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Project-Team HIPERCOM

High performance communication

IN COLLABORATION WITH: Laboratoire d'informatique de l'école polytechnique (LIX), Laboratoire de recherche en informatique (LRI)

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THEME
Networks and Telecommunications

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Project-Team HIPERCOM

Keywords: Wireless Networks, Sensor Networks, Network Protocols, Network Modeling, Adaptive Algorithm, MANETs, VANETs, WSNs, Information Theory, Routing, Quality Of Service, Delay Tolerant Networks

Hipercom is a bi-localized project-team at INRIA Paris - Rocquencourt and INRIA Saclay - Ile de France.

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2. Overall Objectives

2.1. Introduction

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

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

The objectives assigned to HIPERCOM were:

- Theoretical limits of wireless networking with the study for instance of massive mobile dense wireless networks, delay tolerant networks and network coding.
- New generation of OLSR, new services and protocols including autoconfiguration of wireless ad hoc networks, localization...
- Wireless sensor networks: cross-layering, energy and bandwidth efficiency,
- Vehicular and mobile applications for intelligent transportation systems as well as military tactical networks.

2.2. Highlights

1. **Organization of MobiHoc 2011**, the Twelfth ACM International Symposium on Mobile Ad Hoc Networking. The HIPERCOM project contributed to the great success of this international conference held in Paris in May 2011. Philippe Jacquet served as General Chair, Christine Anocq as Local Arrangement Co-chair, Thomas Clausen as Finance Co-chair, Paul Muhlethaler, Anis Laouiti and Pascale Minet as Workshop Co-chairs, Emmanuel Baccelli as Registration Chair, Cédric Adjih as Web Chair.
2. **Contribution to the OCARI shows**. Pascale Minet, Cédric Adjih, Ichrak Amdouni and Ridha Soua were active contributors as well as LIMOS, TELIT and EDF to the two OCARI shows organized by EDF. The fist one in September was given for EDF executives. The second one in December was larger. Invited people came from government agencies and industries. The goal was to prove the feasibility of an OCARI wireless sensor network in industrial environments, focusing on time constrained traffic and energy efficiency.
3. , **Habilitation à Diriger des recherches**. Aline carneiro Viana got her HDR entitled *Putting data delivery into context: Design and evaluation of adaptive networking support for successful communication in wireless self-organizing networks* from UPMC-Sorbonne University on the 14th December 2011.

3. Scientific Foundations

3.1. Analytical information theory

Participant: Philippe Jacquet.

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: Cédric Adjih, Emmanuel Baccelli, Thomas Clausen, Philippe Jacquet, Salman Malik, Yacine Mezali, Pascale Minet, Paul Mühlethaler, Yasser Toor.

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.

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, Aline Carneiro Viana, Salman Malik, Yacine Mezali.

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: Cédric Adjih, Aline Carneiro Viana, Emmanuel Baccelli, Thomas Clausen, Philippe Jacquet, Pascale Minet, Paul Mühlethaler, Yasser Toor, Ichrak Amdouni, Ridha Soua, Erwan Livolant.

Abstract. Algorithms are designed 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 emphasizes 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. Energy efficient wireless sensor networks

Abstract. Energy efficiency is a key property in wireless sensor networks.

Various techniques are used to contribute to energy efficiency, see for instance the survey we published at the WMNC 2011 conference. In the OCARI2 project, we have designed and implemented an energy efficient routing protocol and a node activity scheduling algorithm allowing router nodes to sleep. We have applied a cross-layering approach allowing the optimization of MAC and network protocols taking into account the application requirements and the environment in which the network operates. This activity has been done in collaboration with our partners EDF, LIMOS and TELIT.

5. Software

5.1. RPL P2P

Participants: Emmanuel Baccelli [correspondant], Matthias Philipp.

P2P-RPL is an implementation of draft-ietf-roll-p2p-rpl, providing reactive discovery of point-to-point routes in low power and lossy networks such as wireless sensor networks. The implementation is based on the Contiki operating system. See also the web page http://contiki-p2p-rpl.gforge.inria.fr/.

- Version: 0.4

5.2. OPERA infrastructure

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

OPERA-infrastructure is the system support code of OPERA, the Optimized Protocol for Energy efficient Routing with node Activity scheduling.

5.3. OPERA perf simul

Participants: Cédric Adjih [correspondant], Ichrak Amdouni.

OPERA-perf-simul is a set of tools for simulation and performance evaluation as well as large scale tests of OPERA, the Optimized Protocol for Energy efficient Routing with node Activity scheduling.

5.4. OPERA protocol

Participants: Cédric Adjih [correspondant], Ichrak Amdouni, Pascale Minet, Saoucene Mahfoudh.

OPERA-protocol is the heart of OPERA, the Optimized Protocol for Energy efficient Routing with node Activity scheduling. It includes EOND a neighborhood discovery protocol, EOSTC a protocol byuiding and maintaining a n energy efficient routing tree and SERENA a node coloring algorithm.

5.5. OPERA validation and tools

Participant: Cédric Adjih [correspondant].

OPERA-validation and tools is a set of tools for validation, debugging, analysis and visualization of OPERA protocol, the Optimized Protocol for Energy efficient Routing with node Activity scheduling. It operates either in a real embedded system or in simulation.

6. New Results

6.1. Massive mobile dense wireless networks

Participants: Cédric Adjih, Aline Carneiro Viana, Emmanuel Baccelli, Philippe Jacquet, Pascale Minet, Paul Mühlethaler, 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. Coloring in wireless networks

Coloring is used in wireless networks to improve communication efficiency, mainly in terms of bandwidth, energy and possibly end-to-end delays. Nodes access the medium according to their color. It is the responsibility of the coloring algorithm to ensure that interfering nodes do not have the same color. First, we established complexity results about the h-hop coloring problem. Second, we focused on wireless sensor networks with grid topologies. We proposed the Vector-Based Coloring Method, denoted VCM, a new method that is able to provide an optimal periodic coloring for any radio transmission range and for any h-hop coloring, h>=1. Third, we also designed OSERENA "Optimized SchEduling RoutEr Node Activity", a distributed coloring algorithm optimized for dense wireless networks.

6.1.2.5. Complexity results about the h-hop coloring problem

In the paper we published at the WMNC 2011 conference, we define the h-hop node coloring problem, with h any positive integer, adapted to two types of applications in wireless networks. We specify both general mode for general applications and strategic mode for data gathering applications. We prove that the associated decision problem is NP-complete.

6.1.2.6. Grid coloring and the Vector-Based Coloring Method

In 2011, we also focused on wireless sensor networks with grid topologies. How does a coloring algorithm take advantage of the regularity of grid topology to provide an optimal periodic coloring, that is a coloring with the minimum number of colors? We propose the Vector-Based Coloring Method, denoted VCM, a new method that is able to provide an optimal periodic coloring for any radio transmission range and for any h-hop coloring, h>=1. This method consists in determining at which grid nodes a color can be reproduced without creating interferences between these nodes while minimizing the number of colors used. We compare the number of colors provided by VCM with the number of colors obtained by a distributed coloring algorithm with line and column priority assignments. We also provide bounds on the number of colors of optimal general colorings of the infinite grid, and show that periodic colorings (and thus VCM) are asymptotically optimal. Finally, we discuss the applicability of this method to a real wireless network.

6.1.2.7. 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.

We have also conducted studies to support intelligent and adaptive forwarding, which allows a good trade-off between reliability and resource-efficiency. We then design a new protocol, called GrAnt, a new prediction-based forwarding protocol for complex and dynamic delay tolerant networks (DTNs). The proposed protocol uses the Ant Colony Optimization (ACO) metaheuristic with a greedy transition rule. This allows GrAnt to select the most promising forwarder nodes or allow for the exploitation of previously found good paths. The main motivation for using ACO is to take advantage of its population-based search and the rapid adaptation of its learning framework. Considering data from heuristic functions and pheromone concentration, the GrAnt protocol includes three modules: routing, scheduling, and buffer management.

6.1.2.8. 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.

Additionally, we have also considered the problem of data collection in global sensing and intermittently connected systems while avoiding the use of costly infrastructures (e.g., 3G). Motivated by the observation that node encounters are sufficient to build a connected relationship graph, we propose to take advantage of such inherent interactions to transform some mobile devices into delegates. We use then opportunistic delegation as a data traffic offload solution by investigating two main questions: (i) How to gain insights into social mobile networking scenarios?, (ii) How to utilize such insights to design solutions to alleviate overloaded 3G networks?. Our solution leverages usage of mobile applications requiring large data transfers by channeling the traffic to a few, socially important users in the network called VIP delegates. Mobile collectors need then only to meet delegates that, in turn, are responsible for gathering data from a subset of standard producers. We first investigate several delegation strategies based on the relative importance of nodes in their social interactions. Second, by considering a prediction strategy that estimates the likelihood of two nodes meeting each other, we investigate how the delegation strategies perform on predicted traces.

6.1.2.9. 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,
- Professors Anelise Munaretto and Myriam Regattieri Delgado from Federal Technological University of Parana (UTFPR), Brazil,
- CNRS researcher Marcelo Dias de Amorim, LIP6/UPMC, France,
- Mathias Boc, CEA LIST, France,
- Computer Science Department, Sapienza University of Rome, Italy,
- University of St. Andrews, UK.
- Professor Leila Saidane, ENSI, Tunisia.

6.2. New generation of OLSR, new services and protocols

Participants: Cédric Adjih, Aline Carneiro Viana, Emmanuel Baccelli, Thomas Clausen, Philippe Jacquet, Pascale Minet, Ichrak Amdouni, Ridha Soua, Erwan Livolant, Paul Mühlethaler, 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
- Localization

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. OSPF extension for wireless mesh networking

Long a near-future myth, ad hoc networks are now becoming a reality as a variety of wireless mesh networks are being deployed. Wireless mesh networks are a specific kind of ad hoc network, where terminals are essentially fixed. Even in such cases, which somewhat resembles usual networks, specific routing protocols have nevertheless to be employed, to cope with the characteristics of wireless, multi-hop communications. Such characteristics include scarce bandwidth over inherently unreliable, versatile, semi-broadcast links, and absence of a central authority in general. One of the main difficulties in this context is to cope with contradictory requirements such as, on one hand, dealing with bandwidth scarcity, which typically requires decreasing control traffic, while on the other hand, dealing with unreliable, versatile links which typically requires increasing control traffic. The two prominent routing protocols that have been developed for ad hoc networks and studied over the past decade, are the IETF standards AODV and OLSR. AODV is based on a reactive scheme (i.e. on-demand flooding to discover a path to a new destination), while OLSR is based on a proactive scheme, which is essentially an optimization of link state routing (i.e. pre- provisioning of paths to all possible destinations). OLSR is to date the most deployed such protocol, as it powers numerous wireless mesh community networks that currently flourish in various cities throughout Europe and North America. Based on this experience, the integration of ad hoc networking in the "standard" networking body is going further in several directions. One direction is the IEEE 802.11s standardization effort, which uses AODV and OLSR-derived algorithms to provide wireless mesh routing capabilities below IP. Another direction, spearheaded by the IETF, is the extension of IP routing standards such as OSPF to support ad hoc routing: in this realm we recently spun RFC 5449, as well as a series of academic publications on the subject. The idea behind extending OSPF to support ad hoc networks comes from a simple observation: OSPF is algorithmically quite similar to OLSR, as both are based on a proactive, link state approach. As on the other hand OSPF is a well-understood, widely deployed, industry-standard protocol, employing it to integrate ad hoc networks with existing infrastructure is considered by users as an easy migration path.

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 WiFi. 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.

6.2.3. Collaborations

- Many contractual collaborations:
  - MoD (QoS, security, interconnection between the OLSR and OSPF routing domains),
  - Hitachi (Vehicular applications, OLSRv2),
- Non contractual:
  - BAE (OLSRv2),
  - Deutsche Telekom Labs/TU-Berlin, Germany,

6.3. Wireless Sensor Networks

Participants: Cédric Adjih, Aline Carneiro Viana, Emmanuel Baccelli, Thomas Clausen, Philippe Jacquet, Pascale Minet, Ichrak Amdouni, Ridha Soua, Erwan Livolant, Paul Mühlethaler, Yasser Toor.

6.3.1. Executive summary

In wireless sensor networks, we focus more particularly on:

- Spatial reuse of the bandwidth,
- Routing according to a cross-layering approach,
- Security,
- Energy efficiency,
- IPv6 support.

6.3.2. Scientific achievements

6.3.2.1. Cryptographic Protocols to Fight Sinkhole Attacks on Tree-based Routing in Wireless Sensor Networks

Wireless Sensor Networks (WSN) are penetrating more and more in our daily life. As a consequence, security has become an important matter for these networks. We introduce two new cryptographic protocols of different complexity and strength in limiting network degradation caused by sinkhole attacks on tree-based routing topologies in Wireless Sensor Networks (WSNs). The main goal of both protocols is to provide continuous operation by improving resilience against, rather than detection of, these attacks. The main benefit of providing resilience is that it allows operating (or graceful degradation) in the presence of attacks. Furthermore, while resilience mechanisms do not dismiss detection mechanisms, detection mechanisms often introduce more complexity and so, more weaknesses to the system, which might not justify their benefits. More specifically our two *RESIlient and Simple Topology-based reconfiguration protocols* are: RESIST-1 and RESIST-0. RESIST-1 prevents a malicious node from modifying its advertised distance to the sink by more than one hop, while RESIST-0 does not allow such lying at the cost of additional complexity.

6.3.2.2. IPv6 Protocol suite for Sensor Networks

Wireless sensor networking is a key element of the Internet of Things (IoT), a substantial part of the billions of smart objects that are soon to blend into the global IP network, from actuators to home appliances, from smart meters, to smart dust. Sensor nodes are devices used for distributed and automated monitoring of various parameters such as temperature, movement, noise or radioactivity levels etc. Sensors are scattered with minimum planning with respect to their precise physical position (including the central role of the sink, if any), and the set of peers with which a sensor can directly communicate through its wireless interface may change rapidly over time due to asynchronous sleep mode strategies, fluctuations in the radio environment, device failure or mobility. Through its wireless interface, a sensor thus connects to a communication link with undetermined connectivity properties. Sensor networks are a challenge to current IP standards, since on the one hand these protocols were designed to work on wired links and on the other hand these protocols were designed to work on machines that do not have drastic constraints in terms of CPU, power capacities, and memory, as sensor nodes do. In consequence, several key standard protocols (including TCP, UDP, DHCP, NDP, SLAAC, and OSPF) do not function correctly in this environment. Nevertheless, IPv6-based sensor networking is a viable long term goal because it would enable generic, large scale, seamless integration of millions of sensing devices using heterogeneous radio technologies, at a low cost, and in a future-proof manner.The Internet Engineering Task Force (IETF) is currently engaged into multiple efforts addressing the limitations of existing standards concerning wireless sensor IP networking. Some of the standards under construction aim at fitting IP formats, especially IPv6 formats, to direct wireless communications using low power radio technologies such as IEEE 802.15.4, which require IP format compression. Other standards in development aim at providing multi-hop wireless sensor communication with IPv6, which requires specific routing protocols, efforts in which we actively participate, prompting numerous joint publications with both industrial and academic partners.

6.3.2.3. Coloring in wireless sensor networks

Graph coloring is used in wireless networks to optimize network resources: bandwidth and energy. We focus on grid topologies that constitute regular topologies for large or dense wireless networks. We consider various transmission ranges and identify a color pattern that can be reproduced to color the whole grid with the optimal number of colors. We obtain an optimal periodic coloring of the grid for the considered transmission range. We then evaluate the performance of a 3-hop distributed coloring algorithm, called SERENA. Through simulation results, we highlight the impact of node priority assignment on the number of colors obtained for any network and grids in particular. We then compare these optimal results on grids with those obtained by SERENA and identify directions to improve SERENA.

6.3.2.4. Coloring algorithm optimized for dense wireless networks

In 2011, we also designed OSERENA "Optimized SchEduling RoutEr Node Activity", a distributed coloring algorithm optimized for dense wireless networks. Network density has an extremely reduced impact on the size of the messages exchanged to color the network. Furthermore, the number of colors used to color the network is not impacted by this optimization. We describe the properties of the algorithm and prove its correctness and termination. Simulation results point out the considerable gains in bandwidth.

6.3.2.5. Multichannel access in wireless sensor networks

In 2011 we started a research activity on multichannel access in wireless sensor networks. A state of the art has been published at the IFIP Wireless Days 2011 Conference.

6.3.3. Collaborations

- Many contractual collaborations:
  - Hitachi (Vehicular applications, OLSRv2),
  - OCARI2 project (industrial wireless sensor network, QoS, cross layer, energy efficiency, routing, node activity scheduling),
  - SAHARA project (wireless sensor network embedded in aircrafts),
  - STIC INRIA-Tunisian Universities: the team of Prof. Leila Saidane at ENSI (Performance improvement in a wireless sensor network),
- Non contractual:
  - BAE (OLSRv2),
  - Freie Universitaet (sensor networks, DHT),
  - Deutsche Telekom Labs/TU-Berlin, Germany,
  - University of Athens, Greece.

6.4. Vehicular and mobile applications

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

6.4.1. 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.

6.4.2. Scientific achievements

6.4.2.1. Military tactical networks

During year 2011, we conducted several expertises about industrial propoals dealing with OLSR use in military tactical networks.

6.4.2.2. 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.

6.4.3. Collaboration

We received support from MoD for this activity.

7. Contracts and Grants with Industry

7.1. DGA/MI

Participants: Cédric Adjih, Pascale Minet, Paul Mühlethaler.

Period: 2007 - 2011

Partners: DGA/MI.
The DGA/MI, French MoD/DGA, contract has been notified in December 2007. It has a duration of 36 months. It focuses on mobile ad hoc networks. DGA/MI 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 DGA/MI 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 were sollicited by DGA/MI for the expertise of European industrial proposals about the design of wireless mobile ad hoc networks supporting tactical military applications. Our comments contributed to improve the solutions presented.

7.2. OCARI2

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

Period: 2010 - 2011

Partners: EDF, LIMOS, TELIT.

At the end of the OCARI (Optimization of Ad hoc Communications in Industrial networks) project, funded by ANR, started in February 2007 and ended in 2010, EDF the coordinator decided to continue the project with a restricted number of partners: TELIT, LIMOS (Clermont Ferrand university) and INRIA. The goal was to prove the feasibility on commercially available cards of the OCARI stack designed during the ANR project and to make a public demonstration of this product. During the year 2011, the OCARI stack has been improved and implemented on the ZE51 module of TELIT based on the Texas Instrument CC2530 Chipset.

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, is 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.
- SERENA, the protocol used to schedule router node activity, is based on three-hop coloring. It allows any node to sleep during the slots that 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. SERENA has been optimized for 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.

These protocols have been implemented in the OCARI stack, operating on a ZE51 module of TELIT.

7.3. SensLab and FIT

Participants: Cédric Adjih, Emmanuel Baccelli, Ala Eddin Weslati.

Period: 2011 - 2021

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

The HIPERCOM team started the development of a testbed for SensLab in 2010. This testbed located in building 21 at Rocqquencourt INRIA center consists now of 40 wireless SensLab nodes. This number will reach 128 nodes by the end of the year 2012.
A location has been found for the new testbed of the EQUIPEX FIT: the basement of building 1 at Rocquencourt. An engineer has been recruited for this project.

7.4. ACRON

Participant: Cédric Adjih.

Period: 2011 - 2014

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

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

7.5. SWAN

Participants: Cédric Adjih, Salman Malik.

Period: 2011 - 2014

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

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

7.6. MOBSIM

Participants: Cédric Adjih, Paul Mühlethaler, Hana Baccouch.

Period: 2011 - 2013

Partners: INRIA Sophia, INRIA Genoble.

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

7.7. SAHARA

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

Period: 2011 - 2014.

Partners: EADS, Astrium, BeanAir, Eurocopter, Oktal SE, Reflex CES, Safran Engineering Systems, CNES, ECE, EPMI,LIMOS.

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

7.8. 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.

7.9. 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.

8. Partnerships and Cooperations

8.1. European Initiatives

8.1.1. FP7 Projet

8.1.1.1. OPNEX

Title: Optimization driven Multi-Hop Network Design and Experimentation

Type: COOPERATION (ICT)

Defi: New paradigms and experimental facilities

Instrument: Specific Targeted Research Project (STREP)

Duration: May 2008 - April 2011

Coordinator: CRTH (Greece)

Others partners: Technicolor, Freie Universitaet Berlin (FUB), Politechnika Poznanska (PUT)

See also: http://www.opnex.eu/

Abstract: OPNEX delivers a first principles approach to the design of architectures and protocols for multi-hop wireless networks. Systems and optimization theory is used as the foundation for algorithms that provably achieve full transport capacity of wireless systems. Subsequently a plan for converting the algorithms termed in abstract network models to protocols and architectures in practical wireless systems is given. Finally a validation methodology through experimental protocol evaluation in real network test-beds is proposed. OPNEX will use recent advances in system theoretic network control, including the backpressure principle, max-weight scheduling, utility optimization congestion control and primal-dual method for extracting network algorithms. These approaches exhibited already vast potential for achieving maximum capacity and full exploitation of resources in abstract network models and found their way to reality in high performance switching architectures and recent variants of TCP that embody the primal-dual optimization principle. Wireless, the fastest growing component of internet today, is also the least understood for the designer due to mobility, rapidly changing topology, radio link unpredictability and volatile load distribution among others. Current approaches used in practice for multi-hop wireless, the basic communication infrastructure for sensor network extensions of the internet, are mostly empirical and heuristic. Our system optimization approach will provide a rigorous integrated system design framework from physical up to network and transport layer that renders itself to validation and comparison with the theoretically optimal performance in terms of throughput, spectrum and energy utilization. The adopted approach on decentralization, communication and computational complexity reduction as well as autonomous operation will lead to implementable algorithms and architectures to be validated eventually in the proposed test-beds.

8.1.2. EDA project

Program: EDA (European Defense Agency

Project acronym: ETARE

Project title: ETARE

Duration: 2008-2011

Coordinator: Thales Italy

Other partners: Thales France and Belgium, Patria Aviation, Oulu university, Selex, Insta, Sapienza university and Elektrobit.

Abstract: 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.

Participants: Cédric Adjih, Philippe Jacquet, Paul Mühlethaler.

8.2. International Initiatives

8.2.1. INRIA Associate Teams

8.2.1.1. RSFCI

Title: Routing in Intermittently Connected Wireless Networks

INRIA principal investigator: Philippe Jacquet

International Partner:

Institution: Macquarie University (Australia)

Laboratory: Department of Computing

Duration: 2009 - 2011

See also: http://hipercom.inria.fr/RSFCI/home.html

We study the problem of routing in intermittently connected wireless networks. In such networks information remains blocked in a connected component as long as the node motion allows to jump into or form a new connected component. This kind of networks are often alternatively refered as Delay/Disruption Tolerant Networks (DTN) and is the focuse of many research efforts worldwide (DARPA, IETF). Our main objective is to specify efficients routing algorithms in delivery time, energy and overhead that allow to forward piece of information or packets toward a distant destination in a remote connected component currently out of reach. Our common studies range from theory to proactice: we focus as well on fundamental issues such as the information propagation speed determination to the specification of a routing algorithm and protocol that approaches this theoretical performances.

8.2.2. Participation In International Programs

8.2.2.1. STIC TUNISIE

Title: Auto-adaptativity of a wireless sensor network with mobile agents : toward a green sensor network.

INRIA principal investigator: Pascale Minet

International Partner:

Institution: ENSI (Tunisia)

Laboratory: CRISTAL

Team leader: Leila Saidane

Duration: 2009 - 2011

Abstract: This project aims to design algorithms and protocols for wireless sensors and mobile agents able to meet application requirements and provide the best performances in the considered environment. To achieve that, a cross-layering approach is considered. The network layer may use the information generated by any other higher or lower layer in the purpose of a better adaptivity to the application or the environment considered. Furthermore, since wireless sensor networks deployment is growing more and more, it is judicious to reduce their ecological impact starting with their design. This project focuses on strategies to improve energy efficiency.

9. Dissemination

9.1. Animation of the scientific community

9.1.1. Editorial boards, steering and program committees

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

Pascale Minet was member of the Gilles Kahn 2011 jury awarding an excellent 2010 PhD thesis in Computer Science.

Pascale Minet was reviewer of the PhD Thesis of:

- Bilel NEFZI, *Mécanismes auto-adaptatifs pour la gestion de la qualité de service dans les réseaux de capteurs sans fil*, PhD thesis of the Institut National Polytechnique de Lorraine, September 2011.
- Nancy EL RACHKIDY,*Cross-layering et routage dans un réseau ad hoc : politique de relais de trame sur un réseau de capteurs sans fil organisé selon une topologie en arbre*, PhD thesis of the Université Blaise Pascal, December 2011.
- Arnaud KAISER, *Mécanismes d'adaptation des réseaux MANET pour le support des jeux vidéo multijoueurs temps réel*, PhD thesis of the Université Paris XIII, December 2011l.
- Wahabou ABDOU, *Optimisation évolutionniste multi-objectifs pour des réseaux ad hoc mobiles : la diffusion robuste et le routage multi-chemins non recouvrant*, PhD Thesis of the Université de Franche-Comté, December 2011.

She was Jury member for the Habilitation à Diriger des Recherches of

- Anthony Busson *Protocoles et évaluation de performances dans les réseaux ad hoc*, University of Paris Sud 11, December 2011.

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.

Pascale Minet was member of the program committee of:

- AdHocNets 2011, Third International ICST Conference on Ad Hoc Networks, September 2011.
- CFIP 2011, Colloque Francophone sur l'Ingnierie des Procoles, May 2011.
- CIT 2011, 11th IEEE International Conference on Computer and Information Technology, September 2011,
- DCNET 2011, International Conference on Data Communication Networking, July 2011,
- GlobeCom 2011 Workshop HeterWMN, December 2011.
- ICN 2011, the 10th International Conference on Networks, January 2011.
- IFIP Wireless Days 2011, October 2011.
- IUCC 2011, the 10th IEEE International Conference on Ubiquitous Computing and Communications, August 2011.
- IWCMC 2011, the 7th International Wireless Communications and Mobile Computing Conference, July 2011.
- Med-Hoc-Net 2011, 11th IEEE/IFIP Mediterranean Ad-Hoc Networking conference, June 2011.
- RTNS 2011, 18th International Conference on Real-Time and Network Systems, September 2011.
- SERA 2011, Int. Conf. on Software Engineering Research & Applications, August 2011.
- SPECTS 2011, International Symposium on Performance Evaluation of Computer and Telecommunication Systems, July 2011.

Pascale Minet was also reviewer for the following journals:

- IEEE Transactions on Vehicular Technology,
- IEEE Transactions on Wireless Communications,
- Real-Time Systems,
- International Journal of Communication Systems,
- Computer Communications 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 2010, **Paul Mühlethaler** is scientific head of the DGA/INRIA partnership.

Cédric Adjih was a co-chair for ACM MOBIHOC 2011. He was also:

- Member of the program committee of AINTEC 2011, *7th Asian Internet Engineering Conference*, November 2011.
- Reviewer for the journal *ACM Transactions on Sensor Networks*
- Reviewer for the MILCOM 2011, *IEEE Military Communications Conference*, November 2011.

Cédric Adjih served also as reviewer for the French ANR (for proposals for the *Young Researchers* program)

Emmanuel Baccelli was a co-chair for ACM MOBIHOC 2011, and is currently TPC for IEEE SECON, IEEE PerGroup, ACM MobileHealth and NovaEnv.

Aline C. Viana served as:

Local arrangement co-chair of ExtremeCom 2011: *3rd Extreme Conference on Communication*, Manaus, Brazil. September 2011.

Publicity chair of ExtremeCom 2011: *3rd Extreme Conference on Communication*, Manaus, Brazil. September 2011.

TPC co-chair of Shadow ACM Conext 2011: *Shadow ACM 7th International Conference on emerging Networking EXperiments and Technologies*. Shadow TPC meeting was in Toronto, Canada. August 2011.

Publication chair of AdHocNets 2011: *3rd International ICST Conference on Ad Hoc Networks*, paris, France. September 2011.

She also served in the program committees for the following conferences/workshops:

Mobility 2011: *1st International Conference on Mobile Services, Resources, and Users*, Barcelona, Spain. October 2011.

WOCN 2011: *IEEE International Conference on Wireless and Optical Communications Neworks*, Paris, France. May 2011.

WPerformance 2011: *Workshop em Desempenho de Sistemas Computacionais e de Comunicacao*, Natal RN, Brazil. Julho 2011.

Ichrak Amdouni gave a presentation entitled *Energy Efficiency and Routing in the OCARI project*, in les Journées thématiques Rescom : Réseaux de Capteurs et leurs applications - Etat de l'art et transfert technologique, 19-20 Oct. 2011, Université Pierre et Marie Curie.

9.1.2. Evaluation committees, consulting

A. Carneiro Viana served as a reviewer for the PhD committee of Natascia Piroso, Sapienza University of Rome, Italy. She has been also performing remote evaluation of short proposals for the EC "Future and Emerging Technologies" programme (EC FET-Open).
Emmanuel Baccelli served as expert reviewer for the french National Research Agency (ANR) in 2011.

9.2. Academic teaching

Philippe Jacquet taught:

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

Emmanuel Baccelli taught:

- class : Mobile networking at Ecole Polytechnique.

Pascale Minet taught:

- Networks and quality of service in Master Systèmes Electroniques et Traitement de l'Information, at INSTN (Saclay).
- Mobile ad-hoc networks: medium access, routing and quality of service in Master Ingénierie informatique of the university of Marne-la-Vallée.
- Mobile ad hoc networks and wireless sensor networks: medium access, routing and energy efficiency in Master ScTIC (Systèmes complexes, Technologies de l'Information et du Contrôle) of the University of Paris 12.

Aline C. Viana was invited as a speaker at the GBR 2011, Beyond Networking workshop, Buzios, Rio de Janeiro, Brazil. October 2011.

9.3. Standardization

The HIPERCOM project-team has been very active in the standardization process at IETF. It made many contributions in the MANET, AUTOCONF and ROLL working groups (see for instance the publication list with the numerous IETF drafts).

10. 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^o RR-4141, http://hal.inria.fr/inria-00072484.

[3] T. H. 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^o 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^o 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^o 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. H. 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^o 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^o 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^o 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^o 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^o 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^o 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] RES 10, HIPERLAN. *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^o RR-3584, http://hal.inria.fr/inria-00073097.

Publications of the year

Doctoral Dissertations and Habilitation Theses

[23] A. CARNEIRO VIANA. *Putting data delivery into context: Design and evaluation of adaptive networking support for successful communication in wireless self-organizing networks*, Université Pierre et Marie Curie - Paris VI, December 2011, Habilitation à Diriger des Recherches, http://hal.inria.fr/tel-00653813/en.

[24] J. A. CORDERO FUERTES. *Link-State Routing Optimization for Compound Autonomous Systems in the Internet*, Ecole Polytechnique X, September 2011.

[25] U. HERBERG. *Performance, Scalability, Automatic Management and Internet Integration of Ad Hoc Networks*, Ecole Polytechnique X, May 2011.

[26] N. MARIYASAGAYAM. *Communication Véhiculaires par géolocalisation pour Systèmes de Transports Intelligents*, Ecole Polytechnique X, June 2011, http://hal.inria.fr/tel-00613174/en.

Articles in International Peer-Reviewed Journal

[27] E. BACCELLI, P. JACQUET, B. MANS, G. RODOLAKIS. *Highway Vehicular Delay Tolerant Networks: Information Propagation Speed Properties*, in "IEEE Transactions on Information Theory", November 2011, p. 1 - 12 [*DOI :* 10.1109/TIT.2011.2174960], http://hal.inria.fr/hal-00651597/en.

[28] M. GOYAL, M. SOPERI, E. BACCELLI, G. CHOUDHURY, A. SHAIKH, H. HOSSEINI, K. TRIVEDI. *Improving Convergence Speed and Scalability in OSPF: A Survey*, in "IEEE Communications Surveys & Tutorials", March 2011, n^{o} 99, p. 1 - 21 [*DOI :* 10.1109/SURV.2011.011411.00065], http://hal.inria.fr/hal-00651596/en.

[29] F. LE FESSANT, A. PAPADIMITRIOU, A. CARNEIRO VIANA, C. SENGUL, E. PALOMAR. *A Sinkhole Resilient Protocol for Wireless Sensor Networks: Performance and Security Analysis*, in "Computer Communications", April 2012, http://hal.inria.fr/hal-00653824/en.

[30] D. NGUYEN, P. MINET, T. KUNZ. *On the Selection of Cluster Heads in MANETs*, in "International Journal of Computer Science Issues, IJCSI", January 2011, vol. 8.

[31] C. SENGUL, A. CARNEIRO VIANA, A. ZIVIANI. *A Survey of Adaptive Services to Cope with Dynamics in Wireless Self-Organizing Networks*, in "ACM Computing Surveys", December 2011, http://hal.inria.fr/hal-00653819/en.

[32] A. C. K. VENDRAMIN, A. MUNARETTO, M. R. DELGADO, A. CARNEIRO VIANA. *GrAnt: Inferring Best Forwarders from Complex Networks' Dynamics through a Greedy Ant Colony Optimization*, in "Computer Networks", December 2011, http://hal.inria.fr/hal-00653830/en.

[33] P. R. WALENGA JUNIOR, M. FONSECA, A. MUNARETTO, A. CARNEIRO VIANA, A. ZIVIANI. *ZAP: A Distributed Channel Assignment Algorithm for Cognitive Radio Networks*, in "Special Issue on Multiple Access Communications in Future-Generation Wireless Networks. Eurasip Journal on Wireless Communications and Networking. Hindawi", July 2011, http://hal.inria.fr/hal-00653850/en.

Invited Conferences

[34] M. H. REHMANI, A. CARNEIRO VIANA, H. KHALIFE, S. FDIDA. *Improving Data Dissemination in Multi-Hop Cognitive Radio Ad-Hoc Networks*, in "Third International ICST Conference on Ad Hoc Networks", Paris, France, September 2011, http://hal.inria.fr/hal-00653839/en.

International Conferences with Proceedings

[35] C. ADJIH, E. BACCELLI, P. JACQUET, P. MINET, M. PHILIPP, G. WITTENBURG. *Deployment Experience with Low Power Lossy Wireless Sensor Networks*, in "IAB Workshop on Interconnecting Smart Objects with the Internet", Prague, Czech Republic, March 2011, p. 1 - 3, http://hal.inria.fr/hal-00651601/en.

[36] I. AMDOUNI, P. MINET, C. ADJIH. *Node coloring in wireless networks: complexity results and grid coloring*, in "WMNC 2011, 4th Joint IFIP Wireless and Mobile Networking Conference", Toulouse, France, October 2011.

[37] S. AZZAZ, L. AZZOUZ SAIDANE, P. MINET. *Repairing Sensors Strategies in Fault-Tolerant Wireless Sensor Networks*, in "PE-WASUN 2011, ACM International Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks", Miami, Florida, October 2011.

[38] E. BACCELLI, P. JACQUET, B. MANS, G. RODOLAKIS. *Information Propagation Speed in Bidirectional Vehicular Delay Tolerant Networks*, in "30th IEEE International Conference on Computer Communications (INFOCOM)", Shanghai, China, June 2011, p. 436 - 440 [*DOI :* 10.1109/INFCOM.2011.5935199], http://hal.inria.fr/hal-00651599/en.

[39] E. BACCELLI, M. PHILIPP, M. GOYAL. *The P2P-RPL Routing Protocol for IPv6 Sensor Networks: Testbed Experiments*, in "19th International Conference on Software, Telecommunications and Computer Networks", Split, Croatia, November 2011, p. 1 - 6, http://hal.inria.fr/hal-00651603/en.

[40] M. BARBERA, J. STEFA, A. CARNEIRO VIANA, M. DIAS DE AMORIM, M. BOC. *VIP Delegation: Enabling VIPs to Offload Data in Wireless Social Mobile Networks*, in "The 7th IEEE International Conference on Distributed Computing in Sensor Systems (DCOSS)", Barcelona, Spain, February 2011, http://hal.inria.fr/hal-00653842/en.

[41] G. BIGWOOD, A. CARNEIRO VIANA, M. BOC, M. DIAS DE AMORIM. *Collaborative Data Collection in Global Sensing Systems*, in "36th IEEE Conference on Local Computer Networks (LCN) - 4-pages", Bonn, Germany, October 2011, http://hal.inria.fr/hal-00653841/en.

[42] T. H. CLAUSEN, U. HERBERG. *Some Considerations on Routing in Particular and Lossy Environments*, in "Proceedings of the 1st Interconnecting Smart Objects with the Internet Workshop", March 2011.

[43] T. H. CLAUSEN, U. HERBERG, M. PHILIPP. *A Critical Evaluation of the "IPv6 Routing Protocol for Low Power and Lossy Networks" (RPL)* -, in "Proceedings of the 5th IEEE International Conference on Wireless & Mobile Computing, Networking & Communication (WiMob)", October 2011.

[44] J. A. CORDERO FUERTES, T. H. CLAUSEN, E. BACCELLI. *MPR+SP: Towards a Unified MPR-based MANET Extension for OSPF*, in "44th Hawaii International Conference on System Sciences", Hawaii, United States, February 2011, p. 1 - 10 [*DOI :* 10.1109/HICSS.2011.313], http://hal.inria.fr/hal-00651595/en.

[45] I. FAJJARI, N. AITSAADI, G. PUJOLLE, H. ZIMMERMANN. *VNR Algorithm: A Greedy Approach For Virtual Networks Reconfigurations*, in "Globecom 2011 - IEEE Global Communications Conference, Exhibition and Industry Forum", Houston, United States, IEEE, 2011, 6, 6 pages, http://hal.inria.fr/hal-00615271/en.

[46] U. HERBERG, T. H. CLAUSEN. *Delay Tolerant Routing with OLSRv2* -, in "Proceedings of the The 9th IEEE/IFIP International Conference on Embedded and Ubiquitous Computing (EUC)", October 2011.

[47] P. JACQUET, S. MALIK. *Local Capacity in Wireless Networks: What Can We Expect Beyond Slotted ALOHA*, in "MobiHoc", May 2011.

[48] N. KAROWSKI, A. CARNEIRO VIANA, A. WOLISZ. *Optimized Asynchronous Multi-channel Neighbor Discovery*, in "IEEE Conference on Computer Communications (Infocom), 5-pages", Shanghai, China, April 2011, http://hal.inria.fr/hal-00653844/en.

[49] S. MALIK, P. JACQUET, C. ADJIH. *On the Throughput Capacity of Wireless Multi-hop Networks with ALOHA, Node Coloring and CSMA*, in "Wireless Days", Oct. 2011.

[50] S. MALIK, P. JACQUET. *On the Optimal Transmission Scheme to Maximize Local Capacity in Wireless Networks*, in "Wireless Days", Oct. 2011.

[51] S. MALIK, P. JACQUET. *Optimizing Local Capacity of Wireless Ad Hoc Networks*, in "WMNC", Oct. 2011.

[52] S. MALIK, A. SILVA, J.-M. KELIF. *Optimal Base Station Placement: A Stochastic Method Using Interference Gradient In Downlink Case*, in "ValueTools", May 2011.

[53] A. MERAIHI NAIMI, C. ADJIH, P. MINET, T. PLESSE. *Experiments with the MOST multicast protocol in a wireless multi-hop network*, in "IWCMC 2011, the 7th International Wireless Communications and Mobile Computing Conference", Istanbul, Turkey, July 2011.

[54] D. NGUYEN, P. MINET, T. KUNZ. *New Findings on the Complexity of Cluster Head Selection Algorithms*, in "WoWMoM 2011, The 12th IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks", Lucca, Italy, June 2011.

[55] R. SOUA, P. MINET. *A survey on energy efficient techniques in wireless sensor networks*, in "WMNC 2011, The 4th Joint IFIP Wireless and Mobile Networking Conference", Toulouse, France, October 2011.

[56] R. SOUA, P. MINET. *A survey on multichannel assignment protocols in wireless sensor networks*, in "The 4th Joint IFIP Wireless Days", Niagara Falls, Ontario, Canada, October 2011.

[57] A. C. K. VENDRAMIN, A. MUNARETTO, M. R. DELGADO, A. CARNEIRO VIANA. *A Greedy Ant Colony Optimization for Routing in Delay Tolerant Networks*, in "IEEE Smart Communication Protocols & Algorithms workshop (SCPA) in conjunction with IEEE Globecom 2011", Houston, United States, December 2011, http://hal.inria.fr/hal-00653838/en.

Scientific Books (or Scientific Book chapters)

[58] E. BACCELLI, T. H. CLAUSEN. *Réseaux*, in "Introduction à la Science Informatique", CRDP, May 2011, p. 237 - 280, http://hal.inria.fr/hal-00651607/en.

[59] J. A. CORDERO FUERTES, E. BACCELLI, P. JACQUET, T. H. CLAUSEN. *Wired/Wireless Compound Networking*, in "Mobile Ad-Hoc Networks: Applications", InTech, January 2011, p. 349 - 375, http://hal.inria.fr/hal-00651600/en.

[60] A. LAOUITI, P. MÜHLETHALER, Y. TOOR. *Broadcast techniques for vehicular ad hoc networks*, in "Wireless technologies in intelligent transportation systems", Transportation Issues, Policies and R&D Series, Nova Science, 2011, p. 205-222, http://hal.inria.fr/hal-00621172/en.

Research Reports

[61] C. ADJIH, E. BACCELLI, P. JACQUET, P. MINET, M. PHILIPP, G. WITTENBURG. *Deployment Experience with Low Power Lossy Wireless Sensor Networks*, INRIA, February 2011, n^{o} RR-7551, http://hal.inria.fr/inria-00567993/en.

[62] I. AMDOUNI, C. ADJIH, P. MINET. *On the Coloring of Grid Wireless Sensor Networks: the Vector-Based Coloring Method*, INRIA, October 2011, n^{o} RR-7756, http://hal.inria.fr/inria-00630233/en.

[63] I. AMDOUNI, P. MINET, C. ADJIH. *Node coloring for dense wireless sensor networks*, INRIA, March 2011, n^{o} RR-7588, http://hal.inria.fr/inria-00582457/en.

[64] I. AMDOUNI, P. MINET, C. ADJIH. *OSERENA, an Optimized Coloring Algorithm for Dense or Large Scale Wireless Networks*, INRIA, November 2011, n^{o} RR-7785, http://hal.inria.fr/inria-00637875/en.

[65] E. BACCELLI, P. JACQUET, B. MANS, G. RODOLAKIS. *Information Propagation Speed in Bidirectional Vehicular Delay Tolerant Networks*, INRIA, July 2011, n^{o} RR-7266, http://hal.inria.fr/inria-00476993/en.

[66] T. H. CLAUSEN, A. COLIN DE VERDIÈRE. *The LLN On-demand Ad hoc Distance-vector Routing Protocol - Next Generation (LOADng)*, INRIA, July 2011, n^{o} RR-7692, http://hal.inria.fr/inria-00611181/en.

[67] T. H. CLAUSEN, U. HERBERG. *A Comparative Performance Study of the Routing Protocols LOAD and RPL with Bi-Directional Traffic in Low-power and Lossy Networks (LLN)*, INRIA, June 2011, n^{o} RR-7637, http://hal.inria.fr/inria-00598157/en.

[68] T. H. CLAUSEN, U. HERBERG. *Delay Tolerant Routing with OLSRv2*, INRIA, June 2011, n^{o} RR-7662, http://hal.inria.fr/inria-00611183/en.

[69] T. H. CLAUSEN, U. HERBERG. *Some Considerations on Routing In Particular and Lossy Environments*, INRIA, February 2011, n^{o} RR-7540, http://hal.inria.fr/inria-00565830/en.

[70] T. H. CLAUSEN, U. HERBERG, M. PHILIPP. *A Critical Evaluation of the "IPv6 Routing Protocol for Low Power and Lossy Networks" (RPL)*, INRIA, May 2011, n^{o} RR-7633, http://hal.inria.fr/inria-00597036/en.

[71] T. H. CLAUSEN, U. HERBERG, J. YI. *Vulnerability Analysis of the Simple Multicast Forwarding (SMF) Protocol for Mobile Ad Hoc Networks*, INRIA, June 2011, n^{o} RR-7638, http://hal.inria.fr/inria-00600690/en.

[72] R. COLE, U. HERBERG. *Performance Analysis of SNMP in OLSRv2-routed MANETs*, INRIA, July 2011, n^{o} RR-7407, http://hal.inria.fr/inria-00523607/en.

[73] J. A. CORDERO FUERTES, P. JACQUET, E. BACCELLI. *A Theoretical Model for Analyzing the Impact of Jitter-based Techniques on Flooding over Wireless Ad Hoc Networks*, INRIA, July 2011, n^{o} RR-7701, http://hal.inria.fr/inria-00612816/en.

[74] J. A. CORDERO FUERTES, M. PHILIPP, E. BACCELLI. *Compound Wired/Wireless Internetworking with OSPF*, INRIA, June 2011, n^{o} RR-7642, http://hal.inria.fr/inria-00599086/en.

[75] P. JACQUET. *Information propagation speed versus transport capacity in mobile ad hoc wireless networks*, INRIA, March 2011, http://hal.inria.fr/inria-00580591/en.

[76] A. C. KOCHEM VENDRAMIN, A. MUNARETTO, M. REGATTIERI DELGADO, A. CARNEIRO VIANA. *GrAnt: Inferring Best Forwarders from Complex Networks' Dynamics through a Greedy Ant Colony Optimization*, INRIA, July 2011, n^{o} RR-7694, http://hal.inria.fr/inria-00610558/en.

[77] G. MAIA, D. L. GUIDONI, A. CARNEIRO VIANA, A. L. L. AQUINO, R. A. F. MINI, A. A. F. LOUREIRO. *ProFlex: A Probabilistic and Flexible Data Storage Protocol for Heterogeneous Wireless Sensor Networks*, INRIA, July 2011, n^{o} RR-7695, http://hal.inria.fr/inria-00610620/en.

[78] M. VALERIO BARBERA, A. CARNEIRO VIANA, M. DIAS DE AMORIM, J. STEFA. *VIP Delegation: Enabling VIPs to Offload Data in Wireless Social Mobile Networks*, INRIA, March 2011, n° RR-7563, http://hal.inria.fr/inria-00573301/en.

Other Publications

[79] E. BACCELLI, C. PERKINS. *Multi-hop Ad Hoc Wireless Communication - Internet-Draft (Work In Progress)*, November 2011, draft-baccelli-manet-multihop-communication-00, http://tools.ietf.org/html/draft-baccelli-manet-multihop-communication.

[80] T. H. CLAUSEN, A. CAMACHO, J. YI, A. COLIN DE VERDIÈRE, Y. IGARASHI, H. SATOH, Y. MORII. *Experience with the LOADng routing protocol for LLNs - Internet-Draft (Work In Progress)*, October 2011, draft-lavenu-lln-loadng-interoperability-report-01, http://tools.ietf.org/html/draft-lavenu-lln-loadng-interoperability-report.

[81] T. H. CLAUSEN, C. DEARLOVE, J. DEAN. *RFC6130: Mobile Ad Hoc Network (MANET) Neighborhood Discovery Protocol (NHDP)*, IETF - Std. Track RFC 6130, March 2011, http://tools.ietf.org/html/rfc6130.

[82] T. H. CLAUSEN, C. DEARLOVE, P. JACQUET. *The Optimized Link State Routing Protocol version 2 (OLSRv2) draft-12 - Internet-Draft (Work In Progress)*, July 2011, draft-ietf-manet-olsrv2-12, https://datatracker.ietf.org/doc/draft-ietf-manet-olsrv2/.

[83] T. H. CLAUSEN, A. COLIN DE VERDIÈRE, J. YI, A. NIKTASH, Y. IGARASHI, H. SATOH, U. HERBERG. *The LLN On-demand Ad hoc Distance-vector Routing Protocol - Next Generation (LOADng) - Internet-Draft (Work In Progress)*, October 2011, draft-clausen-lln-loadng-01, http://tools.ietf.org/html/draft-clausen-lln-loadng.

[84] M. GOYAL, E. BACCELLI, A. BRANDT, J. MARTOCCI. *A Mechanism to Measure the Quality of a Point-to-point Route in a Low Power and Lossy Network - Internet-Draft (Work In Progress)*, October 2011, draft-ietf-roll-p2p-measurement-02, http://tools.ietf.org/html/draft-ietf-roll-p2p-measurement.

[85] M. GOYAL, E. BACCELLI, J. MARTOCCI. *he Direction Field in Routing Metric/Constraint Objects Used in RPL - Internet-Draft (Work In Progress)*, February 2011, draft-goyal-roll-metrics-direction-00, http://tools.ietf.org/id/draft-goyal-roll-metrics-direction.

[86] M. GOYAL, E. BACCELLI, M. PHILIPP, A. BRANDT, J. MARTOCCI. *Reactive Discovery of Point-to-Point Routes in Low Power and Lossy Networks - Internet-Draft (Work In Progress)*, November 2011, draft-ietf-roll-p2p-rpl-05, http://tools.ietf.org/html/draft-ietf-roll-p2p-rpl.

[87] M. GOYAL, N. DEJEAN, D. BARTHEL, E. BACCELLI, J. MARTOCCI. *DIS Modifications - Internet-Draft (Work In Progress)*, September 2011, draft-goyal-roll-dis-modifications-00, http://tools.ietf.org/html/draft-goyal-roll-dis-modifications.

[88] U. HERBERG, T. H. CLAUSEN. *Cryptographical Signatures in NHDP draft-00 - Internet-Draft (Work In Progress)*, July 2011, draft-ietf-manet-nhdp-sec-00, http://tools.ietf.org/html/draft-ietf-manet-nhdp-sec-00.

[89] U. HERBERG, T. H. CLAUSEN. *Cryptographical Signatures in NHDP draft-01 - Internet-Draft (Work In Progress)*, March 2011, draft-herberg-manet-nhdp-sec-01, http://tools.ietf.org/html/draft-herberg-manet-nhdp-sec.

[90] U. HERBERG, T. H. CLAUSEN. *Cryptographical Signatures in NHDP draft-02 - Internet-Draft (Work In Progress)*, July 2011, draft-herberg-manet-nhdp-sec-02, http://tools.ietf.org/html/draft-herberg-manet-nhdp-sec.

[91] U. HERBERG, T. H. CLAUSEN. *MANET Cryptographical Signature TLV Definition draft-03 - Internet-Draft (Work In Progress)*, March 2011, draft-ietf-manet-packetbb-sec-03, http://tools.ietf.org/html/draft-ietf-manet-packetbb-sec.

[92] U. HERBERG, T. H. CLAUSEN. *MANET Cryptographical Signature TLV Definition draft-04 - Internet-Draft (Work In Progress)*, July 2011, draft-ietf-manet-packetbb-sec-04, http://tools.ietf.org/html/draft-ietf-manet-packetbb-sec.

[93] U. HERBERG, T. H. CLAUSEN. *MANET Cryptographical Signature TLV Definition draft-05 - Internet-Draft (Work In Progress)*, July 2011, draft-ietf-manet-packetbb-sec-05, http://tools.ietf.org/html/draft-ietf-manet-packetbb-sec.

[94] U. HERBERG, T. H. CLAUSEN. *MANET Cryptographical Signature TLV Definition draft-06 - Internet-Draft (Work In Progress)*, September 2011, draft-ietf-manet-packetbb-sec-06, http://tools.ietf.org/html/draft-ietf-manet-packetbb-sec.

[95] U. HERBERG, R. COLE, T. H. CLAUSEN. *Definition of Managed Objects for the Optimized Link State Routing Protocol version 2 draft-02 - Internet-Draft (Work In Progress)*, January 2011, draft-ietf-manet-olsrv2-mib-03, http://tools.ietf.org/id/draft-ietf-manet-olsrv2-mib-03.txt.

[96] P. LEVIS, T. H. CLAUSEN, J. HUI, O. GNAWLI, J. KO. *RFC6206: The Trickle Algorithm*, IETF - Std. Track RFC 6206, March 2011, http://tools.ietf.org/html/rfc6206.

[97] A. SZWABE, P. MISIOREK, M. URBANSKI, E. BACCELLI. *OLSRv2 Backpressure Traffic Engineering Extension - Internet-Draft (Work In Progress)*, May 2011, draft-szwabe-manet-backpressure-olsrv2-02, https://datatracker.ietf.org/doc/draft-szwabe-manet-backpressure-olsrv2/.

[98] A. SZWABE, A. NOWAK, E. BACCELLI, J. YI, B. PERREIN. *Multi-path for Optimized Link State Routing Protocol version 2 - Internet-Draft (Work In Progress)*, May 2011, draft-szwabe-manet-multipath-olsrv2-02, http://tools.ietf.org/id/draft-szwabe-manet-multipath-olsrv2.