Activity Report 2014

Team HIPERCOM2

High PERformance COMmunications

RESEARCH CENTER
Paris - Rocquencourt

THEME
Networks and Telecommunications

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Team HIPERCOM2

Keywords: Wireless Sensor Networks, Manets, Vanets, Network Protocols, Cognitive Radio Networks

Creation of the Team: 2013 January 01.

1. Members

Research Scientists
Pascale Minet [Team leader, Inria, Researcher, HdR]
Cédric Adjih [Inria, Researcher, until March 2014]
Paul Muhlethaler [Inria, HdR]

Faculty Members
Selma Boumerdassi [CNAM, Professor, Delegation Inria]
Dana Marinca [Univ. Versailles, Associate Professor, Delegation Inria, until August 2014]

Engineers
Ichrak Amdouni [Inria, granted by Univ. Pierre et Marie Curie, until September 2014]
Hana Baccouch [Inria, until Sep 2014, granted by ANR HIPERCOM- ASTRID project]
Vincent Ladeveze [Inria, until Apr 2014, granted by Univ. Pierre et Marie Curie]
Erwan Livolant [Inria, granted by Caisse des Dépôts et Consignations]
Alaeddine Weslati [Inria, until Sep 2014, granted by Univ. Pierre et Marie Curie]

PhD Students
Nesrine Ben Hassine [Inria, granted by Caisse des Dépôts et Consignations, from Apr 2014]
Younes Bouchaala [Inria, granted by VEDECOM, from December 2014]
Ines Khoufi [Inria, granted by Caisse des Dépôts et Consignations]
Dimitrios Milioris [Bell Labs (Alcatel), granted by CIFRE]
Ridha Soua [Inria, granted by Conseil Régional d'Ile-de-France, until Feb 2014]

Post-Doctoral Fellows
Claudio Greco [Inria, until Sep 2014, granted by Fondation Digiteo- Triangle de la Physique]
Antonia Masucci [Inria, until Sep 2014, granted by ANR HIPERCOM- ASTRID project]
Mohamed Zayani [Inria, until Apr 2014, granted by ANR HIPERCOM- ASTRID project]

Visiting Scientists
Nadjib Achir [Univ. Paris XIII, Associate Professor, HdR]
Merouane Debbah [SUPELEC, HdR]
Philippe Jacquet [Bell Labs (Alcatel), HdR]
Anis Laouiti [France Telecom]

Administrative Assistant
Christine Anocq [Inria]

2. Overall Objectives

2.1. Overall Objectives

The Hipercom2 team aims to design, evaluate and optimize the telecommunication algorithms. The aimed areas are protocols and standards dealing with communication support and quality of service management in wireless networks. The activity fields are centered around the new networks and services supporting internet. Although we address the whole spectrum of telecommunication domain, practically the Hipercom2 team is specialized in wireless sensor networks, vehicular networks, mobile ad hoc networks and mesh networks. However the thematic extends to the information theory as well as network and traffic modelling.

The scientific foundations are the following:

- Methodology for telecommunication algorithm evaluation,
- Traffic and network architecture modeling,
- Algorithm design, evaluation and implementation,
- Simulation of network algorithms and protocols.

The objectives assigned to HIPERCOM2 were:

- Wireless ad hoc networks: modeling and protocol design,
- Wireless sensor networks: cross-layering, energy and bandwidth efficiency, deployment,
- Vehicular and mobile applications for intelligent transportation systems as well as military tactical networks.

3. Research Program

3.1. Methodology of telecommunication algorithm evaluation

We develop our performance evaluation tools towards deterministic performance and probabilistic performance. Our tools range from mathematical analysis to simulation and real life experiment of telecommunication algorithms.

One cannot design good algorithms without good evaluation models. Hipercom project team has an historically strong experience in performance evaluation of telecommunication systems, notably when they have multiple access media. We consider two main methodologies:

- Deterministic performance analysis,
- Probabilistic performance analysis

In the deterministic analysis, the evaluation consists in identifying and quantifying the worst case scenario for an algorithm in a given context. For example to evaluate an end-to-end delay. Mathematically it consists into handling a (max,+) algebra. Since such algebra is not commutative, the complexity of the evaluation of an end-to-end delay frequently grows exponentially with the number of constraints. Therefore the main issue in the deterministic evaluation of performance is to find bounds easier to compute in order to have practical results in realistic situations.

In the probabilistic analysis of performance, one evaluate the behavior of an algorithm under a set of parameters that follows a stochastic model. For example traffic may be randomly generated, nodes may move randomly on a map. The pionneer works in this area come from Knuth (1973) who has systematized this branch. In the domain of telecommunication, the domain has started a significant rise with the appearance of the problematic of collision resolution in a multiple access medium. With the rise of wireless communication, new interesting problems have been investigated.

The analysis of algorithm can rely on analytical methodology which provides the better insight but is practical in very simplistic models. Simulation tools can be used to refine results in more complicated models. At the end of the line, we proceed with real life experiments. To simplify, experiments check the algorithms with 10 nodes in maximum, simulations with 100 nodes maximum, analytical tools with more 1,000 nodes, so that the full range of applicability of the algorithms is investigated.

3.2. Traffic and network architecture modeling

One needs good and realistic models of communication scenarios in order to provide pertinent performance evaluation of protocols. The models must assess the following key points:

- The architecture and topology: the way the nodes are structured within the network
- The mobility: the way the nodes move
- The dynamics: the way the nodes change status
- The traffic: the way the nodes communicate

For the architecture there are several scales. At the internet scale it is important to identify the patterns which dictate the node arrangement. For example the internet topology involves many power law distribution in node degree, link capacities, round trip delays. These parameters have a strong impact in the performance of the global network. At a smaller scale there is also the question how the nodes are connected in a wireless network. There is a significant difference between indoor and outdoor networks. The two kinds of networks differ on wave propagation. In indoor networks, the obstacles such as walls, furniture, etc, are the main source of signal attenuations. In outdoor networks the main source of signal attenuation is the distance to the emitter. This lead to very different models which vary between the random graph model for indoor networks to the unit graph model for outdoor networks.

The mobility model is very important for wireless network. The way nodes move may impact the performance of the network. For example it determines when the network splits in distinct connected components or when these components merge. With random graph models, the mobility model can be limited to the definition of a link status holding time. With unit disk model the mobility model will be defined according to random speed and direction during random times or random distances. There are some minor complications on the border of the map.

The node dynamic addresses the elements that change inside the node. For example its autonomy, its bandwidth requirement, the status of server, client, etc. Pair to pair networks involve a large class of users who frequently change status. In a mobile ad hoc network, nodes may change status just by entering or leaving the coverage area.

The traffic model is very most important. There are plenty of literature about trafic models which arose when Poisson models was shown not to be accurate for real traffics, on web or on local area networks. Natural traffic shows long range dependencies that do not exist in Poisson traffic. There are still strong issues about the origin of this long range dependencies which are debated, however they have a great impact on network performance since congestions are more frequent. The origin are either from the distribution of file sizes exchanged over the net, or from the protocols used to exchange them. One way to model the various size is to consider on/off sources. Every time a node is on it transfers a file of various size. The TCP protocol has also an impact since it keeps a memory on the network traffic. One way to describe it is to use an on/off model (a source sending packets in transmission windows) and to look at the superposition of these on/off sources.

3.3. Algorithm design, evaluation and implementation

The conception of algorithms is an important focus of the team. We specify algorithms in the perspective of achieving the best performance for communication. We also strive to embed those algorithms in protocols that involve the most legacy from existing technologies (Operating systems, internet, Wifi). Our aim with this respect is to allow code implementations for real life experiment or embedded simulation with existing network simulators. The algorithm specified by the project ranges from multiple access schemes, wireless ad hoc routing, to deployment of wireless sensor nodes as well as joint time slot and channel assignment in wireless networks. In any of these cases the design emphasize the notions of performance, robustness and flexibility. For example, a flooding technique in mobile ad hoc network should save bandwidth but should not stick too much close to optimal in order to be more reactive to frequent topology changes. Some telecommunication problems have NP hard optimal solution, and an implementable algorithm should be portable on very low power processing unit (e.g. sensors). Compromise have to be found and quantified with respect to nearly optimal solution.

3.4. Simulation of network algorithms and protocols

The performance of algorithms and protocols designed by the team have to be evaluated in various conditions: various configurations and various scenarii. The team uses different simulation tools. Historically, the first one was NS2 and some deployment algorithms are developed with NS2, taking advantage of its library and our previous works. We are now contributing to the development of NS3, enriching it with new modules (e.g. wireless medium access). For rapid simulation results and to validate design choices, we resort to Java home-made simulation tools (e.g. joint time slot and channel allocation).

4. Application Domains

4.1. Introduction

The HIPERCOM2 team addresses the following application domains:

- military, emergency or rescue applications,
- industrial applications,
- vehicular networks,
- smart cities,
- Internet of Things.

These application domains use the four types of wireless networks:

- wireless mesh and mobile ad hoc networks,
- wireless sensor networks,
- vehicular networks,
- cognitive radio networks.

4.2. Wireless mesh and mobile ad hoc networks

A mobile ad hoc network is a network made of a collection of mobile nodes that gather spontaneously and communicate without requiring a pre-existing infrastructure. Of course a mobile ad hoc network use a wireless communication medium. They can be applied in various contexts:

- military;
- rescue and emergency;
- high speed access to internet.

The military context is historically the first application of mobile ad hoc networks.
The rescue context is halfway between military and civilian applications. In emergency applications, heterogeneous wireless networks have to cooperate in order to save human lifes or bring the situation back to normal as soon as possible. Wireless networks that can be quickly deployed are very useful to assess damages and take the first decisions appropriate to the disaster of natural or human origin. The primary goal is to maintain connectivity with the humans or the robots (in case of hostile environment) in charge of network deployment. This deployment should ensure the coverage of an interest area or of only some interest points. The wireless network has to cope with pedestrian mobility and robots/vehicles mobility. The environment, initially unknown, is progressively discovered and usually has many obstacles. These obstacles should be avoided. The nodes of the wireless network are usually battery-equipped. Since they are dropped by a robot or a human, their weight is very limited. The protocols supported by these nodes should be energy efficient to increase network lifetime. Furthermore, in case of aggressive environment, sensor nodes should be replaced before failing. Hence, in such conditions, it is required to predict the failure time of nodes to favor a predictive maintenance.
Mobile ad hoc network provide an enhanced coverage for high speed wireless access to the internet. The now very popular WLAN standard, WiFi, provides much larger capacity than mobile operator networks. Using a mobile ad hoc network around hot spots will offer high speed access to much larger community, including cars, busses, trains and pedestrians.

4.3. Vehicular Networks and Smart Cities

Vehicular ad hoc networks (VANET) are based on short- to medium-range transmission systems that support both vehicle-to-vehicle and vehicle-to-roadside communications. Vehicular networks will enable vehicular safety applications (safety warnings) as well as non-safety applications (real-time traffic information, routing support, mobile entertainment, and many others). We are interested in developing an efficient routing protocol that takes advantage of the fixed network infrastructure deployed along the roads. We are also studying MAC layer issues in order to provide more priority for security messages which have stringent delivery constraints.

Smart cities share with the military tactical networks the constraint on pedestrian and vehicular mobility. Furthermore, the coexistence of many networks operating in the same radio spectrum may cause interferences that should be avoided. Cognitive radio takes advantage of the channels temporarily left available by the primary users to assign them to secondary users. Such an opportunistic behavior can also be applied in wireless sensor networks deployed in the cities. Smart cities raise the problem of transmitting, gathering, processing and storing big data. Another issue is to provide the right information at the right place: where it is needed.

4.4. Wireless sensor networks in industrial applications and Internet of Things

Concerning wireless sensor networks, WSNs, we tackle the three following issues:

- Energy efficiency is a key property in wireless sensor networks. Various techniques contribute to save energy of battery-equipped sensor nodes. To name a few, they are: energy efficient routing protocols, node activity scheduling, adjustment of transmision power, reduction of protocols overhead, reduction of data generated and transmitted. In the OCARI network, an industrial wireless sensor network, we have designed and implemented an energy efficient routing protocol and a node activity scheduling algorithm allowing router nodes to sleep. We have applied a cross-layering approach allowing the optimization of MAC and network protocols taking into account the application requirements and the environment in which the network operates. We have observed the great benefit obtained with node activity scheduling. In networks with low activity, opportunistic strategies are used to address low duty cycles.
- Large scale WSNs constitute another challenge. Large autonomous wireless sensors in the internet of the things need very well tuned algorithms. Self-organization is considered as a key element in tomorrow's Internet architecture. A major challenge concerning the integration of self-organized networks in the Internet is the accomplishment of light weight network protocols in large ad hoc environments.
- Multichannel WSNs provide an opportunity:
  - to increase the parallelism between transmissions. Hence, it reduces the data gathering delays and improves the time consitency of gathered data.
  - to increase the robustness against interferences and perturbations possibly caused by the coexistence of other wireless networks.

4.5. Cognitive Radio Networks

Usually in cognitive radio, the secondary users are in charge of monitoring the channel to determine whether or not the primary users are active in the area. If they are not, the secondary users are allowed to use the spectrum left unused by the primary users. We are interested in two issues:

- Design and modeling of a new access scheme based on a generalized Carrier Sense Multiple Access scheme using active signaling. This scheme allows the primary users to capture the bandwidth even if the secondary users are transmitting in the area.
- Design of a time slot and channel assignment to minimize the data gathering performed by secondary users. This assignment should work with different detection schemes of primary user presence.

5. New Software and Platforms

5.1. OPERA and OCARI Software

Participants: Cédric Adjih, Ichrak Amdouni, Pascale Minet, Ridha Soua, Erwan Livolant.

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 Hipercom2 team: http://opera.gforge.inria.fr/index.html

Erwan Livolant, Pascale Minet from Inria as well as Tuan Dang from EDF and Maurice Sellin from DCNS showed the wireless sensor network OCARI during the Inria-Industry Meeting devoted to Telecommunications organized by Inria at Rocquencourt in November 2014. Two types of demonstration were done: one illustrating the internal behavior of OCARI and the other one illustrating a fire detection in a DCNS ship.

5.2. SAHARA Software

Participants: Erwan Livolant, Pascale Minet, Ridha Soua.

The software module DimTool developed in 2014 by the Hipercom2 team in the SAHARA project has been registered by the APP in January 2014. It helps to dimension the network parameters of the SAHARA wireless sensor network and evaluate the feasibility of a given application.

5.3. CONNEXION Software

Participants: Ines Khoufi, Pascale Minet, Erwan Livolant.

In 2014, we developped two softwares to compute the positions of:

- sensor nodes that ensure full coverage of a 2-D area with irregular shape and containing obstacles.
- relay nodes that maintain a robust connectivity of each point of interest with the sink. The area may contain obstacles.

With regard to the wireless sensor network OCARI, in 2014 we developed the interface of wireless temperature sensors PT100 with the OCARI stack. We also gave our support to CEA for the development of the OCARI interface of smoke detectors. With Telecom ParisTech, we interconnected OCARI with the industrial facility backbone based on OPC/UA via a gateway implemented on a Raspberry Pi. More precisely, we developed the serial interface between the OCARI network coordinator and the OPC/UA server.

5.4. NS3 Network Coding Software

Participants: Cédric Adjih, Ichrak Amdouni, Hana Baccouch.

One output of the GETRF project, was the creation of a solution for Network Coding, called DragonNet. DragonNet is a complete modular solution. This solution is responsible of: coding, decoding, maintaining necessary information and the associated signaling. It is designed to be extensible. A variant of DragonNet has been specified for wireless sensor networks and implemented.

As a follow-up to the ADT MOBSIM (and the previous module EyWifi), DragonNet was also integrated as a module for the ns-3 simulation tool.

5.5. FIT IoT-LAB Platforms

Participants: Cédric Adjih, Alaeddine Weslati, Vincent Ladeveze, Ichrak Amdouni.

This is a joint work with Emmanuel Baccelli from Inria Saclay.

Period: 2011 - 2021

Partners: Inria (Lille, Sophia-Antipolis, Grenoble), INSA, UPMC, Institut Télécom Paris, Institut Télécom Evry, LSIIT Strasbourg.

- Deployment: During the year 2014, the practical deployment has been finished, at the location planned for this testbed of the EQUIPEX FIT: the basement of building 1 at Rocquencourt. Ten external nodes have also been integrated.

The testbed is offering most of the planned 344 open nodes, including 120 WSN430 nodes, 200 Cortex A8 based nodes, 24 Cortex M3.

- Opening: The official opening of the Rocquencourt was done in November 2014, at that point all IoT-LAB (and OneLab) users could run experiments in the M3 and A8 nodes from the site. See https://www.iot-lab.info/deployment/rocquencourt/ for more information.
- Support of external projects: Support for RIOT-OS and OpenWSN projects has been developed for IoT-Lab hardware and is being tested.
  - RIOT-OS, a joint work between Inria and FU-Berlin to create an Operating System for the Internet of Things.
  - OpenWSN, an open-source protocol stack for Internet of Things developed by UC Berkley.
- Demonstration: the project IoT-LAB in general had been demonstrated in several events during the year
  - March 2014: Description of IoT-LAB, and test of IoT-LAB nodes at the IETF 6TiSCH plugfest during IETF-89 in London https://bitbucket.org/6tisch/meetings/wiki/140306a_ietf89_london_plugfest
  - July 2014: Demonstration of IoT-LAB (Contiki RPL experiments) at:
    - the Bits-n-Bytes event of IETF-90 in Toronto http://www.ietf.org/meeting/90/ietf-90-bits-n-bites.html
    - the LLN plugfest of IETF-90 in Toronto https://bitbucket.org/6tisch/meetings/wiki/140720a_ietf90_toronto_plugfest
  - November 2014: Demonstration of IoT-LAB for use of scientific experiments, with network coding at MASS 2014 (http://mass2014.eecs.utk.edu/)

Moreover, during 2014, Ichrak Amdouni was in charge of:

- Testing the support of new switches in FIT IoT-LAB Paris-Rocquencourt site.
- Experimenting network coding protocols in the FIT IoT-LAB platform.

6. New Results

6.1. Highlights of the Year

- Hipercom 2 took part to the Inria-Industry meeting focusing on Telecommunications organized by Inria at Rocquencourt in November 2014. We presented a demonstration of the OCARI wireless sensor network.
- Hipercom 2 organized an Inria-DGA day "Software Defined Network (SDN) & MANET" at Paris in October 2014.

6.2. New Results about Wireless Sensor Networks

6.2.1. Node activity scheduling and routing in Wireless Sensor Networks

Participants: Cédric Adjih, Ichrak Amdouni, Pascale Minet.

The need to maximize network lifetime in wireless ad hoc networks and especially in wireless sensor networks requires the use of energy efficient algorithms and protocols. Motivated by the fact that a node consumes the least energy when its radio is in sleep state, we achieve energy efficiency by scheduling nodes activity. Nodes are assigned time slots during which they can transmit and they can turn off their radio when they are neither transmitting nor receiving. Compared to classical TDMA-based medium access scheme, spatial bandwidth use is optimized: non interfering nodes are able to share the same time slots, collisions are avoided and overhearing and interferences are reduced.

In 2014, we study the issue of delay optimization and energy efficiency in grid wireless sensor networks (WSNs). We focus on STDMA (Spatial Reuse TDMA)) scheduling, where a predefined cycle is repeated, and where each node has fixed transmission opportunities during specific slots (defined by colors). We assume a STDMA algorithm that takes advantage of the regularity of grid topology to also provide a spatially periodic coloring ("tiling" of the same color pattern). In this setting, the key challenges are: 1) minimizing the average routing delay by ordering the slots in the cycle 2) being energy efficient. Our work follows two directions: first, the baseline performance is evaluated when nothing specific is done and the colors are randomly ordered in the STDMA cycle. Then, we propose a solution, ORCHID that deliberately constructs an efficient STDMA schedule. It proceeds in two steps. In the first step, ORCHID starts form a colored grid and builds a hierarchical routing based on these colors. In the second step, ORCHID builds a color ordering, by considering jointly both routing and scheduling so as to ensure that any node will reach a sink in a single STDMA cycle. We study the performance of these solutions by means of simulations and modeling. Results show the excellent performance of ORCHID in terms of delays and energy compared to a shortest path routing that uses the delay as a heuristic. We also present the adaptation of ORCHID to general networks under the SINR interference model.

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

Participants: Pascale Minet, Ridha Soua, Erwan Livolant.

Applying WSNs in industrial environment requires fast and reliable data gathering (or data convergecast). If packets are forwarded individually to the sink, it is called raw data convergecast. We resort to the multichannel paradigm to enhance the data gathering delay, the robustness against interferences and the throughput. Since some applications require deterministic and bounded convergecast delays, we target conflict free joint time slot and channel assignment solutions that minimize the schedule length. Such solutions allow nodes to save energy by sleeping in any slot where they are not involved in transmissions.

After a comprehensive survey on multichannel assignment protocols in wireless sensor networks, we study raw convergecast in multichannel wireless sensor networks (WSNs) where the sink may be equipped with multiple radio interfaces. We propose $Wave$,a simple, efficient and traffic-aware distributed joint channel and time slot assignment for raw convergecast. Our target is to minimize the data gathering delays and ensure that all packets transmitted in a cycle are delivered to the sink in this cycle, assuming no packet loss at the physical layer. We evaluate the number of slots needed to complete the convergecast by simulation and compare it to the optimal schedule and to a centralized solution. Simulations results indicate that our heuristic is not far from the optimal bound for raw convergecast. Unlike most previously published papers, $Wave$ does not suppose that all interfering links have been removed by channel allocation. In addition, $Wave$ is able to easily adapt to traffic changes. $Wave$ could be used to provide the schedule applied in the $802.15.4e$ TSCH based networks.

6.2.3. Optimized WSN Deployment

Participants: Ines Khoufi, Pascale Minet, Erwan Livolant.

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 a temporary industrial worksite, damage assessment after a disaster.... Many of these applications require the full coverage of the area considered. 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.

In the literature, many studies assume that this area is rectangular and adopt the classical deployment in triangular lattice that has been proved optimal. In real life, things are more complex. For instance, in an industrial worksite, the area to cover has an irregular shape with many edges and is not necessarily convex. Moreover, few papers take obstacles into account. Those that do assume that obstacles are constituted by a juxtaposition of rectangles that seems an unrealistic assumption. In real deployments, the shape of obstacles may be irregular. 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. That is why we focus on the deployment of wireless sensor nodes in an arbitrary realistic area with an irregular shape, and with the presence of obstacles that may be opaque. Moreover, we propose a method that tends to minimize the number of sensor nodes needed to fully cover such an area.

Mobile robots can be used to deploy static wireless sensor nodes to achieve the coverage and connectivity requirements of the applications considered. Many solutions have been provided in the literature to compute the set of locations where the sensor nodes should be placed. We show how this set of locations can be used by a mobile robot to optimize its tour to deploy the sensor nodes to their right locations. In order to reduce both the energy consumed by the robot, its exposure time to a hostile environment, as well as the time at which the wireless network becomes operational, the optimal tour of the robot 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 Robot Deploying Sensor nodes problem, in short RDS. We first show how this problem differs from the well-known traveling salesman problem. We then propose an integer linear program formulation of the RDS 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.

6.2.4. 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 formalization.

6.2.5. 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.

6.2.6. 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.

6.2.7. Opportunistic routing cross-layer schemes for low duty-cycle wireless sensor networks

Participants: Mohamed Zayani, Paul Muhlethaler.

This is a joint work with Nadjib Aitsaadi from University of Paris 12.
The opportunistic aspect of routing is suitable with such networks where the topology is dynamic and protocols based on topological information become inefficient. Previous work initiated by Paul Muhlethaler and Nadjib Aitsaadi consisted in a geographical receiver-oriented scheme based on RI-MAC protocol (Receiver-Initiated MAC). This scheme is revised and a new contribution proposes to address the same problem with a sender-oriented approach. After scrutinising different protocols belonging to this classification, the B-MAC protocol is chosen to build a new opportunistic cross-layer scheme. Our choice is motivated by the ability of this protocol to provide to a sender the closest neighbor to the destination (typically a sink). In other words, such a scheme enables us to obtain shorter paths in terms of hops which would increase the efficiency of information delivery. In counterparts, as it relies on long preambles (property of B-MAC) to solicit all the neighborhood, it needs larger delays and energy consumption (1% of active time). Nevertheless, this proposal remains interesting as the studied networks are dedicated to infrequent event detection and are not real time-oriented.

When we use BMAC with opportunistic routing, one main advantage is that there is no transmission when there is no event detected in the network in contrast to RI-MAC where beacons of awaking nodes are periodically sent. However, when an event occurs in the area monitored, the end-to-end delay to deliver the alert packet to the sink is much greater with BMAC than with RI-MAC. This may pose problem to some real-time applications. We have propose a scheme where, instead of sending a long preamble to gather all the neighbor nodes, the packet is directly sent. The acknowledgement of the packet allows tthe sender to know whether (or not) the progression towards the destination is sufficient. If it is not the case the packet is sent again. More neighbor node will be awaken and the progression towards the destination will be improved. The selection of the relay terminates when the progression towards the destination is above a given threshold. Actually this relaying scheme encompasses two levels of opportunism. The first level consists in selecting only the awake nodes, the second level consists in selecting the best nodes among the awake nodes. We can show that doing so only slightly increase the number of hops to reach the sink whereas the delay per hop is largely reduced. Thus the end-to-end is very significantly reduced and we still have the property that there is no transmission when there is no event detected in the network.

6.3. Cognitive Radio Networks

6.3.1. Multichannel time slot assignment in Cognitive Radio Sensor Networks

Participants: Ons Mabrouk, Pascale Minet, Ridha Soua, Ichrak Amdouni.

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). In 2013 we focused on the MultiChannel Time Slot Assignment problem (MC-TSA) in CRSN and proposed an Opportunistic centralized TIme slot assignment in COgnitive Radio sensor networks (OTICOR). This latter 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 show that, even in the presence of several PUs, the average throughput granted to SUs remains important. We also show how to get the best performances of OTICOR when the channel occupancy by PUs is known.

In 2014, we proposed 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. To achieve our goal, we propose an optimized version of our previous scheduling algorithm Opportunistic centralized TIme slot assignment in COgnitive Radio sensor networks (OTICOR). This algorithm 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 shown through simulations that using the control period for data transmission minimizes the schedule length and maximizes the throughput.

6.4. Mobile ad hoc and mesh networks

6.4.1. Development and implementation of a network coding module for NS3

Participants: Cédric Adjih, Ichrak Amdouni, Hana Baccouch.

DragonNet is a complete modular solution of network coding. This solution is responsible of coding, decoding, maintaining necessary information and the associated signaling. It is designed to be extensible. A variant of DragonNet was specified for wireless sensor networks and implemented.

As a follow-up to the ADT MOBSIM (and the previous module EyWifi), DragonNet was also integrated as a module for the NS-3 simulation tool.

6.4.2. Optimized Broadcast Scheme for Mobile Ad hoc Networks

Participants: Nadjib Achir, Paul Muhlethaler.

The main objective is to select the most appropriate relay nodes according to a given cost function. Basically, after receiving a broadcast packet each potential relay node computes a binary code according to a given cost function. Then, each node starts a sequence of transmit/listen intervals following this code. In other words, each 0 corresponds to a listening interval and each 1 to a transmit interval. During this active acknowledgment signaling period, each receiver applies the following rule: if it detects a signal during any of its listening intervals, it quits the selection process, since a better relay has also captured the packet. Finally, we split the transmission range into several sectors and we propose that all the nodes within the same sector use the same CDMA orthogonal spreading codes to transmit their signals. The CDMA codes used in two different sectors are orthogonal, which guarantees that the packet is broadcast in all possible directions. The obtained results demonstrate that our approach outperforms the classical flooding by increasing the delivery ratio and decreasing the number of required relays and thus the energy-cost.

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

6.5.1. Learning in wireless sensor networks

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

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 short-term, average-term and long-term 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.

In 2014, we applied on-line learning strategies to predict the quality of a wireless link in a WSN, based on the LQI metric 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. The model we propose learns on-line how to adapt to dynamic changes of the environment to compute efficient predictions. It presents a very good reactivity and adaptability. The simulations using traces collected in a real WSN based on the IEEE 802.15.4 standard have shown that the past time-windows which are effective for the prediction should have medium durations, about 200-400ms. The time windows durations less than 200ms do not give a good prediction, while durations larger than 400ms are efficient only in low variations environment. We note that these results strongly depend on the real traces, but the great advantage of the model is that it is self-adaptive to input traces profile. In this context, because of data normalization, the impact of loss functions is limited: entropy and square loss functions seem to give better and more stable predictions. Also, the experts prediction method should be adapted to traces profile. For low variation environment values, the average on past time windows is a good approximation. For high variation environment, a method predicting smoothed values close to minimum real values is more appropriate. Hence, the predicted values will be stabilized around the low values, avoiding estimations varying too much. Simulation results also show that for both types of experts (AMW and SES), the best expert depends on the phase considered. This is the reason why a forecaster is needed. Furthermore, the predictions of the EWA forecaster using SES experts are shown to be reactive and accurate. This combination minimizes the cumulated loss regarding the real LQI values, compared with any other combination such as EWA-AMW, BE-AMW and BE-SES, given by decreasing performance order.

6.5.2. Prediction and energy efficiency for datacenters

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

The exponential development of Information and Communication Technologies (ICT) have led to an over consumption of services and data shared in networks. From computing in companies to unified communications through social networks and Internet of Things, the use of ICT a reach the highest level ever. The complexity involved by these different services reveals the limits of computing in companies and leads a majority of organisms to partially or completely host the management of there information system in data centers. The latter are larger and larger and are composed of buildings containing powerful computing equipments and air-conditionning systems. 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.

6.6. Vehicular Ad hoc NETworks (VANETs)

6.6.1. Congestion Control in VANETs

Participants: Paul Muhlethaler, Anis Laouiti.

We have reviewed the schemes of Congestion Control in VANETs for safety messages. The solutions proposed are: to adapt the generation rate, to adapt the transmission power or to adapt the carrier sense threshold. Some mechanisms employ different states depending on the channel load. Some other schemes use recursive adaptation of their parameters (e.g. LIMERIC). According to a few studies the recursive adaptation system provide a better adaptation of the VANET to the channel load. We will study how the transmission rate and the carrier sense threshold (or transmission power) can be best adapted in order to send CAM: Car Awareness Messages with the highest rate and to the furthest vehicles while maintaining the total load below a given threshold. We will also study the better combination of transmission rate and the carrier sense threshold for the CAM.

6.6.2. TDMA schemes for VANETs

Participants: Mohamed Hadded, Paul Muhlethaler, Anis Laouiti.

This is a joint work with Leila Saidane and Rachid Zabrouba from ENSI (Tunisia).

Vehicular Ad-hoc NETworks (VANETs) help improving traffic safety and efficiency. Each vehicle can exchange information to inform other vehicles about the current status of the traffic flow or a dangerous situation such as an accident. Road safety and traffic management applications require a reliable communication scheme with minimal transmission collisions, which thus increases the need for an efficient Medium Access Control (MAC) protocol. However, the MAC in a vehicular network is a challenging task due to the high speed of the nodes, frequent changes in topology, the lack of an infrastructure, and various QoS requirements. Recently several Time Division Multiple Access (TDMA)-based medium access control protocols have been proposed for vehicular ad hoc networks in an attempt to ensure that all the vehicles have enough time to send safety messages without collisions and reducing end-to-end delay and packet loss rate. We have identified the reasons for using the collision-free medium access control paradigm in VANETs. We have then presented a novel topology-based classification and we provide an overview of TDMA-based MAC protocols that have recently been proposed for VANETs. We have focus on the characteristics of these protocols as well as their benefits and limitations. Finally we have given a qualitative comparison, and we have discussed some open issues that need to be tackled in future studies to improve the performance of TDMA-based MAC protocols for vehicle to vehicle V2V communication.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

7.1.1. OCARI2

Participants: Ichrak Amdouni, Pascale Minet, Cédric Adjih, Ridha Soua.

Partners: EDF, Inria.

The OCARI (Optimization of Ad hoc Communications in Industrial networks) project, funded by ANR, started in February 2007 and ended in 2010, EDF the coordinator decided to continue the project that deals with wireless sensor networks in an industrial environment. It aims at responding to the following requirements which are particularly important in power generation industry and in warship construction and maintenance:

- Support of deterministic MAC layer for time-constrained communication,
- Support of optimized energy consumption routing strategy in order to maximize the network lifetime,
- Support of human walking speed mobility for some particular network nodes, (e.g. sinks).

The development of OCARI targets the following industrial applications:

- Real time centralized supervision of personal dose in electrical power plants,
- Condition Based Maintenance of mechanical and electrical components in power plants as well as in warships,
- Environmental monitoring in and around power plants,
- Structure monitoring of hydroelectric dams.

To meet the requirements of supported applications (remote command of actuators, tele-diagnostic...), new solutions are brought to manage several communication modes, ranging from deterministic data transfers to delay tolerant transfers. A key issue is how to adapt routing algorithms to the industrial environment, taking into account more particularly limited network resources (e.g.; bandwidth), node mobility and hostile environment reducing radio range. The OCARI project aimed at developing a wireless sensor communication module, based on IEEE 802.15.4 PHY layer.

In 2014, Inria took part with EDF to the specification of a simplified OCARI stack for a porting to a 32 bit platform and provided support to the SME in charge of developing this stack.

7.2. Bilateral Grants with Industry

Participants: Paul Muhlethaler, Gerard Le Lann.

This work aims at improving the reliability of some SAGEM communications systems.

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. ANR

8.1.1.1. GETRF

Participants: Paul Muhlethaler, Pascale Minet, Cédric Adjih, Emmanuel Baccelli, Philippe Jacquet.

Period: 2012 - 2014.

Partners: DGA/MI, Inria (coordinator), Alcatel-Lucent.

The GETRF project aims at improving the effectiveness of communications mechanisms and technologies capable of functioning in extreme conditions and GETRF also aims at opening ways for solutions that are close to the optimum. The following areas will be addressed:

- Compromise time / maximum efficiency for coloring (TDMA), which can be used to take into account the asymmetry of traffic delays to optimize routing.
- Significant energy savings for opportunistic routing (in power saving mode) even where traffic control is limited and where the nodes are idle most of the time ("low-duty cycle")
- From a completely different point of view, the finding optimal network capacity for opportunistic routing variants when designed for mobile networks
- Robustness to mobility and to changes in network conditions (difficult connectivity, foes, ...) extreme network coding - which is moreover an innovative technology in itself applied here in MANETs, at the network and/or application layer, rather than at the physical/or theoretical level as in other proposals.

The project focuses on four technical approaches which are:

- Coloring for the development of a TDMA system for energy saving and delay control,
- Cross-layer (MAC/routing) mechanism for "low-duty-cycle" mode
- Network coding,
- Opportunistic routing and mobile mobility to use relays to minimize retransmissions of packets with a target time.

The first two approaches are intended to provide energy efficient sensor networks. The second two approaches try to provide mechanisms for building ad hoc networks capable of handling high node mobility.

In this last year of the project we finalize our studies on the four main mechanism of the GETRF project:

- energy saving mechanisms using synchronous techniques,
- energy saving mechanisms using asynchronous techniques,
- network coding,
- mobile routing.

In the last deliverable of the project, we study how these techniques can be combined. We also present how to improve asynchronous techniques for energy saving and how to adapt mobile routing to other assumptions.

8.1.2. Competitivity Clusters

8.1.2.1. SAHARA

Participants: Pascale Minet, Ridha Soua, Erwan Livolant.

Period: 2011 - 2014.

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 2014, we provided support to the SMEs in the SAHARA project for the implementation of network algorithms and protocols.

8.1.2.2. CONNEXION

Participants: Pascale Minet, Ines Khoufi, Erwan Livolant.

Period: 2012 - 2016.

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

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

The HIPERCOM2 team is focuses more particularly on the interconnection of the OCARI wireless sensor network with the industrial facility backbone and deployment algorithms of wireless sensors. In November 2014, 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);
- can be interconnected via a gateway to the industrial facility backbone OPC/UA ROSA developed by Telecom ParisTech to reach the KASEM system in charge of predictive maintenance developed by Predict.

All the chain ranging from the physical sensors, the OCARI wireless network, the OPC/UA bus to the KASEM software was integrated to allow information originated from wireless sensor nodes to be displayed on the KASEM console.

We also focus on deployment algorithms for mobile wireless sensor networks in a temporary worksite or after a disaster. These deployments must ensure coverage and network connectivity. In 2013 we studied solutions to ensure full coverage of the area to monitor as well as network connectivity. We proposed solutions in a first step for autonomous mobile wireless sensor nodes and in a second step for static ones. In May 2014, we showed in a Connexion demonstration a tool displaying the deployment of wireless static sensor nodes in an indoor environment. Since these static nodes are deployed by a mobile robot, we studied how to optimize the exposition duration of a robot in an hostile environment. We also focused on network connectivity, more particularly on how to ensure a reliable connectivity to the sink of sensor nodes located at some points of interest. Our goal is 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.

8.1.2.3. SWAN

Participants: Cédric Adjih, Claudio Greco.

Period: 2011 - 2014

Partners: CNRS, Supélec, Université Paris-Sud (L2S), LTCI, LRI, Inria and IEF.

SWAN, Source-aWAre Network coding, is a DIMLSC DIGITEO project. It deals with network coding for multimedia.

8.2. European Initiatives

8.2.1. FP7 & H2020 Projects

Paul Muhlethaler was reviewer of the projects:

- E3NETWORK (Energy Efficient E-band transceiver for backhaul of the future networks)
- TROPIC (Distributed computing, storage and radio resource allocation over cooperative femtocells)

8.3. International Initiatives

8.3.1. Participation In other International Programs

8.3.1.1. AWSN 2014

Program: Euromediterranean 3+3

Title: Auto-adaptivity in 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

See the Web site: http://hipercom.inria.fr/euromed/

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.

In 2014, the AWSN project organized two workshops reserved to AWSN teams:

- Workshop in Rabat in October 2014.
- Workshop in Rocquencourt in December 2014.

The AWSN project organized also open workshops and conferences:

- the RAWSN 2014 workshop in Marrakech in May 2014 organized by the Moroccan team: see the program on http://www.netys.net/rawsn2014/, workshop held in conjunction with NETYS 2014.
- the PEMWN 2014 conference in Sousse in November 2014, organized by the Tunisian and French teams, see the program on https://sites.google.com/site/pemwn2014/final-program

8.4. International Research Visitors

8.4.1. Visits of International Scientists

- **Leila Saidane**, ENSI, Tunis, Tunisia, February and September 2013,
- **Mohammed Erradi**, ENSIAS, Rabat, Morocco, September 2013,
- **Abdellatif Kobbane**, ENSIAS, Rabat, Morocco, September 2013.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific events organisation

9.1.1.1. general chair, scientific chair

Pascale Minet was co-chair with Leila Saidane of PEMWN 2014, organized in Sousse, Tunisia.

Selma Boumerdassi was chair of:

- The International Workshop on Trusted Platforms for Mobile and Cloud Computing (TPMCC 2014), April 2014 ;
- The International Workshop on Energy Management for Sustainable Internet-of-Things and Cloud Computing (EMSICC 2014), August 2014.

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

9.1.1.2. member of the organizing committee

Paul Muhlethaler organized the DGA Inria workshop on Telecommunication and networking: "Software Defined Network (SDN) & MANET" in October 2014.

Christine Anocq was member of the organizing committee of the international conference PEMWN 2014.

9.1.2. Scientific events selection

9.1.2.1. member of the conference program committee

Pascale Minet was member of the program committee of:

- Ad Hoc Nets 2014, 6th International ICST Conference on Ad Hoc Networks, August 2014.
- DCNET 2014, International Conference on Data Communication Networking, August 2014,
- GLOBECOM 2014, IEEE Global Telecommunications Conference Selected Areas in Communications, December 2014.
- ICC 2014, IEEE International Conference on Communications, June 2014
- ICN 2014, International Conference on Networks, January 2014.
- IFIP Wireless Days 2014, November 2014.
- IROS 2014, IEEE/RSJ International Conference on Intelligent Robots and Systems, September 2014.
- Med-Hoc-Net 2014, 14th IEEE/IFIP Mediterranean Ad-Hoc Networking conference, June 2014.
- PECCS 2014, 4th international conference on Pervasive and Embedded Computing and Communication Systems, February 2014. and Adaptive Wireless Sensor Networks, in conjunction with NETYS 2013, Marrakech, Morocco, April 2013.
- RTNS 2014, 21st International Conference on Real-Time and Network Systems, September 2014.
- SNPD 2014, 13th International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing, June 2014.

Paul Muhlethaler was also member of:

- the Steering commitee of MobileHealth 2014, 4th ACM MobiHoc Workshop on Pervasive Wireless Healthcare In Conjunction With MobiHoc 2014 Conference, June 2014, Athens, Greece,
- the Technical committee of the third International conference on Performance Evaluation and Modeling in Wireless Networks, PEMWN 2014, November 2014, Sousse, Tunisia.

Cédric Adjih was member of the program committee of:

- AINTEC 2014, ACM Asian Internet Engineering Conference, November 2014.
- PEMWN 2014, 3rd International Conference on Performance Evaluation and Modeling in Wireless Networks, November 2014, Sousse, Tunisia.

Selma Boumerdassi was member of the program committee for:

- IEEE Global Telecommunications Conference, GLOBECOM 2014;
- IEEE International Conference on Communications, ICC 2014;
- International Workshop on Communicating Objects and Machine to Machine for Mission-Critical Applications, COMMCA 2014;
- IEEE Symposium on Computer Applications and Industrial Electronics, ISCAIE 2014;
- IEEE Symposium on Wireless Technology and Applications, ISWTA 2014.

Nadjib Achir was member of the program committee for:

- IEEE Global Telecommunications Conference, GLOBECOM 2014;
- IEEE International Conference on Communications, ICC 2014;
- IEEE Wireless Communications and Networking Conference, WCNC 2014;
- IEEE Consumer Communications & Networking Conference, CCNC 2014;
- Global Information Infrastructure and Networking Symposium, GIIS 2014.

9.1.3. Journal

9.1.3.1. member of the editorial board

Nadjib Achir acted as guest editor of the special issue "Planning and Deployment of Wireless Sensor Networks", of the International Journal of Distributed Sensor Networks.

9.1.3.2. reviewer

Pascale Minet was reviewer for the following journals:

- IEEE Transactions on Parallel and Distributed Systems
- International Journal of Sensor Networks,
- International Journal of Information and Communication Technology,
- Journal of Communications,
- Journal of Network and Computer Applications,
- Computer Communications Journal,
- Ad Hoc Networks Journal,
- Mathematical Problems in Engineering,
- Wireless Networks.

Paul Muhlethaler was reviewer for the following journals:

- IEEE Transactions on Wireless Communications,
- IEEE Transactions on Vehicular Technology,
- IEEE Transactions on Information Theory.

Nadjib Achir was reviewer for:

- Sensor Networks (MDPI),
- Wireless Communications and Mobile Computing (Wiley),
- Internet of Things Journal (IEEE),
- Ad Hoc Networks Journal (Elsevier).

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Licence : **Ichrak Amdouni** taught "Principe et architecture des réseaux" and "Réseaux locaux et équipements actifs" at the university of Versailles Saint-Quentin (L1).

Master : **Pascale Minet** taught:

- Networks and quality of service in Master Systèmes Electroniques et Traitement de l'Information, at INSTN (Saclay).
- Mobile ad-hoc networks: medium access, routing and quality of service in Master Ingénierie informatique of the University of Marne-la-Vallée.
- 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.

9.2.2. Supervision

PhD :

- **Ridha Soua**, "Wireless Sensor Networks in Industrial Environment: Energy Efficiency, Delay and Scalability", University Pierre et Marie Curie - Paris 6, February 2014, Pascale Minet, adviser, Nadjib Achir, examinator.
- Ines Ben Jemaa, "Multicast communications for cooperative vehicular systems", Mines ParisTech, December 2014, Paul Muhlethaler, co-adviser, Nadjib Achir, reviewer.

9.2.3. Juries

HdR : Nadjib Achir, "Wireless Networks: Deployment and Quality of Service Provisioning", University Paris 13, 2014, Paul Muhlethaler, examinator.

PhD :

- Hicham Lakhlef, "Algorithmes distribués pour l'optimisation du déploiement des microbots MEMS"W, University of Franche Comté, November 2014, Pascale Minet, examinator.
- Zayneb Trabelsi Ayoub, "Déploiement large échelle des réseaux de capteurs sans fil IEEE 802.15.4 ZigBee", ENSI, Tunisia, november 2014, Paul Muhlethaler, reviewer, Pascale Minet, examinator.
- Salsabil Gherairi, "Garantie des délais des trafics temps réel pour les réseaux de capteurs sans fil", ENSI, Tunisia, Novemver 2014, Pascale Minet, examinator.
- Rima Hatoum, "Algorithmes d'ordonnancement inter-couches avec adaptation de modulation et de codage dans des réseaux hétérogènes", University of Paris 6, June 2014, Nadjib Achir, reviewer.
- Ibtissem Boulanouar, "Algorithmes de suivi de cible mobile pour les réseaux de capteurs sans fil", University of Paris Est, June 2014, Nadjib Achir, reviewer.
- Sara Mehar, "Le véhicule comme source et consommateur d'informations : collecte, dissémination et traitement de données pour une mobilité durable", University of Bourgogne, December 2014, Paul Muhlethaler, president.

9.3. Popularization

- **the Inria-Industry meeting focusing on Telecommunications**, in Rocquencourt, November 2014. The HIPERCOM2 team was very active and presented demonstrations of Wireless Sensor Networks. The demonstration prepared by Erwan Livolant, Cédric Adjih, Ichrak Amdouni, Pascale Minet concerned the principles of wireless sensor networks, the energy-efficient routing protocol, the node coloring algorithm running in the OCARI network to maximize network lifetime. Tuan Dang from EDF presented the new OCARI platform. Maurice Sellin from DCNS explained the deployment of an OCARI network in a DCNS ship, the application supported is fire detection and OCARI sensor nodes are provided by ADWAVE.
- Nadjib Achir, Cédric Adjih, Hana Baccouch, Ichrak Amdouni, Erwan Livolant and Ridha Soua explained the principles of communication and routing in wireless sensor networks and organized several demonstrations for undergraduates and students who visited Inria in February 2014.

10. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

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Articles in International Peer-Reviewed Journals

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