Activity Report 2015

Team EVA

Wireless Networking for Evolving & Adaptive Applications

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Paris - Rocquencourt

THEME
Networks and Telecommunications

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Team EVA

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

Keywords:

Computer Science and Digital Science:

1. - Architectures, systems and networks
1.2.1. - Dynamic reconfiguration
1.2.3. - Routing
1.2.4. - QoS, performance evaluation
1.2.5. - Internet of things
1.2.6. - Sensor networks
1.2.8. - Network security
3.4. - Machine learning and statistics

Other Research Topics and Application Domains:

6.3.2. - Network protocols
6.3.3. - Network services
6.4. - Internet of things
7.2.1. - Smart vehicles
7.2.2. - Smart road
8.1.2. - Sensor networks for smart buildings

1. Members

Research Scientists

Paul Muhlethaler [Inria, Team leader, HdR]
Pascale Minet [Inria, Researcher, HdR]
Thomas Watteyne [Inria, Starting Researcher Position]

Engineers

Tengfei Chang [Inria, started November 2015]
Ines Khoufi [Inria]
Erwan Livolant [Inria]

PhD Students

Jonathan Muñoz [CIFRE with GridBee, started November 2015]
Nesrine Ben Hassine [Inria]
Younes Bouchaala [Vedecom]
Mohamed Elhadad [Cotutelle France/Tunisia]
Fatma Marzouk [Cotutelle France/Tunisia]

Post-Doctoral Fellow

Malisa Vucinic [2/3-time, paid by KU Leuven, started November 2015]

Visiting Scientists

Carlos Oroza [PhD student, UC Berkeley, USA, 19-30 October 2015]
Diego Dujovne [Professor, Universidad Diego Portales, Chile, 28-31 July 2015]
Sami Malek [PhD student, UC Berkeley, USA, 26 May - 12 June 2015]

Administrative Assistant

Christine Anocq [Inria]

Others

Nadia Boufares [PhD in Tunisia visit in October 2015]
Rolland Tewouda Tchabgou [Inria, Internship from Mar 2015 until Aug 2015]
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Selma Boumerdassi [CNAM, Associate Professor]
Samia Bouzefrane [CNAM, Associate Professor]
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Dana Marinca [Univ. Versailles, Associate Professor]

2. Overall Objectives

2.1. Overall Objectives

It is forecast that the vast majority of Internet connections will be wireless. The EVA project will grasp this opportunity and focus on wireless communication. EVA will tackle 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 will be made to ensure that the results provided by EVA will have the greatest possible impact on 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 will be central to the work in EVA, as EVA will focus on such crucial issues as power conservation, connectivity, determinism1, reliability and latency. Wireless sensor network (WSN) deployments will also be a new key subject, especially for emergency situations (e.g. after a disaster). Industrial process automation and environmental monitoring will be considered in greater depth.

3. Research Program

3.1. Generalities

EVA will inherit its expertise in designing algorithms and protocols from HiPERCOM2 (e.g. OLSR). EVA will also inherit know-how in modeling, simulation, experimentation and standardization. Armed with this know-how and experience, we feel confident that the results we expect to obtain will be 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. Both centralized and 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.
- Centralized Scheduling in TSCH networks. Centralized scheduling may allow efficient collision-free schedules to be calculated, but may not scale, or be applicable to quickly changing topologies. The objective of our research is to determine how large the network can be, and how fast its topology can change. This study will be conducted using the model defined in the first point, and will take into account the related communication overhead (amount of data and latency).

- 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 generally 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.

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.

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

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

1. **Thomas Watteyne** and Brett Warneke (Linear Technology) received the IPSO CHALLENGE 2015 People's Choice Award with the project "HeadsUp! : Monitoring the Post-surgery Position of Retinal Detachment Patients". 3 December 2015.
2. Danny Hughes, Nelson Matthys, Fan Yang, Wilfried Daniels (KU Leuven, Belgium) and **Thomas Watteyne** received Third Place in the IPSO CHALLENGE 2015, with the project "MicroPnP: Harnessing the Power of IPv6 for Ultra Low Power, Zero-configuration IoT Networks". 2 December 2015.
3. **Thomas Watteyne** elevated to IEEE Senior Member. August 2015.

Meeting & Seminars

TUTORIALS AND KEYNOTES

1. **Keynote** address by **Thomas Watteyne**.
   Nuts and Bolts for Industrial IoT Middleware. ACM/IFIP/USENIX Middleware conference (Middleware), 7-11 December 2015, Vancouver, Canada.
2. **Tutorial** organized by Inria-EVA.
   OpenWSN & OpenMote: Hands-on Tutorial on Open Source Industrial IoT. Thomas Watteyne, Xavier Vilajosana, Pere Tuset. IEEE Global Telecommunications Conference (GLOBECOM), San Diego, CA, USA, 6-10 December 2015.
3. **Tutorial** organized by Inria-EVA.
   OpenWSN Tutorial [presented by Xavi Vilajosana] Workshop Internet Of Things / Equipex FIT IoT-LAB, Lille, France, 15 October 2015.
4. "Demi-heure de la science" presentation by **Thomas Watteyne**.
   Wireless In the Woods: Monitoring the Snow Melt Process in the Sierra Nevada. 3 September 2015, Rocquencourt, France.
5. **Keynote** address by **Thomas Watteyne**.
   The Rise of the Industrial IoT. International Conference on Ad Hoc Networks (AdHocNets), 31 August - 2 September 2015 San Remo, Italy.
6. **Invited Professor Leila Saidane**, from ENSI, Tunisia. She stayed in the EVA team from 18 November to 18 December 2015 to prepare common publications and identify further research directions.

STANDARDIZATION

1. **Standardization** meeting co-chaired by Inria-EVA
   6TiSCH working group meeting at IETF 94, 1-6 November 2015, Yokohama, Japan.
2. **Standardization** meeting co-chaired by Inria-EVA
   6TiSCH working group meeting at IETF 93, 19-24 July 2015, Prague, Czech Republic.
3. **Hackathon** organized by Inria-EVA.
   OpenWSN/6TiSCH Hackathon, Czech Republic, 19 July 2015.
4. **Interop event** organized by ETSI and Inria-EVA
   First ETSI 6TiSCH plugtest (interop event) in Prague, Czech Republic, 17-18 July 2015.
5. **Standardization** meeting co-chaired by Inria-EVA
   6TiSCH working group meeting at IETF 92, 22-27 March 2015, Dallas, TX, USA.

ORGANIZATION OF WORKSHOPS AND CONFERENCES

1. **PEMWN 2015** international conference on Performance Evaluation and modeling in Wired and wireless Networks, cochaired by Leila Saidane, **Pascale Minet** and Farouk Kamoun, held in Hammamet, Tunisia, November 2015.
2. **Workshop** organized by Inria-EVA.
   Inria-DGA day on "Software Defined Network (SDN) & MANET" in Paris, October 2015.

INVITED PROFESSORS AND CELEBRATIONS

1. **Pascale Minet** and **Paul Muhlethaler** were invited to celebrate the 30 years of ENSI, Tunisia in November 2015.
2. **Leila Saidane**, professor at ENSI, Tunisia, stayed within the EVA team one month to initiate new common research directions.

6. New Software and Platforms

6.1. OpenWSN (Software)

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

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 2015:

- Development:
  - Moving the project from UC Berkeley to Inria (**Thomas Watteyne**)
  - Implementation of a layer-2 security based on AES-128 and CCM* (Malisa Vucinic)
  - Implementation of draft-ietf-6tisch-minimal (Tengfei Chang)
  - Implementation of draft-dujovne-6tisch-6top-sf0 (Tengfei Chang)
  - Implementation of draft-wang-6tisch-6top-sublayer (Tengfei Chang)
  - Creation of "Golden Image" used as a reference during interoperability testing (Tengfei Chang)
- Recognition:
  - OpenWSN was selected by ETSI as the 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**
    OpenWSN & OpenMote: Hands-on Tutorial on Open Source Industrial IoT. Thomas Watteyne, Xavier Vilajosana, Pere Tuset. IEEE Global Telecommunications Conference (GLOBECOM), San Diego, CA, USA, 6-10 December 2015.
  - **Tutorial**
    OpenWSN Tutorial [presented by Xavi Vilsajosana] Workshop Internet Of Things / Equipex FIT IoT-LAB, Lille, France, 15 October 2015.
  - **Hackathon**

OpenWSN/6TiSCH Hackathon, Czech Republic, 19 July 2015.

- **Interop event**
  First ETSI 6TiSCH plugtest (interop event) in Prague, Czech Republic, 17-18 July 2015.

6.2. OPERA and OCARI (Software)

Participants: Erwan Livolant, Pascale Minet.

The OPERA software was developed by the Hipercom2 team in the OCARI project (see https://ocari.org/). 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 2015, Erwan Livolant maintained the code and corrected some bugs.

6.3. CONNEXION (Software)

Participants: Ines Khoufi, Pascale Minet, Erwan Livolant.

These developments are part of the CONNEXION project. In 2015, Ines khoufi developped two softwares:

- a distributed algorithm, called OA-DVFA, to deploy autonomous and mobile sensor nodes to ensure full coverage of a 2-D area with unknown obstacles. It is based on virtual forces and virtual grid.
- an algorithm, called MRDS, to compute the tours of mobile robots in charge of placing static sensor nodes at the positions given (e.g. points of interest). This is a multi-objective optimization problem: to minimize the deployment duration, to balance the durations of robots tours and to minimize the number of robots used. A genetic heuristic is used to solve this problem.

With regard to the wireless sensor network OCARI, in 2015 we designed and developed the mobility support for OCARI. The solution proposed to support mobility in the OCARI network is simple and limits the overhead induced by mobile nodes. This mobility support is designed to be efficient in its use of resources (e.g. bandwidth, energy, memory). The properties of energy efficiency, determinism, latency and robustness provided by OCARI to static wireless sensor nodes are ensured. In the absence of mobile nodes, the OCARI network behaves exactly as without mobility support and exhibits exactly the same performances. Similarly, the overhead induced by mobile sinks is paid only if mobile sinks are present. Data gathering by the static sink, being the most important objective of the OCARI network from the application point of view, its performances are not altered by mobility support. Data gathering by a mobile sink is a new functionality provided by mobility support. This mobility support has been demonstrated with a mobile robot embedding a sensor node and transfering its data to the static sink via router nodes that depend on the position of the robot.

With Telecom ParisTech, the integration of OCARI in a Service-Oriented Architecture using the OPC-UA/ROSA middleware went on. More precisely, we developed the creation of services corresponding to newly available physical sensor measurements and the suppression of services that are no longer available.

Erwan Livolant developed an OCARI frame dissector plugin for Wireshark (https://www.wireshark.org) available from the Git repository at OCARI website (https://www.ocari.org/gitlab/tools/wireshark.git). 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.

6.4. SAHARA (Software)

Participants: Erwan Livolant, Pascale Minet.

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.

6.5. FIT IoT-LAB (Platform)

Participant: Thomas Watteyne.

Note well: IoT-lab is NOT strictly speaking 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 highlight Inria-EVA activity and contribution to the IoT-lab testbed in 2015.

- The Paris-Rocquencourt deployment has been stable throughout 2015.
- Thomas Watteyne and the OpenWSN community have been using the platform (all sites, not just Rocquencourt) extensively throughout 2015. Highlights include:
  - Nicola Accettura (then postdoc at UC Berkeley) created scripts to automate running OpenWSN on the IoT-lab, under the co-supervision of Thomas Watteyne and Prof. Kris Pister. Source code is available at https://github.com/openwsn-berkeley/openwsn-on-iotlab.
  - This work was presented during the OpenWSN hackathon held in conjunction with the IETF93 standardization meeting in Prague in July 2015.
  - Prof. Diego Dujovne from Universidad Diego Portales (Chile) visited Thomas Watteyne in July 2015 to work on the Mercator project (https://github.com/openwsn-berkeley/mercator) to collect Dense Wireless Connectivity Datasets for the IoT on the IoT-lab.
- The Inria-EVA team supported the IoT-lab admin team to remove malfunctioning batteries from the Inria-Rocquencourt deployment in December 2015.
- Thomas Watteyne integrated the IoT-lab admin team in December 2015. Together, they are working on a smaller test deployment with the Inria-EVA premises at Inria-Paris, on which development will be done to:
  - Allow commercial hardware to be plugged into the IoT-lab gateways.
  - Allow multiple motes to be plugged into the same IoT-lab gateway.
  - Use the IoT-lab for deploying and verifying the correct functioning of the OpenWSN implementation on all supported hardware board.
  - Use the IoT-lab for deploying and verifying the correct functioning of the OpenWSN implementation at small/medium/large scale.
- The activities above are lead by Tengfei Chang from the Inria-EVA team, under the supervision of Thomas Watteyne, and in close collaboration with the IoT-lab core team.

7. New Results

7.1. Wireless Sensor Networks

7.1.1. Time slot and channel assignment in multichannel Wireless Sensor Networks

Participants: Pascale Minet, Ridha Soua, Erwan Livolant.

Wireless sensor networks (WSNs) play a major role in industrial environments for data gathering (convergecast). Among the industrial requirements, we can name a few like 1) determinism and bounded convergecast latencies, 2) throughput and 3) robustness against interferences. The classical IEEE 802.15.4 that has been designed for low power lossy networks (LLNs) partially meets these requirements. That is why the IEEE 802.15.4e MAC amendment has been proposed recently. This amendment combines a slotted medium access with a channel hopping (i.e. Time Slotted Channel Hopping TSCH). The MAC layer orchestrates the medium accesses of nodes according to a given schedule. Nevertheless, this amendment does not specify how this schedule is computed. We propose a distributed joint time slot and channel assignment, called $Wave$ for data gathering in LLNs. This schedule targets minimized data convergecast delays by reducing the number of slots assigned to nodes. Moreover, $Wave$ ensures the absence of conflicting transmissions in the schedule provided. In such a schedule, a node is awake only during its slots and the slots of its children in the convergecast routing graph. Thus, energy efficiency is ensured. We describe in details the functioning of $Wave$, highlighting its features (e.g. support of heterogeneous traffic, support of a sink equipped with multiple interfaces) and properties in terms of worst case delays and buffer size. We discuss its features with regard to a centralized scheduling algorithm like $TMCP$ and a distributed one like $DeTAS$. Simulation results show the good performance of $Wave$ compared to $TMCP$. Since in an industrial environment, several routing graphs can coexist, we study how $Wave$ supports this coexistence.

7.1.2. 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.

7.1.3. Distributed and Optimized Deployment of WSNs

Participants: Ines Khoufi, Pascale Minet.

This is a joint work with Telecom SudParis: Anis Laouiti.
We are witnessing the deployment of many wireless sensor networks in various application domains such as pollution detection in the environment, intruder detection at home, preventive maintenance in industrial process, monitoring of temporary industrial worksites, damage assessment after a disaster.... Wireless sensor networks are deployed to monitor physical phenomena. The accuracy of the information collected depends on the position of sensor nodes. These positions must meet the application requirements in terms of coverage and connectivity, which therefore requires the use of deployment algorithms. We distinguish two cases: firstly when the nodes are autonomous, and secondly when they are static and the deployment is assisted by mobile robots. In both cases, this deployment must not only meet the application's coverage and connectivity requirements, but must also minimize the number of sensors needed while satisfying various constraints (e.g. obstacles, energy, fault-tolerant connectivity). We distinguished two cases: autonomous and mobile wireless sensor nodes on the one hand, and static wireless sensor nodes on the other hand.

We propose a distributed and optimized deployment of mobile and autonomous sensor nodes to ensure full coverage of the 2D-area considered, as well as network connectivity. With the full coverage of the area, any event occurring in this area is detected by at least one sensor node. In addition, the connectivity ensures that this event is reported to the sink in charge of analyzing the data gathered from the sensors and acting according to these data. This distributed algorithm, called OA-DVFA, can run in an unknown area with obstacles dicovered dynamically. We distinguish two types of obstacles: the transparent ones like ponds in outdoor environment, or tables in an indoor site that only prevent the location of sensor nodes inside them; whereas the opaque obstacles like walls or trees prevent the sensing by causing the existence of hidden zones behind them: such zones may remain uncovered. Opaque obstacles are much more complex to handle than transparent ones and

require the deployment of additional sensors to eliminate coverage holes. OA-DVFA is based on virtual forces to obtain a fast spreading of sensor nodes and uses a virtual grid to stop node oscillations and save energy by making sleep redundant nodes. It automatically detects when the maximum area coverage is reached.
We also considered 3D volumes and proposed an algorithm, called 3D-DVFA, also based on virtual forces, to ensure full coverage of 3D volumes and ensure network connectivity. This is a joint work with Nadya Boufares from ENSI, Tunisia. Since applications of such 3D deployments may be limited, we focus on 3D surface covering, where the objective is to deploy wireless sensor nodes on a 3D-surface (e.g. a mountain) to ensure full area coverage and network connectivity. To reach this goal we propose 3D-DVFA-SC, a distributed deployment algorithm based on virtual forces strategy to move sensor nodes.

7.1.4. WSN deployment assisted by mobile robots

Participants: Ines Khoufi, Pascale Minet.

This is a joint work with Telecom SudParis: Anis Laouiti.
Autonomous deployment may be expensive when the number of mobile sensor nodes is very high. In this case, an assisted deployment may be necessary: the nodes' positions being pre-computed and given to mobile robots that place a static sensor at each position. In order to reduce both the energy consumed by the robots, their exposure time to a hostile environment, as well as the time at which the wireless network becomes operational, the optimal tour of robots is this minimizing the delay. This delay must take into account not only the time needed by the robot to travel the tour distance but also the time spent in the rotations performed by the robot each time it changes its direction. This problem is called the Multiple Robot Deploying Sensor nodes problem, in short MRDS. We first show how this problem differs from the well-known traveling salesman problem. We adopt two approaches to optimize the deployment duration. The first one is based on game theory to optimize the length of the tours of two robots (TRDS), and the second is based on a multi-objective optimization, for multiple robots (MRDS). The objectives to be met are: optimizing the duration of the longest tour, balancing the durations of the robot tours and minimizing the number of robots used, while bypassing obstacles.

The TRDS problem is modeled as a non-cooperative game with two players representing the mobile robots, these robots compete for the selection of the sensor nodes to deploy. Each robots tends to maximize its utility function.

We then propose an integer linear program formulation of the MRDS problem. We propose various algorithms relevant to iterative improvement by exchanging tour edges, genetic approach and hybridization. The solutions provided by these algorithms are compared and their closeness to the optimal is evaluated in various configurations.

7.1.5. Sinks Deployment and Packet Scheduling for Wireless Sensor Networks

Participants: Nadjib Achir, Paul Muhlethaler.

The objective of this work is to propose an optimal deployment and distributed packet scheduling of multi-sink Wireless Sensors networks (WNSs). We start by computing the optimal deployment of sinks for a given maximum number of hops between nodes and sinks. We also propose an optimal distributed packet scheduling in order to estimate the minimum energy consumption. We consider the energy consumed due to reporting, forwarding and overhearing. In contrast to reporting and forwarding, the energy used in overhearing is difficult to estimate because it is dependent on the packet scheduling. In this case, we determine the lower-bound of overhearing, based on an optimal distributed packet scheduling formulation. We also propose another estimation of the lower-bound in order to simulate non interfering parallel transmissions which is more tractable in large networks. We note that overhearing largely predominates in energy consumption. A large part of the optimizations and computations carried out in this work are obtained using ILP (Integer Linear Programming) formalization.

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.

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. Cognitive Radio Networks

7.2.1. Multichannel time slot assignment in Cognitive Radio Sensor Networks

Participants: Ons Mabrouk, Pascale Minet.

This is a joint work with Hanen Idoudi and Leila Saidane from ENSI, Tunisia.
The unlicensed spectrum bands become overcrowded causing an increased level of interference for current wireless sensor nodes. Cognitive Radio Sensor Networks (CRSNs) overcome this problem by allowing sensor nodes to access opportunistically the underutilized licensed spectrum bands. The sink assigns the spectrum holes to the secondary users (SUs). Therefore, it must rely on reliable information about the spectrum holes to protect the primary users (PUs). We focused on the MultiChannel Time Slot Assignment problem in CRSN and tackled this problem: first at the level of a cluster (i.e. Intra-cluster multichannel scheduling), second at the level of several clusters coexisting in the same CRSN (i.e. inter-cluster multichannel scheduling).

In 2013, we proposed an Opportunistic centralized TIme slot assignment in COgnitive Radio sensor networks (OTICOR) for the Intra-cluster multichannel scheduling. OTICOR differs from the existing schemes in its ability to allow non-interfering cognitive sensors to access the same channel and time slot pair. OTICOR takes advantages of spatial reuse, multichannel communication and multiple radio interfaces of the sink. We proved through simulations that a smaller schedule length improves the throughput. Applying OTICOR, we showed that, even in the presence of several PUs, the average throughput granted to SUs remains important. We also showed how to get the best performances of OTICOR when the channel occupancy by PUs is known.

In 2014, we extended this Intra-cluster multichannel scheduling algorithm by proposing two ways for the sink to determine the available channels and alert the SUs if an unexpected activity of PU occurs. Our objective is to design an algorithm able to detect the unexpected presence of PUs in the multi-hop network while maximizing the throughput. If the estimation of PU presence is accurate, a channel sensing at the beginning of the slotframe is sufficient. This algorithm, called Frame-ICMS (Frame Intra-Cluster Multichannel Scheduling), takes advantage of the slots dedicated to the control period by allowing noninterfering cognitive sensors to access the control/data channel and time slot pair. We showed through simulations that using the control period also for data transmission minimizes the schedule length and maximizes the throughput. However, if the estimation of PU presence is not accurate, channel sensing should be done before each slot. We proposed the Slot-ICMS algorithm.

In 2015, we focused on inter-cluster multichannel scheduling algorithm. We considered the coexistence of different clusters in a same CSRN, each cluster having an intra-cluster multichannel scheduling algorithm. Our goal is to obtain a better scalability without loosing the properties provided by OTICOR:

- collision-free schedule,
- minimized data gathering delays,
- sleeping periods per node to save node's energy.

However, the co-existence of several clusters in the same environment may lead to conflicts in the allocation of time slots and channels between these clusters. To avoid inter-cluster collisions, we donot require that different clusters use different channels, we assign distinct channels only to nodes having one-hop neighbors out of their cluster. Once the problem of inter-cluster collision is avoided, each cluster head schedules the transmissions of its members independently. This whole solution exhibits good performances as shown by the simulation results.

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

7.3.1. Learning in networks

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

This work is a joint work with Dominique Barth (University of Versailles-Saint-Quentin). To guarantee an efficient and dynamic management of network resources and services we intend to use a powerful mathematical tool: prediction and learning from prediction. Prediction will be concerned with guessing the evolution of network or network components state, based on knowledge about the past elements and/or other available information. Basically, the prediction problem could be formulated as follows: a forecaster observes the values of one or several metrics giving indications about the network state (generally speaking the network represents the environment). At each time t, before the environment reveals the new metric values, the forecaster predicts the new values based on previous observations. Contrary to classical methods where the environment evolution is characterized by stochastic process, we suppose that the environment evolution follows an unspecified mechanism, which could be deterministic, stochastic, or even adaptive to a given behavior. The prediction process should adapt to unpredictable network state changes due to its non-stationary nature. To properly address the adaptivity challenge, a special type of forecasters is used: the experts. These experts analyse the previous environment values, apply their own computation and make their own prediction. The experts predictions are given to the forecaster before the next environment values are revealed. The forecaster can then make its own prediction depending on the experts' "advice". The risk of a prediction may be defined as the value of a loss function measuring the discrepancy between the predicted value and the real environment value. The principal notion to optimize the behavior of the forecasters is the regret, seen as a difference between the forecaster's accumulated loss and that of each expert. To optimize the prediction process means to construct a forecasting strategy that guarantees a small loss with respect to defined experts. Adaptability of the forecaster is reflected in the manner in which it is able to follow the better expert according to the context.

Our purpose is to apply on-line learning strategies to:

- Wireless Sensor Networks (WSNs) to predict the quality of a wireless link in a WSN, based on the LQI metric for instance and take advantage of wireless links with the best possible quality to improve the packet delivery rate. We model this problem as a forecaster prediction game based on the advice of several experts. The forecaster learns on-line how to adjust its prediction to better fit the environment metric values. A forecaster estimates the LQI value using the advice of experts.
- Content Delivery Networks (CDNs) to predict the number of solicitations of video contents to cache the contents with the highest popularity.
- Data centers require a huge amount of energy. As an example, in 2014, the electric consumption of all date centers will be larger than 42 TWh, and after 2020 the CO2 production will be larger then 1.27 GTons, ie. more than the aeronautic industry (GeSI SMARTer 2020 report). These "frightening" figures led the research community to work on the management of energy consumption. Several tracks have been explored, among which the optimization of computation and load balancing of servers. At present, we work on tools dedicated to traffic prediction, thus allowing a better management of servers. Our work consists in modeling the traffic specific to data centers and apply different statistical prediction methods.

7.3.2. Tools for learning and prediction

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

In 2015, Nesrine Ben Hassine developped an extraction tool to provide real traces from YouTube. these real traces are used as a learning sample by the different prediction algorithms used.

Nesrine Ben Hassine and Dana Marinca extended their simulation tool developed in Python to integrate:

- various prediction strategies SES (Single Explonential Smoothing), DES (Double Exponential Smoothing), Basic and enhanced basic, strategies based on averages (e.g. Average on a Moving Window), regressions (e.g. polynomial or Savitzky Golay), as well as prediction strategies adapting dynamically their parameters according to the loss obtained.
- various loss functions (e.g. absolute value, square). The prediction accuracy is evaluated by a loss function as the discrepancy between the prediction value and the real number obtained.
- different forecaster strategies: Best expert, Exponential Weighted Average, K Best-Experts, etc.

With these tools, we can now tune parameters of prediction strategies and evaluate them.

7.3.3. Popularity prediction in CDNs

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

To predict the popularity of video contents, expressed as the number of solicitations, we compared three prediction strategies: Single Exponential Smooting (SES), Double Exponential Smoothing (DES) and Basic. The best tuning of each strategy is determined, depending on the considered phase of the solicitation curve. For DES, values of the smoothing factor close to 1 probide the best results. We study the behavior of each strategy within a phase and around a phase change, where a phase is defined as an interval of time during which a measured metric remains relatively stable.

Basic expert makes large errors at the phase change, but it quickly corrects its prediction and it is the expert having the closest prediction to the real value within a phase. DES expert provides also good quality predictions within a phase. Since DES and Basic experts outperform the SES expert, we recommend the use of on the one hand, the best DES expert per phase within a phase and on the other hand, the Basic expert to automatically detect phase changes, because of its better reactivity. This self-learning and prediction method can be applied to optimize resources allocation in service oriented architectures and self-adaptive networks, more precisely for cache management in CDNs.

7.3.4. Automatic phase detection in popularity evolution of video contents

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

In Content Delivery Networks (CDNs) where experts predict the number of solicitations of video contents, simulations based on real YouTube traces show that the accuracy of prediction is improved by splitting the video content profile in contiguous phases. A phase is an interval of time during which a measured metric remains relatively stable. The best expert per phase outperforms the best expert on the whole video content profile. Different prediction methods are compared and also different phase change-points detection methods are evaluated:

- the R tool using Bayesian inference,
- the Basic expert (an important loss may indicate a phase change),
- a fixed time interval (e.g. each week).

The goal is to identify the method (or method parameters) minimizing the cumulated discrepancy compared to real solicitations of video contents. The use of this machine learning method allows the Content Delivery Network to self-adapt to users solicitations by caching the most popular contents near the end users. More generally, such method can be applied to decide which contents should be replicated to improve the performance of audio and video applications and maximize the satisfaction degree of users.

7.4. VANETs

7.4.1. Protocols for VANETs

Participants: Nadjib Achir, Younes Bouchaala, Mohamed Elhadad Or Hadded, Paul Muhlethaler, Oyunchimeg Shagdar.

7.4.1.1. Synthetic study of TDMA protocols for VANETs

Recently several Time Division Multiple Access (TDMA)-based medium access control protocols have been proposed for VANETs in an attempt to ensure that all the vehicles have enough time to send safety messages without collisions and to reduce the end-to-end delay and the packet loss ratio. In this paper, we identify the reasons for using the collision-free medium access control paradigm in VANETs. We then present a novel topology-based classification and we provide an overview of TDMA-based MAC protocols that have been proposed for VANETs. We focus on the characteristics of these protocols, as well as on their benefits and limitations. Finally, we give a qualitative comparison, and we discuss some open issues that need to be tackled in future studies in order to improve the performance of TDMA-based MAC protocols for vehicle to vehicle (V2V) communications.

7.4.1.2. A stable clustering protocol for VANETs

VANETs have a highly dynamic and portioned network topology due to the constant and rapid movement of vehicles. Currently, clustering algorithms are widely used as the control schemes to make VANET topology less dynamic for Medium Access Control (MAC), routing and security protocols. An efficient clustering algorithm must take into account all the necessary information related to node mobility. In this paper, we propose an Adaptive Weighted Clustering Protocol (AWCP), specially designed for vehicular networks, which takes the highway ID, direction of vehicles, position, speed and the number of neighboring vehicles into account in order to enhance the stability of the network topology. However, the multiple control parameters of our AWCP, make parameter tuning a nontrivial problem. In order to optimize the protocol, we define a multi-objective problem whose inputs are the AWCP's parameters and whose objectives are: providing stable cluster structures, maximizing data delivery rate, and reducing the clustering overhead. We address this multi-objective problem with the Nondominated Sorted Genetic Algorithm version 2 (NSGA-II). We evaluate and compare its performance with other multi-objective optimization techniques: Multi-objective Particle Swarm Optimization (MOPSO) and Multi-objective Differential Evolution (MODE). The experiments reveal that NSGA-II improves the results of MOPSO and MODE in terms of spacing, spread, ratio of non-dominated solutions, and inverse generational distance, which are the performance metrics used for comparison.

7.4.1.3. Using Road IDs to Enhance Clustering in Vehicular Ad hoc Networks

Vehicular ad hoc networks (VANETs) where vehicles act as mobile nodes is an instance of Mobile Ad hoc NETworks (MANETs), which are essentially developed for intelligent transportation systems. A challenging problem when designing communication protocols in VANETs is coping with high vehicle mobility, which causes frequent changes in the network topology and leads to frequent breaks in communication. The clustering technique is being developed to reduce the impact of mobility between neighboring vehicles. In this paper, we propose an Adaptive Weighted Cluster Protocol for VANETs, which is a road map dependent and uses road IDs and movement direction in order to make the clusters structure as stable as possible. The experimental results reveal that AWCP outperforms four other most commonly used clustering protocols in terms of control packet overhead, the packet delivery ratio, and the average cluster lifetime, which are the most usual metrics used for comparing performance.

7.4.2. Models for VANETs

Participants: Nadjib Achir, Younes Bouchaala, Guy Fayolle, Paul Muhlethaler, Oyunchimeg Shagdar.

7.4.2.1. Model of IEEE 802.11 broadcast scheme with infinite queue

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 stabillity (ergodicity) conditions are obtained and interpreted in terms of maximum throughput. Several approximations related to these models are also discussed.

7.4.2.2. Model and optimization of CSMA

We have studied the maximum throughput of CSMA in scenarios with spatial reuse. The nodes of our network will be a Poisson Point Process (PPP) of a one or two dimensional space. The one dimensional well fits 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 all these assumptions, we analytically study the density of throughput of successful transmission and we show that it can be optimized with the carrier-sense threshold.

7.4.2.3. Performance analysis of IEEE 802.11 broadcast schemes

We have analyzed different broadcast strategies in IEEE 802.11p Vehicular Ad-hoc NETworks (VANETs). The first strategy is the default IEEE 802.11p strategy. Using a model derived from the Bianchi model, we provide the network performance in terms of throughput and success rate. The second strategy is to use an acknowledgment technique similar to the acknowledgment with point-to-point traffic. A node will send its broadcast packet as in the default case,but it requires an acknowledgment from a neighbor node. This node may be a random neighbor or may be selected according to precise rules. We analyze this second strategy in terms of throughput and success rate. Somewhat surprisingly, we show that this second strategy improves the delivery ratio of the transmitted packets but reduces the overall throughput. This means that if the CAM messages (Cooperative Awareness Messages) are broadcasted, the total number of packets actually delivered will be greater with the default strategy than with the improved strategy. We propose a third strategy which consists in using the default strategy for normal packets, but we add random redundant transmissions to ensure greater reliability for very important packets. We show that with this simple technique, not only do we obtain suitable reliability, but we also achieve larger global throughput than with the acknowledgment-oriented technique. We have also computed network performance in terms of throughput and success rate with respect to the network parameters and to analyze their impact on performances.

7.5. Models for wireless networks

7.5.1. Interference and SINR coverage in spatial non-slotted Aloha networks

Participants: Bartek Blaszczyszyn, Paul Muhlethaler.

We propose two analytically tractable stochastic-geometric models of interference in adhoc networks using pure (non-slotted) Aloha as the medium access. In contrast the slotted model, the interference in pure Aloha may vary during the transmission of a tagged packet. We develop closed form expressions for the Laplace transform of the empirical average of the interference experienced during the transmission of a typical packet. Both models assume a power-law path-loss function with arbitrarily distributed fading and feature configurations of transmitters randomly located in the Euclidean plane according to a Poisson point process. Depending on the model, these configurations vary over time or are static. We apply our analysis of the interference to study the Signal-to- Interference-and-Noise Ratio (SINR) outage probability for a typical transmission in pure Aloha. The results are used to compare the performance of non-slotted Aloha to the slotted one, which has almost exclusively been previously studied in context of wired ad-hoc networks.

7.5.2. Random linear multihop relaying in a general field of interferers using spatial Aloha

Participants: Bartek Blaszczyszyn, Paul Muhlethaler.

We study a stationary Poisson pattern of nodes on a line embedded in an independent planar Poisson field of interfering nodes. Assuming slotted Aloha and the signal-to-interference-and-noise ratio capture condition, with the usual power-law path loss model and Rayleigh fading, we explicitly evaluate several local and end-to-end performance characteristics related to the nearest-neighbor packet relaying on this line, and study their dependence on the model parameters (the density of relaying and interfering nodes, Aloha tuning and the external noise power). Our model can be applied in two cases: the first use is for vehicular ad-hoc networks, where vehicles are randomly located on a straight road. The second use is to study a “typical” route traced in a (general) planar ad-hoc network by some routing mechanism. The approach we have chosen allows us to quantify the non-efficiency of long-distance routing in “pure ad-hoc” networks and evaluate a possible remedy for it in the form of additional “fixed” relaying nodes, called road-side units in a vehicular network. It also allows us to consider a more general field of interfering nodes and study the impact of the clustering of its nodes on the routing performance. As a special case of a field with more clustering than the Poison field, we consider a Poisson-line field of interfering nodes, in which all the nodes are randomly located on random straight lines. In this case our analysis rigorously (in the sense of Palm theory) corresponds to the typical route of this network. The comparison to our basic model reveals a paradox: clustering of interfering nodes decreases the outage probability of a single (typical) transmission on the route, but increases the mean end-to-end delay

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.

8.2. Bilateral Grants with Industry

8.2.1. Gridbee CIFRE

Participants: Thomas Watteyne, Jonathan Muñoz.

- 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.

8.2.2. SAGEM

Participants: Paul Muhlethaler, Gerard Le Lann.

This work aims at improving the reliability of some SAGEM communications systems. A few "altruist" algorithms using the inherent broadcast capabilities of wireless transmission have been analyzed.

9. Partnerships and Cooperations

9.1. National Initiatives

9.1.1. Competitivity Clusters

9.1.1.1. SAHARA

Participants: Pascale Minet, Erwan Livolant.

Period: 2011 - 2015.

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

SAHARA is a FUI project, labelled 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.

During year 2015, we provided support to the SMEs in the SAHARA project for the implementation of network algorithms and protocols.

9.1.1.2. 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 May and June 2015, we contributed with our Connexion partners to a demonstration showing that OCARI:

- supports wireless sensors of various types (e.g. temperature sensor PT100, smoke detector produced by CEA, fire alarm produced by ADWAVE, various types of flowmeters by Krohne);
- supports mobile nodes and collects their data using router nodes depending on the location of the node embedded in a mobile robot.

All the chain ranging from the physical sensors, the OCARI wireless network, the OPC/UA bus to the KASEM software was integrated to build a Service-Oriented Architecture where new services are created when new sensor nodes are deployed. Services corresponding to sensor nodes that are no longer available, are suppressed. After a service discovery, clients can select the types of measurements made by the sensor nodes they want to visualize.

In June 2015, the CONNEXION project organized an open workshop where EXERA (group of users of instrumentation and systems) was invited. **Pascale Minet** and Erwan Livolant contributed to a demonstration illustrating the integration of the OCARI wireless sensor network, the OPC-UA/ROSA middleware and the KASEM predictive maintenance system in an industrial application. A video presenting this integration was made with the participation of EDF, Inria, Telecom ParisTech, KASEM and CEA.

We also focused on deployment algorithms for mobile wireless sensor networks in temporary worksites or after a disaster. These deployments must meet coverage and connectivity requirements. In 2015 we studied solutions to ensure full coverage of the area to monitor as well as network connectivity. We proposed the OA-DVFA distributed algorithm to deploy autonomous and mobile wireless sensor nodes in a 2D area in the presence of unknown obstacles that are progressively discovered. This distributed algorithm combines the advantages of virtual forces for a fast spreading of sensor nodes and those of a virtual grid avoiding node oscillations and allowing a simple detection of redundant nodes. We also tackled the problem of deploying static sensor nodes, assisted by mobile robots that place the sensor nodes at the positions computed. The solution proposed, called MRDS, solves a multi-objective optimization problem by using a genetic algorithm.

We also studied network connectivity, more particularly how to ensure a reliable connectivity of the sink with each sensor node located at some point of interest (PoI). Our goal was to find the best trade-off between the number of relay nodes deployed and the length of the paths connecting each PoI to the sink.

9.1.2. 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. FP7 & 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 TROPIC (Distributed computing, storage and radio resource allocation over cooperative femtocells) project.

9.2.2. Collaborations with Major European Organizations

European Telecommunications Standards Institute (ETSI)

Co-organization First ETSI 6TiSCH plugtest (interop event) in Prague, Czech Republic, 17-18 July 2015.

9.3. International Initiatives

9.3.1. Inria International Labs

9.3.1.1. REALMS

Type: Associate Team

Inria International Lab: Inria@SiliconValley

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: https://realms-team.github.io/

Inria contact: **Thomas Watteyne**

9.3.2. Inria International Partners

9.3.2.1. Declared Inria International Partners

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

University of California, Berkeley, CA, USA

- 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.

University of Michigan, Ann Arbor, MI, USA

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

KU Leuven, Belgium

- Collaboration with Prof. Danny Hughes, Prof. Wouter Joosen, Dr. Nelson Matthys, Fan Yang, Wilfried Daniels on MicroPnP and on security for the IoT.
- Dr. Malisa Vucinic, postdoctoral researcher at KU Leuven, works part time in the Inria-EVA team.
- We won Third Place in the IPSO CHALLENGE 2015 for common project MicroPnP, see Section 5.1.
- Joint publication(s) in 2015: [35].

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.
- We won the IPSO CHALLENGE 2015 People's Choice Award for common project HeadsUp!, see Section 5.1.
- Joint publication(s) in 2015: [44].

9.3.2.2. Informal International Partners

University of California, Berkeley, CA, USA

- Collaboration with Prof. Kris Pister, Dr. Nicola Accettura, Dr. Kazuki Muraoka and David Burnett on OpenWSN and 6TiSCH standardization.
- Joint publication(s) in 2015: [5], [16], [10].

Universitat Oberta de Catalunya, Barcelona, Spain

- Collaboration with Prof. Xavi Vilajosana and Dr. Pere Tuset on OpenWSN, 6TiSCH standardization and OpenMote technologies.
- We organized two OpenWSN/OpenMote tutorials together, see Section 5.1.
- Joint publication(s) in 2015: [16], [17], [41], [15].

University of Luxembourg, Luxembourg

- Collaboration with Prof. Thomas Engel and Dr. Maria-Rita Palattella on 6TiSCH standardization.
- Joint publication(s) in 2015: [10], [13], [15].

Universidad Diego Portales, Chile

- Collaboration with Prof. Diego Dujovne on OpenWSN and 6TiSCH standardization.
- Joint publication(s) in 2015: [10].

University of Science and Technology, Beijing, China

- Collaboration with Prof. Qin Wang and Tengfei Chang on 6TiSCH standardization and OpenWSN.
- Joint publication(s) in 2015: [5], [10].

University of Southern California, CA, USA

- Collaboration with Prof. Bhaskar Krishnamachari, Pedro Henrique Gomes and Pradipta Gosh on OpenWSN and 6TiSCH-based research.
- Joint publication(s) in 2015: [40].

University of Bari, Italy

- Collaboration with Prof. Alfredo Grieco, Prof. Gennaro Boggia, Dr. Giuseppe Piro and Savio Sciancalepore on security for the IoT.
- Joint publication(s) in 2015: [10].

Swedish Institute of Computer Science (SICS), Sweden

- Collaboration with Prof. Olaf Landsiedel, Dr. Simon Duquennoy and Beshr Al Nahas on distributed scheduling for TSCH networks.
- Joint publication(s) in 2015: [28].

University of Trento, Italy

- Collaboration with Dr. Oana Iova on routing in the IoT.
- Joint publication(s) in 2015: [9].

IMEC, Netherlands

- Collaboration with Dr. Pouria Zand on 6TiSCH standardization.
- Joint publication(s) in 2015: .

9.3.3. Participation In other International Programs

9.3.3.1. 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: TPropose 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.

9.3.3.2. AWSN

Program: Euromediterranean 3+3

Title: Adaptive Wireless Sensor Networks

Inria principal investigator: **Pascale Minet**

International Partners (Institution - Laboratory - Researcher):

University of Catania (Italy) - DIEEI - Lucia Lo Bello

Ecole Nationale Supérieure d'Informatique et d'Analyse des Systèmes (Morocco) - ND-SRG - Mohamed Erradi

Ecole Nationale des Sciences de l'Informatique (Tunisia) - CRISTAL - Leila Azouz Saidane

Duration: Jan 2012 - Dec 2015

Wireless sensor networks (WSNs) allow the development of numerous applications in various domains, such as security and surveillance, environment protection, precision agriculture, intelligent transportation, homecare of elderly and disabled people... Communication in such WSNs has to cope with limited capacity resources, energy depletion of sensor nodes, important fluctuations of traffic in the network, changes in the network topology (radio link breakage, interferences ...) or new application requirements. In the AWSN project, we focus on the different techniques to be introduced in the WSNs to make them auto-adaptive with regard to these various changes, while meeting the application requirements. Thus, we address:

- network deployment and redeployment in order to fulfill the application requirements,
- QoS (Quality of Service) optimization taking into account real-time traffic and dynamic bandwidth allocation,
- energy efficiency and replacement of failed sensor node,
- component generation and dynamic adaptation of the application.

After the mid-term evaluation, the last topic has been replaced by the use of game theory in WSNs, where the Moroccan team is leader.

Three applications have been identified to apply the results obtained within the AWSN project: e-health, precision agriculture and Industrial WSNs with cooperative mobile robot applications. The first three topics previously defined have to be addressed in all these applications. A hierarchical architecture with different types of networks is present: WBAN and/or WSN, wireless or wired LAN, interconnected to the Internet. In addition, mobile nodes exist in these applications (e.g. mobile sinks with nurses and doctors as well tractors and farm machines, mobile robots).

In 2015, the AWSN project organized two workshops open to students and researchers:

- Workshop in Rabat in November 2015.
- Workshop in Rocquencourt in December 2015.

The AWSN project organized also open international workshops and conferences:

- RAWSN 2015: Agadir, May 2015, organized by the Moroccan team, http://www.fsdmfes.ac.ma/rawsn/
- WINCOM 2015: Marrakech, October 2015, organized by the Moroccan team, http://www.wincom-conf.org/
- the PEMWN 2015 conference in Hammamet in November 2015, 4th edition organized by the Tunisian and French teams, see the program on https://sites.google.com/site/pemwn2015/final-program

The outcomes of the AWSN project are multiple:

- Degrees obtained: 2 HDR, 5 PhD and 11 Masters.
- Hiring: 6 Assistant Professors in Tunisia.
- Internships: 5 internships of Tunisian students at Inria.
- Invited Professor: Leila saidane was invited at Inria for a month in 2015.
- Publications: 13 international journals and 49 international conferences

9.4. International Research Visitors

9.4.1. Visits of International Scientists

- **Carlos Oroza**, PhD student, UC Berkeley, USA, 19-30 October 2015
- **Prof. Diego Dujovne**, Professor, Universidad Diego Portales, Chile, 28-31 July 2015
- **Sami Malek**, PhD student, UC Berkeley, USA, 26 May - 12 June 2015
- **Leila Saidane**, ENSI, Tunis, Tunisia, October, November and December 2015
- **Mohammed Erradi**, ENSIAS, Rabat, Morocco, September 2015
- **Abdellatif Kobbane**, ENSIAS, Rabat, Morocco, September 2015

9.4.1.1. Internships

- **Kevin Tewouda**, internship on simulation of wireless networks with NS3, March-August 2015.

9.4.2. Visits to International Teams

9.4.2.1. Research stays abroad

- **Thomas Watteyne**, visits to Prof. Glaser's team at UC Berkeley, as part of the REALMS associate team (Section 9.3.1.1), 10-16 May, 1-17 August, 30 November-4 December 2015.

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 and Farouk Kamoun of PEMWN 2015, organized in Hammamet, Tunisia, November 2015.
- **Thomas Watteyne**
  1. Co-chair, IETF 6TiSCH standardization working group.
  2. Technical Program Committee Chair and Local Chair, EAI Conference on Interoperability in IoT (InterIoT), Paris, France, October 2016.
  3. General Chair, Second ETSI 6TiSCH plugtests, Paris, France, 2-4 February 2016.
  4. Technical Program Committee Chair, EAI Conference on Interoperability in IoT (InterIoT), part of the IOT360 Summit, Rome, Italy, 28-29 October 2015.
  5. Chair, OpenWSN/6TiSCH Hackathon, Czech Republic, 19 July 2015.
  6. Chair, First ETSI 6TiSCH plugtests, Prague, Czech Republic, 17-18 July 2015.
  7. Program co-chair of the 1st International Workshop on IoT challenges in Mobile and Industrial Systems (IoTSys), in conjunction with MobiSys, Florence, Italy, 18 May 2015.
- 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 2015), August 2015.
  2. chair of the International Conference on Mobile, Secure and Programmable Networking (MSPN 2015), June 2015.

10.1.1.2. Organizing Committee Member

- **Paul Muhlethaler**
  1. organized the DGA Inria workshop on Telecommunication and networking "Cloud, cloudlet & MANET" in October 2015.
- **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 2015

10.1.2. Scientific Events Selection

10.1.2.1. Conference Program Committee Member

- **Paul Muhlethaler**

1. Steering Committee Member of MobileHealth 2015, 5th EAI International Conference on Wireless Mobile Communication and Healthcare, October 14–16, 2015, London, Great Britain
2. Technical Committee of the fourth International conference on Performance Evaluation and Modeling in Wireless Networks, PEMWN 2015, November 2015, Hammamet , Tunisia.

- **Pascale Minet**
  1. TPC Member CIT 2015, 15th IEEE International Conference on Computer and Information Technology, May 2015,
  2. TPC Member DCNET 2015, 6th International Conference on Data Communication Networking, July 2015,
  3. TPC Member DMEMS 2015, Workshop on design, control and software implementation for distributed MEMS, September 2015.
  4. TPC Member ICN 2015, 14th International Conference on Networks, April 2015.
  5. TPC Member IUCC 2015, the 14th IEEE International Conference on Ubiquitous Computing and Communications, October 2015.
  6. TPC Member PEMWN 2015, 4th International Conference on Performance Evaluation and Modeling in Wired and Wireless Networks, November 2015.
  7. TPC Member PECCS 2015, 5th international conference on Pervasive and Embedded Computing and Communication Systems, February 2015.
  8. TPC Member RAWSN 2015, 3rd International Workshop on RFID And Adaptive Wireless Sensor Networks, May 2015.
  9. TPC Member RTNS 2015, 23th International Conference on Real-Time and Network Systems, November 2015.
  10. TPC Member WINCOM 2015, 1st International Conference on Wireless Networks and Mobile Communications, October 2015.
- **Thomas Watteyne**
  1. TPC Member IEEE International Conference on Communications (ICC), Selected Areas in Communications (SAC), 2015, 2016.
  2. TPC Member International Conference on Embedded Wireless Systems and Networks (EWSN), 2016.
  3. TPC Member IEEE World Forum on Internet of Things (WF-IoT), 2015.
  4. TPC Member International Workshop on Internet of Things, Machine to Machine and Smart Services Applications (IoT), part of International Conference on Collaboration Technologies and Systems (CTS), 2015.
  5. TPC Member IEEE Wireless Communications and Networking Conference (WCNC), 2015.
  6. TPC Member IEEE International Conference on Embedded Software and Systems (ICESS), 2015.
- Nadjib Achir
  1. TPC Member IEEE Global Telecommunications Conference, GLOBECOM 2015;
  2. TPC Member IEEE International Conference on Communications, ICC 20145;
  3. TPC Member Personal, Indoor and Mobile Radio Communications, PIMRC 2015.
  4. TPC Member IEEE Wireless Communications and Networking Conference, WCNC 2015;
  5. TPC Member IEEE Consumer Communications & Networking Conference, CCNC 2015;

6. TPC Member Global Information Infrastructure and Networking Symposium, GIIS 2015.
7. TPC Member International Conference On Network of the Future, NoF 2015.

- Selma Boumerdassi
  1. TPC Member IEEE Global Telecommunications Conference, GLOBECOM 2015;
  2. TPC Member IEEE International Conference on Communications, ICC 2015;
  3. TPC Member International Workshop on Communicating Objects and Machine to Machine for Mission-Critical Applications, COMMCA 2015;
  4. TPC Member International Conference on Open and Big Data, OBD, 2015;
  5. TPC Member International Conference on New Technologies of Information and Communication, NTIC, 2015;
  6. TPC Member International Conference on Performance Evaluation and Modeling in Wired and Wireless Networks, PEMWN, 2015;
  7. TPC Member International Conference on Advances in Computing, Communications and Informatics, ICACCI, 2015;

10.1.3. Journal

10.1.3.1. Editorial Board Member

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

10.1.3.2. Journal Reviewer

- **Paul Muhlethaler**
  1. Reviewer Annals of telecommunications
  2. Reviewer IEEE Transactions on Wireless Communications
  3. Reviewer IEEE Transactions on Vehicular Technology
  4. Reviewer IEEE Transactions on Information Theory
  5. Reviewer International Journal of Distributed Sensor Networks. Hindawi.
- **Pascale Minet**
  1. Reviewer Real-Time Systems
  2. Reviewer International Journal of Distributed Sensor Networks
  3. Reviewer Computer Communications Journal
  4. Reviewer Annals of telecommunications
  5. Reviewer ACM Computing Surveys
- **Thomas Watteyne**
  1. Reviewer Springer Journal of Internet Services and Applications, 2015.
  2. Reviewer IEEE Internet of Things (IoT) Journal, 2015.
  3. Reviewer IEEE Transactions on Industrial Informatics, 2015.
- Nadjib Achir
  1. Reviewer Sensor Networks (MDPI)
  2. Reviewer Wireless Communications and Mobile Computing (Wiley)

   3. Reviewer Internet of Things Journal (IEEE)
   4. Reviewer Ad Hoc Networks Journal (Elsevier)
- Selma Boumerdassi
   1. Reviewer Ad Hoc Networks Journal (Elsevier);
   2. Reviewer The journal of Future Generation Computer Systems (Elsevier).

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Master:

- **Thomas Watteyne** taught an Intensive 1-week course on IoT, with associated hands-on labs. ENSTA ParisTech. Together with Quentin Lampin and Dominique Barthel, 12-18 November 2015.
- **Thomas Watteyne** taught a 3-hour class on “Getting your Hands Dirty With the Industrial IoT”. IoT360 Summer School, Rome, Italy, 27 October 2015.
- **Thomas Watteyne** taught a 1-day crash course on the Industrial IoT, ParisTech, 30 September 2015.
- **Thomas Watteyne** taught a 3-hour class on “Deterministic Wireless Sensor Networks”, Ecole Temps Reel (ETR), with Pascal Thubert, Rennes, France, 28 August 2015.
- **Thomas Watteyne** taught a 1h class on the Silicon Valley at KULAK, Kortrijk, Belgium, 17 March 2015.
- **Thomas Watteyne** taught an Intensive 1-week course on IoT, with associated hands-on labs. ENSTA ParisTech. Together with Quentin Lampin and Dominique Barthel, 19-23 January 2015.
- **Pascale Minet** taught “Déploiement de réseaux de capteurs sans fil : couverture et connectivité” in Master Systèmes et Services pour l’Internet des Objets of the University of Marne-la-Vallée.
- **Pascale Minet** taught Mobile ad hoc networks and wireless sensor networks: medium access, routing and energy efficiency in Master ScTIC (Systèmes complexes, Technologies de l’Information et du Contrôle) of the University of Paris 12.
- **E-learning**

  Thomas Watteyne recorded a MOOC on the Internet of Things (IoT) together Prof. Mischa Dohler from with King’s College London, FutureLearn platform, 3-week course, first course on 23 November 2015. Over 20,000 registered!

10.2.2. Supervision

PhD :

- Ines Khoufi, “Autonomous or assisted deployment by mobile robots of wireless sensor networks: coverage and connectivity issues”, University Pierre et Marie Curie - Paris VI, September 2015, **Pascale Minet** adviser, Anis Laouiti, co-adviser.
- Ines Ben Jemaa, “Multicast communications for cooperative vehicular systems”, Mines ParisTech, December 2014, **Paul Muhlethaler** co-adviser, Nadjib Achir reviewer.

10.2.3. Juries

HdR:

- Kinda Khawam, “Radio resource management in heterogeneous networks”, University of Paris Sud, November 2015, **Pascale Minet** examiner.

- Anis Laouiti, “From mobile ad hoc networks to smart cities”, University of Paris Sud, September 2015, **Pascale Minet** examiner.

PhD:

- Kevin Roussel, “Évaluation et amélioration des plates-formes logicielles pour réseaux de capteurs sans-fil, pour optimiser la qualité de service et l’énergie”, Université de Lorraine, viva 17 December 2015, **Thomas Watteyne** examiner.
- Antonio O. Gonga, “Mobility and Multi-channel Communications in Low-power Wireless Networks”, KTH Electrical Engineering, viva on 14 January 2016, **Thomas Watteyne** examiner.
- Roudy Dagher, “Sur la radionavigation dans les villes intelligentes du futur – Le cas des réseaux de capteurs sans fils”, Inria-Lille, viva 6 October 2015,, **Thomas Watteyne** examiner.
- Georgios Z. Papadopoulos, “Improving Medium Access in Dynamic Wireless Sensor Networks”, ICube lab, University of Strasbourg, 28 September 2015, **Thomas Watteyne** examiner.
- Ons Mabrouk, “Communications opportunistes dans les réseaux de capteurs radio cognitive”, University of La Manouba, ENSI, Tunis, November 2015, **Pascale Minet** examiner.
- Jean-Baptiste Dupe, “Ordonnancement et gestion de ressources pour un système de télécommunications haut débit : optimisation de la bande passante satellite”, University of Toulouse, October 2015, **Pascale Minet** reviewer.
- Rafik Zitouni, “Software defined radio for cognitive wireless sensor networks”, University of Paris Est, October 2015, **Pascale Minet** reviewer.
- Tanguy Ropitault, “Routage et performances dans les réseaux CPL pour le smart grid”, Telecom Bretagne, Juin 2015, **Pascale Minet** reviewer.
- Rana Diab, “HMC-MAC : un protocole MAC hybride et multi-canal pour les réseaux de capteurs sans fil”, Université Blaise Pascal, Clermont-Ferrand, June 2015, **Pascale Minet** reviewer.
- Dimitrios Millioris, “Trend Detection and Information Propagation in Dynamic Social Networks”, Ecole Polytechnique, April 2015, **Paul Muhlethaler** examiner.
- Guangyu Li “Adaptive and Opportunistic QoS-based Routing Protocol in VANETs” University of Paris Saclay July 2015, Paul **Paul Muhlethaler** reviewer.
- Zakia Khalfallah “Underwater Wireless Sensor Network Deployment for Water Pollution Monitoring in Rivers”, UPMC December 2015, **Paul Muhlethaler** examiner.
- Ines Khoufi, “Autonomous or assisted deployment by mobile robots of wireless sensor networks: coverage and connectivity issues”, University Pierre et Marie Curie - Paris VI, September 2015, Nadjib Achir reviewer.
- Oussama Stiti, “Étude de l’urbanisation des accès virtuels et stratégie de métamorphose de réseaux ”, University Pierre et Marie Curie - Paris VI, November 2015, Nadjib Achir reviewer.
- El Hadj Malick Ndoye, “Réseaux de capteurs sans fil linéaires : impact de la connectivité et des interférences sur une méthode d’accès basée sur des jetons circulants”, Université Blaise Pascal, Clermont-Ferrand, June 2015, Nadjib Achir reviewer.
- Sabrina Naimi, “Gestion de la mobilité dans les réseaux Ad Hoc par anticipation des métriques de routage”, Université Paris Sud and ENIT (Tunisia), July 2015, Anis Laouiti reviewer.

10.3. Popularization

10.3.1. Web Presence

- https://team.inria.fr/eva/
- https://twitter.com/InriaEVA

10.3.2. Demos

- We deployed a 15-mote network at the SolutionsCOP21 expo at the Grand Palais in Paris, held alongside the COP21 meeting, 4-10 December 2015. French President Francois Hollande and Minister of Research Thierry Mandon came by the demo.
- The EVA team organized several demonstrations of wireless sensor networks for undergraduates who visited Inria in February and December 2015.

10.3.3. Talks

- The Rise of the Industrial IoT! Inria-DGA day, Paris, France, 15 October 2015, **Thomas Watteyne**.
- Wireless In the Woods: Monitoring the Snow Melt Process in the Sierra Nevada. "demi-heure de la science" seminar. 3 September 2015, Rocquencourt, France, **Thomas Watteyne**.
- From Smart Dust to 6TiSCH: building the Industrial Internet of Things. 4th International Symposium on Sensor Science (I3S), 13-15 July 2015, Basel, Switzerland, **Thomas Watteyne**.
- Reaching Industrial-class Reliability with a Converged IPv6 Network in the Smart Building. Joint presentation with Pascal Thubert (Cisco). MEITO day on Smart Buildings, 21 May 2015, Rennes, France, **Thomas Watteyne**.
- OpenWSN: Having FUN with TSCH and the IoT-LAB. FUN research team seminar, Inria-Lille, 3 April 2015, Lille, France, **Thomas Watteyne**.
- Determinism in the IoT: the example of 6TiSCH and OpenWSN. IRTF T2TRG meeting, 22 March 2015, Dallas, TX, USA, **Thomas Watteyne**.

10.3.4. Panels

- **Thomas Watteyne** chair, panel on "Sensing and Networking", Inria@Silicon Valley annual workshop (BIS), 13 May 2015, Berkeley, CA, USA.

10.3.5. In the News

- Article on IPSO CHALLENGE 2015, Inria-Paris Newsletter, 15 December 2015.
- Interview of **Thomas Watteyne** in Smart Insights on "The Internet of Important Things", Issue 15, number IV, 14 December 2015.
- "Two Inria technologies rewarded at the IPSO Challenge 2015 in San Jose", FrenchTechHub newsletter, 10 December 2015.
- "Interview: **Thomas Watteyne**, EVA research team and REALMS associate team, presents his research, his collaboration with California and the IPSO Challenge". Inria@SiliconValley newsletter, October 2015.
- "Two Inria-EVA projects make it to IPSO CHALLENGE semi-finals", inria.fr, October 2015.
- IPSO Alliance Announces Semi-Finalists for IPSO Challenge 2015, Reuters, August 2015.

10.4. Others

10.4.1. Position held at Inria

Paul Muhlethaler is the scientific director of the DGA-Inria partnership.

11. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

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[2] C. ADJIH, E. BACCELLI, E. FLEURY, G. HARTER, N. MITTON, T. NOEL, R. PISSARD-GIBOLLET, F. SAINT-MARCEL, G. SCHREINER, J. VANDAELE, T. WATTEYNE. *FIT IoT-LAB: A Large Scale Open Experimental IoT Testbed – A valuable tool for IoT deployment in Smart Factories*, in "IEEE ComSoc Multimedia Technical Committee E-Letter", December 2015, https://hal.inria.fr/hal-01208387

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