Saidane and **Pascale Minet** and Farouk Kamoun , held in Paris, France, November 2016. Pascale Minet was general co-chair with Leila Saidane from ENSI (Tunisia) of the PEMWN 2016 conference, the 5th 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/pemwn2016/). This conference was held at CNAM in Paris, 22-24 November 2016. It was sponsored by Inria, CNAM and ENSI. The organization co-chairs were Samia Bouzefrane and Selma Boumerdassi. Three tutorials were given:

  - *Internet of Vehicles: From Intelligent Grid to Autonomous Cars and Vehicular Clouds* by Mario Gerla, Professor, University of California, Los Angeles.
  - *5G: Can we make it by 2020?* by Merouane Debbah, Mathematical and Algorithmic Sciences Lab, Huawei, France.
  - *Internet of Things, hyper-massive wireless networks, where are the theoretical limits?* by Philippe Jacquet, NOKIA, France.

  Sixteen papers have been selected by the technical program committee and presented during the three days of the PEMWN 2016 conference.

- ***InterIoT 2016*** The 2nd EAI International Conference on Interoperability in IoT was co-organized by Nathalie Mitton, Thomas Noël (general co-chairs) and Thomas Watteyne (TPC chair). It took place 26-27 October 2016 in Paris, France.

Tutorials

- Standards for the Industrial IoT: a Hands-on Tutorial with OpenWSN and OpenMote. Xavier Vilajosana, Pere Tuset-Peiro, Tengfei Chang, **Thomas Watteyne**. IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Valencia, Spain, 4-8 September 2016.
- Introduction to the IETF 6TiSCH stack with OpenWSN & OpenMote. **Thomas Watteyne**, Xavier Vilajosana, Pere Tuset-Peiro, Tengfei Chang. International Conference on Telecommunications (ICT), Thessaloniki, Greece, 16-18 May 2016.

Standardization Activities

- ***Standardization*** *meeting co-chaired by Inria-EVA*
  6TiSCH working group meeting at IETF 97, 17 November 2016, Seoul, South Korea.
- ***Standardization*** *meeting co-chaired by Inria-EVA*
  6TiSCH working group meeting at IETF 96, 18 July 2016, Berlin, Germany.
- ***Interop event*** *organized by ETSI and Inria-EVA*
  ETSI 6TiSCH 3 plugtests, 15-16 July 2016, Berlin, Germany.
- ***Standardization*** *meeting co-chaired by Inria-EVA*
  6TiSCH working group meeting at IETF 95, 4 April 2016, Buenos Aires, Argentina.
- ***Standardization*** *meeting co-chaired by Inria-EVA*
  ETSI 6TiSCH 2 plugtests, 2-4 February 2016, Paris, France.

Real-World Deployments

The networking technology developed at Inria-EVA has reached the level of maturity for it to be used in real-world deployment. We have worked on 3 main sets of deployments in 2016:

- **Save the Peaches** (http://www.savethepeaches.com/), a 23-node network in Western Argentina which monitors temperature and humidity to be predict frost events in peach orchards.
- **SnowHow** (http://www.snowhow.io/), a set of 18 low-power wireless networks (945 sensors total) deployed throughout the Californian Sierra Nevada to monitor the snowpack.
- *(current work)* A Smart Building deployment in the Inria-Paris research center.

From a networking point of view, these deployments SolSystem (see Section 6.8) as a back-end solution. Sensor data and network statistics are available at our Inria-Paris servers (https://sol.paris.inria.fr/) seconds after they were measured in the field.

Distinguished Visitors

- ***Invited Professor Mario Gerla***, from UCLA, USA. He stayed in the EVA team during 2 1-week stays (31 August-23 September, 10-20 December) to work with the EVA team on shock-wave mitigation using vehicular ad hoc networks.
- ***Invited Professor Leila Saidane***, from ENSI, Tunisia. She stayed in the EVA team from 28 November to 2 December 2016 to prepare common publications and identify further research directions.
- ***Invited Professor Diego Dujovne***, from Universidad Diego Portales, Chile. He stayed in the EVA team for a 1-week visit (22-31 July 2016) to integrate sensors in the low-power wireless platforms, to be deployed in Argantina as part of the PEACH project.
- ***Invited Professor Steven Glaser***, from UC Berkeley, USA. He stayed in the EVA team for a 1-week visit (21-25 June 2016) to explore funding opportunities beyond the REALMS associate team.
- ***Invited Professor Branko Kerkez***, from U. Michigan, USA. He stayed in the EVA team for a 1-week visit (17-22 June 2016) to work on the Internet of Water (2 papers submitted). This visit was part of the REALMS associate team.

6. New Software and Platforms

6.1. OpenWSN (Software)

Participants: Tengfei Chang, Jonathan Muñoz, Malisa Vucinic, Thomas Watteyne.

OpenWSN (http://www.openwsn.org/) 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.

The OpenWSN ADT started in 2015, with Research Engineer Tengfei Chang who joined the EVA team.

Highlights for 2016:

- Development:
  - better (continuous) testing of the existing OpenWSN code.
  - Build a image for a RaspberryPi which contains the OpenVisualizer preinstalled.
  - Port OpenWSN to the First prototype of the “Single-Chip uMote” (SCuM), developed in Prof. Pister’s lab at UC Berkeley.
  - Create a Virtual Machine image with all OpenWSN development tools preinstalled.
  - Implementation of 6TiSCH standards as they appear, including revisions.
  - Maintenance of the “Golden Image” used as a reference during interoperability testing
- Recognition:
  - OpenWSN remains ETSI’s reference implementation for IETF 6TiSCH-related standards. It is therefore the base for the ETSI’s Golden Device for 6TiSCH standards, including IEEE802.15.4e TSCH, 6LoWPAN and RPL.
- Events:
  - **Tutorial**
    Standards for the Industrial IoT: a Hands-on Tutorial with OpenWSN and OpenMote. Xavier Vilajosana, Pere Tuset-Peiro, Tengfei Chang, **Thomas Watteyne**. IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Valencia, Spain, 4-8 September 2016.
  - **Tutorial**

Introduction to the IETF 6TiSCH stack with OpenWSN & OpenMote. **Thomas Watteyne**, Xavier Vilajosana, Pere Tuset-Peiro, Tengfei Chang. International Conference on Telecommunications (ICT), Thessaloniki, Greece, 16-18 May 2016.

- **Interop Event**
  ETSI 6TiSCH 3 plugtests, 15-16 Juny 2016, Berlin, Germany
- **Interop Event**
  ETSI 6TiSCH 2 plugtests, 2-4 Februay 2016, Paris, France

This software appears in https://bil.inria.fr/.

6.2. OPERA and OCARI (Software)

Participants: Erwan Livolant, Pascale Minet.

The OPERA software was developed by the Hipercom2 team in the OCARI project It includes EOLSR, an energy efficient routing protocol and OSERENA, a coloring algorithm optimized for dense wireless networks. It was registered by the APP. In 2013, OPERA has been made available for download as an open software from the InriaGForge site: https://gforge.inria.fr/scm/?group_id=4665

In 2014, OPERA has been ported on a more powerful platform based on the Atmel transceiver AT86RF233 and on a 32 bits microcontroler Cortex M3. More details and documentation about this software are available in the website made by the Eva team: http://opera.gforge.inria.fr/index.html

In 2016, Erwan Livolant developed extensions to allow the remote management of the OCARI network and the transmission of commands to sensors and actuators.

6.3. F-Interop (Software)

Participants: Remy Leone, Thomas Watteyne.

F-Interop is revolutionizing the way interoperability events are conducted. We are building a cloud-based system which allows implementors to meet online to test their implementations against one another, verify compliance in a automated way, and verify the performance of their implementations on large scale testbeds. This significantly cuts down time-to-market for standards-based solutions, and eventually leads to more standards-based products on the market. The F-Interop platform starts by targeting 6TiSCH, 6LoWPAN and CoAP standards, but our ambition is for F-Interop to become the standard way of doing interoperability, at least at the IETF IoT level.

This implementation is done as part of the H2020 F-Interop project. More information at http://www.f-interop.eu/.

This software appears in https://bil.inria.fr/.

6.4. 6TiSCH Simulator (Software)

Participants: Malisa Vucinic, Thomas Watteyne.

The 6TiSCH simulator allows one to conduct high-level simulator of an IETF 6TiSCH network and answer questions such as How long does it take the nodes to join the network? What is the average power consumption? What does the latency distribution look like?

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.

This implementation is done as part of the H2020 ARMOUR project and the standardization activities of the Inria-EVA team at the IETF. It is published under an open-source BSD license and maintained at https://bitbucket.org/6tisch/simulator/.

This software appears in https://bil.inria.fr/.

6.5. 6TiSCH Wireshark Dissector (Software)

Participants: Jonathan Muñoz, Thomas Watteyne.

The goal of this project is to maintain Wireshark dissectors for 6TiSCH (and 6TiSCH-related) standards up-to-date.

Implementation on the dissectors is done through an open-source repository, stable code is regularly contributed back to the main Wireshark code base.

This implementation is done as part of the collaboration with Gridbee and the standardization activities of the Inria-EVA team at the IETF. It is published under an open-source BSD license and maintained at https://github.com/openwsn-berkeley/dissectors.

This software appears in https://bil.inria.fr/.

6.6. Mercator (Software)

Participants: Keoma Brun-Laguna, Thomas Watteyne.

Mercator allows one to evaluate the connectivity in a low-power wireless network. It is a collection of tools, including the firmware to load on the devices, the scripts that automate the measurements of the connectivity and the tools to structure and display results.

The firmware is written as part of the OpenWSN project. Scripts and analysis tools are written in Python.

It is published under an open-source BSD license and maintained at https://github.com/openwsn-berkeley/mercator.

This software appears in https://bil.inria.fr/.

6.7. CONNEXION (Software)

Participants: Pascale Minet, Erwan Livolant.

In the CONNEXION project, the integration of the OCARI wireless sensor network in a Service-Oriented Architecture using the OPC-UA/ROSA middleware went on with Telecom ParisTech. More precisely, we developed the remote managment of the OCARI network as well as the possibility to generate commands to the sensors and actuators.

Erwan Livolant developed an OCARI frame dissector plugin for Wireshark (https://www.wireshark.org) available from the Git repository at OCARI website. This tool displays the contents of the packets sniffed for the MAC, the NWK and the Application layers, taking into account the specificities of OCARI.

6.8. SolSystem (Software)

Participants: Keoma Brun-Laguna, Thomas Watteyne.

SolSystem is a back-end solution for a low-power wireless mesh network based on SmartMesh IP. It defines how low-power wireless devices must format and transfer sensor data, and the tools to gather, store and display sensor data.

This system is used in several deployments, including http://savethepeaches.com/ and http://snowhow.io/.

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).

It is published under an open-source BSD license. Information and overview at http://www.solsystem.io/.

This software appears in https://bil.inria.fr/.

6.9. Argus (Software)

Participants: Remy Leone, Thomas Watteyne.

Share your low-power wireless sniffer through the cloud!

Imagine you are a team of low-power wireless enthusiasts developing the next generation of products in standards. One essential tool in your toolkit is a low-power wireless sniffer, which shows you the frames which fly through the air.

Rather than requiring each person in your team to have a sniffer, Argus allows you to put in a share a sniffer through the cloud.

There are three piece to 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.

It is published under an open-source BSD license, maintained at https://github.com/openwsn-berkeley/argus.

This software appears in https://bil.inria.fr/.

6.10. SAHARA (Software)

Participants: Ines Khoufi, Erwan Livolant, Pascale Minet.

Ines Khoufi developed modules for the simulation of the Time Slotted Channel Hopping (TSCH) on the ns3 simulation tool. These modules include multi-interface management and transmission management according to a given schedule.

Erwan Livolant developed a SAHARA frame dissector plugin for Wireshark (https://www.wireshark.org). This tool displays the contents of the packets sniffed for the MAC and the NWK layers, taking into account the specificities of the SAHARA project.

6.11. FIT IoT-LAB (Platform)

Participants: Thomas Watteyne, Tengfei Chang.

Note well: IoT-lab is *not* a project of Inria-EVA. It is a large project which runs from 2011 to 2021 and which involves the following other partners Inria (Lille, Sophia-Antipolis, Grenoble), INSA, UPMC, Institut Télécom Paris, Institut Télécom Evry, LSIIT Strasbourg. This section highlights Inria-EVA activity and contribution to the IoT-lab testbed in 2016.

The Inria-EVA team has been using the platform extensively throughout 2016. During the process, we have been interacting closely with the IoT-lab team of engineers.

IoT-lab-related activities include:

- **Running OpenWSN networks at scale**. The IoT-lab has been an incredibly powerful tool to verify the scalability of the protocols and implementations in OpenWSN (Section 6.1). *Lead: Tengfei Chang*.
- **Assessing connectivity with Mercator**. The Mercator project (Section 6.6) is targetted at measuring the connectivity of the IoT-lab platform in time, space and frequency. *Lead: Keoma Brun-Laguna*.
- **16-channel Sniffer with Argus**. We are currently working extending the Argus project (Section 6.9) with support for IoT-lab motes. That is, rather than using a 16-channel sniffer, turn 16 IoT-lab nodes into a distributed multi-frequency sniffer. *Lead: Remy Leone*.

- **IoT-lab for Interop Testing with F-Interop**. Through the H2020 F-Interop project, we are developing the tools (see Section 6.3) to run an F-Interop user's code on the IoT-lab to verify conformance and interoperability. *Lead: Remy Leone*.
- **Scalable Security Solution with H2020 ARMOUR**. Through the H2020 ARMOUR project, Inria-EVA is testing whether security solutions standardized at the IETF are scalable. *Lead: Malisa Vucinic*.

7. New Results

7.1. Wireless Sensor Networks

7.1.1. Deployment of Wireless Sensor Networks

Participants: Ines Khoufi, Pascale Minet, Anis Laouiti.

In 2016, we studied two types of deployment for wireless sensor networks:

- those ensuring full area coverage and network connectivity;
- those covering some given Points of Interest (PoI) and ensuring network connectivity.

Deployment of sensor nodes to fully cover an area has caught the interest of many researchers. However, some simplifying assumptions are adopted such as the knowledge of obstacles, a centralized algorithm... To cope with these drawbacks, we propose OA-DVFA (Obstacles Avoidance Distributed Virtual Forces Algorithm), a self-deployment algorithm to ensure full area coverage and network connectivity. This fully distributed algorithm is based on virtual forces to move sensor nodes. We show how to avoid the problem of node oscillations and to detect the end of the deployment in a distributed way. We evaluate the impact of the number, shape and position of obstacles on the coverage rate, the distance traveled by all nodes and the number of active nodes. Simulation results show the very good behavior of OA-DVFA. This work done in collaboration with Anis Laouiti has been presented at the CCNC 2016 conference [35].

We also focus on wireless sensor networks deployed to cover some given Points of Interest (PoIs), achieve connectivity with the sink and be robust against link and node failures. The Relay Node Placement problem (RNP) consists in minimizing the number of relays needed and the maximum length of the paths connecting each PoI with the sink. We propose a solution that determines the positions of relay nodes based on the virtual grid computed by the optimal deployment for full area coverage. We compare our solution with two different solutions based respectively on (1) the straight line that builds the shortest path between each PoI and the sink, (2) the Steiner point that connects PoIs together. We then extend these algorithms to achieve k-connectivity. Our solution outperforms the Steiner points solution in terms of maximum path length on the one hand, and the straight line solution in terms of total number of relay nodes deployed on the other hand. We also apply our solution in an area containing obstacles and show that it provides very good performances. This study has been presented at the MASS 2016 conference [34].

7.1.2. Path Planning of Mobile Wireless Nodes Gathering Data

Participants: Ines Khoufi, Pascale Minet, Nadjib Achir.

Mobile wireless nodes in charge of collecting data from static wireless sensor nodes constitute a very attractive solution for wireless sensor networks, WSNs, where the application requirements in terms of node autonomy are very strong unlike the requirement in terms of latency. Mobile nodes allow wireless sensor nodes to save energy.

In 2016 we focused on the path planning problem of mobile wireless nodes gathering data according two different objectives:

- to ensure the monitoring of a given area;
- to visit some given Points of Interest (PoI) in a delay less than a given latency.

For the first objective, we are interested in area monitoring using Unmanned Aerial Vehicles (UAVs). Basically, we propose a path planning approach for area monitoring where UAVs are considered as mobile collectors. The area to be monitored is divided into cells. The goal is to determine the path of each UAV such that each cell is covered by exactly one UAV, fairness is ensured in terms of the number of cells visited by each UAV and the path of each UAV is minimized. To meet our goal, we proceed in two steps. In the first step, we assign to each UAV the cells to visit. In the second step, we optimize the path of each UAV visiting its cells. For the first step, we propose two solutions. The first solution is based on cluster formation, each cluster is made up of the set of cells monitored by a same UAV. The second solution is based on game theory and uses coalition formation to determine the cells to be monitored by each UAV. In the second step and for both solutions, we propose to apply optimization techniques to minimize the path of each UAV that visits all its cells. This study done in collaboration with Nadjib Achir was presented at the PEMWN 2016 conference [32].

For the second objective, we use game theory to model the problem. Game theory is often used to find equilibria where no player can unilaterally increase its own payoff by changing its strategy without changing the strategies of other players. In this paper, we propose to use coalition formation to compute the optimized tours of mobile sinks in charge of collecting data from static wireless sensor nodes. The associated coalition formation problem has a stable solution given by the final partition obtained. However, the order in which the players play has a major impact on the final result. We determine the best order to minimize the number of mobile sinks needed. We evaluate the complexity of this coalition game in terms of the number of rounds and the processing time needed to get convergence, as well as the impact of the number of collect points on the number of mobile sinks needed and on the maximum tour duration of these mobile sinks. In addition, we show how to extend the coalition game to support different latencies for different types of data. Finally, we formalize our problem as a multi-objective optimization problem. We compare the coalition game with a genetic algorithm: for 20 nodes to visit, the coalition game requires a processing time 327 times less than the genetic algorithm. The coalition game provides a scalable solution. These results have been presented at the IPCCC 2016 conference. This work was done in cooperation Mohamed-Amine Koulali and Abdellatif Kobbane [33].

7.1.3. Centralized Scheduling in TSCH-based Wireless Sensor Networks

Participants: Erwan Livolant, Pascale Minet, Thomas Watteyne.

Scheduling in an IEEE802.15.4e TSCH(Time Slotted Channel Hopping 6TiSCH) low-power wireless network can be done in a centralized or distributed way. When using centralized scheduling, a scheduler installs a communication schedule into the network. This can be done in a standards-based way using CoAP. In this study, we compute the number of packets and the latency this takes, on real-world examples. The result is that the cost is very high using today's standards, much higher than when using an ad-hoc solution such as OCARI. We conclude by making recommendations to drastically reduce the number of messages and improve the efficiency of the standardized approach.

7.1.4. Using an IEEE 802.15.4e TSCH network

Participants: Ines Khoufi, Pascale Minet, Erwan Livolant, Thomas Watteyne.

Most wireless sensor networks that are currently deployed use a technology based on the IEEE 802.15.4 standard. However, this standard does not meet all requirements of industrial applications in terms of latency, throughput and robustness. That is why the IEEE 802.15.4e amendment has been designed, including the Time Slotted Channel Hopping (TSCH) mode.

In 2016, we evaluated the time needed for a joining node to detect beacons advertising the TSCH network. This time may be long due to channel hopping in the TSCH network. The beacon advertising policy is left unspecified by the standard. We propose DBA, a Deterministic Beacon Advertising algorithm. DBA ensures a collision-free and regular transmission of beacons on all the frequencies used by the TSCH network. DBA outperforms two solutions already published that are Random Horizontal and Random Vertical. Some results have been presented as a poster at the IPCCC 2016 conference [48].

The medium access in a TSCH network is ruled by a schedule that determines for each pair (slot offset, channel offset) the transmitting node(s) and the receiving node(s). Each node in the TSCH network must have this schedule. The question is how to install it on all nodes. We proposed and evaluated different ways of installing a schedule in a TSCH network, comparing them in terms of the number of messages required. This study has been presented at the AdHocNow 2016 conference [36].

7.1.5. The OCARI Wireless Sensor Network

Participants: Erwan Livolant, Pascale Minet, Mohammed Tahar Hammi.

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, which should authenticate them before they join the network. OCARI is a wireless sensor network technology providing optimized protocols in order to reduce the energy consumption.

To enhance OCARI security and ensure a robust authentication of devices, we propose a strong authentication method based on the One Time Password algorithm and deployed at the MAC layer. This method is specially designed to be implemented on devices with low storage and computing capacities. This work has been done in collaboration with Mohammed Tahar Hammi from Telecom ParisTech and presented at the PEMWN 2016 conference [30].

We also evaluated the performances of the building of an OCARI network. The goal was to identify the most time consuming steps among node association, neighborhood discovery, routing tree building, stabilization of the routing tree and node coloring.

7.1.6. 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. This study was published in [21]. 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.

7.1.7. Massive MIMO Cooperative Communications for Wireless Sensor Networks

Participants: Nadjib Achir, Paul Muhlethaler.

This work is a 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.

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

7.2.1. Machine Learning in Networks

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

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. The idea developed hereafter consists in using prediction techniques 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.

We consider various prediction methods, called 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 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. This study has been presented at the IWCMC 2016 conference [18].

In the paper presented at the WiMob 2016 conference [18], we apply these prediction methods to caching. We first selected the best experts in charge of predicting the popularity of video contents in real traces of YouTube. We tuned the parameters of the DES expert. We proved that the well-known LFU caching strategy can also be considered as a prediction based strategy on the Basic expert. Simulation results show that the DES prediction-based caching strategy provides similar Hit Ratio to the well-known LFU caching strategy. These results are usually close to the optimal ones that can be achieved only when knowing in advance the popularity of each video content for the next day, which is an unrealistic assumption. The exception occurs when a content whose popularity was very poor becomes suddenly very popular with millions of solicitations. In such a case, the accuracy of prediction methods becomes poor. This opens a research direction where the knowledge of societal events is taken into account to improve the prediction.

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

7.3.1. Protocols for VANETs

7.3.1.1. An Infrastructure-Free Slot Assignment Algorithm for Reliable Broadcast of Periodic Messages in VANETs

Participants: Mohamed Elhadad, Paul Muhlethaler, Anis Laouiti.

We have designed a novel **D**istributed **T**DMA based **MAC** protocol, named DTMAC, developed specifically for a highway scenario. DTMAC is designed to provide the efficient delivery of both periodic and event-driven safety messages. The protocol uses the vehicles' location and a new slot reuse concept to ensure that vehicles in adjacent areas have a collision-free schedule. Simulation results and analysis in a highway scenario have been carried out to evaluate the performance of DTMAC and compare it with the VeMAC protocol.

We propose a completely distributed and infrastructure free TDMA scheduling scheme which exploits the linear feature of VANET topologies. The vehicles' movements in a highway environment are linear due to the fact that their movements are constrained by the road topology. Our scheduling mechanism is also based on the assumption that each road is divided into N small fixed areas, denoted by $x_i, i = 1, ..., N$ (see Figure 1). Area IDs can be easily derived using map and GPS Information.

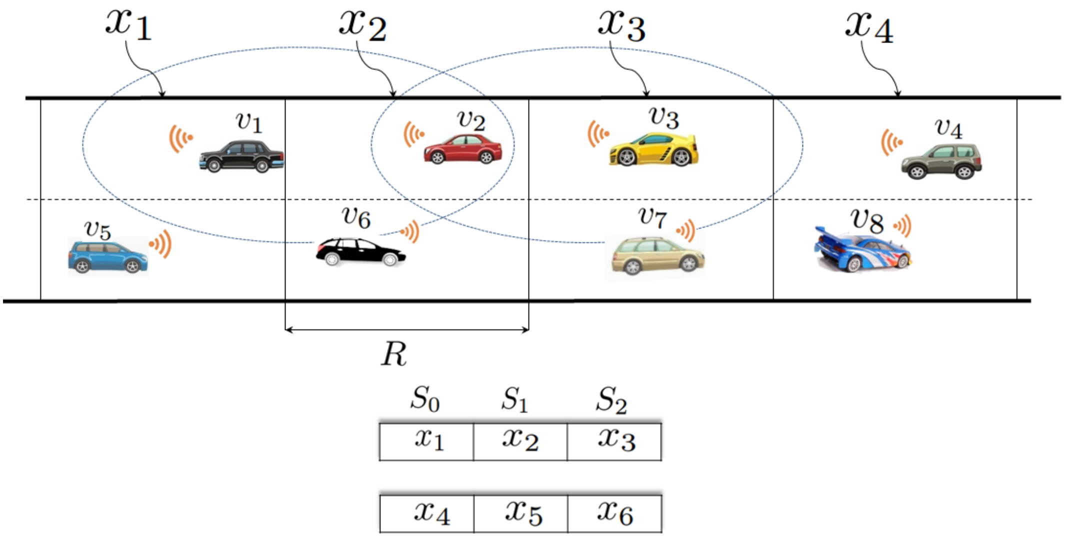

Figure 1. TDMA slots scheduling principle.

The time slots in each TDMA frame are partitioned into three sets S_0, S_1 and S_2 associated with vehicles in three contiguous areas: x_i, x_{i+1} and x_{i+2}, respectively (see Figure 1). Each frame consists of a constant number of time slots, denoted by τ and each time slot is of a fixed time duration, denoted by s. Each vehicle can detect the start time of each frame as well as the start time of a time slot. In the VANET studied, all the vehicles are equipped with a GPS and thus the one-Pulse-Per-Second (1PPS) signal that a GPS receiver gets from GPS satellites can be used for slot synchronization.

To prevent collisions on the transmission channel, our TDMA scheduling mechanism requires that every packet transmitted by any vehicle must contain additional information, called Frame Information (FI). For the frame, this field gives the status of the slot (Idle, Busy, Collision) and the ID of the vehicles accessing each slot with the characteristic of the data sent: periodic or event-driven safety messages.

The simulation results show that, compared to VeMAC which is the reference in terms of TDMA protocols for VANETs, DTMAC provides a lower rate of access and merging collisions, which results in significantly improved broadcast coverage. For further details see [27].

7.3.1.2. *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 2, 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).

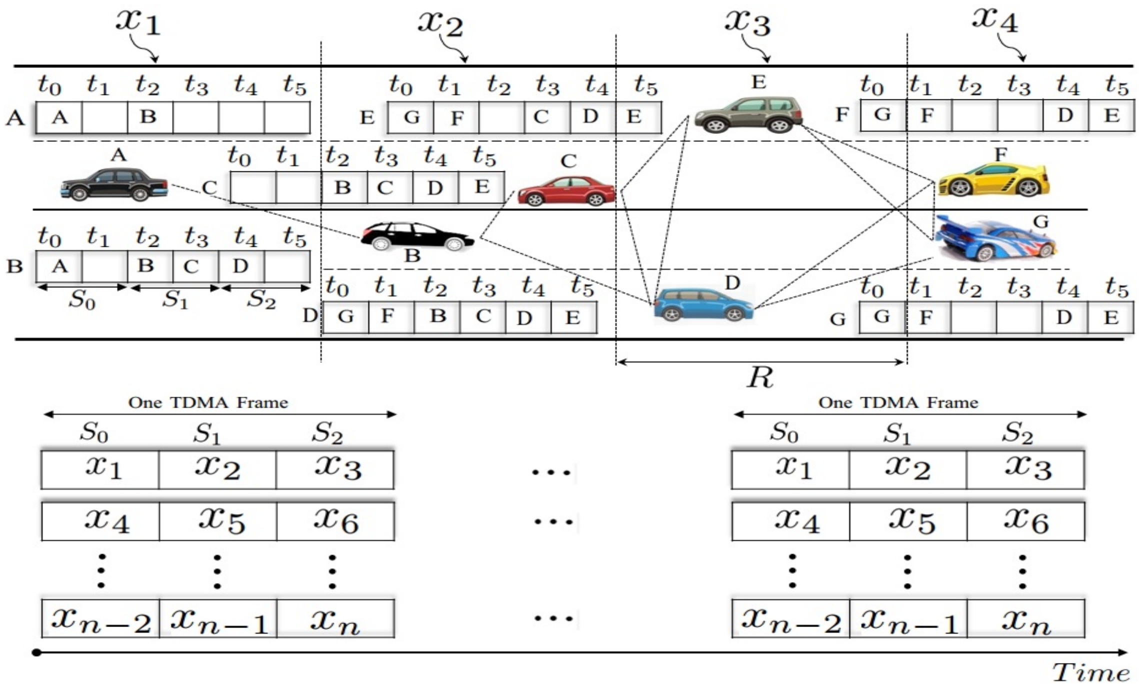

Figure 2. VANET network using DTMAC scheduling scheme.

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 2. 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 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.

7.3.1.3. CTMAC: a Centralized TDMA for VANETs

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

We have designed an infrastructure-based TDMA scheduling scheme which exploits the linear feature of VANET topologies. The vehicles' movements in a highway environment are linear due to the fact that their movements are constrained by the road topology. Our scheduling mechanism is also based on the assumption that the highway is equipped with some RSUs (i.e. one RSU for each $2 \times R\ meters$, where R is the communication range). Note that each area is covered by one RSU installed on the side of the highway and in the middle of the corresponding area. The time slots in each TDMA frame are partitioned into two sets S_1, S_2 associated with vehicles in two adjacent RSU areas (see Figure 3). Each frame consists of a constant number of time slots, denoted by τ and each time slot is of a fixed time duration, denoted by s. Each vehicle can detect the start time of each frame as well as the start time of a time slot.

The CTMAC scheduling mechanism uses a slot reuse concept to ensure that vehicles in adjacent areas covered by two RSUs have a collision-free schedule. The channel time is partitioned into frames and each frame is further partitioned into two sets of time slots S_1 and S_2. These sets are associated with vehicles moving in the adjacent RSU areas. These sets of time slots are reused along the highway in such a way that no vehicles belonging to the same set of two-hop neighbors using the same time slot. As shown in Figure 3, the vehicles in the coverage area of RSU_1 and those in the coverage area of RSU_2 are accessing disjoint sets of time slots. As a result, the scheduling mechanism of CTMAC can decrease the collision rate by avoiding the inter-RSUs interference without using any complex band. Each active vehicle keeps accessing the same time slot on all subsequent frames unless it enters another area covered by another RSU or a merging collision problem occurs. Each vehicle uses only its allocated time slot to transmit its packet on the control channel.

The simulation results reveal that CTMAC significantly outperforms the VeMAC and ADHOC MAC protocols. in terms of transmission collisions and the overhead required to create and maintain the TDMA schedules, see [28].

7.3.1.4. A Flooding-Based Location Service in VANETs

Participants: Selma Boumerdassi, Paul Muhlethaler.

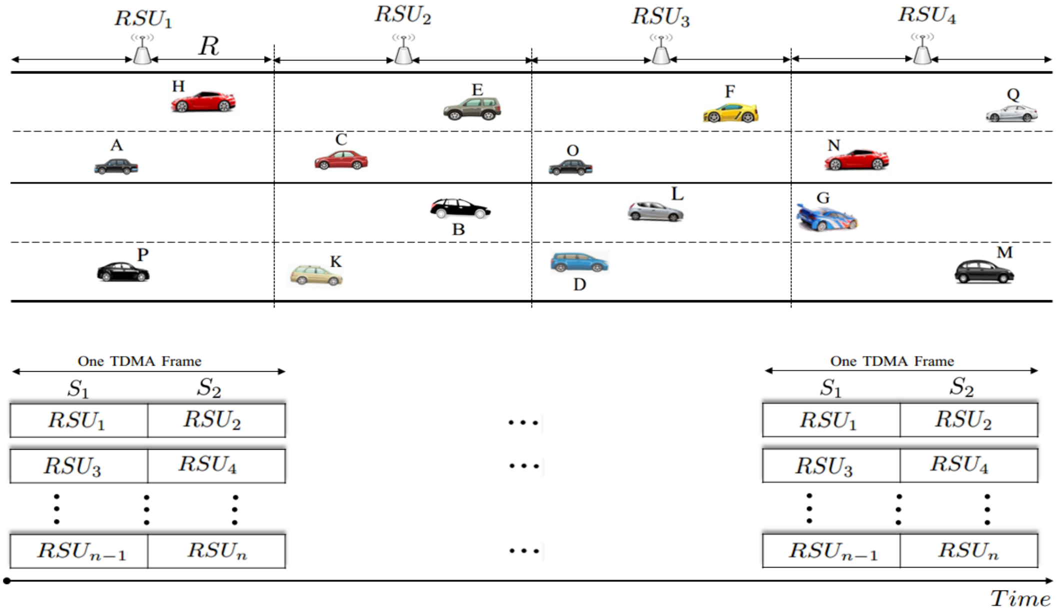

Figure 3. TDMA slots scheduling mechanism of CTMAC

This work was 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.

7.3.2. Models for Wireless Networks and VANETs

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

Participants: Younes Bouchaala, Paul Muhlethaler, Nadjib Achir.

This work has been 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.

7.3.2.2. Model of IEEE 802.11 Broadcast Scheme with Infinite Queue

Participant: Paul Muhlethaler.

This work has been in collaboration with Guy Fayolle (Inria RITS).

We have analyzed the so-called back-off technique of the IEEE 802.11 protocol in broadcast mode with waiting queues. In contrast to existing models, packets arriving when a station (or node) is in back-off state are not discarded, but are stored in a buffer of infinite capacity. As in previous studies, the key point of our analysis hinges on the assumption that the time on the channel is viewed as a random succession of transmission slots (whose duration corresponds to the length of a packet) and mini-slots during which the back-off of the station is decremented. These events occur independently, with given probabilities. The state of a node is represented by a two-dimensional Markov chain in discrete-time, formed by the back-off counter and the number of packets at the station. Two models are proposed both of which are shown to cope reasonably well with the physical principles of the protocol. The stability (ergodicity) conditions are obtained and interpreted in terms of maximum throughput. Several approximations related to these models are also discussed. The results of this study are in [2].

7.3.2.3. Model and optimization of CSMA

Participants: Younes Bouchaala, Paul Muhlethaler, Nadjib Achir.

This work has been 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. 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.

7.3.2.4. Adaptive CSMA

Participants: Nadjib Achir, Younes Bouchaala, Paul Muhlethaler.

This work has been 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.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. CNES

Participants: Ines Khoufi, Pascale Minet, Erwan Livolant.

Partners: CNES, Inria.

Following the SAHARA project that ended in 2015, CNES decided to fund a study about the use of wireless sensor networks in space environment. This new project started in November 2015 and will end in November 2016.

For CNES we studied how to use a IEEE 802.15.4e TSCH (Time Slotted Channel Hopping) network in the space launch vehicles. We proposed new solutions and evaluated their performances with the NS3 simulation tool.

8.1.2. OpenMote

Participant: Thomas Watteyne.

Inria-EVA has signed an long-standing Memorandum of Understanding with OpenMote Technology.

8.2. Bilateral Grants with Industry

8.2.1. Gridbee CIFRE

Participants: Jonathan Muñoz, Thomas Watteyne.

- Title: km-scale Industrial Networking
- Type: CIFRE agreement
- Period: Nov 2015 - Oct 2018
- Coordinator: **Thomas Watteyne**
- Goal: CIFRE agreement with Gridbee (http://www.gridbeecom.com/) to apply 6TiSCH-style scheduling on top of long-range IEEE802.15.4g radios. Implementation of those solutions on OpenWSN.

9. Partnerships and Cooperations

9.1. National Initiatives

9.1.1. ANR

The Inria-EVA team has not been involved in an ANR project in 2016.

9.1.2. Competitivity Clusters

9.1.2.1. SAHARA

Participants: Pascale Minet, Erwan Livolant.

Period: 2011 - 2016.

Partners: EADS (coordinator), Astrium, BeanAir, CNES, ECE, EPMI, Eurocopter, GlobalSys, Inria, LIMOS, Oktal SE, Reflex CES, Safran Engineering Systems.

SAHARA is a FUI project, labeled by ASTECH and PEGASE, which aims at designing a wireless sensor network embedded in an aircraft. The proposed solution should improve the embedded mass, the end-to-end delays, the cost and performance in the transfers of non critical data.

This project ended in March 2016. After a presentation of the SAHARA project at the IEEE WISEE 2015 conference (Wireless for Space and Extreme Environments), we were selected to write a book chapter entitled “Multichannel Wireless Sensor Networks for Aircraft: Challenges and Issues” in the Wiley book “Wireless sensor systems for extreme environments: space, underwater, underground and industrial”.

9.1.2.2. CONNEXION

Participants: Pascale Minet, Ines Khoufi, Erwan Livolant.

Period: 2012 - 2016.

Partners: EDF (coordinator), All4Tec, ALSTOM, AREVA, Atos WorldGrid, CEA, CNRS / CRAN, Corys TESS, ENS Cachan, Esterel Technologies, Inria, LIG, Predict, Rolls-Royce Civil Nuclear, Telecom ParisTech.

The Cluster CONNEXION (Digital Command Control for Nuclear EXport and renovatION) project aims to propose and validate an innovative architecture platforms suitable control systems for nuclear power plants in France and abroad. This architecture integrates a set of technological components developed by the academic partners (CEA, Inria, CNRS / CRAN, ENS Cachan, LIG, Telecom ParisTech) and based on collaborations between major integrators such as ALSTOM and AREVA, the operator EDF in France and “techno-providers” of embedded software (Atos WorldGrid, Rolls-Royce Civil Nuclear, Corys TESS, Esterel Technologies, All4Tec, Predict). With the support of the competitiveness clusters System@tic, Minalogic and Burgundy Nuclear Partnership,the project started in April 2012. The key deliverables of the project covered several topics related demonstration concern-driven engineering models for the design and validation of large technical systems, design environments and evaluation of HMI, the implementation of Wireless Sensor Network context-nuclear, buses business object or real-time middleware facilitating the exchange of heterogeneous data and distributed data models standardized to ensure consistency of digital systems.

The EVA team focuses more particularly on the interconnection of the OCARI wireless sensor network with the industrial facility backbone and deployment algorithms of wireless sensors.

In the Cluster Connexion project, the goal for the EVA team was to design and implement new functionnalities for the OCARI wireless sensor network to allow it to:

- support the mobility of some sensor nodes (targeted application: remote dosimetry to monitor the exposition of people to radiations),
- transmit commands to sensors/actuators (e.g. configuration parameters, regeneration order),
- ensure data gathering during node recoloring,
- remotely manage the parameters of the OCARI network,
- aggregate in a single frame several heterogeneous measures originated from different sensors on a same wireless node,
- use a generic format for the measures: type, length, value.
- integrate this network to the middleware of context-aware services, OPC-UA/ROSA.

The demonstrator “a mobile connected worksite” developed in the Cluster Connexion project meets several objectives:

- Make the wireless sensor networks more reliable in an ionisating environment ionisant;
- Make easier the diagnostic and the repairing by means of the aggregation of data originated from heterogeneous sources;
- Take into account the requirements of information security in the architectures;
- Ensure a continuum of solutions for the industrial involved.

The Industrial IoT (Internet of Things) solution proposed by Connexion is an integrated chain, from the wireless sensor& actuator network up to the surveillance, diagnostic and health infrastructure monitoring applications, using a context-aware middleware fitting the industrial environment.

At the end of the Cluster Connexion project, we made the demonstration of a command/control loop for the regeneration of wireless sensor nodes in collaboration with CEA, Predict, Telecom ParisTech, EDF, ATOS and Inria highlighting the following steps:

- the upstream flow of health indicators from electronic devices,
- detection of an abnormal behavior by a monitoring software (KASEM),
- generation of a regeneration command and transmission of this command to the misbehaving sensor node.
- regeneration of the involved sensor
- insertion of the regenerated sensor in the OCARI network.

When the Cluster Connexion project ended, the results obtained with regard to the OCARI network and the OPC-UA/ROSA middleware have been transferred to the Task Force ConnexSensors hosted by AFNeT. The goals of the ConnexSensors TaskForce are:

- Federate industrial companies around an IoT solution IoT including wireless sensor & actuator networks and a standardized industrial middleware.
- Jointly valorize the OCARI wireless sensor & actuator network and the OPC-UA/ROSA middleware.
- Deploy the Connexion demonstrator in the basemenet of interested industrials.
- Ensure that industrials will keep the mastership of their data.
- Ensure the perennity of the solution proposed.

9.1.3. Other collaborations

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.

9.2. European Initiatives

9.2.1. H2020 Projects

9.2.1.1. F-Interop

Type: H2020

Objective: Design and implement a cloud-based interoperability testing platform for low-power wireless standards.

Duration: Nov 2015 - Oct 2017

Coordinator: UPMC (FR)

Other partners: iMinds (BE), ETSI (FR), EANTC (DE), Mandat International (CH), DigiCat (UK), UL (LU), Inria (FR), Device Gateway (CH)

Inria contact: **Thomas Watteyne**

9.2.1.2. ARMOUR

Type: H2020

Objective: Security for the IoT

Duration: Dec 2015 – Nov 2017

Coordinator: UPMC (FR)

Other partners: Inria (FR), Synelixis (EL), Smartesting (FR), Unparallel (PT), JRC (BE), Ease Global Market (FR), Odin Solutions (ES)

Inria-EVA contact: **Thomas Watteyne**

9.2.1.3. Project Reviewing

- **Paul Muhlethaler** was reviewer for the E3Network project (E-band transceiver for the backhaul infrastructure of the future networks). The transceiver designed in the E3Network project will use modern digital multi-level modulations to achieve high spectral efficiency. This together with the huge bandwidth will enable high capacities above 10 Gbps.

9.2.2. Collaborations in European Programs, Except H2020

The Inria-EVA team has not participated in non-H2020 European Programs in 2016.

9.2.3. Collaborations with Major European Organizations

European Telecommunications Standards Institute (ETSI)

co-organize two ETSI 6TiSCH plugtests in 2016 (in Paris in February, in Berlin in July).

9.3. International Initiatives

9.3.1. Inria International Labs

9.3.1.1. REALMS Associate Team

Type: Associate Team

Inria International Lab: Inria@SiliconValley

Title: Real-Time Real-World Monitoring Systems

Associate teams: Inria-EVA, Prof. Glaser's team (UC Berkeley), Prof. Kerkez's team (University of Michigan, Ann Arbor)

Duration: 2015-2017

Objective: Prof. Glaser's and Prof. Kerkez's teams are revolutionizing environmental monitoring by using low power wireless TSCH networks to produce continuous environmental data accessible in real time. They are successfully deploying these networks to study mountain hydrology, observe water quality in urban watersheds, and build intelligent urban stormwater grids. The REALMS associate team conducts research across the environmental engineering and networking research domains. Its 3-year goal is to develop easy-to-use real-world network monitoring solutions to provide real-time data for environmental and urban applications. This goal leads to the following objectives: building a long-term large-scale public connectivity dataset of the networks deployed; using that dataset to model TSCH networks; and building an ecosystem of tools around this technology.

website: http://www.snowhow.io/

Inria contact: **Thomas Watteyne**

9.3.1.2. DIVERSITY Associate Team

Type: Associate Team

Inria International Lab: Inria@SiliconValley

Title: Measuring and Exploiting Diversity in Low-Power Wireless Networks

Associate teams: Inria-EVA, Prof. Bhaskar Krishnamachari's team, USC, CA, USA

Duration: 2016-2018

Objective: The Grand Challenge of the DIVERSITY associate team is to develop the networking technology for tomorrow's Smart Factory. The two teams come 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.

Inria contact: **Thomas Watteyne**

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

9.3.2.1. Tassili

The Tassili project (N° MDU 17MDU988 - Campus France N° 37459VF) "Gestion des caches et orchestration intelligentes dans un environnement réseau virtulaisé" is a project in collaboration with Algeria and France. On the French side, the project is leaded by Samia Bouzefrane (associated professor at CNAM) and **Paul Muhlethaler** (EVA team Inria). On the Algerian side is leaded by the University Mouloud Mammeri of Tizi-Ouzou (UMMTO) représented by Mehammed Daoui (associated professor).

This project will start in January 2017 and will last three years. Three PhD theses will be conducted in co-tutelle between CNAM and UMMTO. This project will support the stay of the tree PhD candidates for a four months visit in France. These two PhD theses will be co-directed by **Paul Muhlethaler**. The first subject is "New intelligent caching and mobility strategies for MEC/ICN based architectures" and the second subject concern the design of a safe architecture for Name Data Networking.

9.3.3. Inria International Partners

9.3.3.1. Declared Inria International Partners

University of California, Berkeley, CA, USA (Glaser)

- Collaboration with Prof. Steven Glaser, Ziran Zhang, Carlos Oroza, Sami Malek and Zeshi Zheng through the REALMS associate team, see Section 9.3.1.1.
- Joint publication in 2016:
  - Long-term Monitoring of the Sierra Nevada Snowpack Using Wireless Sensor Networks. Ziran Zhang, Steven Glaser, Thomas Watteyne, Sami Malek. IEEE Internet of Things Journal, special issue on Large-scale Internet of Things: Theory and Practice, to appear in 2016.
  - Demo: SierraNet: Monitoring the Snow Pack in the Sierra Nevada. Keoma Brun-Laguna, Carlos Oroza, Ziran Zhang, Sami Malek, Thomas Watteyne, Steven Glaser. ACM International Conference on Mobile Computing and Networking (MobiCom), Workshop on Challenged Networks (CHANTS), 7 October 2016, New York, NY, USA.
  - (Not so) Intuitive Results from a Smart Agriculture Low-Power Wireless Mesh Deployment. Keoma Brun-Laguna, Ana Laura Diedrichs, Diego Dujovne, Rémy Léone, Xavier Vilajosana, Thomas Watteyne. ACM International Conference on Mobile Computing and Networking (MobiCom), Workshop on Challenged Networks (CHANTS), 7 October 2016, New York, NY, USA.
  - SOL: An End-to-end Solution for Real-World Remote Monitoring Systems. Keoma Brun-Laguna, Thomas Watteyne, Sami Malek, Ziran Zhang, Carlos Oroza, Steven Glaser, Branko Kerkez. IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Valencia, Spain, 4-7 September 2016.

University of Southern California, CA, USA

- Collaboration with Prof. Bhaskar Krishnamachari through the DIVERSITY associate team, see Section 9.3.1.2.
- Joint publication in 2016:
  - Insights into Frequency Diversity from Measurements on an Indoor Low Power Wireless Network Testbed. Pedro Henrique Gomes, Ying Chen, Thomas Watteyne, Bhaskar Krishnamachari. IEEE Global Telecommunications Conference (GLOBECOM), Workshop on Low-Layer Implementation and Protocol Design for IoT Applications (IoT-LINK), Washington, DC, USA, 4-8 December 2016.
  - Reliability through Time-Slotted Channel Hopping and Flooding-based Routing. Pedro Henrique Gomes, Thomas Watteyne, Pradipta Gosh, Bhaskar Krishnamachari. International Conference on Embedded Wireless Systems and Networks (EWSN), Dependability Competition, ACM, Graz, Austria, 14-15 February 2016.

Universidad Tecnologica Nacional, Mendoza, Argentina

- Collaboration with Ana Laura Diedrichs, Juan Carlos Taffernaberry, Gustavo Mercado through the SticAmSud PEACH project.
- Joint publication(s) in 2016:
  - PEACH: Predicting Frost Events in Peach Orchards Using IoT Technology. Thomas Watteyne, Ana Laura Diedrichs, Keoma Brun-Laguna, Javier Emilio Chaar, Diego Dujovne, Juan Carlos Taffernaberry, Gustavo Mercado. EAI Endorsed Transactions on the Internet of Things, to appear in 2016.
  - A Demo of the PEACH IoT-based Frost Event Prediction System for Precision Agriculture. Keoma Brun-Laguna, Ana Laura Diedrichs, Javier Emilio Chaar, Diego Dujovne, Juan Carlos Taffernaberry, Gustavo Mercado, Thomas Watteyne. IEEE International Conference on Sensing, Communication and Networking (SECON), poster and demo session, London, UK, 27-30 June 2016

University of Michigan, Ann Arbor, MI, USA

- Collaboration with Prof. Branko Kerkez through the REALMS associate team, see Section 9.3.1.1.

Linear Technology/Dust Networks, Silicon Valley, USA

- Collaboration with Prof. Kris Pister, Dr. Brett Warneke, Dr. Lance Doherty, Dr. Jonathan Simon and Joy Weiss on SmartMesh IP and 6TiSCH standardization.

9.3.3.2. Informal International Partners

University of California, Berkeley, CA, USA (Pister)

- Collaboration with Prof. Kris Pister through the IETF 6TiSCH working group.
- Joint publication in 2016:
  - Simple Distributed Scheduling with Collision Detection in TSCH Networks. Kazushi Muraoka, Thomas Watteyne, Nicola Accettura, Xavi Vilajosana, Kris Pister. IEEE Sensors Letters, to appear in 2016.

Open University of Catalunya, Spain

- Collaboration with Xavi Vilajosana and Pere Tuset through IETF 6TiSCH working group and the OpenWSN project.
- Joint publication(s) in 2016:
  - Distributed PID-based Scheduling for 6TiSCH Networks. Marc Domingo-Prieto, Tengfei Chang, Xavier Vilajosana, Thomas Watteyne. IEEE Communications Letters, vol PP, Issue 99, March 2016.

    - Poster Abstract: A Benchmark for Low-power Wireless Networking. Simon Duquennoy, Olaf Landsiedel, Carlo Alberto Boano, Marco Zimmerling, Jan Beutel, Mun Choon Chan, Omprakash Gnawali, Mobashir Mohammad, Luca Mottola, Lothar Thiele, Xavier Vilajosana, Thiemo Voigt, Thomas Watteyne. ACM Conference on Embedded Networked Sensor Systems (ACM Sensys), Stanford, CA, USA, 14-16 November 2016.
    - Rover: Poor (but Elegant) Man's Testbed. Zacharie Brodard, Hao Jiang, Tengfei Chang, Thomas Watteyne, Xavier Vilajosana, Pascal Thubert, Geraldine Texier. ACM International Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks (PE-WASUN), Valletta, Malta, 13-17 November 2016.
    - Determinism Through Path Diversity: Why Packet Replication Makes Sense. Jesica de Armas, Pere Tuset, Tengfei Chang, Ferran Adelantado, Thomas Watteyne, Xavier Vilajosana. International Conference on Intelligent Networking and Collaborative Systems (INCoS), Ostrava, Czech Republic, 7-9 September 2016.
    - OpenWSN & OpenMote: Demo'ing A Complete Ecosystem for the Industrial Internet of Things. Tengfei Chang, Pere Tuset-Peiro, Jonathan Munoz, Xavier Vilajosana, Thomas Watteyne. IEEE International Conference on Sensing, Communication and Networking (SECON), poster and demo session, London, UK, 27-30 June 2016.
    - OpenMote+: a Range-Agile Multi-Radio Mote. Pere Tuset, Xavier Vilajosana, Thomas Watteyne. International Conference on Embedded Wireless Systems and Networks (EWSN), NexMote Workshop, ACM, Graz, Austria, 14-15 February 2016.
    - Numerous IETF Internet-Drafts.

University of Science and Technology, Beijing, China

- Collaboration with Qin Wang through IETF 6TiSCH working group. Tengfei Chang, engineer at Inria-EVA, comes from her team
- Joint publication(s) in 2016:
    - On-the-Fly Bandwidth Reservation for 6TiSCH Wireless Industrial Networks. Maria-Rita Palattella, Thomas Watteyne, Qin Wang, Kazuki Muraoka, Nicola Accettura, Diego Dujovne, Alfredo Grieco, Thomas Engel. IEEE Sensors Journal, 15 January 2016.
    - LLSF: Low Latency Scheduling Function for 6TiSCH Networks. Tengfei Chang, Thomas Watteyne, Qin Wang, Xavier Vilajosana. IEEE International Conference on Distributed Computing in Sensor Systems (DCOSS), Washington, DC, USA, 26-28 May 2016.

University of Bari, Italy

- Collaboration with Savio Sciancalepore, Giuseppe Piro and Gennaro Boggia through IETF 6TiSCH and OpenWSN.
- Joint publication in 2016:
    - Link-layer Security in TSCH Networks: Effect on Slot Duration. Savio Sciancalepore, Malisa Vucinic, Giuseppe Piro, Gennaro Boggia, Thomas Watteyne. Wiley Transactions on Emerging Telecommunications Technologies (ETT), to appear in 2016.

University of Trento, Italy

- Collaboration with Oana Iova through IETF 6TiSCH working group.

- Joint publication(s) in 2016:
  - The Love-Hate Relationship between IEEE802.15.4 and RPL. Oana Iova, Fabrice Theoleyre, Thomas Watteyne, Thomas Noel. IEEE Communications Magazine, to appear in 2016.

TU Berlin, Germany

- Collaboration with Vlado Handziski, Adam Wolisz through IETF 6TiSCH working group.
- Joint publication(s) in 2016:
  - Industrial Wireless IP-based Cyber Physical Systems. Thomas Watteyne, Vlado Handziski, Xavier Vilajosana, Simon Duquennoy, Oliver Hahm, Emmanuel Baccelli, Adam Wolisz. Proceedings of the IEEE, Vol. PP, Issue 99, pp. 1-14, March 2016.

Mandat International, Switzerland

- Collaboration with Sebastien Ziegler through the H2020 F-Interop project
- Joint publication(s) in 2016:
  - F-Interop – Online Platform of Interoperability and Performance Tests for the Internet of Things. Sébastien Ziegler, Serge Fdida, Cesar Viho, Thomas Watteyne. Conference on Interoperability in IoT (InterIoT), Paris, France, 26-28 October 2016.

KU Leuven, Belgium

- Collaboration with Prof. Danny Hughes, Prof. Wouter Joosen, Dr. Nelson Matthys, Fan Yang, Wilfried Daniels on MicroPnP.

Inria-EVA has a strong relationship with ENSI (Tunisia) and ENSIAS (Morocco). A significant part of our PhD students come from these engineering schools.

9.3.4. Participation in Other International Programs

9.3.4.1. PEACH

Program: STIC-AmSud 2015

Title: PEACH - PrEcision Agriculture through Climate researcH

Inria principal investigator: **Thomas Watteyne**

International Partners (Institution - Laboratory - Researcher):

Escuela de Informática y Telecomunicaciones, Universidad Diego Portales, Santiago, Chile. Coordinator: Prof. Diego Dujovne

Universidad Tecnológica Nacional - Facultad Regional Mendoza, Grupo de I&D en Tecnologías de la Información y Comunicaciones (GridTICS). Coordinator: Prof. Gustavo Mercado

DHARMa Lab, Universidad Tecnológica Nacional, Facultad Regional Mendoza, Argentina.

Cátedra de Fisiología Vegetal, Facultad de Ciencias Agrarias, Universidad Nacional de Cuyo, Mendoza, Argentina.

Duration: 2016-2017

Goal: Propose a design methodology for a lowpower wireless IoT sensing network, given the requirements and restrictions of a Machine Learning model to predict frost events in peach orchards and vineyards.

9.4. International Research Visitors

9.4.1. Visits of International Scientists

- Professors/Researchers:
  - **Mario Gerla**, Professor, UCLA, USA, visit 10-20 December 2016
  - **Leila Saidane**, Professor, ENSI, Tunis, Tunisia, visit November 2016
  - **Felipe Lalanne**, Reseacher, Inria Chile, Chile, visit 19–26 October 2016
  - **Mario Gerla**, Professor, UCLA, USA, visit 31 August - 23 September 2016
  - **Diego Dujovne**, Professor, Universidad Diego Portales, Chile, visit 22-31 July 2016
  - **Ruben Milocco**, Universidad Nacional Comahue, Argentina, visit July 2016
  - **Branko Kerkez**, Professor, U. Michigan, USA, visit 17-22 June 2016
  - **Steven Glaser**, Professor, UC Berkeley, USA, visit 21-25 March 2016
  - **Xavi Vilajosana**,Professor, UOC/OpenMote, Spain, visit 2-4 February 2016
- PhD Students:
  - **Travis Massey**, PhD Student, UC Berkeley, USA, visit 22 July 2016
  - **Carlos Oroza**, PhD Student, UC Berkeley, USA, visit 23-29 July 2016
  - **David Burnett**, PhD Student, UC Berkeley, USA, visit 13-15 June 2016
  - **Filip Barac**, PhD Student, Mid Sweden University, Sweden, visit 8-19 February 2016

9.4.2. Internships

- **Jiangnan Yang**, internship on simulation of wireless TDMA networks with NS3, March-August 2016.

9.4.3. Visits to International Teams

9.4.3.1. Research Stays Abroad

- **Keoma-Brun Laguna**, stay in Prof. Glaser's lab at UC Berkeley, USA, August 2016.
- **Thomas Watteyne**, stay in Prof. Glaser and Prof. Pister's labs at UC Berkeley, USA, August 2016.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Event Organization

10.1.1.1. General Chair, Scientific Chair

- **Pascale Minet**
  1. co-chair with Leila Saidane of PEMWN 2016, organized in Paris (at the CNAM), France, November 2016.
- **Thomas Watteyne**
  1. Co-chair with Fabrice Theoleyre and Antoine Gallais of a special session on "Industrial Internet of Things: Constraints, Guarantees, and Resiliency" at the 23rd IEEE International Conference on Telecommunications (ICT), Thessaloniki, Greece, 16-18 May 2016.
  2. Technical Program Committee Chair and Local Chair, EAI Conference on Interoperability in IoT (InterIoT), Paris, France, October 2016.
  3. Demo Chair, IEEE International Conference on Sensing, Communication and Networking (SECON), London, UK, 27-30 June 2016.
  4. General Chair, Second ETSI 6TiSCH plugtests, Paris, France, 2-4 February 2016.
- Nadjib Achir

  1. track chair of the Internet of Things (IoT) track of the Selected Areas in Communications Symposium of IEEE Global Telecommunications Conference 2014

- Selma Boumerdassi
  1. chair of the International Workshop on Energy Management for Sustainable Internet-of-Things and Cloud Computing (EMSICC 2016), August 2016.
  2. chair of the International Conference on Mobile, Secure and Programmable Networking (MSPN 2016), June 2016.

10.1.1.2. Member of the Organizing Committee

- **Pascale Minet**
  1. chaired the session entitled “Wireless Sensor networks II” at the IEEE MASS 2016 conference held in Brasilia in October 2016.
- **Paul Muhlethaler**
  1. have invited two presenters Laurent Georges (ESIEE) and Nadjib Ait Saadi (Paris XII) at EVA-MIMOVE-RITs seminar. Laurent Georges presented his work on software radio and Nadjib Ait Saadi on virtualisation and communication in data centers.
- **Thomas Watteyne**
  1. Demo Chair, IEEE International Conference on Sensing, Communication and Networking (SECON), London, UK, 27-30 June 2016.
- Christine Anocq
  1. member of the organizing committee of the international conference PEMWN 2016

10.1.2. Scientific Events Selection

The list of conferences Inria-EVA researcher participated in as Technical Program Committee (TPC) members:

- **Nadjib Achir**
  1. TPC Member IEEE Global Telecommunications Conference, GLOBECOM 2016.
  2. TPC Member IEEE International Conference on Communications, ICC 2016.
  3. TPC Member Personal, Indoor and Mobile Radio Communications, PIMRC 2016.
  4. TPC Member IEEE Wireless Communications and Networking Conference, WCNC 2016.
  5. TPC Member IEEE Consumer Communications & Networking Conference, CCNC 2016.
  6. TPC Member Global Information Infrastructure and Networking Symposium, GIIS 2016.
  7. TPC Member International Conference On Network of the Future, NoF 2016.
  8. TPC Member of the fourth International conference on Performance Evaluation and Modeling in Wireless Networks, PEMWN 2016.
- **Selma Boumerdassi**
  1. TPC Member IEEE Global Telecommunications Conference, GLOBECOM 2016
  2. TPC Member IEEE International Conference on Communications, ICC 2016
  3. TPC Member International Conference on Open and Big Data, OBD, 2016
  4. TPC Member International Conference on Performance Evaluation and Modeling in Wired and Wireless Networks, PEMWN, 2016
  5. TPC Member International Conference on Platform Technology and Service, PlatCon, 2016
- **Pascale Minet**
  1. CSCN 2016, IEEE Conference on Standards for Communications and Networking, October 2016.

2. CCNC 2016, 13th Annual IEEE Consumer Communications and Networking Conference, January 2016.
3. DCNET 2016, 7th International Conference on Data Communication Networking, July 2016.
4. PEMWN 2016, 5th International Conference on Performance Evaluation and Modeling in Wired and Wireless Networks, November 2016.
5. PECCS 2016, 6th International conference on Pervasive and Embedded Computing and Communication Systems, July 2016.
6. RTNS 2016, 24th International Conference on Real-Time and Network Systems, November 2016.
7. Wireless Days, IFIP international conference, March 2016.
8. WiSEE 2016, IEEE International Conference on Wireless for Space and Extreme Environments, September 2016.

- **Paul Muhlethaler**
  1. 3rd International Workshop on Energy Management for Sustainable Internet-of-Things and Cloud Computing (EMSICC 2016) 24 August 2016 Vienna.
  2. Technical Committee of the International Conference on Mobile, Secure and Programmable Networking MSPN’ 2016, June 1 - 3 2016, Paris, France.
  3. Steering Committee Member of MobileHealth 2016, 6th EAI International Conference on Wireless Mobile Communication and Healthcare, November 14–16, 2016, Milan, Italia
  4. Technical Committee of the fourth International conference on Performance Evaluation and Modeling in Wireless Networks, PEMWN 2016, 22-24 November 2016, Paris, France.
- **Thomas Watteyne**
  1. TPC Member IFIP/IEEE International Symposium on Integrated Network Management, workshop on Future Networks for Secure Smart Cities (FNSSC), 2017.
  2. TPC Member IEEE International Conference on Communications (ICC), Selected Areas in Communications (SAC), 2015, 2016, 2017.
  3. TPC Member IEEE International Conference on Telecommunications (ICT), Thessaloniki, Greece, 16-18 May 2016.
  4. TPC Member IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), 2008, 2009, 2013, 2016.
  5. TPC Member International Conference on Embedded Wireless Systems and Networks (EWSN), 2016.

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

- **Nadjib Achir**
  1. guest editor of the special issue “Planning and Deployment of Wireless Sensor Networks”, of the International Journal of Distributed Sensor Networks.
- **Thomas Watteyne**
  1. Editor, EAI Transactions on Internet of Things since 2015.
  2. Editor, IEEE Internet of Things (IoT) Journal 2014-2016.

10.1.3.2. Reviewer - Reviewing Activities

- **Nadjib Achir**
  1. Sensor Networks (MDPI)

  2. Wireless Communications and Mobile Computing (Wiley)
  3. Internet of Things Journal (IEEE)
  4. Ad Hoc Networks Journal (Elsevier)
- **Selma Boumerdassi**
  1. The Journal of Human-centric Computing and Information Sciences (Springer).
- **Pascale Minet**
  1. Annals of Telecommunications,
  2. Ad Hoc Networks,
  3. International Journal of Distributed Sensor Networks,
  4. International Journal of Networked and Distributed Computing,
  5. Journal of Sensor and Actuator Networks,
  6. Computer Communications Journal,
  7. Sensors Journal.
- **Paul Muhlethaler**
  1. Annals of telecommunications
  2. Ad Hoc Networks,
  3. Journal of Distributed Sensor Networks,
  4. Journal of Networked and Distributed Computing,
  5. IEEE Transactions on Wireless Communications
  6. IEEE Transactions on Vehicular Technology
  7. IEEE Transactions on Information Theory
  8. International Journal of Distributed Sensor Networks. Hindawi.

10.1.4. Invited Talks and Panels

- **Thomas Watteyne**: SmartMesh IP: a ready-to-use IoT Solution. Inria-Chile, 2 December 2016.
- **Thomas Watteyne**: From Smart Dust to 6TiSCH: Academic and Commercial Background on TSCH Technology, Sensor Platform for HEalthcare in a Residential Environment (SPHERE) seminar, University of Bristol, Bristol, UK, 6 October 2016.
- **Thomas Watteyne** was panelist on “A Not So Politically Correct Reality Check about the IoT”, ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc), Paderborn, Germany, 5-8 July 2016.
- **Thomas Watteyne**: A Not So Politically Correct Reality Check about the IoT. ACM MobiHoc, Paderborn, Germany, 6 July 2016.
- **Thomas Watteyne** was panelist on “IoT & quantified self” at the open Inria conference on “Digital Sciences and Technologies for Health”, Futur en Seine Festival, Paris, France, 10 June 2016.
- **Thomas Watteyne**: HeadsUp! Long-Term Real-Time Patient Position Monitoring. International Conference on Digital Sciences and Technologies for Health, Futur en Seine Festival, Paris, France, 10 June 2016.
- **Thomas Watteyne** was panelist on “IoT & Smart City” at the Inria@Silicon Valley annual workshop (BIS), Paris, France, 9 June 2016.
- **Thomas Watteyne**: PEACH: Predicting Frost Events in Peach Orchards Using IoT Technology, Inria@Silicon Valley annual workshop (BIS), “IoT & Smart City” panel, Paris, France, 9 June 2016.
- **Thomas Watteyne**: Overview (Industrial) IoT Standardization Efforts at IETF. ITU Meeting, Geneva, Switzerland, 10 May 2016.

- **Thomas Watteyne**: Having fun with Industrial IoT, University of Southern California, Los Angeles, CA, USA, 1 April 2016.
- **Thomas Watteyne**: Not-so-Politically Correct Food for Thought on NGIoT, US-Europe Invited Workshop on Next-Generation IoT (NGIOT), Los Angeles, CA, USA, 31 March 2016.
- **Thomas Watteyne**: Industrial IoT Standards and not-to-industrial applications, GDR SOC-SIP/RSD, Paris, France, 30 March 2016.

10.1.5. Leadership within the Scientific Community

- **Thomas Watteyne** is co-chair of IETF 6TiSCH standardization working group.
- **Thomas Watteyne** is Senior member of the IEEE since 2015.

10.1.6. Scientific Expertise

- **Paul Muhlethaler**is a reviewer for the European Commission. He regularly reviews project; this year he was at the last review meeting of E3Network a project dedicated to high-speed radio links in the E-band.
- **Thomas Watteyne** and Tengfei Chang consulted for ETSI as part of the “panel of experts” to prepare the Test Description and Golden Image for the ETSI 6TiSCH 3 plugtests, held on 15-16 July 2016 in Berlin, Germany.
- **Thomas Watteyne** and Tengfei Chang consulted for ETSI as part of the “panel of experts” to prepare the Test Description and Golden Image for the ETSI 6TiSCH 2 plugtests, held on 2-4 February 2016 in Paris, France.

10.1.7. Research Administration

- **Pascale Minet** was member of the evaluation committee in charge of recruiting an Assistant Professor at the University of Auvergne, Clermont-Ferrand in April and May 2016.
- **Pascale Minet** was a member of the EDITE Doctoral School’s Grant Allocation Committee (June 2016).
- **Thomas Watteyne** is member 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

License:

- **Thomas Watteyne** taught a 2-h course on industrial IoT at University of Southern California (USC), USA, 1 April 2016.

Master:

- **Thomas Watteyne** and Keoma Brun-Laguna taught a 4-day course on IoT, with associated hands-on labs. ENSTA ParisTech. Together with Dominique Barthel, 12-15 December 2016.
- **Thomas Watteyne** taught a 1/2-day crash course on the Industrial IoT, ParisTech, 5 October 2016.

10.2.2. Supervision

PhD:

- Mohamed Hadded, “Design and Optimizaion of Access Control Protocols in Vehicular Ad Hoc Networks (VANETs)”, EDITE - Télécom Sud-Paris, November 2016, **Paul Muhlethaler** adviser, Anis Laouiti, co-adviser.

PhD in progress:

- Nesrine Ben Hassine “Learning algorithms for network resource management”, UVSQ, Sept 2017 (expected), **Pascale Minet** adviser, co-adviser Dana Marinca.
- Younes Bouchaala “Handling Safety Messages in Vehicular Ad Hoc Networks (VANETs)”, UVSQ, Sept 2017 (expected), **Paul Muhlethaler** adviser.
- Keoma Brun-Laguna “Limits of Time Synchronized Channel Hopping” *(tentative title)*, EDITE - UPMC, Dec 2018 (expected), **Thomas Watteyne** adviser.
- Jonathan Muñoz “km-scale Industrial Networks” *(tentative title)*, EDITE - UPMC, Oct 2018 (expected), **Thomas Watteyne** adviser.

10.2.3. Juries

HdR:

- Gerard Chalhoub, “Enhanced communications in data collection multihop wireless sensor networks”, University of Auvergne, June 2016, **Pascale Minet** examinator.

PhD:

- Guillaume Gaillard, “Opérer les réseaux de l’Internet des Objets”, University of Lyon - INSA. Viva on 19 December 2016. **Pascale Minet** reviewer.
- Mohamed Hadded “Design and Optimization of Access Control Protocols in Vehicular Ad Hoc Networks (VANETs)” Thèse de Telecom Sud Paris. Viva on 30 Novembre 2016. Anis Laouiti examiner, **Paul Muhlethaler** examiner.
- Naourez Mejri, “Vers une ville intelligente au service du citoyen mobile: découverte de l’infrastructure d’accès et gestion intelligente de parkings”, University of La Manouba, ENSI, Tunis. Viva in November 2016. **Pascale Minet** examiner, **Paul Muhlethaler** reviewer.
- Nour Brinis Khay, “Stratégies de collecte de données dans les réseaux de capteurs”, University of La Manouba, ENSI, Tunis. Viva in November 2016. **Pascale Minet** examiner.
- Alexandre Ragaleux, “Mécanismes D’Accès Multiple dans les Réseaux Sans Fil Large Bande”, Université Pierre et Marie Curie. Viva on 22 September 2016. **Nadjib Achir** reviewer.
- Remy Leone “Intelligent Gateway for Low-Power Wireless Networks” (“Passerelle intelligente pour réseaux de capteurs sans fil contraints” in French), Telecom ParisTech, France, under the supervision of Jean Louis Rougier and Vania Conan. Viva on 24 June 2016. **Thomas Watteyne** examiner.
- Kevin Roussel, “Évaluation et amélioration des plates-formes logicielles pour réseaux de capteurs sans-fil, pour optimiser la qualité de service et l’énergie”, Inria Nancy/ Université de Lorraine, France, under the supervision of Ye-Qiong Song and Olivier Zendra. Viva on 3 June 2016. **Thomas Watteyne** examiner.
- Samira Chouikhi “Tolérance aux pannes dans un réseau de capteurs sans fil multi-canal ” University of Paris East Marne-La-Vallée. Viva in June 2016. **Pascale Minet** examiner, **Paul Muhlethaler** reviewer.
- Jin Cui, “Data aggregation in wireless sensor networks”, University of Lyon - INSA. Viva in June 2016. **Pascale Minet** reviewer.
- Mohamed Nidhal Mejri “Securing vehicular networks against denial of service attacks”, Université Paris 13. Viva on 19 May 2016. **Paul Muhlethaler** president, **Nadjib Achir** examiner.
- Chiraz Houaida, “Vers des mécanismes de routage robustes et optimisés dans un réseau sans-fil métropolitain et collaboratif”, University of Toulouse. Viva in May 2016. **Pascale Minet** reviewer.

- Antonio O. Gonga, “Mobility and Multi-channel Communications in Low-power Wireless Networks”, KTH Electrical Engineering, under the supervision of Prof. Mikael Johansson. Viva on 14 January 2016. **Thomas Watteyne** examiner.

10.3. Popularization

10.3.1. Demos

Inria-EVA is working with the Inria-Paris management team to install a permanent demo on the Inria-Paris premises in Q1 2017. Pieces of the same demo have been presented to all people and teams visiting the lab. For example, the high school students from the Lycee Louis-Le-Grand on 1 June 2016.

10.3.2. Videos

The following videos were prepared with the audio/video team of Inria.

1. Interview of **Thomas Watteyne** during the “Nouveaux Arrivants” workshop. To be published.
2. “Save The Peaches” details the Smart Agriculture deployment. Featuring **Thomas Watteyne** and Keoma Brun-Laguna.
   - English version: https://www.youtube.com/watch?v=_qGSH8l0Vkk
   - French version: https://www.youtube.com/watch?v=cZvGw7DyIzI

10.3.3. In the News

1. **Thomas Watteyne** featured in “Experto en IoT realiza webinar con Inria Chile”. Inria-Chile newsletter, December 2017.
2. Interview of **Thomas Watteyne**: “In Argentina alone, connected agriculture could have saved 10,000 jobs in one year”, Inria Homepage, November 2016.
3. Interview of **Thomas Watteyne** in “La Gazette”, the Inria-Paris newsletter, on Smart Agriculture, October 2016.
4. **Thomas Watteyne** featured in “Outcome Report from the US-Europe Invited Workshop on Next-Generation Internet of Things @USC”, Inria-SiliconValley Newsletter, 26 July 2016.
5. Keoma Brun-Laguna presented the PEACH project during the annual Math exhibition in Paris, on 28 May 2016.
6. **Thomas Watteyne** featured in “Inria deploys a wireless sensor network in Argentina to save peaches”, Inria-Paris homepage, 22 April 2016.
7. **Thomas Watteyne** featured in “Great fun at the OpenWSN & OpenMote tutorial at IEEE GLOBECOM in San Diego!”, Inria-SiliconValley Newsletter, 17 March 2016.
8. **Thomas Watteyne** featured in “6TiSCH cherche à concilier protocole IPv6, réseau radio maillé et performance industrielle”, L’embarque, 8 February 2016.

10.3.4. Web Presence & Social Media

- The Inria-EVA team maintains the following websites:
  - https://team.inria.fr/eva/
  - http://www.savethepeaches.com/
  - http://www.snowhow.io/
  - http://www.solsystem.io/
  - http://www.headsup.tech/
- The Inria-EVA team maintains the Twitter accounts:
  - EVA (https://twitter.com/InriaEVA), 180 tweets
  - OpenWSN (https://twitter.com/openWSN), 88 tweets

- savethepeaches (https://twitter.com/peachesthesave), 73 tweets
- HeadsUp! (https://twitter.com/heads_up_tech), 28 tweets
- REALMS team (https://twitter.com/realms_team), 28 tweets
- SOLsystem (https://twitter.com/S0Lsystem), 16 tweets
- snowhow (https://twitter.com/snowhow_io), 14 tweets

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[2] G. FAYOLLE, P. MUHLETHALER. *A Markovian Analysis of IEEE 802.11 Broadcast Transmission Networks with Buffering*, in "Probability in the Engineering and Informational Sciences", June 2016, vol. 30, n^{o} 3, 19 p. [*DOI :* 10.1017/S0269964816000036], https://hal.inria.fr/hal-01166082

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Invited Conferences

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