Activity Report 2013

Team HIPERCOM2

High PERformance COMmunications

RESEARCH CENTER
Paris - Rocquencourt

THEME
Networks and Telecommunications

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Team HIPERCOM2

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

Creation of the Team: 2013 January 01.

1. Members

Research Scientists

Pascale Minet [Team leader, Inria, Researcher, HdR]
Cédric Adjih [Inria, Researcher]
Paul Muhlethaler [Inria, HdR]

Faculty Members

Selma Boumerdassi [CNAM, Professor, Delegation Inria, from Sep 2013]
Dana Marinca [Univ. Versailles, Associate Professor, Delegation Inria, from Feb 2013]

External Collaborators

Nadjib Achir [Univ. Paris XIII, Associate Professor, Delegation Inria, from Jan 2013]
Philippe Jacquet [Bell Labs (Alcatel), from Jan 2012, HdR]
Anis Laouiti [France Telecom, from Jan 2013]

Engineers

Ichrak Amdouni [Inria, granted by ANR HIPERCOM- ASTRID project, from Feb 2013]
Hana Baccouch [Inria, granted by ANR HIPERCOM- ASTRID project, from Oct 2013]
Vincent Ladeveze [Inria, granted by the Ministry of Higher Education and Research's "Equipements d'Excellence", from Oct 2013]
Erwan Livolant [Inria, granted by Conseil Régional d'Ile-de-France, from Oct 2011]
Saoucene Ridene [Inria, granted by Caisse des Dépôts et Consignations, from Jan 2013 until Aug 2013]
Alaeddine Weslati [Inria, granted by the Ministry of Higher Education and Research's "Equipements d'Excellence", from Jan 2013]

PhD Students

Ines Khoufi [Inria, granted by Caisse des Dépôts et Consignations, from Sept 2012]
Dimitrios Milioris [Bell Labs, Alcatel-Lucent, granted by CIFRE, from Nov 2011]
Ridha Soua [Inria, granted by Conseil Régional d'Ile-de-France, from Dec 2010]
Ons Mabrouk [ENSI, Granted by Tunisia, from Sep 2013]

Post-Doctoral Fellows

Claudio Greco [Inria, granted by Fondation Digiteo- Triangle de la Physique, from Sep 2013]
Antonia Masucci [Inria, granted by ANR HIPERCOM- ASTRID project, from Oct 2013]
Mohamed Zayani [Inria, granted by ANR HIPERCOM- ASTRID project, from Apr 2013]

Administrative Assistant

Christine Anocq [Inria,shared with AOSTE and GANG]

Others

Ahmed Amari [Inria, Master Student, from Apr 2013 until Aug 2013]
Asma Khadraoui [Inria, Master Student, from Apr 2013 until Sep 2013]
Merouane Debbah [SUPELEC, from Jan 2013 until Dec 2013, HdR]

2. Overall Objectives

2.1. Introduction

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 aimed 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 mobile ad hoc networks, mesh networks, wireless sensor networks and vehicular 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,
- Vehicular and mobile applications for intelligent transportation systems as well as military tactical networks.

2.2. Highlights of the Year

- **PhD Thesis**: Ichrak Amdouni got her PhD Thesis, entitled "Wireless Self-adaptive Ad hoc and Sensor Networks: Energy Efficiency and Spatial Reuse", University Pierre et Marie Curie - Paris VI, February 2013, with Pascale Minet as adviser and Cedric Adjih.
- **PEMWN 2013**: The HIPERCOM2 team actively contributed to the technical and practical organization of the PEMWN 2013 workshop, Performance Evaluation and Modeling of Wireless Networks, held in Hammamet in November 2013. Pascale Minet and Leila Saidane from ENSI (Tunis) were co-general chairs. Cedric Adjih and Paul Muhlethaler were members of the program committee. Christine Anocq was in charge of the pre-registration.
- **Demonstration of OCARI**: The HIPERCOM2 team and more precisely, Cedric Adjih, Ichrak Amdouni, Ines Khoufi, Pascale Minet and Ridha Soua made presentations and demonstrations of the routing protocol and the coloring algorithm of OCARI, an energy-efficient wireless sensor network supporting determinism.

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 protcols

the perforamnce of algorithms and procols 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:
  - on the one hand, to increase the parallelism between transmissions. Hence, it reduces the data gathering delays and improves the time consitency of gathered data.
  - on the other hand, 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. Software and Platforms

5.1. Software and Platforms

5.1.1. Platforms

5.1.1.1. SensLab and FIT

Participants: Cédric Adjih, Alaeddine Weslati, Vincent Ladeveze.

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 2013, most of the practical deployment has been planned, designed and realized. A location has been found for the new testbed of the EQUIPEX FIT: the basement of building 1 at Rocquencourt. The preparation of the deployment space, power, GPS and network infrastructures for the deployment of IoT-Lab testbed has been finished: including designing and installing support structures, amenaging space (ventilation, ...), acquiring and installing network equipment, servers, GPS, ...

The Senslab testbed has been moved to the building 1 and has been integrated into the new platform. Deployment is in a finalization phase and should go in beta testing starting from Q1 2014. The testbed will offer 344 open nodes, including 120 WSN430 nodes, 200 Cortex A8 based nodes, 24 Cortex M3.

- 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.
  - IoT-Lab hardware based on STM stm32f1 series ARM Cortex-M3 MCU and Atmel AT86RF231 radio transceiver.

5.1.2. Software

5.1.2.1. NS3

Participants: Cédric Adjih, Hana Baccouch.

Ey-Wifi, Elimination-Yield for WiFi networks, is a module developed for the ns-3 simulation tool to integrate the features of the EY-NPMA channel access scheme. EY-NPMA (Elimination-Yield Non-Pre-emptive Priority Multiple Access) is a contention based protocol using active signaling (black burst): a node requests access to the medium by transmitting a burst signal. More precisely, the channel access cycle comprises three phases: priority phase, elimination phase and yield phase.

This software was developped thanks to the ADT MOBSIM.

The Ey-Wifi module has been publically released and is available, along with a detailed tutorial explaining how to use it, at: http://hipercom.inria.fr/Ey-Wifi

5.1.2.2. OPERA

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

The OPERA software was developed by the Hipercom2 team in the OCARI project. They include EOLSR, an energy efficient routing protocol and OSERENA, a coloring algorithm optimized for dense wireless networks. OPERA 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

More details and documentation about this software are available in the website made by the Hipercom2 team: http://opera.gforge.inria.fr/index.html

5.1.2.3. SAHARA

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

The software modules developed by the Hipercom2 team in the SAHARA project have been registered by the APP in July 2013:

- Mundi-Safeti V1.0, Reference: IDDN.FR.001.270022.000.S.P.2013.000.10000
- SAHARA-Network V1.0, Reference: IDDN.FR.001.270021.000.S.P.2013.000.10000

6. New Results

6.1. Wireless Sensor Networks

6.1.1. 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 our work about time slots assignment, two cases are studied. First, when nodes require equal channel access, we use node coloring. Second, when nodes have heterogeneous traffic demands, we designed the traffic aware time slot assignment algorithm TRASA. Unlike the majority of previous works, we generalize the definition of node coloring and slot allocation problems. Indeed, we set the maximum distance between two interfering nodes as a parameter of these problems. We prove that they are NP-complete, making heuristic approaches inevitable in practice. A central directive of this thesis is to design self-adaptive solutions. This adaptivity concerns many aspects such as the mission given by the application, the heterogeneity of node traffic demands, the network density, the regularity of network topology, and the failure of wireless links.

In the GETRF project, we target the energy efficiency in wireless sensor networks. We proposed node activity scheduling approaches that determine active and inactive slots for sensor nodes as to enable them to turn off their radio and save energy in the inactive slots.

1. First, we proposed a scheduling algorithm based on node coloring of grid sensor networks called VCM. This proposal was strengthen with mathematical analysis of the optimal number of colors needed to color an infinite grid. VCM produced an optimal number of colors when the transmission range tends to infinity. Also, this algorithm does not require message exchange between sensors to determine colors.

2. Second, this work was extended to adapt it to general graphs: the graph is divided into cells and the color of the cell is the color of the node on the left bottom of the cell. Nodes inside the cell are scheduled successively.

In addition to the energy efficiency, we targeted the delay optimization for data collection applications in grid wireless sensor networks. We profit from the previous work VCM and integrate it with a new hierarchical routing method to minimize data collection delays.

6.1.2. 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 appli- cations 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. We extend existing multichannel results to take into account a sink equipped with multiple radio interfaces and heterogeneous traffic demands. Indeed, we compute the theoretical bounds, that is the minimum number of time slots needed to complete convergecast, in various topologies with different traffic demands. These bounds are provided for different acknowledgment policies. For each of them, we provide a graph-based interference model. We also give optimal schedules that achieve these optimal bounds. We formalize the problem of multichannel slot assignment using integer linear programming and solve with GLPK tool for small configurations.

We propose MODESA, a centralized joint time slot and channel assignment algorithm. We prove the optimality of MODESA in lines, multilines and balanced trees topologies. By simulations, we show that MODESA outperforms TMCP, a well known subtree-based scheduling. We improve MODESA with different channel allocation strategies depending on the channel selection criteria (channels load balancing or preference of channels with the best qualities). Moreover, we show that resorting to multipath routing minimizes the convergecast delay. This work is extended in MUSIKA to take into account multi-sinks WSNs and traffic differentiation: the problem is formalized using integer linear programming and solved with GLPK. Simulations results show that the schedule length is minimized and the buffer size is reduced. We then address the adaptivity challenge. The slot assignment should be more flexible and able to adapt to application and environment variability (e.g., alarms, temporary additional demands). Theoretical bounds on the number of additional slots intro- duced to cope with traffic changes, are given. AMSA, an incremental solution, is proposed. Its performances are evaluated in two cases: retransmissions or temporary changes in appli- cation needs.

6.1.3. WSN Redeployment

Participants: Pascale Minet, Saoucene Ridene, Ines Khoufi.

This is a joint work with Telecom SudParis: Anis Laouiti.
In many applications (e.g military, environment monitoring), wireless sensors are randomly deployed in a given area. Unfortunately, this deployment is not efficient enough to ensure full area coverage and total network connectivity. Hence, all the considered area must be covered by sensors ensuring that any event is detected in the sensing range of at least one sensor. In addition, the sensor network must be connected in terms of radio communication in order to forward the detected event to the sink(s). Thus, a redeployment algorithm has to be applied in order to achieve these two goals.

In this context, we have proposed redeployment algorithms based on virtual forces. DVFA, is our Distributed Virtual Forces Algorithm. Each node in the network executes DVFA and computes its new position based on information collected from its neighbors. Performance evaluation shows that DVFA gives very good coverage rate (between 98% and 100%) and ensures the connectivity between sensors.

Moreover, in a real environment, obstacles such as trees, walls and buildings may exist and they may impact the deployment of wireless sensors. Obstacles can prohibit the network connectivity between nodes and create some uncovered holes or some accumulation of sensors in the same region. Consequently, an efficient wireless sensors deployment algorithm is required to ensure both coverage and network connectivity in the presence of obstacles. We have focused on this problem and enhanced our Distributed Virtual Force Algorithm (DVFA) to cope with obstacles. Simulation results show that DVFA gives very good performances even in the presence of obstacles.

6.1.4. 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.

Starting from a simulator coded by Nadjib Aitsaadi for the receiver-oriented scheme, the new scheme has been coded under many variants. On top of ideal techniques, a realistic variant has been considered and modelled. Its particularity can be summarized in the election process of the next hop. Indeed, it is based on sending bursts by the potential candidates to receive a packet from a sender. These bursts express the closeness of each candidate to the destination and correspond to the binary complement of the distance to this destination.

The opportunistic cross-layer scheme, when designed with RI-MAC, has shown solid performances in carrying the information about a rare event detection to a sink. This is verified for an event detected by several nodes. Nevertheless, the efficiency of such a design becomes less obvious when the detection is performed by a very small number of nodes. the opportunistic routing using RI-MAC relies on a minor set of potential candidates to forward a packet. In other words, a sender can only select an awake neighbor (typically closer to the sink) as the next hop. To overcome this limitation, we initially proposed to limit the number of hops to reach the sink.The principle of B-MAC perfectly matches with this idea. It is also important to highlight the ability of an opportunistic cross-layer built over B-MAC to avoid collisions. B-MAC- and RI-MAC-based proposals are suitable to convey emergency packets in dense and large WSNs when the event is reported by a significant set of nodes. When this set is limited, the sake of efficiency rather suggests a scheme based on B-MAC. It should be remembered that the proposed schemes extremely limit the energy consumption compared to classical networks.

6.1.5. Data dissemination in Urban Environment

Participants: Belhaoua Asma, Nadjib Achir, Paul Muhlethaler.

Over the last decade, wireless sensor networks have brought valid solutions to real-world monitoring problems. Sensors are now incorporated in all our modern life facilities, such as mobile phones, vehicles, buses, bus stations, bikes, etc. For example, mobile phones, with their increasing capabilities are used as voice communication device but also as a sensing device able to collect data such as image, audio, GPS position, speed, etc. All these sensors could play an important role in the provisioning of a multitude of dynamic information about their environmental trends. Considering that, WSN could be considered as a valid solution to urban monitoring problems by bringing new services for the city or for the citizens. According to the last requirement, the main question that we need to answer is how the data could be collected and/or transmitted? Several algorithms were developed recently for sensor data gathering in WSN. However, the majority of existing works on WSN has focused only on specific areas applications, such as environmental monitoring, military target tracking, weather forecast, home automation, intrusion detection, etc. In this training we studied the existing strategies of dissemination in Delay/ Disruption Tolerant Networks (DTN). The main objective is to identify those that can be applied to urban environments. We implemented and tested several strategies in the WSNet network simulator on a dense network.

6.2. Cognitive Radio Networks

6.2.1. 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.
Current Wireless Sensor Networks (WSNs) are deployed over unlicensed frequency bands that face an increased level of interference from various wireless systems. Cognitive Radio Sensor Networks (CRSNs) overcome this problem by allowing sensor nodes to access new spectrum bands to minimize interferences. In this paper, we focus on the MultiChannel Time Slot Assignment problem (MC-TSA) in CRSN. Each sensor node is assigned the number of time slots it needs to transfer its own data as well as the data received from its children in the rooting tree rooted at the sink without interfering with other secondary users. Besides, sensor nodes cannot transmit on a channel occupied by a primary user. Our objective is to increase the network throughput offered to sensor nodes. We start by formulating the MC-TSA problem as an Integer Linear Program where the goal is to minimize the number of slots in the schedule.We then propose an Opportunistic centralized TIme slot assignment in COgnitive Radio sensor networks (OTICOR). We evaluate its performance in terms of number of slots and throughput.

6.2.2. Leader election in Cognitive Radio Networks

Participants: Paul Muhlethaler, Dimitrios Milioris.

This is a joint work with Philippe Jacquet from Alcatel-Lucent Bell Labs.

In this sudy we have introduced a new algorithm (green election) to achieve a dis- tributed leader election in a broadcast channel that is more efficient than the classic Part-and-Try algorithm. The algorithm has the adavantage of having a reduced overhead $log(log(N))$ rather than $log(N)$. More importantly the algorithm has the a greatly reduced energy consumption since it requires $O(N^{1/k})$ burst transmissions instead of $O(N/k)$, per election, k being a parameter depending on the physical properties of the medium of communication.

One of the applications of green election is for wireless col- lision algorithms in particular in cognitive wireless networks where the secondary network is WiFi IEEE 802.11. Since the green election is low energy consuming, it can be used as a systematic and repetitive medium access control that will naturally prevail over the WiFi CSMA scheme.

6.3. Development, implementation and distribution of the Ey-Wifi module for the NS3 simulation tool

Participants: Hana Baccouch, Cédric Adjih, Paul Muhlethaler.

Ey-Wifi module is an ns-3 module developed within the Mobsim project. Ey-Wifi stands for Elimination-Yield for WiFi networks. The main goal of Ey-Wifi is to integrate the features of the EY-NPMA channel access scheme in the ns-3 Wifi module. EY-NPMA (Elimination-Yield Non-Pre-emptive Priority Multiple Access) is a contention based protocol that has been used as the medium access scheme in HIPERLAN type 1. The main advantages of EY-NPMA are: low collision rate, more determinism and priority support. EY-NPMA is based on active signaling (black burst): a node requests access to the medium by transmitting a burst signal. More precisely, the channel access cycle comprises three phases : priority phase, elimination phase and yield phase. Compared to Wifi, EY-NPMA adds the transmission of a burst in the elimination phase: it reduces the number of nodes, that will compete in next "yield" phase (equivalent to the contention window based access of WiFi).

Furthermore, the performances of Ey-Wifi have been evaluated and compared with those of Wifi with ns-3. Distribution of Ey-Wifi module: The module and a tutorial explaining how to use it, are available at: http://hipercom.inria.fr/Ey-Wifi

6.4. Mobile ad hoc and mesh networks

6.4.1. Geographic routing and location services

Participants: Selma Boumerdassi, Pascale Minet, Paul Muhlethaler.

Thanks to its scalable nature, geographic routing is an interesting alternative to topological routing for ad-hoc networks. In fact, in order to set up such a network, each node needs to know the location of the others and location services are in charge to provide such an information.

Two kinds of location services have been provided using either a flooding or a rendez-vous, a node in the network being chosen as a server for the rendez-vous. In the scope of our research, we have proposed different mechanisms based on social groups and/or communities and studied their impact on the control traffic of various protocols. For example, based on the simulations of SLS and SFLS using NS-2, we have demonstrated that the social behaviour of nodes has a strong impact on location services and therefore that next-generation location services should take the relationships between the network users into account.

6.4.2. Optimized Broadcast Scheme for Mobile Ad hoc Networks

Participants: Ahmed Amari, Nadjib Achir, Paul Muhlethaler.

In this training we propose an optimized broadcasting mechanism, which uses very limited signaling overhead. 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.

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

Participants: Dana Marinca, Pascale Minet.

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. We intend to use and improve this prediction technique to design dynamically adaptive regret matching algorithms that will be applied to dynamically manage the resources in wireless networks, especially in sensor networks. These algorithms will allow the network to choose an optimal behavior, otherwise called a correlated equilibrium, from a defined behaviors' set. This behavior will be able to evolve in time to adapt to the network context evolution. We will focus mainly but not exclusively on applications like: the choice of communication channels depending on the predicted quality of transmission, energy efficiency, network nodes deployment, efficient routing, and intelligent switching between available technologies in a multi-technology context.

6.6. Vehicular Ad hoc NETworks (VANETs) for car merging

Participant: Paul Muhlethaler.

This is a joint work with Oyunchimeg Shagdar from the IMARA team.
Cooperative Adaptive Cruise Control (CACC) systems are intended to make driving safer and more efficient by utilizing information exchange between vehicles (V2V) and/or between vehicles and infrastructures (V2I). An important application of CACC is safe vehicle merging when vehicles join a main road, achieved by compiling information on the movement of individual main road vehicles. To support such road safety applications, the IEEE standardized the 802.11p amendment dedicated to V2V and V2I communications.

In this study, we have seek answers to the questions as to whether the IEEE 802.11p can support merging control and how the communications performance is translated into the CACC performance. We have built an analytical model of the IEEE 802.11p medium access control (MAC) for transmissions of the ETSI-standardized Cooperative Awareness Messages (CAM) and Decentralized Environmental Notification Messages (DENM) to support merging control. We have also developed a highway merging decision algorithm. Using computer simulations, packet delivery ratio (PDR), and packet inter-reception (PIR) time of IEEE 802.11p-based V2V and V2I communications and their impact on the CACC performance have been investigated. Our study has disclosed several useful insights including that PIR and throughput provide a good indication of the CACC performance, while improving PDR does not necessarily enhance the CACC performance. Moreover, thanks to its ability to reliably provide information at constant time intervals, the V2I structure offers a better support for CACC than V2V.

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 2013, Inria took part with EDF to the specification of a simplified OCARI stack for a porting to a 32 bit platform.

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.

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. Inria is in charge of coordinating the academic partners. During year 2013, we specified the protocols for layer 3. We organized demonstrations in March at Rocquencourt and in July 2013 at Suresnes to prove our concepts.

8.1.2.2. CONNEXION

Participants: Pascale Minet, Saoucene Ridene, 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 CONNECTION (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 involved in wireless sensor networks coping with node mobility. We focused on deployment and redeployment algorithms for mobile wireless sensor networks after a disaster. We began with a state of the art. Many works in the literatures deal with this issue. We distinguish:

- Grid based approach: sensors will redeploy according to a predetermined grid.
- The computational geometry based approach uses the Voronoi diagram and the Delaunay triangulation.
- The virtual force based approach is based on virtual forces to move sensors.

The virtual force based approach presents many advantages such as simplicity and fast coverage. That is why we adopt this approach. However, the distributed version is prone to node oscillations that consume energy. We proposed two distributed algorithms to reduce node oscillations: ADVFA that adapts to the effective number of operational sensor nodes and GDVFA that takes advantage of grid to avoid these oscillations and to easily detect redundant nodes that can sleep to save energy.

8.1.2.3. SMARTMESH

Participants: Cédric Adjih, Alaeddine Weslati.

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

Period: 2010 - 2013.

Partners: SAGEM, CEA, Telecom SudParis, Ineo Defense, IEF, Orelia, Prodomo, Reflex CES, Evitech, Accuwatt.

SMARTMESH is a System@tic project, focused on the design of intelligent wireless sensor mesh networking for video surveillance and intrusion alarm systems.

In 2013, Inria finalized the communication subsystem comprising the following elements:

- Communication hardware using Senslab nodes (WSN430), directly connected to “SMARTMESH” nodes, with 802.15.4 radio.
- Communication software based on an extended version of the Contiki-OS
- Extensions of RPL routing protocol: P2P-RPL and MLN-RPL (Multi-Level Neighborhood RPL, for filtering appropriate links).
- Adaptation of the Contiki-OS 802.15.4 MAC layer for enabling better performance.
- Development of a cross-layering transport layer, to allow the efficient transport of large burst of data (images), on top of the 6lowpan/802.15.4 layer: a “burst-mode” communication protocol.

During the year 2013, the different components of the SMARTMESH project have been integrated to develop a specific application of area surveillance, with an easily deployable system. The system comprises a number of sensors: audio sensors, PIR sensors, infrared cameras, standard camera; a number of sophisticated signal processing algorithms (audio, video, distributed fusion and tracking, energy management); the communication susbsystem itself; and a control/supervising terminal (displaying alarms, and tracks in real time).

Ten SMARTMESH prototype nodes have been created, integrating the different components. They have been tested in deployments in the military camp of Beynes (mostly from december 2012 to february 2013). The deployments had been planned with a map describing orientation and positions of the sensors of the nodes.

A demonstration of the entire SMARTMESH project was successfully conducted on 22 february, with the following application: detection of human "intruders", and of vehicles, and tracking of their motion.

8.1.2.4. ACRON

Participant: Cédric Adjih.

Period: 2011 - 2013

Partners: Supélec (Télécommunications), Inria, ENS TREC, Inria HIPERCOM, Université Paris-Sud, IEF.

ACRON is a DIMLSC DIGITEO project. It deals with analysis and design of self-organized wireless networks. The HIPERCOM team project will study the theoretical limits of wireless networking.

In 2013, we finalized a protocol for diffusion in Vehicular Networks (VANETs) using network coding: the "DONC" diffusion protocol (joint work with Anthony Busson and Farhan Mirani in particular). The protocol is combining network coding with delay-based broadcast.

8.1.2.5. 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.

8.1.2.6. MOBSIM

Participants: Cédric Adjih, Paul Muhlethaler, Hana Baccouch.

Period: 2011 - 2013

Partners: Inria Sophia, Inria Genoble.

MOBSIM is an ADT, Action of Technology Development. It aims at developping the NS3 simulation tool. The HIPERCOM team focuses on routing protocols and MAC protocol (namely the EY-NPMA protocol Elimination Yield Non-Preemptive Multiple Access). An engineer has been recruited for this project.

Thanks to the ADT, a module for the simulator ns-3 has been released: Ey-Wifi. It is available, along with a detailed tutorial explaining how to use it, at: http://hipercom.inria.fr/Ey-Wifi

8.2. International Initiatives

8.2.1. Participation In other International Programs

8.2.1.1. AWSN 2013

Program: Euromediterranean 3+3

Title: Auto-adaptivity in Wireless Sensor Networks

Inria principal investigator: Pascale Minet

International Partners:

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 also: 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 2013, the AWSN project organized two workshops reserved to AWSN teams:

- Workshop in Rocquencourt in September 2013.
- Workshop in Catania in December 2013.

The AWSN project organized also two open workshops:

- RAWSN 2013 in Marrakech in May 2013 organized by the Moroccan team: see the program on http://www.netys.net/rawsn2013/, workshop held in conjunction with NETYS 2013.
- PEMWN 2013 workshop in Hammamet in November 2013, organized by the Tunisian and French teams, see the program on https://sites.google.com/site/pemwn2013/final-program

8.3. International Research Visitors

8.3.1. 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. Scientific Animation

Pascale Minet was member of the program committee of:

- AdHocNets 2013, 5th International ICST Conference on Ad Hoc Networks, October 2013.
- DCNET 2013, International Conference on Data Communication Networking, July 2013,
- ETFA 2013, 18th IEEE International Conference on Emerging Technologies & Factory Automation, September 2013.
- ICN 2013, the 12th International Conference on Networks, January 2013.

- IFIP Wireless Days 2013, November 2013.
- IUCC 2013, the 12th IEEE International Conference on Ubiquitous Computing and Communications, August 2013.
- IWCMC 2013, the 9th International Wireless Communications and Mobile Computing Conference, July 2013.
- PAEWN 2013, International workshop on Performance Analysis and Enhancement of Wireless Networks, November 2013.
- PECCS 2013, 3rd international conference on Pervasive and Embedded Computing and Communication Systems, February 2013.
- RAWSN 2013, first International Workshop on RFID and Adaptive Wireless Sensor Networks, in conjunction with NETYS 2013, Marrakech, Morocco, April 2013.
- RTNS 2013, 20th International Conference on Real-Time and Network Systems, September 2013.
- SERA 2013, Int. Conf. on Software Engineering Research & Applications, August 2013.
- SNPD 2013, 12th International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing, June 2013.

Pascale Minet was also reviewer for the following journals:

- IEEE Transactions on Vehicular Technology,
- The International Journal of Networked and Distributed Computing,
- International Journal of Communication Systems,
- International Journal of Distributed Sensor Networks,
- Computer Communications Journal,
- Ad Hoc Networks journal.

Paul Muhlethaler was reviewer for the following projects:

- the call 8 of the European commission: "Networks of the future".
- ANR projects,
- ASTRID projects.

Paul Muhlethaler was reviewer for the following journals:

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

Paul Muhlethaler was also member of:

- the Steering commitee of MobileHealth 2013, 3rd ACM MobiHoc Workshop on Pervasive Wireless Healthcare In Conjunction With MobiHoc 2013 Conference, June 2013, Hilton Head Island, South Carolina, USA,
- the Technical committee of the second International Workshop on Performance Evaluation and Modeling in Wireless Networks, PEMWN 2013, November 2013, Hammamet, Tunisia.

Cédric Adjih was member of the program committee of:

- AINTEC 2013, ACM Asian Internet Engineering Conference, November 2013.
- PEMWN 2013, 2nd International Workshop on Performance Evaluation and Modeling in Wireless Networks, November 2013, Hammamet, Tunisia.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Licence : **Ichrak Amdouni** taught "Imperative programming" at Univeristy 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 : **Ichrak Amdouni**, "Wireless Self-adaptive Ad hoc and Sensor Networks: Energy Efficiency and Spatial Reuse", University Pierre et Marie Curie - Paris VI, February 2013, Pascale Minet, adviser.

9.2.3. Juries

HdR : Rami Langar, "Urban wireless networks: mobility, routing and resource management concerns ", University Pierre et Marie Curie, Sorbone universities, December 2013, Paul Muhlethaler, reviewer.

PhD :

- Mouhannad Alattar, "Security supervision of mobile ad hoc networks: a lightweight, robust and reliable intrusion detection system", University of Franche-Comté, July 2013, Pascale Minet, reviewer.
- David Fotue, "Agrégation et routage efficace de donnés dans les réseaux de capteurs sans fil", Telecom ParisTech, October 2013, Pascale Minet, president.
- Skander Azzaz, "Maintenance proactive des réseaux de capteurs sans fil", ENSI, Tunisia, Novemver 2013, Pascale Minet, examinator.
- Abir Ben Ali, "Contrôle de congestion dans les applications multimédia dans l'Internet sans fil", ENSI, Tunisia, November 2013, Paul Muhlethaler, reviewer.
- Ahmed Soua, "Réseaux véhiculaires: dissémination, routage et collecte de données: modèles et algorithmes", Telecom SudParis & University Pierre et Marie Curie, Sorbone universities, November 2013, Paul Muhlethaler, examinator.

9.3. Popularization

- **Futur en Seine**, in Paris, June 2013. The HIPERCOM2 team was very active and presented demonstrations of Wireless Sensor Networks with a focus on the context of Smart Cities. The demonstration prepared by Cédric Adjih, Ichrak Amdouni, Hana Baccouch, Ridha Soua and Ala-Edin Weslati 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; along with application of wireless sensor networks to Smart Cities. The open testbeds for wireless sensor networks, Senslab and Equipex-FIT were also presented: what do they offer and how to use them.
- Nadjib Achir, Cédric Adjih, Hana Baccouch, Ichrak Amdouni 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 2013.

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