INRIA

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team hipercom

High performance communication

Paris - Rocquencourt, Saclay - Île-de-France

Theme : Networks and Telecommunications

Activity Report

2010

Table of contents

1. Team

Research Scientists

Philippe Jacquet [Team Leader, Ingénieur Général en Chef des Mines(DR), HdR]
Pascale Minet [Research Associate (CR), HdR]
Paul Mühlethaler [Ingénieur en Chef de l'Armement (DR), HdR]
Cédric Adjih [Research Associate (CR)]
Emmanuel Baccelli [Research Associate (CR)]

Faculty Members

Thomas Clausen [Assistant Professor Polytechnique]
Khaldoun Al Agha [LRI (Paris XI), HdR]
Tara Ali-Yahiya [LRI (Paris XI)]
Lila Boukhatem [LRI (Paris XI), HdR]
Lin Chen [LRI (Paris XI)]
Steven Martin [LRI (Paris XI)]
Anis Laouiti [INT (Evry)]

Technical Staff

Yasser Toor [INRIA, Engineer]
Naimi Meraihi [INRIA, Engineer]

PhD Students

Iskander Banaouas [INRIA PhD]
Yacine Mezali [INRIA PhD]
Saoucene Ridene [INRIA PhD]
Ichrak Amdouni [INRIA PhD]
Salman Malik [INRIA PhD]
Ridha Soua [INRIA PhD]
Juan-Antonio Cordero [INRIA PhD]
Ulrich Herberg [Polytechnique PhD]
Marienestor Mariyasagayam [CIFRE Hitachi PhD]
Mohammad Abdul Awal [LRI (Paris XI) PhD]
Youghourta Benfattoum [LRI (Paris XI) PhD]
Lana Iwaza [LRI (Paris XI) PhD]
Nour Kadi [LRI (Paris XI) PhD]
Sara Medlej [LRI (Paris XI) PhD]
Simon Odou [LRI (Paris XI) PhD]
Joseph Rahmé [LRI (Paris XI) PhD]
Despina Triantafyllidou [LRI (Paris XI) PhD]

Post-Doctoral Fellows

Nadjib Ait Saadi [INRIA, Post Doc]
Alonso Silva [INRIA, Post Doc]
Ignacy Gawedzki [LRI (Paris XI), Post Doc]

Visiting Scientists

Leila Saidane [November 2010, ENSI (Tunisia)]
Nikita Vvedenskaya [October-November 2010 IITP (Russia)]
Wojciech Szpankowski [Purdue University (USA)]
Yutaka Takahashi [Kyoto]
Walter Grote [Universidad Santa Mar'a (CHILE)]

Administrative Assistant

Christine Anocq [shared time (with Gang and Aoste)]

Others

Skander Azzaz [December 2010 (ENSI)]
Chiraz Houaidia [December 2010 (ENSI)]
Nesrine Ben Mariem [August 2010 (ENSI)]
Chayma Zidi [August 2010 (ENSI)]
Brinis Nour [August 2010 (ENSI)]

2. Overall Objectives

2.1. Introduction

Hipercom project-team aims to design, evaluate and optimize the telecommunication algorithms. The aimed areas are protocols, new telecommunication standards and quality of service management in 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 Hipercom project team is specialized in local area networking, local loops, in particular mobile ad hoc networking. However the thematic extends to the information theory and modelization of internet graph and traffics.
The scientific foundations are the following:

- Analytic information theory,
- Methodology for telecommunication algorithm evaluation,
- Traffic and network architectures evaluation,
- Algorithms conception and implementation

The objectives assigned to HIPERCOM were:

- Massive mobile dense wireless networks
- New services and protocols
- Wireless and backbone integration
- Convergence 4G manet internet

The last objective about the convergence between 4G and manet has been put aside to the benefit of the three other objectives. The main reason is because there is no real demand in this very technological item.

2.2. Highlights

The HIPERCOM project-team took part in the OCARI project (Optimization of Communications in Ad hoc Industrial Networks), funded by the ANR. The project coordinator was EDF, the industrial partners were DCNS and TELIT and the research partners LIMOS, LATTIS, LRI and INRIA.
The role of the HIPERCOM project-team was to design and specify:

- an energy efficient routing protocol (EOLSR) meeting the application needs. EOLSR uses only nodes with sufficient residual energy to build the routes and selects the one minimizing the energy consumed by the transmission of a message from the source to the final destination.
- a node activity scheduling based on node coloring (SERENA). SERENA allows nodes to sleep and thus save energy, transparently to the upper layers. SERENA contributes to reduce interferences insofar as nodes with the same color can transmit simultaneously without interfering.
- an energy model of network node that is battery equipped. This model provides a good accuracy in realistic operational conditions, better than the traditional linear one.

This project ended in June 2010 by a final review meeting. ANR qualified the project of excellent and exemplary by the results obtained, quality of cooperation between the partners and the industrial perspectives.

In 2011, a full scale test of the OCARI network will be performed in an EDF site. EDF, INRIA, LIMOS and TELIT actively contribute to this experimentation and performance evaluation.

3. Scientific Foundations

3.1. Analytical information theory

Participants: Philippe Jacquet, Yacine Mezali, Wojciech Szpankowski.

Glossary

Information theory Branch of mathematics dedicated to the quantification of the performance of a medium to carry information. Initiated by Shannon in 1948.

Abstract. Information theory and analytical methods play a central role in the networking technology. It identifies the key parameter that must be quantified in order to characterize the performance of a network.

The analytical information theory is part of the foundations of the Hipercom project. This is a tool box that has been collected and adapted from the areas of the analysis of algorithms and the information theory. It provides powerful tool for the analysis of telecommunication algorithms. The analysis of the behavior of such algorithms in their asymptotic range are fundamental in order to identify their critical parts. It helps to design and properly scale the protocols. Application of analytical information theory ranges from channel capacity computations, compression algorithm performance evaluation, predictor designs.

3.2. Methodology of telecommunication algorithm evaluation

Participants: Mohammad Abdul Awal, Cédric Adjih, Khaldoun Al Agha, Tara Ali-Yahiya, Emmanuel Baccelli, Youghourta Benfattoum, Lila Boukhatem, Lin Chen, Thomas Clausen, Lana Iwaza, Philippe Jacquet, Nour Kadi, Saoucene Ridene, Steven Martin, Sara Medlej, Pascale Minet, Paul Mühlethaler, Simon Odou, Joseph Rahmé, Yasser Toor, Despina Triantafyllidou.

Abstract. 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 to identify and quantify 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 systemized 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.

3.3. Network traffic and architecture models

Participants: Cédric Adjih, Philippe Jacquet, Salman Malik, Yacine Mezali, Naimi Meraihi.

Glossary

Power laws probability distributions that decays has inverse power of the variable for large values of the variable. Power laws are frequent in economic and statistical analysis (see Pareto law). Simple models such as Poisson processes and finite state Markov processes don't generate distributions with power laws.

Abstract. Network models are important. We consider four model problems: topology, mobility, dynamics and traffic models.

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 a coverage area, or because some other nodes leaves the coverage area.

The traffic model is very most important. There are plenty 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 dependences that don't exist in Poisson traffic. There are still strong issues about the origin of this long range dependences 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.

3.4. Algorithm conception and implementation

Participants: Mohammad Abdul Awal, Cédric Adjih, Khaldoun Al Agha, Tara Ali-Yahiya, Emmanuel Baccelli, Youghourta Benfattoum, Lila Boukhatem, Lin Chen, Thomas Clausen, Lana Iwaza, Nour Kadi, Philippe Jacquet, Steven Martin, Saoucene Ridene, Sara Medlej, Naimi Meraihi, Pascale Minet, Paul Mühlethaler, Simon Odou, Joseph Rahmé, Despina Triantafyllidou, Yasser Toor.

Abstract. Algorithms are conceived with focal point on performance. The algorithms we specify in detail range between medium access control to admission control and quality of service management.

The conception of algorithms is an important focus of the project 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 imbedded simulation with existing network simulators. The algorithm specified by the project ranges from multiple access schemes, wireless ad hoc routing, mobile multicast management, Quality of service and admission controls. 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 be performing such to 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 are found are quantified with respect to the optimal solution.

4. Application Domains

4.1. Wireless mobile ad hoc networks

Abstract. Mobile wireless networks have numerous applications in rescue and emergency operation, military tactical networking and in wireless high speed access to the internet.

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 the most obvious application of mobile ad hoc networks.
Soldiers invading a country won't susbscribe in advance to the local operator. On the reverse side, home units won't use their local operators firstly because they will likely be disrupted in the first hours of the conflict, and secondly because a wireless communication via an operator is not stealth enough to protect the data and the units. In Checheny, a general has been killed by a missile tracking the uplink signal of his portable phone.
The rescue context is halfway between military and civilian applications. In the september 11 disaster, most of the phone base station of the area have knocked out in less than twenty minutes. The remaining base stations were unable to operate because they could not work in ad hoc mode. The Wireless Emergency Rescue Team recommanded afterward that telecom operators should provide ad hoc mode for their infrastructure in order to operate in emergency situation in plain cooperation with police, firemen and hospital networks.
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.

4.2. Services over mobile networks

Abstract. New wireless network calls for new services that fullfil the requirement in terms of mobility and capacity.

The generalization of a new generation of mobile networks calls for a new set of services and applications. For example:

- Indoor and outdoor positioning
- Service discovery and localisation
- Multicast and quality of services

Quality of service has become the central requirement that users expect from a network. High throughput, service continuity are critical issue for multimedia application over the wireless internet where the bandwidth is more scarce than in the wired world. A significant issue in the ad-hoc domain is that of the integrity of the network itself. Routing protocols allow, according to their specifications, any node to participate in the network - the assumption being that all nodes are behaving well and welcome. If that assumption fails - then the network may be subject to malicious nodes, and the integrity of the network fails. An important security service over mobile networks is to ensure that the integrity of the network is preserved even when attacks are launched against the integrity of the network.

4.3. Community Network

Abstract. There is an increasing demand to deploy network within a community, rural or urban, with cabled or wireless access.

Community networks or citizen network are now frequent in big cities. In America most of the main cities have a community network. A community network is using the communication resource of each member (ADSL, Cable and wireless) to provide a general coverage of a city. Pedestrian in the street or in city mails can communicate via a high speed mobile mesh network. This new trend now appears in Europe with many experiments of the OLSR routing protocol in Paris, Lille, Toulouse, Berlin, Bruxelles, Seattle. The management of such networks is completely distributed and makes them very robust to faults. There is room for smart operators in this business.

4.4. Vehicular Networks

Abstract. Intelligent transport systems require efficient wireless telecommunications.

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.

4.5. Large ad hoc networks with sensor nodes

Abstract. 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.

In this domain, Hipercom's activity with wireless sensor nodes in collaboration with the Freie Universitaet in Berlin explores various solutions, including extensions of OLSR (for example DHT-OLSR) using programmable sensor nodes co-designed by the Freie Universitaet, and provides one of the largest testbeds of this kind, to date.

4.6. Wimax

Abstract. OFDMA is a promising technology for future generation of wireless networks.

In multi-user wireless environments, one of the reliable solutions is OFDMA (Orthogonal Frequency Division Multiple Access) technology which is being considered as a modulation and multiple access method for 4th generation wireless networks. The high bandwidth of OFDMA comes from thousands of orthogonal subcarriers which are assigned by groups to the mobile stations. Since the channel condition of a mobile station changes over time due to the fading, interference and path loss, the next generation wireless systems use adaptive modulation and coding (AMC) techniques to change their sending rates based on the channel quality information. Reducing the channel information feedback overhead is one of the major challenges in OFDMA systems. Therefore, we proposed the use of a dynamic channel predictor to reduce the feedback overhead and to improve the overall throughput and spectral efficiency of the system.

5. Software

5.1. OLSR softwares

Participants: Cédric Adjih [correspondant], Emmanuel Baccelli, Thomas Clausen, Philippe Jacquet, Saoucene Ridene, Naimi Meraihi, Pascale Minet, Paul Mühlethaler, Yasser Toor.

Abstract. The routing protocol OLSR has been implemented in Linux and Windows for real experiment with Wireless LAN networks. There are also implementations for simulator such as NS-2 and Opnet.

The current version of OLSR, called OOLSR (for Object oriented OLSR), is IETF RFC compliant with multiple interfaces and tunable mobility parameters and has been fully tested during the three successive OLSR Interops in San Diego, August 2004, Paris August 2005 and Tokyo/Niigata 2006 . This version runs with Linux and Windows. The linux daemon is very easy to install and can be downloaded from the web page. There have been more than 6000 downloads of the code which is exceptional for a routing protocol. This version also contains feature adaptable to wireless driver, such as the signal power monitor.
Related to OLSR, we have implemented and successfully tested in linux the Multicast routing protocol SMOLSR (Simple Multicast on OLSR) that efficiently broadcast data on wireless networks using MultiPoint Relays and the MOLSR (Multicast over OLSR) protocol. We have also implemented the MOST protocol (Multicast Overlay Spanning Trees) that forwards data to multicast group members on an overlay tree built on an OLSR shortest path tree.
Numerous code (including one in Python) have been developped for experiment and simulation (NS-2, Opnet). See http://hipercom.inria.fr/olsr/.
Other modules have been added to OOLSR dealing with autoconfiguration, security and QoS. Some of these modules have been experimented on the CELAR platform consisting of 18 nodes.
The code development of the next version of OLSR (OLSRv2) is being done and experimented at Hipercom@LIX with jOLSRv2.
Support for routing protocols has been integrated with AgentJ in NS2 (Hipercom@LIX).
Extensions to OLSRv2 are being implemented including autoconfiguration (AUTOLSR) and multicast (MPRFlood, Mostv2) at INRIA Rocquencourt. An automated node installation and management software was developed and used to deploy testbeds (including the one at CELAR) and perform measurements.

6. New Results

6.1. Massive mobile dense wireless networks

Participants: Cédric Adjih, Khaldoun Al Agha, Emmanuel Baccelli, Youghourta Benfattoum, Lin Chen, Philippe Jacquet, Nour Kadi, Saoucene Ridene, Steven Martin, Yacine Mezali, Pascale Minet, Paul Mühlethaler, Yutaka Takahashi, Yasser Toor.

6.1.1. Executive summary

Scaling properties of mobile ad hoc network lead to an increase of global capacity when the network density increases or when the packets can be stored for a while in mobile nodes instead of being immediately retransmitted.

Gupta and Kumar have shown in 2000 that the transport capacity per node in a multihop ad hoc network decreases in *1 / sqrt(N log N)*, *N* being the number of nodes in the network. Therefore the global capacity of the network increases in *sqrt(N) / sqrt(log N)*. This is a surprising result since in wired network a collection of nodes connected to a single communication resource has a transport capacity that just remains constant (*i.e.* the average per node capacity decreases in *1/N*).

Therefore adding space to a multihop wireless network increases the capacity: this is the space capacity paradox.
When nodes randomly move, it turns to be more advantageous to store packets for a while on mobile routers instead of forwarding them immediately like hot potatoes. When the mobile router moves closer to the destination, then it can delivers packets on a much smaller number of hops. Of course the delivery delay is much longer, but the network capacity also increases by slowing non urgent packets. This is the time capacity paradox: by slowing packets, nodes mobility increases network capacity. This was hinted the first time by Grossglauser and Tse in 2002.

The great challenge is to find the good protocol and tunings that allow to adjust the delivery delay from zero to infinity in order to get a continuous increase in capacity. The challenge is two-sided: one has to keep the delivery delay between reasonable bounds and one has to consider realistic mobility models.
Existing protocols for Mobile Ad Hoc Networks (MANET) are highly efficient in routing data between mobile nodes that belong to the same connected component (cf. the protocols which have received the RFC status by the manet group of IETF). What about a disconnected network where source and destination may be located in two different connected components? In this case usual routing protocols drop packet due to host unreachable as no end-to-end route exists at that time.

A simple idea is to allow the router that has no available route to the destination to keep the packet in buffer until the conditions become more appropriate for forwarding. The forwarding conditions will change because of mobility: the router can move closer to the destination so that they belong to the same connected component and the packet can be delivered.

Indeed, the network may be continuously partitionned due to high mobility, and the traditional approach to allow a mobile node to wait for the network to be fully connected (i.e. form a unique component) or to wait to be in range of the destination may lead to unacceptable delays. Furthermore, concrete applications, such as Defence and Disaster-Relief, cannot always rely on such assumptions.

Nevertheless, even if the communicating nodes may never be within the same connected component, it is important to observe that a “communication path” may be available through time using intermediate nodes that are temporarily within reach of each other while moving, hence making such networks viable for critical applications. Depending on the nature of the environment, these networks are now commonly referred as Intermittently Connected MANET and Delay Tolerant Networks.
In between stands the problem of the fully connected network that forms a single connected component, but for which maintening full knowledge of the topology would simply make the network collapse under its huge control traffic. In fact this is the main problem that wireless network engineering has to face, in most experiments the generation of control traffic is the main source of disruption.

6.1.2. Scientific achievements

6.1.2.1. Scaling and spatial capacity in non uniform wireless networks

We found a more precise instance of Gupta- Kumar result by using a simple but realistic network model based on slotted ALOHA with Poisson traffic. It turns out that when the traffic density increases then the average node neighborhood area shrinks so that the average encircled traffic load remains constant with an analytical expression..

In their original model Gupta and Kumar assume that the traffic density is constant, which is far from realistic. However we have derived similar generalized results when the traffic density is not uniform. In this case, the heavier is the local traffic, the smaller are the local neighborhood and the larger is the number of hops needed to cross the congested region. Therefore the shortest paths (in hop number as computed by OLSR) will have a natural tendancy to avoid congested are. The path tend to follow trajectory that have analogy in non linear optic with variable indices.

6.1.2.2. Time capacity and node mobility

We have defined a protocol that takes advantage of node mobility in a general way. In short the packet stay with its host router as long as the latter does not evade too fast from its next hop (computed via a shortest path protocol such as OLSR). In the way we understand "too fast" stands the tuning parameters we discussed above. There is no need to have node geographical location and to physically measure motion vector, since everything can be done via the analysis of the dynamic of neighborhood intersections. We analytically derived performance evaluation under random walk mobility models. We plan to simulate the protocol in a real mobility scenario. This algorithm has application in Intelligent Transport System.

6.1.2.3. Overhead reduction in large networks

The first limitation of multihop wireless network is the size of the overhead per node that increases linearly with the size of the network. This is a huge improvement compared to classic internet protocols which have quadratic overhead increases. Nevertheless this till limit the network size to some thousands. We have analyzed the performance of OLSR with Fisheye feature that significantly reduce the overhead with respect to distance. In theory the overhead reduction allows to network size of several order of magnitude. Anyhow the tuning of the overhead attenuation with distance must be carefully done when the network is mobile, in order to avoid tracking failure. We showed that an overhead reduction within square root of the network size achieve this goal.

An alternative way to overhead reduction is ad hoc hierarchical routing and Distributed Hashing Table. Work has just begun in this area.

6.1.2.4. Opportunistic routing

The model of wireless networks based on dynamic graph does not well assess the real processes in a wireless network. In particular the range of transmission can greatly vary between packets, the graph keeping only the average range. Opportunistic routing consists into taking advantage of temporary extension of the transmission range in orger to gain several hops.

We have strong established theoretical performance limits in opportunistic routing. The limits are based on realistic interference scenarios in slotted Aloha. We have also investigated the impact of mobility on this theoretical limits.

We have designed an opportunistic routing protocol whose performance are within a small margin of the theoretical limits.

6.1.2.5. Intermittent and delay tolerant networks

We consider the problem of routing in these networks, with the sole assumption that the speed of the node mobility is less than the speed of transmitting a packet to a neighbour. We compare this problem with sound propagation in liquid. We show that various pattern of mobility and network clustering can be described by a single parameter such as the information speed propagation.

We introduce new algorithms that route a packet toward a remote destination. The different algorithms vary depending on the buffering and the capacity capabilities of the network (i.e. if one or more copies of a packet can be sent and/or be kept). All algorithms are based on link aging rumors across connected components. The packet bounces from connected components to connected components, thanks to node mobility. We establish several analytical properties using an analogy with the sound propagation in liquid where molecules creates temporary connected components where sounds travel very fast.

Previous models assumed that the propagation of information path evolves like in a dynamic Erdos-Renyi graph leading to an epidemic flooding in O(log n) or O(1), n being the number of nodes in the network. We disprove the Erdos-Renyi model by showing via space-time considerations that the set of information path from a source to a destination is in fact much smaller than the path set in the Erdos-Renyi model. This lead to a much larger minimal delay in square root of n instead of log n. This correspond to a bounded maximal information propagation speed, whose estimate depends on the mobility model and the node density, and is root of multivariate explicit Bessel formulas.

6.1.2.6. Network Coding

We study network coding for multi-hop wireless networks. We focus on the case of broadcasting where one source transmits information to all nodes in the network. Our goal is energy-efficient broadcast, that is, minimizing the total number of transmissions for broadcasting to the entire network. Note that this is a different problem for the classical problem of capacity maximization ; and assuming we are far from the network capacity limit, hence in fact, we could assume interference-free transmissions.

Our previous results, they had shown that network coding (and a simple coding strategy) was able to reach optimality for assymptotically large and dense networks, with assympotically 100 % of the received transmissions being useful (innovative). We extended the results with the combined use of connected dominating sets and network coding: we were able to quantify (and bound) the benefits of network coding in networks where the area of the network stays fixed, and only the density increases.

We have proved that the performance of wireless random network coding are optimal in the following network model: the Erdos-Renyi random graph model and the unit disk random graph model. In particular we show in the Erdos-Renyi the network coding capacity rate outperform any Connected Dominating Set strategy by a factor of order log n. In the unit disk model we gain is larger than 60%. The result is based on the analysis of the connectivity stretch ratio of the random graphs. The connectivity stretch ratio is the ratio of the smallest degree over the connectivity number, and the connectivity stretch ratio tends to one in the two graph models.

6.1.3. Collaborations

- Professor Bernard Mans, Macquarrie University, Sydney, Australia,
- TREC INRIA team,

6.2. New services and protocols

Participants: Mohammad Abdul Awal, Cédric Adjih, Khaldoun Al Agha, Tara Ali-Yahiya, Ichrak Amdouni, Emmanuel Baccelli, Youghourta Benfattoum, Lila Boukhatem, Lin Chen, Thomas Clausen, Walter Grote, Lana Iwaza, Philippe Jacquet, Nour Kadi, Saoucene Ridene, Steven Martin, Sara Medlej, Naimi Meraihi, Pascale Minet, Paul Mühlethaler, Simon Odou, Joseph Rahmé, Despina Triantafyllidou, Yasser Toor.

6.2.1. Executive summary

The user of a mobile network very quickly experience problems with quality of service: links fade, connectivity disrupts, delays accumulate.

In a wireless network, the set of neighbors which with one node can communicate depends on transmission range, and numerous factors, and in addition the transmission range is often lower than the interference range (the range within which a node prevents correct transmissions of other nodes). Thus bandwidth reservation, a crucial step of quality of service, is an important and difficult problem.

The services and protocols that need careful adaptation are

- Connectivity continuity
- Bandwidth reservation
- Delay routing
- Connectivity control
- Autoconfiguration
- Security
- Energy efficiency

The connectivity continuity is the most important problem. Trivial in the wired world where a link failure is a rare event, it becomes problematic in the mobile world where link failure caused by mobility are frequent and normal. The first experiments of mobile ad hoc networks with regular internet protocols miserably failed simply because either the protocol was to slow to recover link failure, or when tuned appropriately was generating such a huge overhead that the network collapsed under its own weight. A new generation of routing protocols has arised that allow a suitable control of connectivity in mobile networks. Among them the *Optimized Link State Routing* combines the optimization of overhead for mobile networks and the full internet legacy. It naturally provides path redundancy which accelerate link failure recovery.

The most important lesson that must be retained is that most of these optimization become NP complete, which is a significant complication compared to their counterpart in the classical wired world. The reason for the NP-completeness is two-sided: on one side the co-interferences make impossible an optimization link by link, on the other side, the large dispersion of performance measurement makes simple heuristic ineffective. As an example, routing with respect to shortest delay average does not guarantee smallest probability of high delay.
Since the bandwidth is scarce, any multimedia application such as video streaming is resource demanding. For example a TV broadcast that uses a mesh network will rapidly exhaust the bandwidth if all connections are point to point. In this case multicast protocols that allows to gather all these point to point connections in a single flow is a need.

There are two classes of multicast protocols: the tree based protocols and the network coding protocols. In the first class the protocols take advantage of the relatively small size of the recipient node set. One can show equivalent results of Gupta and Kumar scaling properties but in the multicast plan when the ratio of recipient versus network size is a fundamental parameter. When this ratio tends to one the performance naturally worsen.

When the recipient set is the whole network, one can apply the network coding scheme with random packet combination. In network coding the packets are no longer isolated: relay nodes makes linear combination of packets and transmitted mixed packets. In theory the performance of network coding is better than isolated packet multicast. In practice network coding is simpler to operate does not need topology management such as spanning trees or Connectedc Dominating Set. The reason for this is highly non intuitive, as if packet superposition was acting like state superposition in quantum mechanic, leading to non expected results.

Quality of service has become the central requirement that users expect from a network. High throughput, service continuity are critical issue for multimedia application over the wireless internet where the bandwidth is more scarce than in the wired world. A significant issue in the ad-hoc domain is that of the integrity of the network itself. Routing protocols allow, according to their specifications, any node to participate in the network - the assumption being that all nodes are behaving well and welcome. If that assumption fails - then the network may be subject to malicious nodes, and the integrity of the network fails. An important security service over mobile networks is to ensure that the integrity of the network is preserved even when attacks are launched against the integrity of the network.

6.2.2. Scientific achievements

6.2.2.1. Optimized Link State Routing (OLSR)

The routing protocol OLSR is universally known in the mobile wireless community (more than 475,000 hits on Google). It has numerous implementations and is used in many wireless networks. It is a proactive protocol with full internet legacy which is based on partial topology information exchange, that non the less provide optimal path with additive metrics (such as BGP/OSPF). It is an experimental RFC within IETF and soon will become a full standard under the name OLSRv2.

6.2.2.2. Bandwidth reservation in mobile ad hoc networks

We have shown that the search of a good path for a new connection that does not destroy the quality of service of existing connections is an NP-hard problem. The result is independent on how the bandwidth nodes interfer as long they interfer at least on one hop. In this area, one contribution was the definition and testing of an efficient reservation algorithm bandwidth reservation, respecting wireless network constraints. A second contribution is more accurate computation of remaining link bandwidth by considering bandwidth on other links multiplied by the average packet retransmission on this link (inverse of packet successful transmission rate).

We have also proposed a solution called QoS-OLSR that enhances OLSR with Quality of Service support. This solution, taking radio interferences into account, ensures that QoS flows, if accepted by the admission control, will receive a bandwidth close to this requested. This solution has been implemented on the MANET/OLSR demonstrator of CELAR (MoD).

6.2.2.3. Multi-metric routing

Quality of service involves finding routes between two nodes in the network that satisfies a number of constraints. These constraints could be the requested bandwidth, the maximum delay, the minimum loss probability, the reliability of links, etc. This problem is NP-Complete because it combines additive metrics in the optimization problem. Hipercom proposed heuristics for finding routes that respect up to four metrics when calculating routes between source and destination. Another QoS issue is the creation of models that estimate the actual value of a metric. For example, computing the available bandwidth or the transfer delay on a link, etc. is very complex in a non-deterministic medium access such as Wi-Fi. To resolve this problem, we developed a model for estimating the available bandwidth in a wireless network. This model is based on considering interfering links in cliques, after which we provide the maximum capacity that could be deployed in a clique. We may still enhance the model by adding a scaling factor to the clique equations in order to become more accurate when compared to real measurements.

In particular we have investigated the metric based on packet delay distribution. Since propagation delays between routers are negligible, most delays occur in queueing and medium access control processing. Contrary to previous common belief there is no need of network synchronization. The objective is to proactively determine the delay in absence of packet data traffic. The estimate of delay distribution is done via analytical method. In order to keep control on quality of service flows we use source routing forwarding options.

6.2.2.4. End-to-end Optimizations, TCP

Transport Control Protocol is an old protocol that ensures end-to-end forwarding between source and destination. With multi-hop networks, TCP suffers from multiple problems such as delays introduced by the routing on wireless simple nodes. From the scalability point of view, changing TCP implies the modification of a billion of TCP/IP stacks that is not possible today. We have been exploring how to find the correct routing protocols in order to optimize the timers' calculation in TCP and increase bandwidth and fairness.

6.2.2.5. Multicasting in mobile ad hoc networks

The goal of multicast protocols is to allow the network to deliver the multicast information to interested users. The multicast protocol builds and maintains a structure that will provide routes to all nodes in the multicast group; hence, they will receive the information multicast in their group. Multicast protocols can be classified according to the following criteria:

- **Multicast structures maintained by the multicast protocol: trees or meshes**. We distinguish:
  - Shared tree. In the shared tree based family only one tree is built for each multicast group. Sources are not required to be a part of the multicast structure; they need an entry point to send their data to (the root of the tree for example, or the nearest tree member).
  - Source tree based. In the source based family, a tree is built for each tuple <source, multicast group>. For each multicast group we have several trees. Notice that IGMPv3 [16] enables multicast source selection, which is straightforward with this kind of multicast tree.
  - Mesh based protocols maintain a structure containing all the participants to the multicast group; all the multicast sources and the multicast receivers. The target is to have several paths from one sender to each destination. Data is relayed and delivered through different paths to the receivers. Hence, it increases the robustness against link breakages. This robustness against the topology changes in mesh based protocols, are however more demanding in terms of bandwidth consumption compared to the tree based protocols which are more efficient in terms of resource usage.

- **Flat/Overlay structure**. In the flat category, all nodes are assumed to handle multicast data and can participate in the multicast structure building and maintenance (tree, mesh). In the overlay category, multicast nodes of a same group build and maintain a virtual structure on top of physical structure that links all the participants using unicast tunnels. In this case, not all nodes within the network are supposed to know about the multicast protocol routing, they only have to forward the encapsulated multicast data that flows inside the unicast tunnels.

6.2.2.6. Performance evaluation of multicast protocols

The HIPERCOM team-project has designed three multicast protocols:

- SMOLSR, an optimized broadcast protocol using the multipoint relays defined in OLSR;
- MOLSR, a multicast protocol maintaining a source tree structure and using the topology information provided by OLSR;
- MOST, a multicast protocol maintaining a shared tree structure and using overlays. It also uses the topology information provided by OLSR.

We have performed extensive simulations on the INRIA cluster with NS2 to quantitatively study the behavior of each protocol in different scenarios and configurations. The quality of the multicast is evaluated by the packet delivery ratio while we have varied:

- the number of multicast groups,
- the number of sources,
- the number of clients in a group,
- the source rate,
- the Broadcast rate,
- the number of network nodes,
- the mobility.

The overhead induced by the multicast traffic is given by the measure of the number of retransmissions per multicast packet, also called average packet forwarding. The measures obtained through NS2 are then compared to those obtained by a graph simulator which shows similar results. With these results, we can deduce the applicability domain of each multicast protocol studied: SMOLSR, MOLSR and MOST.

6.2.2.7. Theoretical upper bound

We have derived a theoretical upper bound of the multicast capacity in wireless network. This result is an extension of Gupta and Kumar result about unicast capacity in wireless network. It is shown that the multicast delivery allows an increase of capacity of the order of the square root of the size of the multicast group compared to the attainable capacity if only parallel unicast connections were used. We have also shown that the protocol MOST actually attains this upper bound.

6.2.2.8. Redeploying mobile wireless sensor networks with virtual forces

Wireless Sensor Networks should be self-organized to enhance the coverage after an initial random deployment. We consider a network of mobile sensors deployed randomly in a known surface S, for example sensors dropped from a helicopter or an airplane. The aim is to redeploy these sensors to fully cover the surface S. The network obtained must also be connected, while ensuring fault tolerance. In this context several solutions have been proposed. The solutions based on virtual forces, VFA, one of the most efficient algorithms proposed in the literature, have the advantage of faster convergence and less complexity.

In our study, we evaluate by simulation the behavior of existing approaches of VFA with respect to four performance criteria: coverage, connectivity, energy consumption and fault tolerance. This performance analysis shows the need for improvements to ensure the performance criteria previously described. This algorithm does not achieve full coverage and connectivity in some cases, even when the number of sensors is sufficient.

A first improvement gives rise to SerializedVFA. Simulations on several scenarios shown improvement in coverage and connectivity in relation to existing versions, and also the limitations of this solution in terms of energy consumed and fault tolerance.
In order to save sensors power for a higher network lifetime, we implemented LmaxSerializedVFA which exhibits good performance concerning the distance travelled by sensors to reach their final positions.
To ensure fault tolerance, we designed DthLmaxSerializedVFA. Simulations of this final version of VFA have shown that it guarantees the four performance criteria with the convergence of the algorithm in a number of iterations better than that achieved by existing versions. It proceeds by serializing and limiting nodes moves as well as increasing the robustness degree.
As a future work, we will propose a decentralized algorithm of virtual forces and make the necessary improvements to ensure our performance criteria.

6.2.2.9. Network coding

In traditional communication systems, nodes exchange data in packets, through relaying by intermediate nodes without modification of their content (routing). Seminal work from Ahlswede, Cai, Li and Yeung in has introduced the idea of network coding, whereby intermediate nodes are mixing information from different flows (different bits or different packets), for instance performing "exclusive or" between packets, before retransmitting them.

The Hipercom team is studying network coding specifically for MANET networks. It is mostly used as an efficient multicast/broadcast method (limiting the number of transmissions), and also as a reliable flooding mecanism. Hence, we are studying network coding in the context exclusively of energy-efficiency (and not capacity maximization).

We have proved theoretical results that extend previously obtained results. In another direction of work, we have designed a practical protocol to perform broadcast with network coding, DRAGONCAST which builds on these theoretical results. The main advantages of DRAGONCAST are its energy-efficiency and its simplicity. We analyzed it by simulations and simple models; it successfully illustres how (and how well) energy-efficient broadcast with a simple method could be performed with network coding.

Our research also aims to optimize the capacity of an ad hoc network by using network coding techniques. Our goal is to take advantage of the properties of ad hoc networks that use shared medium (radio interface) and also common forwarding nodes (MPR in OLSR for example), in order to increase their capacity.

6.2.2.10. Autoconfiguration

Thomas Clausen is co-chair of the IETF working group *Autoconfiguration in MANET*.

A preconditioning for all routing protocols, OLSR included, is that each node is identifiable through an unique identifier We have developed, and published, a simple auto-configuration mechanism for OLSR networks, aiming a solving the simple but common problem of one or more nodes emerging in an existing network. Our solution is simple, allowing nodes to acquire an address in two steps: first, acquiring a locally unique address from a neighbor node. Then, with that locally unique address and using the neighbor from which the address was acquired as proxy, obtaining a globally unique address.

Furthermore, autoconfiguration also addresses the problem of keeping the consistency of a nomadic network while changing frequently its attachment to the internet. A mobile network (MONET) is a specific network which has the ability to move as a unit while maintaining its connectivity to Internet. Examples of such networks are those deployed in public transportation systems (buses, trains, taxis, etc.) allowing travelers to exchange information and access to the global Internet. Our main research topic in this area concerns radio resource management during mobility. We proposed a resource reservation strategy which can be used by the MONET's mobile router to prepare the grouped handover of all the supported traffic flows. This strategy is based on the predictive movement of MONET networks and showed good results in terms of lost packets and handover dropping probability.

6.2.2.11. Security in OLSR

In ad hoc networks, security is a very important issue since routing nodes are anonymous. In this case, any node, could change its correct information, insert false information, take the identity of other nodes, etc. All the attacks are very easy because anybody could enter and exit the network and also the medium is wireless and open. Moreover, for the survival of a network, we need the willingness of the nodes in order to route packets to the final destination. If nodes do not cooperate correctly, the routing becomes inefficient. Our solution was to develop two different approaches, one based on intrusion detection that checks the incoherence in the routing protocols and then sends alerts to nodes in order to deactivate the intruders and the second is based on flow conservation that permits to check nodes that avoid forwarding. We introduced the latter property into QoS mechanisms, in order to introduce security as a metric in the routing protocol and to find reliable and secure links.

This issue is a hot issue in ad hoc networks since these networks are inherently open networks. We have reached the following results:

1. we have designed two security mechanisms to counter most of the attacks when we assume that there is no compromized nodes in the network; the first one has been implemented on the MANET/OLSR demonstrator of CELAR (MoD).
2. in presence of compromized nodes we have proposed mechanisms to detect compromised nodes or links and to remove such nodes or links in a numerous configurations of attacks.

A significant issue in the ad-hoc domain is that of the integrity of the network itself. Routing protocols allow, according to their specifications, any node to participate in the network - the assumption being that all nodes are behaving well and welcome. If that assumption fails - then the network may be subject to malicious nodes, and the integrity of the network fails.

An important security service over mobile networks is to ensure that the integrity of the network is preserved even when attacks are launched against the integrity of the network.

Hipercom@LIX has allied with TANC@LIX - a research group specialised in cryptography and security, which has developed strong security mechanisms yielding short cryptographic signatures which can be rapidly verified.

The goal of this Hipercom/TANC alliance is to develop secure OLSR networks, suitable for real-world deployments where network integrity is paramount.

This effort is supported by DIGITEO Labs.

6.2.2.12. OLSR with metrics

In practical networks, one property of many networks is that wireless transmissions may be done with the same equipment but with different parameters, such as modulations (with various payloads), transmission power, etc...This is true, for instance, for 802.11 networks, where different modulations are standardized.

However in the common OLSR routing protocol, this is not addressed, since the view is a binary view of links, which are considered either symmetrical (and then equivalent) or not usuable.

The question is how to take into account this ability to transmit in several manners, so that routing (with OLSR) is performed efficiently. We have proposed an extension of the OLSR routing protocol using metrics, that are well adapted to wireless networks with the characteristics of 802.11 networks.

6.2.2.13. Cross layer, sensor networks, energy efficiency

The diversity of the applications supported by wireless sensor networks explain the success of this type of network. These applications concern as various domains as environmental monitoring, wildlife protection, emergency rescue, home monitoring, target tracking, exploration mission in hostile environments... Sensor nodes are characterized by a small size, a low cost, an advanced communication technology, but also a limited amount of energy. This energy can be very expensive, difficult or even impossible to renew. That is why, energy efficient strategies are required in such networks in order to maximize network lifetime.

Solutions to maximize network lifetime can be classified into four categories:

- *Topology control:* These strategies adjust the transmission power of wireless nodes to spare energy;
- *Reduction of the volume of information transferred:* These strategies aggregate data with or without clustering, optimize network flooding, tune the periodicity of information refreshment;
- *Nodes activity scheduling:* as the sleeping state is the radio state consuming the least energy, these strategies make nodes sleep in order to spare energy, while ensuring network and application functions.
- *Energy efficient routing:* Such strategies notice that a multihop transmission is energy consuming and reducing the energy spent in the transmission of a packet from its source to its destination would increase network lifetime. Moreover, avoiding nodes with a low residual energy would also contribute to prolong network lifetime. Avoiding nodes that already have a high traffic load would reduce medium access contention, collisions if the medium access type is CSMA-CA and then spare energy lost in useless transmissions.

6.2.2.14. Energy efficient routing

Energy efficiency is a key issue in wireless ad hoc and sensor networks. Energy efficient routing is a way to improve energy efficiency and prolong network lifetime. We have shown how to extend the standardized OLSR routing protocol, in order to make it energy efficient. We have first defined an energy model for multihop transmissions. The energy cost of a one-hop transmission is evaluated, taking into account the energy lost in transmitting, receiving, overhearing and interferences. We have then evaluated the energy cost of multihop transmissions. Because of radio interferences, the selection of a unicast path, between a source and a destination, ensuring that each node has sufficient residual energy is NP-hard (see Mans 2006).

The OLSR extension we propose, called EOLSR, selects the path minimizing the energy consumed in the end-to-end transmission of a flow packet and avoids nodes with low residual energy. To take into account residual node energy, the native selection of multipoint relays of OLSR is changed. It considers the weighted residual energy of the multipoint relay candidate and its 1-hop neighbors. The cost associated with a multipoint relay candidate represents the maximum transmission duration that can be sustained by this node. Each two-hop neighbor must be covered by the candidate of maximum cost. These new multipoint relays are called EMPRs. They are used to build energy efficient routes, whereas the native MPRs are used to optimize network flooding. No additional message is required in EOLSR. In order to select the EMPRs, the Hello messages include the residual energy of the sending node and of its one-hop neighbors. In order to compute the energy cost of a flow, we need to know the number of nodes up to two-hop of the node considered, assuming that interferences are limited to two hops. Hence, the TC (Topology Control) messages include the number of nodes belonging to the interference area of the TC originator.

We show by simulation that EOLSR outperforms the solution that selects routes minimizing the end-to-end energy consumption, as well as the solution that builds routes based on node residual energy. We also compare EOLSR with a two-path source routing strategy: DL a two-path source routing with different links and DN a two path source routing with different nodes. As expected, native OLSR provides the smallest network lifetime. This shows that the selection of the shortest path is not sufficient to save energy. Concerning the two multipath source routing strategies, DN provides better results than DL. This is not surprising insofar as energy is dissipated per nodes and not per wireless link. Hence, DL that allows common nodes in the two paths can exhaust the energy of these common nodes more quickly. The main conclusion of these simulation runs is that EOLSR significantly outperforms DN and DL whatever the number of nodes. EOLSR prolonges the network lifetime of 50% compared with OLSR for a network of 200 nodes. This extensive performance evaluation allows us to conclude that EOLSR maximizes both network lifetime and the amount of data delivered.

We then show how we can improve the benefit of energy efficient routing using cross layering. Information provided by the MAC layer improves the reactivity of the routing protocol and the robustness of routes. Moreover, taking into account the specifities of some applications like data gathering allows the routing protocol to reduce its overhead by maintaining routes only to the sink nodes. We propose the strategic mode of EOLSR for that purpose.

The EOLSR protocol will be implemented in the OCARI project aiming at developing a wireless sensor communication module, based on IEEE 802.15.4 PHY layer and supporting EDDL and HART application layer and targeting applications in power generation industry and in warship construction and maintenance.

6.2.2.15. Nodes activity scheduling

In wireless ad hoc and sensor networks, an analysis of the node energy consumption distribution shows that the largest part is due to the time spent in the idle state. This result is at the origin of SERENA, an algorithm to SchEdule RoutEr Nodes Activity. SERENA allows router nodes to sleep, while ensuring end-to-end communication in the wireless network. The idea is to assign a color to each node, while using a small number of colors and ensuring that two nodes with the same color can transmit without interfering. This color is mapped into a slot in which the node can transmit its messages. Any node stays awake only during its slots and the slots assigned to its one-hop neighbors, it sleeps the remaining time. We propose a generic solution able to adapt to different application requirements: general or tree-based communications, broadcast, immediate acknowledgement of unicast transmissions... The impact of each additional requirement is evaluated by simulation. For instance, for general communications with immediate acknowledgement, two-hop coloring is no longer sufficient, three-hop coloring is required.

An originality of this work lies in taking into account real wireless propagation conditions. Unidirectionnal links, late node arrivals, appearance of new links and node mobility can create color conflicts. A cross-layering approach with the MAC layer is used to solve these conflicts. We also show how cross-layering with the application layer can improve the coloring performance for data gathering applications. In such applications, the freshness and time consistency of data collected from the sensors must be ensured. SERENA enables collected data to reach the sink in a single cycle, minimizing the end-to-end delays. This property is obtained by obliging a node to select a color higher than its parent. Hence, it will transmit before its parent that aggregates the data received from its children.

A performance evaluation allows us to compare SERENA coloring algorithm with existing ones such as Distributed Largest First, denoted DLF, both in terms of number of colors and complexity. SERENA and DLF use a similar number of colors, whereas the complexity of SERENA expressed in numbers of rounds is significantly lower. Moerover, it turns out that the number of colors used by SERENA depends (i) strongly on the network density and (ii) weakly on the number of nodes. We have also compared SERENA with TDMA-ASAP that does not support immediate acknowledgement of unicast transmissions. The immediate acknowledgement is very useful in a wireless environment prone to message losses.

Simulation results show that SERENA maximizes both network lifetime as well as the amount of data delivered to the application. Moreover SERENA improves efficiency in the the node energy consumption. The first benefit of SERENA is that less energy is lost in the idle state. Indeed, if a node has nothing to transmit and its one-hop neighbors are not transmitting, the node is sleeping. The second benefit is that SERENA contributes to significantly reduce the interference phenomenon that becomes negligible. Hence, SERENA considerably improves the energy efficiency of wireless ad hoc and sensor networks. Moreover, SERENA increases the utilization of network resources such as bandwidth by means of spatial reuse.

The SERENA protocol will be implemented in the OCARI project. A strong cooperation with the MAC layer enables an efficient time slot allocation and an early detection of color conflicts. This cooperation improves the performances of SERENA in a network where bandwidth and energy are limited.

In order to reduce the overhead induced by the coloring algorithm SERENA, we have optimized the messages used to color the network nodes, both in the general case (three-hop coloring) and in the tree case used by data gathering applications. These messages do no longer contain the priority and color of all the one-hop and two-hop neighbors, but still ensure that the nodes color themselves according to the order given by their priority. Hence, it is possible to use SERENA, even in case of large and dense networks.

SERENA with the optimized messages is implemented in C and will be embedded in wireless sensors implementing the MACARI protocol developped by LIMOS.

6.2.2.16. *Real-time networking*

In a real-time constrained network, some of the applications coexisting in the network require bounds on their worst case end-to-end response times and jitters to have a behavior compliant with their specifications (e.g. voice over IP, control-command applications, multimedia applications, distributed interactive games). To provide deterministic guarantees on these times, we developed an approach, called "trajectory approach", based on flow scheduling. More precisely, assuming that flows are scheduled in each node according to fixed and/or dynamic priorities, our worst case analysis allow establishing upper bounds on the real-time constraints. These results address many applications. They enable to derive, for example, a simple admission control in charge of deciding whether a new flow can be accepted or not, by verifying that the new flow will not experiment a worst case response time greater than its end-to-end deadline and that the acceptance of this new flow will not compromise real-time guarantees given to the already accepted flows.

6.2.2.17. *Optimized routing in low capacity sensor networks*

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.

In this domain, Hipercom's activity with wireless sensor nodes in collaboration with the Freie Universitaet in Berlin explores various solutions, including extensions of OLSR (for example DHT-OLSR) using programmable sensor nodes co-designed by the Freie Universitaet, and provides one of the largest testbeds of this kind, to date.

Additionally, we're happy to make available a muOLSR for Scatterweb implementation.

6.2.2.18. *Protocols for vehicular networks*

We have achieved numerous studies and design of protocols for vehicular networks and more spefically for V2V (Vehicle-to-Vehicle) network.

First we have studied the channel occupancy induced by the OLSR proactive routing protocol used in a linear Vehicular Ad hoc Network (VANET). Unlike previous studies, which usually use simulations to evaluate the overhead, we have proposed a simple analytical model to carry out this evaluation. Moreover, we did not evaluate the total overhead induced by the routing protocol as is usually proposed, but, for a given node, the channel occupation induced by the routing protocol.

We have studied flooding techniques for safety applications in VANETs. The typical scenario is the diffusion of an alert message after a car crash in a platoon of vehicles. The packet is diffused with the pure flooding, the multipoint relay (MPR) diffusion of OLSR and a geographic aware protocol. For OLSR we have introduced a variant (Robust-MPR) to improve the reliability. Different realistic scenarios were considered and various parameters such as vehicle density, and background traffic load were scrutinized. We have shown that the Robust-MPR and the geographic aware protocol satisfy the requirements of the safety applications while using considerably less overhead than pure flooding.

We have shown that the geographic aware protocols can be improved for the diffusion of an alert message by using opportunistic routing. We have designed OB-VAN (Opportunistic Broadcast for VANets) a new protocol that uses this idea. One of the novelty of this protocol is the use of an active signalling technique in the acknowledgement procedure to select the best relay taking advantage of the reception pattern of each message. We have studied OB-VAN in a linear VANET and have shown that it outperforms the flooding for the delay and the amount of overhead. However the delivery ratio of OB-VAN may be insufficient for safety applications. This remark has led to the design of R-OB-VAN which is a reliable variant of OB-VAN. With extensive simulations, we have shown that R-OB-VAN maintains a high delivery ratio even in the presence of packet loss due to shadowing.

We have studied the performance of the Aloha scheme in linear VANETs. This analysis assumes a SINR (Signal over Interference plus Noise Ratio) based model. In this model, we have derived the probability of a successful transmission between two vehicles at a distance of R meters. We have also computed the mean throughput according to Shannon's law. In these two models, we have optimized the two quantities directly linked to the achievable network throughput i.e., the mean packet progress and the density of transport.

Finally, we have studied the utilization of opportunistic routing and shown that this technique is also beneficial for point to point traffic. It decreases the delay and increases the throughput compared with shortest path first routing. Moreover, we have also shown that opportunistic routing for point to point traffic eases considerably the optimization of the MAC scheme e.g. the transmission probability for Aloha and the carrier sense threshold for CSMA.

6.2.3. Collaborations

- Many contractual collaborations:
  - MoD (QoS, security, interconnection between the OLSR and OSPF routing domains),
  - Hitachi (Vehicular applications, OLSRv2),
  - OCARI project (QoS, cross layer, energy efficiency),
  - SARAH project (QoS, localization),
  - Com2react (vehicular applications, multicast),
  - STIC INRIA-Tunisian Universities: the team of Prof. Leila Saidane at ENSI (Performance improvement in a sensor network),
  - Luceor (OLSR with metrics).
- Non contractual:
  - BAE (OLSRv2),
  - Freie Universitaet (sensor networks, DHT).

6.3. Integration wireless and backbone

Participants: Cédric Adjih, Emmanuel Baccelli, Thomas Clausen, Philippe Jacquet, Saoucene Ridene, Pascale Minet, Paul Mühlethaler, Yasser Toor.

6.3.1. Executive summary

We have the following vision: in the future mobile internet and static internet will have their core deeply intricated. This means that mobile ad hoc networks will be attached to the core network, form extension and even be part of it. For example in disaster area, a wireless network could replace the destroyed infrastructure and help to the emergency operations.

With this perspective items such as Autoconfiguration, Security are of crucial importance. However there is a potential conflict between a large population of fixed nodes based on ancient protocol and a smaller but more dynamic population based on new protocols. In the integration both population must cooperate in an hybrid protocol.

The difficulty is to build protocols that are as dynamic and efficient as MANET protocols but can support the legacy of the old and heavy internet protocols. The challenge is nevertheless achievable, because the dynamic part of the network needs less frequent updates from the fixed part of the network. Moreover the natural abondance of resource in the fixed part of the network allows it to support the more frequent updates from the mobile part.

OLSR has been found to be the natural best candidate for this challenge since it gathers dynamic and optimization with internet legacy.

6.3.2. Scientific achievements

6.3.2.1. Optimized Database exchange and check

The problem of unreliable broadcast and less frequent update is that a missing routing information information can lead to lasting problems (loops, disconnections). We have specified an integrity check of distributed databases. We have replaced the heavy check done in wired world that exchanges database headers line by line by a collective check based on signature broadcast and exchange. That way the routing database are synchronized more quickly and discrepant part identified with a logarithmic cost instead of a cost linear to the database size.

6.3.2.2. OSPF-MPR

The INRIA proposal is based on OLSR, in particular the optimization feature called MultiPoint Relay. The overhead reduction is similarly based on flooding reduction, and topology reduction. In particular OSPF-MPR supports optimized routing based on general additive metrics as in OSPF and adapt its topology reduction to those metrics. Compared to OLSR, OSPF-MPR has a feature called adjacency reduction inherited from OSPF, using broadcasted acknowledgement that enhances routing database synchronization. This feature is also optimized with MPR.

6.3.2.3. Gateway OSPF/OLSR

The MANET extension protocols being largely experimental, we have developed a software that enable a gateway between OSPF and OLSR and allows the convergence of both protocols on existing software. This software has been implemented on the MANET/OLSR demonstrator of CELAR (MoD).

6.3.3. Collaboration

We received support from MoD for this activity.

7. Contracts and Grants with Industry

7.1. CELAR

Participants: Cédric Adjih, Philippe Jacquet, Pascale Minet, Paul Mühlethaler, Naimi Meraihi.

The CELAR (Centre d'Electronique de l'Armement, French MoD/DGA) contract has been notified in December 2007. It has a duration of 27 months. It focuses on mobile ad hoc networks. CELAR is interested in the standardization done at the IETF and more particularly within the MANET and AUTOCONF groups, where the HIPERCOM team-project is active. Furthermore, this contract addresses topics that belong to DARPA's recent initiatives about new military wireless networks able to adapt to changing conditions. These networks will be self-forming, self-healing, self-configuring and self-optimizing. They will provide an intelligent relaying and an intelligent power management. All these topics are present in the CELAR contract:

- OLSRv2: identification of the differences with the previous version and expected benefits;
- Multicast protocols: analysis and performance evaluation of three multicast protocols: SMOLSR, MOLSR and MOST;
- Autoconfiguration in IPv6: choice of a solution adapted to military applications;
- Dynamic routing over a hierarchical topology: when does a hierarchical routing outperforms a flat one?
- Adaptive routing on high frequency (HF) links;
- Merge of networks.

Three of them are leading an implementation on a real platform comprising 18 nodes. Nodes are equipped with 802.11b cards and measurements tools on Linux. They implement the OLSR routing protocol. This testbed allows CELAR to make demonstrations with a real mobile ad-hoc network, and evaluate the potential benefits of such a network in military tactical applications, with a special focus on performances and reliability.

- OLSRv2,
- Autoconfiguration,
- Multicast.

This year, we have worked on the specification, implementation and experimentation oftwo multicast protocols MOST and SMOLSR on the MANET/OLSR demonstrator, comprising 9 laptops, operating with IPv6. We have made experiments on video and particular voice applications by emulating military codecs in order to prove the concept of multicasting for military audio-conferences. We have evaluated performances of each protocol and have shown satisfying delays and jitters with MOST protocol.

7.2. OCARI

Participants: Ichrak Amdouni, Saoucene Ridene, Pascale Minet, Khaldoun Al Agha, Joseph Rahmé.

The OCARI (Optimization of Ad hoc Communications in Industrial networks) project, funded by ANR, started in February 2007. It has a duration of 36 months. The industrial partners are EDF (coordinator), DCN and One-RF. The academic partners are LIMOS (Clermont Ferrand university), LATTIS (Toulouse university), LRI (Paris Sud university) and INRIA.
The OCARI project 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),
- Support of IEC61804/EDDL and HART application layer.

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 will be 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 aims at developing a wireless sensor communication module, based on IEEE 802.15.4 PHY layer and supporting EDDL and HART application layer. The INRIA contribution concerns more particularly energy efficient routing and node activity scheduling.

- The energy efficient extension of OLSR, called EOLSR, will be implemented on top of the MAC protocol defined by LATTIS and LIMOS. The MAC protocol is a variant of ZigBee ensuring some determinism and quality of service and allowing leave nodes (e.g. sensor, actuator) as well as router nodes to sleep. The EOLSR protocol avoids nodes with low residual energy and selects the routes minimizing the energy consumed by an end-to-end transmission. EMPRs (multipoint relays taking into account the residual energy) are used to build energy efficient routes. We have shown by simulations that EOLSR increases the network lifetime and outperforms multipath routing (both with different links and with different nodes). The specifications of the EOLSR protocol have been delivered to the industrial partners.
- SERENA, the protocol used to schedule router node activity, is based on three-hop coloring. It allows any node to sleep during the slots thaht are attributed neither to its color nor to its one-hop neighbors. SERENA contributes to a more efficient use of energy: less energy is spent in the idle and interference states. Hence, network lifetime is considerably increased. Specifications of SERENA adapted to the specific context of OCARI (i.e.; very limited bandwidth 250kbps, small size messages 127 bytes, limited memory and limited processing power) have been delivered.

Moreover, INRIA has specified the network layer implementing EOLSR and SERENA. INRIA has defined the message format as well as the network primitives offered to the application layer and management entity. Furthermore, primitives between the network and MAC layers have been specified in cooperation with LIMOS.

7.3. SARAH

Participants: Philippe Jacquet, Juan-Antonio Cordero, Khaldoun Al Agha, Steven Martin, Simon Odou.

The SARAH project, Service Ad hoc/Filaires: Développement d'une Architecture de Réseau Intégré, is an ANR project. It aims at developing an integrated architecture of network. It started in 2007. The partners are ALCATEL, FT R&D, LIP6, LRI, LSIIT, LSR-IMAG, SNCF, ENST, INRIA.

7.4. WIMAX

Participants: Khaldoun Al Agha, Steven Martin.

Period: October 2007 - September 2010

Partners: INRIA, LRI

This project aims to define new metric estimation models and to develop routing algorithms for a better management and QoS support in auto-organizing data networks.

7.5. TRAFIC

Participant: Lila Boukhatem.

Period: December 2006 - February 2010

Partners: LRI, Telecom Paris-Tech, Irseem/Esigelec, Arion

Trafic project, ArchitecTure pour les Réseaux véhiculaire A Forte mobIlité groupée pour la gestion de serviCes temps réel, is an ANR project. It aims at exploiting road state environment and inter-vehicle communication in order to define a hybrid architecture which allows a reliable and predictive group mobility management. Efficient routing protocol and handover mechanisms will be developed based on traffic state information and a predictive mobility approach.

7.6. NC2

Participants: Khaldoun Al Agha, Cédric Adjih, Philippe Jacquet, Nour Kadi.

Period: Oct 2008 - Sep 2012

Partners: L2S; INRIA; MIT (USA) ; AUTH (Greece)

This project aims at enabling collaborations between French and foreign researchers working in the area of computer science and information theory. The objective is to design new optimized solutions for data transmission on shared medium networks. The expected developed research works aim to combine data information using network coding approach.

7.7. RAF

Participants: Paul Mühlethaler, Khaldoun Al Agha, Steven Martin, Simon Odou.

The RAF project, Réseaux ad hoc A Forte efficacité, belongs to the competitiveness cluster SYSTEM@TIC PARIS-REGION. It aims at designing self configuring ad hoc networks using reservation based access protocols using both time and frequency multiplexing. The project has three components : the study of ad hoc networks using a smart relaying function at the Phy/MAC level, the study and design of protocols for ad hoc networks solving simultaneously the access problem using reservation based techniques and the relaying issue for multi hop communication, the realization of a prototype using the IEEE 802.16e (WiMAX Mobile) technology.
The partners are Thalès, Alcatel Lucent, EADS, IEF, INRIA, LRI, Sagem DS, and Supelec.
In this project INRIA is more particularly in charge of optimization and performance evaluation of Ad Hoc networks devoted to security and rescue applications.

INRIA has compared the time division multiple access (TDMA) approachs where time slots are reserved within a radius of n-hop around the transmitter with conventional (Carrier Sense Multiple Access) CSMA protocol controlled by the carrier sense threshold. INRIA has studied the signal to interference and noise ratio (SINR) that is obtained by the two approaches. This study shows that on medium size networks it is difficult to obtain large SINR with a high probability with the TDMA approach whereas it is easy with the CSMA approach.
INRIA has also compared these two approaches in the classical outage model where a packet is received if its SINR is above a given threshold. With this model the TDMA approach offers a sigthly better performance in terms of global throughput than the CSMA approach. The path loss exponent can be changed without changing this result.
The TDMA approach and the CSMA approach are then compared in a model of dynamic coding idealized by Shannon's well-known law. In this model TDMA sigthly outperforms CSMA for every value of path loss exponent between 3 and 5.

7.8. MOBISIC

Participants: Philippe Jacquet, Emmanuel Baccelli.

The MOBISIC project belongs to the competitiveness cluster SYSTEM@TIC PARIS-REGION. It aims at designing and experimenting a modular system (Plug & Play), scalable adapted to events securing and local crisis management. The partners are THALES, ALCATEL, SAGEM, GEMALTO, BERTIN Technologies, EVITECH, SINOVIA, SODERN, CEA, INRIA.

7.9. EXPESHARE

Participant: Philippe Jacquet.

The EXPESHARE project, EXPErience SHAring in mobile peer communities, is an ITEA2 project. The aim is to allow virtual communities to exchange multimedia contents and experiences in a legal and secured way, using different types of personal assistants. The partners are Gemalto, INRIA, INT Evry, City Passenger, NXP Semiconductors, Evry university, Transatel, Brieftec, Capricode, CBT, Comverse, Engineering SpA, Innovalia, Kutalab, Nextel, Nokia, Philips, Shunra Software, SoftwareQuality Systems, Telefonica, University of Oulu, Paderborn university, Politechnica de valencia University, La Spenzia Roma university.

7.10. ETARE

Participants: Cédric Adjih, Philippe Jacquet, Paul Mühlethaler.

ETARE is a project of EDA (European Defense Agency). The goal of the ETARE project is to ease the requirement to transmit more and more information and to interconnect the users in ad hoc networks. These ad hoc networks will link together the different elements on the battlefield (vehicles, foot soldiers, helicopters) and possibly connect them with naval forces. This will be possible through High Data Rate Networking waveforms, which will also insure interoperability between forces.

In this project, INRIA's contribution is focused on network layer. INRIA studies the various protocol's ability to handle heterogeneous ad hoc networks as well as QoS features. INRIA has delivered a draft document for this study with the following issues

- Legacy routing protocols and geographic aware protocols,
- Overhead of routing protocols,
- General QoS architecture and application of this architecture for CSMA and TDMA protocols.

7.11. OPNEX

Participants: Philippe Jacquet, Emmanuel Baccelli, Cédric Adjih, Paul Mühlethaler, Khaldoun Al Agha.

Period: 2008 - 2011.

Partners: Centre Of Research and Technology Hellas, Politechnika Poznanska, Thomson Research, Freie Universitaet Berlin.

OPNEX is an European FP7 project which aims at designing architectures and protocols for multi-hop wireless networks. In this project, systems and optimization theory are used as the foundation for algorithms that achieve full transport capacity of wireless systems.

7.12. e-comp@gnon

Participants: Emmanuel Baccelli, Philippe Jacquet, Cédric Adjih, Anis Laouiti, Salman Malik.

Period: 2008 - 2011

Partners: Archos, SCNF, Telecom SudParis, DGE, Deveryware.

E-comp@gnon is a System@tic project. The goal is the realization of a new type of multimedia terminal, enhanced with wireless ad hoc IP connectivity based on the OLSR protocol.

7.13. SMARTMESH

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

Period: 2009 - 2012

Partners: SAGEM, CEA, Telecom SudParis, Tunecharger, Ineo, Orelia, Prodomo.

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

7.14. CRYPTONET

CRYPTONET is a OMT funded by DIGITEO (with one engineer: Jerome Milan), at Hipercom@LIX, with a partnership with TANC@LIX.

Duration: one year

The goal is to secure jOLSRv2 using ECC.

7.15. Pop-Up Networking

Pop-Up Networking is an Hitachi Collaboration on data propagation in new network models for smart meetering at Hipercom@LIX.

7.16. Wireless Sensor Networks

Wireless Sensor Networks (Industrial) is a collaboration at Hipercom@LIX with Hitachi for routing in WSNs

Duration: April 2009 - April 2010

7.17. FlashLINQ

FlashLINQ is a collaboration between Qualcomm and Hipercom@LIX.

The objective is the study of properties and exploitation of new wireless link type and protocol stack.

Duration: September 2009 - September 2010

8. Dissemination

8.1. Animation of the scientific community

Philippe Jacquet belongs to the editorial board of the DMTCS journal.

Philippe Jacquet has been invited speaker in the following events:

- WiOpt workshop in Avignon, 2010

Pascale Minet was reviewer of the 'Habilitation Diriger des Recherches' of Jean-Luc Scharbarg, "Contribution l'analyse temporelle des réseaux temps réel embarqués", University of Toulouse, September 2010.
She was reviewer of the PhD Thesis of:

- Azza Jedidi, "Mise en oeuvre de nouveaux services dans le cadre du couplage d'un réseau de diffusion de télévision mobile personnelle et d'un réseau cellulaire 3G", University of Rennes, November 2010.
- Bashir Yahya, "Energy efficient and quality of service aware protocols for wireless sensor networks", University of Versailles SaintQuentin, November 2010.
- Patrick Sondi Obwang, "Le routage á qualité de service dans les réseaux mobiles ad hoc", University of Valenciennes and Hainaut-Cambresis, December 2010.

Pascale Minet was chairperson of the jury for the PhD Thesis of Amel Hamdi, "Contrôle dynamique des réseaux et allocation/ordonnancement de ressources dans les réseaux grille", University of ParisSud 11, December 2010.
She was also member of the jury for the PhD Thesis of Teck Aguilar, "Vers un protocole de routage géographique avec contention et communications coopératives pour les réseaux de capteurs", Telecom & Management SudParis, University of Paris 6, December 2010.
Pascale Minet was also member of the Gilles Kahn 2010 jury awarding a 2009 PhD thesis.
Pascale Minet took an active part in the dissemination of the results obtained in the OCARI project, dealing with energy efficient industrial wireless sensor networks. During the ETSI M2M workshop, organized by ETSI in October 2010 at Sophia, Pascale Minet and Tuan Dang (EDF) presented a poster summarizing the results obtained in the OCARI project. Furthermore, at the L2I workshop organized by LIMOS, University of Clermont-Ferrand, in June 2010, she gave a presentation entitled "Bénéfices du cross-layering sur le coloriage dun réseau sans fil", based on the work of INRIA in the OCARI project.
She was member of the program committee of:

- AdHocNets 2010, International Conference on Ad Hoc Networks, August 2010,
- CIT 2010, 10th IEEE International Conference on Computer and Information Technology, June 2010,
- DCNET 2010, International Conference on Data Communication Networking, July 2010,
- ECRTS 2010, 22nd EUROMICRO Conference on Real-Time Systems, July 2010.
- HPCC2010, International Conference on High Performance Computing and Communications, June 2010.
- ICCCN2008, International Conference on Computer Communications and Networks, August 2008.
- ICETE 2010, International Joint Conference on e-Business and telecommunications, July 2010.
- IFIP Wireless Days, October 2010.
- Med-Hoc-Net 2010, 9th annual Mediterranean Ad-Hoc Networking conference, June 2010.
- PAEWN 2010, Int. workshop on Performance Analysis and Enhancement of Wireless Networks, April 2010.
- RTNS 2010, 17th International Conference on Real-Time and Network Systems, November 2010.
- SERA 2010, Int. Conf. on Software Engineering Research & Applications, May 2010.
- SNPD 2010, 10th International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing, June 2010.
- SPECTS 2010, International Symposium on Performance Evaluation of Computer and Telecommunication Systems, July 2010.
- WINSYS 2010, International Conference on Wireless Information Networks and Systems, July 2010.

Besides these conferences, she was reviewer for the following international conferences:

- PIMRC 2010, IEEE International Symposium on Personal, Indoor and Mobile Radio Communications,
- European Wireless 2010.

Pascale Minet was also reviewer for the following journals:

- IEEE/ACM Transactions on Networking,
- IEEE Transactions on Industrial Informatics,
- IEEE Transactions on Vehicular Technology,
- IEEE Transactions on Wireless Communications,
- Simulation Modelling Practice and Theory,
- Ad Hoc Networks journal.

Paul Mühlethaler was reviewer for the following journals and international conferences:

- IEEE ITS Magazine,
- IEEE/ACM Transactions on Networking,
- ISCIS,
- ISIT,
- VTC spring.

Since july, Paul Mühlethaler is scientific head of the DGA/INRIA partnership.

Cédric Adjih was reviewer for GLOBECOM 2010.

Emmanuel Baccelli was :

- member of the technical program committee for PerCom 2010,
- reviewer for IEEE GLOBECOM 2010.

Khaldoun Al Agha was member of the program committee for:

- IEEE Wireless Communications & Networking Conference,
- IASTED International Conferences on Wireless Communications (WC),
- IFIP Networking,
- IFIP Mediterranean Ad Hoc Networking Conference (Med-Hoc-Net),
- IFIP/IEEE Wireless days.

Lila Boukhatem was member of the program committee:

- IEEE InVeNet 2010,
- IEEE International Workshop on Intelligent Vehicular Networks,
- IFIP/IEEE Wireless days.

Lin Chen participates to the program committee of:

- Conference on Decision and Game Theory for Security 2010.

8.2. Teaching

Philippe Jacquet taught:

- class : Mobile networking (Polytechnique),
- class: Telecommunication. Master COMASIC (Polytechnique)

Emmanuel Baccelli taught:

- graduate course on Mobile and Wireless Networks, at Ecole Polytechnique, France.
- vacataire for INF567: Réseaux mobiles et sans fils, with Pr. Philippe Jacquet.

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 “Informatique Fondamentale et Applications” 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.

Khaldoun Al Agha, Lila Boukhatem, Steven Martin, Lin Chen and Tara Ali-Yahia are teachers at the Computer Science department and IUT of Paris-Sud university. They teach every year:

- in the M2R Informatique MASTER (University of Paris-Sud), classes: Mobile networks, Broadband networks
- in L1, L3, M1, M1 Miage, M2 Professionnel and CCI MASTERS (University of Paris-Sud), classes: Networks architecture, Telecommunication, Mobile networking, Security.
- in Ingé1, Ingé2 and Ingé3 levels (IFIPS - Institut de de Formation des Ingénieurs de la faculté Paris-Sud), classes: Networks architecture, Telecommunication, Mobile networking.

Thanks to the contacts created during the IETF meetings, we have started a fruitful close collaboration with Niigata University (prof. K. Mase) about mobile ad hoc networking. Common IETF drafts have been submitted. since buffer capacity might be limited on wireless routers.

Through common IETF activities with R. Wakikawa and K. Uehara, Hipercom has developped strong links with Keio University in Japan. This has recently been formalized through a "memo of understanding", between Hipercom and Keio University. Several joint academic publications as well as IETF publications have been the fruits of this collaboration on various subjects such as porting OLSR on BSD-ZEBRA, MANET-NEMO convergence, OLSR for IPv6.
This collaboration is also enabling Hipercom to take part in the WIDE consortium in Japan uniting Keio University (with J. Murai, the japanese Internet pioneer) and several industry heavy weights such as Hitachi, Mitsubishi, KDDI, NTT and other japanese universities and companies. This initiative is among other things organizing a large scale testing of OLSR on vehicles (with a prospect for testing OLSR on 1500 cars), which promises to be an extremely valuable experience for Hipercom, as no such scale study has been carried out to date.

Within the project STIC INRIA - Tunisian Universities, entitled ‘Auto-adaptativity of a sensor netork with mobile robots: toward a green sensor network’, Professor Leila Azouz Saidane from ENSI was invited by INRIA in July and November. Five of her students, Nour Brinis, Nesrine Ben Mariem, Chayma Zidi, Chiraz Houaidia and Skander Azzaz came at INRIA for a training in August for the first three and in December for the two others. Pascale Minet was invited at ENSI in April and September.

8.3. Standardization

The HIPERCOM project plays an important part in the standardization process. More precisely, it is active at:

- IETF in the following working groups:
  - AUTOCONF: T. Clausen is chairman and E. Baccelli is an important contributor;
  - MANET: see the numerous contribtions of T. Clausen, and P. Jacquet.
  - OSPF: E. Baccelli, T. Clausen and J.-A. Cordero Fuertes are important contributors;
  - ROLL: Thomas Clausen and Emmanuel Baccelli participate in this new working-group; Thomas Clausen is author of the RPL protocol.
- IEEE: HIPERCOM has pending patents with regard to 802.11;
- ETSI: Philippe Jacquet is the INRIA official contact;
- Car2Car: Paul Mühlethaler is the INRIA official contact;
- NATO: Pascale Minet made four presentations about OLSR and its extensions.

8.3.1. OLSRv2 Standardization

The year is 2003, and the IETF has published OLSR as RFC3626....and you'd think that'd be the end of it.

Alas, in 2005, the IETF decided that time had come to advance OLSR from Experimental RFC onto Standards Track, and so, the Hipercom team once again swung into action and OLSRv2 saw the light of day. Based on the same algorithms and ideas as OLSR contained in RFC3626, OLSRv2 builds on the experience gained by a wide community from tests and deployments over the years since RFC3626, and features a more modular and extensible architecture, while being simpler and more efficient than its predecessor.

Standardization is progressing, and we're organizing annual Interop/Workshops, specifically for implementors of OLSRv2 and its constituent parts. In 2008, the OLSR Interop/Workshop was in Ottawa, and in 2009, the OLSR Interop/Wokshop will be in Vienna.

Additionally, we're happy to make available some OLSRv2 Protocol Suite Interop Tools on-line.

Being modular, by design, OLSRv2 is made up from a number of generalized building blocks, standardized independently and applicable also for other MANET protocols. Currently, RFC5148 - Jitter Considerations in Mobile Ad Hoc Networks, RFC5444 - Generalized MANET Packet / Message Format and RFC5497 - Representing Multi-Value Time in Mobile Ad Hoc Networks (MANETs) are published as RFCs, with the remaining constituent parts (NHDP and OLSRv2) being in the final phases of standardization.

As with OLSR (RFC3626), OLSRv2 is being edited by Thomas Clausen (Hipercom@LIX), with contributions from the rest of Hipercom, and from industrial and academic partners world-wide.

The implementation and experimental efforts are being lead by Ulrich Herberg (Hipercom@LIX).

8.3.2. MANET Autoconfiguration

One of the assumptions, often brought forward when discussing MANETs is, that they're self-organizing and that a pre-determined infrastructure can not be assumed present to ensure correct operation.

For this to hold true, routers in a MANET must be able to self-configure with their necessary interface parameters – notably, they must be able to acquire suitable and unique prefixes for assigning addresses to hosts, associated to a MANET router. In the dynamic environment of a MANET, this presents a quite unique challenge.

The IETF AUTOCONF working group, chartered in the fall of 2005 with the task of developing MANET autoconfiguration protocols for IPv6. The working group is co-chaired by Thomas Clausen (Hipercom @LIX).

8.3.3. OSPF for MANETs

OSPF does not work 'as is' on mobile ad hoc networks. OSPF's trademark as a generic Internet routing solution is thus somewhat endangered by the emergence of MANETs.

Since 2005, the IETF is addressing this novelty and working on the standardization of an extension of OSPF for mobile ad hoc networks. Hipercom of course actively participates in this process, since it builds up on MANET experience with proactive routing, and thus OLSR-derived techniques.

We consider a wireless extension for OSPF based on OLSR (RFC3626), the MANET proactive protocol that has emerged as the simplest and most robust solution for mobile ad hoc routing.

This extension has been published as RFC5449 - OSPF MPR Extension for Ad Hoc Networks and defines an OSPFv3 MANET interface type, allowing OSPFv3 deployments including also areas with MANET characteristics.

Hipercom's OSPF standardization effort is being lead by Emmanuel Baccelli.

The implementation and experimental efforts are being lead by Juan Antonio Cordero Fuertes (Hipercom@LIX).

8.4. Associated teams and other international projects

The HIPERCOM project-team works with:

- University of Macquarie, Sidney, Australia: Prof. Bernard Mans: "Algorithmics for Extremely Mobile Wireless Networks",
- ENSI, Tunis, Tunisia: Prof. Leila Saidane: "Performance improvement in a sensor network by means of mobile robots".

9. Bibliography

Major publications by the team in recent years

[1] C. ADJIH, L. GEORGIADIS, P. JACQUET, W. SZPANKOWSKI. *Is the internet fractal ?*, in "SODA 2002", San Francisco, USA, 2002.

[2] C. ADJIH, P. JACQUET, N. VVEDENSKAYA. *Performance evaluation of a single queue under multi-user TCP connections*, INRIA, March 2001, n° RR-4141, http://hal.inria.fr/inria-00072484.

[3] T. CLAUSEN, P. JACQUET, A. LAOUITI, P. MÜHLETHALER, P. MINET, A. QAYYUM, C. ADJIH, L. VIENNOT. *RFC 3626 - Optimized Link State Routing Protocol*, in "Optimized Link State Routing Protocol (OLSR)", MANET working group, 2003.

[4] L. GEORGE, S. KAMOUN, P. MINET. *First come first served: some results for real-time scheduling*, in "ISCA 14th int. conf. on Parallel and Distributed Computing System PDCS'2001", Dallas, Texas, August 2001.

[5] L. GEORGE, D. MARINCA, P. MINET. *A solution for a deterministic QoS in multimedia systems*, in "International Journal on Computer and Information Science", October 2000, vol. 1, n° 3, p. 106-119.

[6] P. JACQUET. *Traffic and queueing from an unbounded set of independent memoryless on/off sources*, in "Self-Similar Network Traffic and Performance Evaluation", Wiley ; editors K. Park and W. Willinger, 2000, n° 11, p. 269-283.

[7] P. JACQUET. *Elements de théorie analytique de l'information, modélisation et évaluation de performances*, Université de Versailles Saint-Quentin, juillet 1998, mémoire d'habilitation, Ph. D. Thesis.

[8] P. JACQUET. *Long term dependences and heavy tails in traffics and queues generated by memoriless on/off sources in series*, INRIA, 1998, n° RR-3516, http://hal.inria.fr/inria-00073168.

[9] P. JACQUET, V. JOLY. *Capacity of retro-information channels*, in "2000 IEEE International Symposium on Information Theory", Sorrento, Italie, June 2000, 182.

[10] P. JACQUET, P. MINET, A. LAOUITI, L. VIENNOT, T. CLAUSEN, C. ADJIH. *Multicast Optimized Link State Routing*, IETF, December 2001.

[11] P. JACQUET, P. MINET, P. MÜHLETHALER, N. RIVIERRE. *Data transfer for HIPERLAN*, in "Wireless Personnal Communications", January 1997, vol. 1, n° 4, special issue on the HIgh PErformance Radio Local Area Network (HIPERLAN).

[12] P. JACQUET, P. MINET, P. MÜHLETHALER, N. RIVIERRE. *Increasing reliability in cable-free radio LANs - low level forwarding in HIPERLAN*, in "Wireless Personnal Communications", January 1997, vol. 1, n° 4, special issue on the HIgh PErformance Radio Local Area Network (HIPERLAN).

[13] P. JACQUET, P. MINET, P. MÜHLETHALER, N. RIVIERRE. *Priority and collision detection with active signaling - the channel accesss mechanism of HIPERLAN*, in "Wireless Personnal Communications", January 1997, vol. 1, n° 4, special issue on the HIgh PErformance Radio Local Area Network (HIPERLAN).

[14] P. JACQUET, W. SZPANKOWSKI. *Analytical depoissonization and its applications*, in "Theoretical Computer Science", 1998, vol. 201, n° 1-2, p. 1–62.

[15] P. JACQUET, W. SZPANKOWSKI. *Entropy calculation via analytic depoissonization*, in "IEEE Transaction on Information Theory", May 1999, vol. 45, n° 4.

[16] S. KAMOUN, P. MINET. *Periodic scheduling of distributed tasks with consistency and hard real-time constraints*, in "International journal of computer and information science", September 2001, vol. 2, n° 3, p. 106-118, ed. International association for computer & information science, ACIS. ISSN 1525-9293.

[17] A. LAOUITI, A. QAYYUM, L. VIENNOT. *Multipoint Relaying: An Efficient Technique for Flooding in Mobile Wireless Networks*, in "35th Annual Hawaii International Conference on System Sciences (HICSS'2001)", IEEE Computer Society, 2001.

[18] P. MINET. *Temps réel, tolérance aux fautes et cohérence dans les systèmes distribués*, Université de Versailles Saint-Quentin, septembre 1998, mémoire d'habilitation, Ph. D. Thesis.

[19] P. MÜHLETHALER. *Contribution à la conception et à l'analyse d'algorithmes pour l'accès multiple et l'ordonnancement sous contraintes temporelles*, Université de Versailles Saint-Quentin, juillet 1998, mémoire d'habilitation, Ph. D. Thesis.

[20] A. QAYYUM. *Analysis and evaluation of channel access schemes and routing protocols in wireless LANs*, Université de Paris Sud, November 2000.

[21] H. RES 10. *Radio Equipment and Systems (RES); HIgh PErformance Radio Local Area Network (HIPERLAN); Functional specification*, ETSI, June 1996.

[22] L. VIENNOT. *Complexity Results on Election of Multipoint Relays in Wireless Networks*, INRIA Rocquencourt, 1998, n° RR-3584, http://hal.inria.fr/inria-00073097.

Publications of the year

Doctoral Dissertations and Habilitation Theses

[23] S. MAHFOUDH. *Efficacité énergétique dans les réseaux ad hoc et de capteurs : routage, ordonnancement de l'activité des noeuds et cross-layering*, University of Paris 6, January 2010.

Articles in International Peer-Reviewed Journal

[24] K. AL AGHA. *Les réseaux de capteurs*, in "Techniques de l'Ingénieur", 2010, to appear.

[25] E. BACCELLI, J. A. CORDERO, P. JACQUET. *OSPF over Multi-Hop Ad Hoc Wireless Communications*, in "International Journal of Computer Networks & Communications", September 2010.

[26] U. HERBERG, T. CLAUSEN. *Security Issues in the Optimized Link State Routing Protocol Version 2 (OLSRV2)*, in "International Journal of Network Security & Its Applications (IJNSA)", April 2010.

[27] N. KADI, K. AL AGHA. *Network Coding Based Flooding in Ad-hoc Wireless Networks Under Mobility Conditions*, in "Annals of Telecommunication, Springer", september-october 2010, vol. 65, n° 9-10.

[28] S. MAHFOUDH, G. CHALHOUB, P. MINET, M. MISSON, I. AMDOUNI. *Node Coloring and Color Conflict Detection in Wireless Sensor Networks*, in "Future Internet", 10 2010, 469..504.

[29] S. MAHFOUDH, P. MINET, I. AMDOUNI. *Energy efficient routing and node activity scheduling in the OCARI wireless sensor network*, in "Future Internet", 8 2010, 308..340.

Articles in Non Peer-Reviewed Journal

[30] G. DOWEK, T. VIÉVILLE, J. ARCHAMBAULT, E. BACCELLI, B. WACK. *Les Ingrédients des Algorithmes*, in "Interstices)i(Journal (Online)", April 2010.

[31] G. DOWEK, T. VIÉVILLE, J. ARCHAMBAULT, E. BACCELLI, B. WACK. *Tout a un Reflet Numérique*, in "Interstices)i(Journal (Online)", January 2010.

International Peer-Reviewed Conference/Proceedings

[32] C. ADJIH, A. MERAIHI NAIMI, P. MINET, T. PLESSE. *IPv6 Autoconfiguration for Mobile Ad-Hoc Networks: AUTOLSR*, in "Information Systems Technology Panel Symposium, IST-092 / RSY -022, "Military Communications and Networks"", Wroclaw, Poland, September 2010.

[33] E. BACCELLI, T. CLAUSEN, R. WAKIKAWA. *IPv6 Operation for WAVE - Wireless Access in Vehicular Environments*, in "Proceedings of IEEE VNC 2010", Jersey City, USA, December 2010.

[34] E. BACCELLI, J. A. CORDERO, P. JACQUET. *Optimization of Critical Data Synchronization via Link Overlay RNG in Mobile Ad Hoc Networks*, in "Proceedings of IEEE MASS 2010", San Francisco, USA, November 2010.

[35] E. BACCELLI, J. A. CORDERO, P. JACQUET. *Using Relative Neighborhood Graphs for Reliable Database Synchronization in MANETs*, in "Proceedings of the Fifth IEEE Workshop on Wireless Mesh Networks (WiMesh 2010)", June 2010.

[36] I. BANAOUAS, P. MÜHLETHALER. *Modeling and Improving CSMA Unfairness in Mobile Ad Hoc Networks*, in "IFIP Annual Mediterranean Ad Hoc Networking IEEE workshop", Juan-Les-Pins, France, June 2010.

[37] I. BANAOUAS, P. MÜHLETHALER. *Sensor collaboration in event detection*, in "Workshop on Interconnections of Wireless Sensor Networks (IWSN'10)", Sanata Barbara, California, June 2010.

[38] Y. BENFATTOUM, S. MARTIN, I. GAWEDZKI, K. AL AGHA. *Manet Routing Considering Intra-flow Interference*, in "APARM'10: Asia-Pacific International Symposium on Advanced Reliability and Maintenance Modeling", Wellington, New Zealand, December 2010.

[39] B. BLASZCZYSZYN, P. MÜHLETHALER, I. BANAOUAS. *Coexistence of radio networks using Aloha*, in "IFIP Wireless Days Conference", Italie Venice, 2010, http://hal.inria.fr/inria-00529904/en.

[40] B. BLASZCZYSZYN, P. MÜHLETHALER. *Stochastic Analysis of Non-slotted Aloha in Wireless Ad-Hoc Networks*, in "Infocom", Etats-Unis San Diego, Xplore, 2010, p. 1 - 9, accepted for IEEE Infocom 2010 [*DOI :* 10.1109/INFCOM.2010.5462086], http://hal.inria.fr/inria-00435236/en.

[41] N. BRAHMI, L. BOUKHATEM, N. BOUKHATEM, M. BOUSSEDJRA, N. D. NUY, H. LABIOD. *End-to-End Routing Through a Hybrid Ad Hoc Architecture for V2V and V2I communications*, in "IFIP/IEEE Med-Hoc-Net'10", Juan-Les-Pins, France, June 2010.

[42] L. CHEN. *A Distributed Access Point Selection Algorithm Based on No-Regret Learning for Wireless Access Networks*, in "IEEE VTC Spring: IEEE 71st Vehicular Technology Conference", Taipei, Taiwan, May 2010.

[43] L. CHEN, S. IELLAMO, M. COUPECHOUX, P. GODLEWSKI. *An Auction Framework for Spectrum Allocation with Interference Constraint in Cognitive Radio Networks* , in "IEEE INFOCOM: 29th IEEE Conference on Computer Communications", San Diego, CA, USA, March 2010.

[44] T. CLAUSEN, U. HERBERG. *Multipoint-to-Point and Broadcast in RPL*, in "Proceedings of the First International Symposium on Frontiers in Ubiquitous Computing, Networking and Applications (NeoFUSION 2010)", September 2010.

[45] T. CLAUSEN, U. HERBERG. *Router and Link Admittance Control in the Optimized Link State Routing Protocol version 2 (OLSRv2)*, in "Proceedings of the 4th International Conference on Network and System Security (NSS 2010)", September 2010.

[46] T. CLAUSEN, U. HERBERG. *Vulnerability Analysis of the Optimized Link State Routing Protocol version 2 (OLSRv2)*, in "Proceedings of the IEEE International Conference on Wireless Communications, Networking and Information Security (WCNIS2010)", June 2010.

[47] M. DI RENZO, L. IWAZA, M. KIEFFER, P. DUHAMEL, K. AL AGHA. *Robust Wireless Network Coding - An Overview*, in "MOBILIGHT'2010: International Conference on Mobile Lightweight Wireless Systems", Barcelona, Spain, May 2010.

[48] U. HERBERG, T. CLAUSEN, R. COLE. *MANET Network Management and Performance Monitoring for NHDP and OLSRv2*, in "Proceedings of the 6th International Conference on Network and Services Management", October 2010.

[49] U. HERBERG, T. CLAUSEN, J. MILAN. *Digital Signatures for Admittance Control in the Optimized Link State Routing Protocol version 2*, in "Proceedings of the International Conference on Internet Technology and Applications (iTAP 2010)", August 2010.

[50] U. HERBERG. *Performance Evaluation of using a Dynamic Shortest Path Algorithm in OLSRv2*, in "Proceedings of the 8th Annual Conference on Communication Networks and Services Research (CNSR)", May 2010.

[51] U. HERBERG, I. TAYLOR. *Development Framework for Supporting Java NS2 Routing Protocols*, in "Proceedings of the 2010 International Workshop on Future Engineering, Applications and Services (FEAS)", May 2010.

[52] P. JACQUET, P. MÜHLETHALER. *Geometric Bucket Trees: Analysis of Linear Bucket Trees*, in "AofA'10", Vienna, Austria, july 2010.

[53] P. JACQUET, P. MÜHLETHALER. *Mean number of transmissions with CSMA in a linear network*, in "IEEE Vehicular Technology Conference VTC2010-Fall", Ottawa, Canada, September 2010.

[54] N. KADI, K. AL AGHA. *Distributed Switched Code (DiSC): A Distributed Rateless Code for Broadcast in Ad-hoc Wireless Networks*, in "IEEE IWCMC'10: The International Wireless Communications and Mobile Computing Conference", Caen, France, June 2010.

[55] N. KADI, K. AL AGHA. *MPR-based Flooding with Distributed Fountain Network Coding*, in "IFIP/IEEE Med-Hoc-Net'10", Juan-Les-Pins, France, June 2010.

[56] N. KADI, K. AL AGHA. *New Degree Distribution to improve LT-Code in Network Coding for Broadcasting in Ad-hoc Wireless Networks*, in "IEEE PIMRC'10: Personal Indoors and Mobile Radio Communications", Istanbul, Turkey, September 2010.

[57] S. MAHFOUDH, P. MINET. *Energy-aware routing in wireless ad hoc and sensor networks*, in "The International Wireless Communications and Mobile Computing Conference, IWCMC'10", Caen, France, June 2010.

[58] B. MARTIN, C. ADJIH, P. MÜHLETHALER, P. JACQUET, S. SCHILLACI. *Enabling technologies as a migration path of tactical networks to future flexible Mobile Ad Hoc Wideband Waveform(s)*, in "Information Systems Technology Panel Symposium, IST-092 / RSY -022, "Military Communications and Networks"", Wroclaw, Poland, September 2010.

[59] A. MERAIHI NAIMI, C. ADJIH, P. MINET, G. RODOLAKIS. *Simulation-based comparison of three wireless multicast routing protocols: MOST, MOLSR and SMOLSR*, in "International Conference on Ad Hoc and Wireless Networks, AdHoc-Now'10", Edmonton, Canada, August 2010.

[60] P. MINET, S. MAHFOUDH, G. CHALHOUB, A. GUITTON. *Node coloring in a wireless sensor network with unidirectional links and topology changes*, in "IEEE Wireless Communications & Networking Conference - WCNC 2010", Australie Sydney, 2010, http://hal.inria.fr/inria-00459543/en.

[61] P. MÜHLETHALER, Y. TOOR, A. LAOUITI. *Suitability of HIPERLANs EY-NPMA for Traffic Jam Scenarios in VANETs ITST'2010*, in "Intelligent Transport Systems Telecommunications,(ITST),2010 10th International Conference on", Kyoto, Japan, November 2010.

[62] J. RAHMÉ, N. FOURTY, K. AL AGHA, A. VAN DEN BOSSCHE. *A Recursive Battery Model for Nodes Lifetime Estimation in Wireless Sensor Networks*, in "IEEE WCNC'10: Wireless Communications and Networking Conference", Sydney, Australia, April 2010.

[63] R. SOUA, L. A. SAIDANE, P. MINET. *Sensors deployment enhancement by a mobile robot in wireless sensor networks*, in "Ninth International Conference on Networks - ICN 2010", France Les Menuires, 2010, http://hal.inria.fr/inria-00459375/en.

[64] W. XIE, M. GOYAL, H. HOSSEINI, J. MARTOCCI, Y. BASHIR, E. BACCELLI, A. DURRESI. *A Performance Analysis of Point-to-Point Routing along a Directed Acyclic Graph in Low Power and Lossy Networks*, in "Proceedings of NBiS 2010", Takayama, Japan, September 2010.

[65] W. XIE, M. GOYAL, H. HOSSEINI, J. MARTOCCI, Y. BASHIR, E. BACCELLI, A. DURRESI. *Routing Loops in DAG-based Low Power and Lossy Networks*, in "Proceedings of the IEEE Advanced Information Networking and Applications (AINA)", Perth, Australia, April 2010.

Research Reports

[66] E. BACCELLI, P. JACQUET, B. MANS, G. RODOLAKIS. *Information Propagation Speed in Bidirectional Vehicular Delay Tolerant Networks*, INRIA, December 2010, n° RR-7266, http://hal.inria.fr/inria-00476993/en.

[67] T. CLAUSEN, E. BACCELLI, R. WAKIKAWA. *IPv6 Operation for WAVE - Wireless Access in Vehicular Environments*, INRIA, September 2010, n° RR-7383, http://hal.inria.fr/inria-00517909/en.

[68] T. CLAUSEN, U. HERBERG. *Comparative Study of RPL-Enabled Optimized Broadcast in Wireless Sensor Networks*, INRIA, May 2010, n° RR-7296, http://hal.inria.fr/inria-00488030/en.

[69] T. CLAUSEN, U. HERBERG. *Multipoint-to-Point and Broadcast in RPL*, INRIA, April 2010, n° RR-7244, http://hal.inria.fr/inria-00470377/en.

[70] T. CLAUSEN, U. HERBERG. *Router and Link Admittance Control in the Optimized Link State Routing Protocol version 2 (OLSRv2)*, INRIA, April 2010, n° RR-7248, http://hal.inria.fr/inria-00472654/en.

[71] T. CLAUSEN, U. HERBERG. *Security Issues in the Optimized Link State Routing Protocol version 2 (OLSRv2)*, INRIA, March 2010, n° RR-7218, http://hal.inria.fr/inria-00460419/en.

[72] T. CLAUSEN, U. HERBERG. *Study of Multipoint-to-Point and Broadcast Traffic Performance in RPL*, INRIA, September 2010, n° RR-7384, http://hal.inria.fr/inria-00517905/en.

[73] T. CLAUSEN, U. HERBERG. *Vulnerability Analysis of the Optimized Link State Routing Protocol version 2 (OLSRv2)*, INRIA, February 2010, n° RR-7203, http://hal.inria.fr/inria-00456376/en.

[74] T. CLAUSEN, U. HERBERG. *Yet Another Autoconf Proposal (YAAP) for Mobile Ad hoc NETworks*, INRIA, July 2010, n° RR-7341, http://hal.inria.fr/inria-00504820/en.

[75] T. CLAUSEN, U. HERBERG, J. MILAN. *Digital Signatures for Admittance Control in the Optimized Link State Routing Protocol version 2*, INRIA, February 2010, n^{o} RR-7216, http://hal.inria.fr/inria-00460057/en.

[76] J. A. CORDERO, E. BACCELLI, P. JACQUET. *OSPF over Multi-Hop Ad Hoc Wireless Communications*, INRIA, April 2010, n^{o} RR-7268, http://hal.inria.fr/inria-00477450/en.

[77] J. A. CORDERO, T. CLAUSEN, E. BACCELLI. *MPR+SP: Towards a Unified MPR-based MANET Extension of OSPF*, INRIA, June 2010, n^{o} RR-7319, http://hal.inria.fr/inria-00492439/en.

[78] U. HERBERG, T. CLAUSEN, R. COLE. *MANET Network Management and Performance Monitoring for NHDP and OLSRv2*, INRIA, June 2010, n^{o} RR-7311, http://hal.inria.fr/inria-00490958/en.

[79] U. HERBERG. *Performance Analysis of SNMP in OLSRv2-routed MANETs*, INRIA, October 2010, n^{o} RR-7407, http://hal.inria.fr/inria-00523607/en.

[80] U. HERBERG. *Performance Evaluation of using a Dynamic Shortest Path Algorithm in OLSRv2*, INRIA, January 2010, n^{o} RR-7174, http://hal.inria.fr/inria-00446110/en.

[81] U. HERBERG, N. MARIYASAGAYAM, T. CLAUSEN. *Comparison of NHDP and MHVB for Neighbor Discovery in Multi-hop Ad Hoc Networks*, INRIA, January 2010, n^{o} RR-7173, http://hal.inria.fr/inria-00446051/en.

[82] P. JACQUET, S. MALIK. *Optimal transmission schemes in wireless networks and their comparison with simple ALOHA based scheme*, INRIA, July 2010, n^{o} RR-7339, http://hal.inria.fr/inria-00504081/en.

[83] P. JACQUET, Y. MEZALI, G. RODOLAKIS. *Indoor Positioning using the IEEE 802.11 Infrastructure*, INRIA, June 2010, n^{o} RR-7294, http://hal.inria.fr/inria-00485454/en.

[84] P. JACQUET, S. WOJCIECH. *New analysis of the asymptotic behavior of the Lempel-Ziv compression algorithm*, INRIA, April 2010, http://hal.inria.fr/inria-00476902/en.

[85] K. MOUGOU. *Redéploiement dans un réseau de capteurs mobiles en fonction de centres d'intérêt*, ENSI Tunis Tunisia, June 2010.

Other Publications

[86] E. BACCELLI, M. TOWNSLEY. *IP Addressing Model in Ad Hoc Networks*, IETF RFC 5889, September 2010, http://tools.ietf.org/html/rfc5889.

[87] B. BLASZCZYSZYN, P. MÜHLETHALER, I. BANAOUAS. *A comparison of Aloha and CSMA in Wireless Ad-Hoc Networks under Different Channel Conditions*, 2010, -, http://hal.inria.fr/inria-00530093/en.

[88] B. BLASZCZYSZYN, P. MÜHLETHALER, Y. TOOR. *Modeling and analysis of slotted and non-slotted Aloha in linear Vehicular Ad-hoc NETworks*, 2010, -, http://hal.inria.fr/inria-00530080/en.

[89] A. BRANDT, E. BACCELLI, R. CRAGIE. *Applicability Statement: The use of RPL in Building and Home Environments draft-00*, draft-brandt-roll-rpl-applicability-home-building-00, April 2010, https://datatracker.ietf.org/doc/draft-brandt-roll-rpl-applicability-home-building/.

[90] T. CLAUSEN, C. DEARLOVE, J. DEAN. *MANET Neighborhood Discovery Protocol (NHDP) draft-12*, draft-ietf-manet-nhdp-12, March 2010, https://datatracker.ietf.org/doc/draft-ietf-manet-nhdp/.

[91] T. CLAUSEN, C. DEARLOVE, J. DEAN. *MANET Neighborhood Discovery Protocol (NHDP) draft-13*, draft-ietf-manet-nhdp-13, July 2010, https://datatracker.ietf.org/doc/draft-ietf-manet-nhdp/.

[92] T. CLAUSEN, C. DEARLOVE, P. JACQUET. *Link Metrics for OLSRv2 draft-05*, draft-dearlove-olsrv2-metrics-05, June 2010, https://datatracker.ietf.org/doc/draft-dearlove-olsrv2-metrics/.

[93] T. CLAUSEN, C. DEARLOVE, P. JACQUET. *The Optimized Link State Routing Protocol version 2 (OLSRv2) draft-11*, draft-ietf-manet-olsrv2-11, April 2010, https://datatracker.ietf.org/doc/draft-ietf-manet-olsrv2/.

[94] M. GOYAL, E. BACCELLI. *Reactive Discovery of Point-to-Point Routes in Low Power and Lossy Networks*, draft-ietf-roll-p2p-rpl-01, October 2010, http://tools.ietf.org/pdf/draft-ietf-roll-p2p-rpl-01.pdf.

[95] U. HERBERG, T. CLAUSEN. *MANET Cryptographical Signature TLV Definition draft-00*, draft-ietf-manet-packetbb-sec-00, June 2010, http://tools.ietf.org/html/draft-ietf-manet-packetbb-sec.

[96] U. HERBERG, T. CLAUSEN. *MANET Cryptographical Signature TLV Definition draft-01*, draft-ietf-manet-packetbb-sec-01, July 2010, http://tools.ietf.org/html/draft-ietf-manet-packetbb-sec-01.

[97] U. HERBERG, T. CLAUSEN. *MANET Cryptographical Signature TLV Definition draft-02*, draft-ietf-manet-packetbb-sec-02, November 2010, http://tools.ietf.org/html/draft-ietf-manet-packetbb-sec-02.

[98] U. HERBERG, T. CLAUSEN. *MANET Cryptographical Signature TLV Definition draft-03*, draft-herberg-manet-packetbb-sec-03, March 2010, http://tools.ietf.org/html/draft-herberg-manet-packetbb-sec.

[99] U. HERBERG, T. CLAUSEN. *Yet Another Autoconf Proposal (YAAP) for Mobile Ad hoc NETworks draft-00*, draft-herberg-autoconf-yaap-00, July 2010, http://tools.ietf.org/html/draft-herberg-autoconf-yaap-00.

[100] U. HERBERG, R. COLE, I. CHAKERES. , draft-ietf-manet-nhdp-mib-06, November 2010, http://tools.ietf.org/html/draft-ietf-manet-nhdp-mib-06.

[101] U. HERBERG, R. COLE, I. CHAKERES. *Definition of Managed Objects for the Neighborhood Discovery Protocol draft-03*, draft-ietf-manet-nhdp-mib-03, March 2010, http://tools.ietf.org/html/draft-ietf-manet-nhdp-mib-03.

[102] U. HERBERG, R. COLE, I. CHAKERES. *Definition of Managed Objects for the Neighborhood Discovery Protocol draft-04*, draft-ietf-manet-nhdp-mib-04, July 2010, http://tools.ietf.org/html/draft-ietf-manet-nhdp-mib.

[103] U. HERBERG, R. COLE, I. CHAKERES. *Definition of Managed Objects for the Neighborhood Discovery Protocol draft-05*, draft-ietf-manet-nhdp-mib-05, November 2010, http://tools.ietf.org/html/draft-ietf-manet-nhdp-mib-05.

[104] U. HERBERG, R. COLE, T. CLAUSEN. *Definition of Managed Objects for the Optimized Link State Routing Protocol version 2 draft-02*, draft-ietf-manet-olsrv2-mib-02, July 2010, http://tools.ietf.org/html/draft-ietf-manet-olsrv2-mib.

[105] P. LEVIS, T. CLAUSEN. *The Trickle Algorithm draft-00*, draft-levis-roll-trickle-00, February 2010, https://datatracker.ietf.org/doc/draft-levis-roll-trickle/.

[106] P. LEVIS, T. CLAUSEN. *The Trickle Algorithm draft-01*, draft-ietf-roll-trickle-01, March 2010, https://datatracker.ietf.org/doc/draft-ietf-roll-trickle/.