Project-Team hipercom

HIgh PERformance COMmunication

Rocquencourt

THEME COM

Activity Report

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2. Overall Objectives

2.1. Overall Objectives

Hipercom project-team aims to design, evaluate and optimize the telecommunication algorithms. The aimed areas are protocols, new telecommunication standards and quality of service management in networks. The aimed activity fields are centered around the new networks and services supporting internet. Although we address the whole spectrum of telecommunication domain, practically the Hipercom project team is specialized in local area networking, local loops, in particular mobile ad hoc networking. However the thematic extends to the information theory and modelization of internet graph and traffics.

The scientific foundations are the following:

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

3. Scientific Foundations

3.1. Analytical information theory

Keywords: *channel capacity*, *compression*, *predictors*.

Participants: Philippe Jacquet, Wojciech Szpankowski.

> **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

Keywords: *deterministic performance*, *probabilistic performance*.

Participants: Cédric Adjih, Emmanuel Baccelli, Philippe Jacquet, Paul Mühlethaler, Pascale Minet, Thomas Clausen, Dang-Quan Nguyen.

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

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

- Deterministic performance analysis,
- Probabilistic performance analysis

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

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

The analysis of algorithm can rely on analytical methology 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

Keywords: *dynamic nodes*, *mobility models*, *network topologies*, *traffic source models*.

Participants: Cédric Adjih, Philippe Jacquet, Amina Naimi, Georges Rodolakis.

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

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

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

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

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 user that 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

Keywords: *Access protocols*, *QoS*, *routing*, *scheduling*.

Participant: all .

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

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

4. Application Domains

4.1. Panorama

Keywords: *Community Networks*, *Services over mobile networks*, *Wireless mobile ad hoc networks*.

4.2. Wireless mobile ad hoc networks

Abstract. Mobile wireless network have numerous application 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 recommended 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.

4.3. 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.

4.4. 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.

5. Software

5.1. Hiperlan driver

Keywords: *Link Layer*, *Routing*.

Participants: Paul Mühlethaler [correspondant], Marc Badel, Saadi Boudjit.

Abstract. Hiperlan 1 and IEEE 802.11s implement multihop routing at link layer

We have implemented a routing function in the driver of WiFi card. This software emulates the architecture of IEEE 802.11s and HIPERLAN type 1.

5.2. OLSR softwares

Keywords: *Internet protocol*, *routing protocol*.

Participants: Cédric Adjih [correspondant], Anis Laouiti, Marc Badel, Farid Sayah, Paul Muhlethaler, Dang Nguyen, Pascale Minet, Thomas Clausen.

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

The current version of OLSR, called OOLSR (for Object oriented OLSR), is IETF RFC compliant with multiple interfaces and tunable mobility parameters and has been fully tested during the three successive OLSR Interops in San Diego, August 2004, Paris August 2005 and Tokyo/Niigata 2006 . This version runs with Linux and Windows. The linux daemon is very easy to install and can be downloaded from the web page. There have been more than 6000 downloads of the code which is exceptional for a routing protocol. This version also contains feature adaptable to wireless driver, such as the signal power monitor.

Related to OLSR, we have implemented and succesfully tested in linux the Multicast routing protocol SMOLSR (Simple Multicast on OLSR) that efficiently broadcast data on wireless networks using MultiPoint Relays and the MOLSR (Multicast over OLSR) protocol. We have also implemented the MOST protocol (Multicast Overlay Spanning Trees) that forwards data to multicast group members on an overlay tree built on an OLSR shortest path tree.

Numerous code (including one in Python) have been developped for experiment and simulation (NS-2, Opnet). See http://hipercom.inria.fr/olsr/.

Other modules have been added to OOLSR dealing with autoconfiguration, security and QoS. Some of these modules have been experimented on the CELAR platform consisting of 18 nodes.

The code development of the next version of OLSR (OLSRv2) is under progress both at INRIA ROCQUEN-COURT and at POLYTECHNIQUE.

6. New Results

6.1. Medium Access Control protocol performance evaluation

Keywords: *MAC*, *collision resolution*, *radio*, *spatial reuse*.

> **Medium Access Control** algorithm locally performed by communicating nodes allowing an efficient access to and a fair share of a communication resource, *i.e.* a radio frequency or a wired medium.

Abstract. Medium Access Control plays a central role in mobile wireless networking. It must be distributed and provide fair access to the medium with an efficient spatial reuse of frequencies.

Design of efficient MAC protocols for ad hoc networks is a real challenge. The bad effect of hidden collisions is already known for long time ago. As shown by Gupta and Kumar in 2000, the global throughput of *ad hoc* networks is inherently limited under a vast class of realistic assumptions. We have analyzed how CSMA protocols should be optimized to offer the throughput foreseen by Gupta and Kumar in their paper. We have shown that a good tuning of CSMA (carrier sense range and transmission range) can actually allow a very significantly increase in the network throughput: more than 100% of gain depending on scenarios.

We have also designed and analyzed an Aloha scheme optimized for multihop network where locations of nodes is known. This study (joint work with TREC) uses tools of stochastic geometry. The network global through is shown to be, with this extremely simple protocol, in the same order of magnitude than the bound provided Gupta and Kumar.

6.2. The space and time capacity paradoxes of mobile ad hoc networks

Keywords: *Scaling properties*, *analytical models*, *routing protocols*, *transport capacity*.

Participants: Philippe Jacquet, Prateek Mittal.

Abstract. 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 $\frac{1}{\sqrt{N \log N}}$, N being the number of nodes in the network. Therefore the global capacity of the network increases in $\frac{\sqrt{N}}{\sqrt{\log N}}$. This is a surprising results 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 $\frac{1}{N}$).

We found a more precise instance of this result by using a simple but realistic network model. At each time slot we assume a Poisson distribution of transmitters. Transmitters emit at the same nominal power and signal have the same isotropic attenuation coefficient. 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. This constant together with the average connection distance gives the factor in front of Gupta and Kumar's $\frac{1}{\sqrt{N \log N}}$.

Therefore adding space to a multihop wireless network increases the capacity: this is the space capacity paradox. The previous model and Gupta and Kumar result 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. More precisely packet routes tends to asymptotically behave like light path under non linear optic, the inverse of local neighborhood radius playing the role of non uniform optical index. This self-adaptation of shortest path protocol such as OLSR hints the fact that more optimized protocols with QoS generally don't significantly outperform basic protocol version.

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 packets: 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: onehas to keep the delivery delay between reasonable bounds and one has to consider realistic mobility models. We have defined a protocol [ref mwcn and itw] 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.

6.3. Flooding in mobile ad hoc networks

Keywords: *Connected Dominating Set*, *Flooding*, *Multi-Point Relays*.

> **Flooding** protocol performed by communicating nodes allowing the dissemination of the same information from one source to all the other nodes in the network.

Abstract. Flooding information plays a central role in mobile ad hoc networking. It is used in order to set or update routing informations over the network. It must be efficient enough in number of retransmission in order to avoid network congestion with control traffic.

Optimizing flooding is a fundamental feature in a multihop wireless network since communication resource is scarce and an overloaded network can completely collapse due to the effect of numerous hidden collisions. On the other side, the way on how flooding operates can impact on the performance of routing protocols. For example reactive protocols extract shortest paths via flooding of the route request packet which is retransmitted exactly once by each node. We have shown that in its current version the shortest path are in average 1.6 time longer than the optimal paths that can be obtained in a proactive protocol such as OLSR.

We have introduced the super-flooding algorithm in which any node retransmits a route request packet copy as often it receives copies via a shorter path than the previously retransmitted route request. This procedure "guarantees" that the shortest path is eventually optimal. Surprisingly the super-flooding does not incur much more overhead than regular flooding, where the route request is retransmitted once by each node. Super-flooding overhead is around twice regular flooding overhead, and it reduces by 60 percent the data traffic overhead.

We have also introduced MPR flooding in a reactive protocol in order to improve the overhead of route request. MPR-flooding greatly improves regular flooding, since only MPR nodes of last hop emitter are eligible for retransmitting the packet. This fact was confirmed by simulation. It also confirmed that MPR-flooding provides much better shortest path than those obtained via regular flooding, since MPR chain contains optimal path and longer chains with no MPR nodes are eliminated.

In particular we have refined the concept of MPR flooding by tuning the concept of coverage, either in order to improve reliability or to decrease the risk of two-hop collisions. We have also specified a source independent dominating set based on MPR sets that can be used as a distributed wireless backbone.

6.4. Optimized Link State Routing (OLSR), OLSR extensions

> **Routing Protocol** Distributed protocol performed by the nodes in a network that allows any source willing to send data to a given destination to activate a chain of dedicated nodes (route) that will forward the packets hop by hop to the destination. Nodes dedicated to forward packets are called router nodes.

Abstract.
The routing protocol is the key component of any mobile ad hoc network, this is the minimum requisite in order to enable communication within the network. We have developed OLSR, an optimized link state routing protocol which is based on MPR flooding. Since OLSR support the whole legacy of internet, it can carry many extensions, some of them specific to mobile ad hoc networking.

The project team has specified the routing protocol based on MPR in mobile ad hoc networks. This protocol has been presented and succesfully defended in the working group MANET of the Internet Engineering Task Force (IETF) and presently is an experimental RFC [3]. The protocol scales particularily well when the network density increases and provides optimal path in terms of hop number.

Another contribution of the project lies in the development of source code of the OLSR routing protocol. This included development of a daemon, able to run on real wireless networks, based on 802.11 ad hoc mode. This allowed to use, test, and evaluate ad-hoc networking in real life. Real world measurements were done on a testbed at INRIA, which enabled enhancements of the protocol, taking into account the instability of real radio links. Later, the project team deployed the OLSR protocol in a bigger network on another site, under partnership; performance was thoroughly evaluated: mobility (with different speeds) ; tests of the reactivity of the routing protocol with respect to topology changes ; good behavior of the protocol in a static configuration (neighborhood, no routing loops) ; analysis of available bandwidth depending on the number of hops, ... The code was also ported to industrial simulation environments (like OPNET), and allowing the test the performance of the OLSR protocol, with more stringent topology and networks (higher number of nodes, higher mobility, ...), and which was the subject of extensive study under those conditions.

The Optimized Link State Routing protocol was, in 2003, standardized by the IETF as RFC3626. Publication of OLSR as RFC lead to a large influx of implementations and practical experiments – which revealed the need for an update for OLSR. The IETF MANET working group is, thus, chartered to produce an OLSRv2 document, with the design team for OLSRv2 being lead by Thomas H. Clausen, and containing members from organizations world wide, including industry, military and academia.

OLSRv2 is, for all intents and purposes, algorithmically equivalent to OLSRv1: the MPR optimization, deployment of partial topology and periodic updates have, in reality as well as theory, been shown to be good ideas and are as such carried over. OLSRv2 does champion several new developments, including through support for IPv6, address-compression in the messages being exchanged, as well as an even more general multi-message packet structure, which greatly reduces the implementation complexity of the protocol. Additionally, a new mechanism for dealing with multiple interfaces has been introduced, with the purpose of simplifying this rather complex task.

All in all, the developments of OLSRv2 are the "logical next step" from OLSRv1 – and the fact that this development happens in the context of the IETF and in collaboration with a large international community serves to solidify the position of OLSR as the chosen ad hoc routing protocol.

6.5. Bandwidth reservation and packet delay estimation in mobile ad hoc networks

Keywords: *QoS routing*, *QoS support*, *Quality of Service*, *admission control*, *bandwidth reservation*, *class*, *link interference*, *packet delay. Queuing)*, *service differentiation*.

Participants: Cédric Adjih, Philippe Jacquet, Anis Laouiti, Pascale Minet, Amina Naimi, Dang-Quan Nguyen.

> **Quality of Service** Set of parameters that allow to tune the communication protocol in order to improve and control the quality perceived by user of the applications using the communication medium.

Abstract. The presence of interferences makes the support of quality of service much more complex in radio wireless networks than in wired networks. We can distinguish three main axes in our work on QoS support:

- bandwidth reservation: we show that the problem of link interference makes NP hard the bandwidth reservation problem even in its incremental form. We specified an admission control based on bandwidth allocation heuristic and a packet delivery delay estimator based on analytical methods.

- estimation of packet delay: How to estimate the delay taken by a packet to join its destination ?

6.5.1. *Bandwith reservation on the presence of interferences*

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

6.5.2. *Distribution of packet delay*

On a different perspective we have also worked on the problem of determining the delay distribution of packet delivery in a multihop mobile ad hoc network. In some application such as video and audio streamings we have to find the route that bounds the probability that packet delay delivery exceeds a certain request threshold. The first problem is to estimate the packet delay distribution. Contrary to previous common belief there is no need of network synchronization. Since propagation delays between routers are negligible, most delays occur in queueing and medium access control processing. The main problem is to determine the delay in absence of packet data traffic. This can be done by using the queueing delay of hello message and since the latter are broadcast packet not retransmitted in case of collision by adjusting their delay to unicast packet by estimating their collision rate thanks to the hello loss detected by the receiver.

The estimate of delay distribution is done via analytical method. A new order of magnitude arises when we target to estimate the impact of the new traffic on the current collision probabilities. If we assume that the interference occurs at a certain number of hops we obtain the new loss probabilities via a matrix fixed point non-linear process. This estimate can be latter updated by exact unicast packet delay estimate when the link is used.

The present objective consists into merging the bandwidth asignment problem and the delay estimate problem in a single quality of service control. The idea is to use bandwidth assignments for admission control and the delay estimate for quality of service control. One the network move the packets route may change and the delay estimate may change, if one connection is not anymore able to achieve its quality of service in term of delay constraint then it is stopped by the source.

In order to keep control on quality of service flows we use source routing forwarding options. Source routing allows route diversity. The sources advertize their route with their bandwidth so that every node in the network can perform the admission control for their own flows.

6.6. Security in mobile ad hoc networks

Keywords: *Attacks*, *bad relaying of packets*, *generation of incorrect control messages*, *integrity of the network*, *signatures*, *time-stamps time-stamps*.

> **Security** Set of mechanisms which ensure the integrity of the ad hoc network even in case of malicious attacks against the network connectivity

Abstract. A significant issue in the ad-hoc network domain is that of the integrity of the network itself. Usually the assumption in an ad hoc network is that all nodes are behaving well and are welcome. If that assumption fails - then the network may be subject to malicious nodes, and the integrity of the network mail fail. An important service is to be able to keep a correct network connectivity even when the network is subject to intruder nodes which try to break the network integrity.

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

- we have designed two security mechanisms to counter most of the attacks when we assume that there is no compromized nodes in the network,

- in presence of compromized nodes we have proposed mechanisms to detect compromised nodes or links and to remove such nodes or links in a numerous configurations of attacks.

We have identified for OLSR five attacks towards the network integrity: the incorrect control message generation attack, the replay attack, the relay attack, the bad data traffic relaying and the bad control traffic relaying attacks. In the incorrect control message generation attacks, intruder nodes try to break the network connectivity by sending incorrect control messages. The replay attack is an incorrect control message generation where the incorrect control messages are the replay of old control messages. The relay attack is an attack where a control message is artificially relayed to another location of the network than the actual location where this message has been sent. This attack result in the creation of non existing links. The bad data or control traffic relaying appears when a node is not correctly relaying data or control traffic.

All these attacks may have important consequences on the network connectivity. Under the assumption that there is compromised node in the network, we have designed a signature mechanism and time-stamps mechanism to counter all the identified attacks except the relay attack. To use these mechanisms, we need to add to OLSR a new dedicated control packet for each control packets conveying information on the network topology. This additional control packet will be used to autenticate the related topological information. These two mechansims ensure that intrude nodes can not be part of the network.

Concerning the relay attack, we have shown that the knowledge by the nodes of their own position can be used to mitigate this latter attack.

If we assume that there are compromised nodes in the network, securing OLSR is much more complex. Dedicated mechanisms can be used to detect compromised nodes or links and to remove such nodes or links. A perfect securisation under such an assumption seems to be out of reach. However, we have shown that using only verifiable symmetric links and checking flows conservation can solve numerous configurations of attacks. In an ad hoc network, the secrecy of transmission between nodes can be obtained in point to point with protocols as IPSec. However this approach is not possible for multicast traffics. In such conditions, it could be interesting to use a shared key. We have started to design a group key agreement protocol deicated for ad hoc network. The secret key that is produced is the result of all the contributions of the members of the group.

6.7. Performance evaluation of routing algorithms in mobile ad hoc networks

Keywords: *IEEE 802.11*, *analytical models*, *real experiments*, *routing protocols*, *simulations*.

IEEE 802.11 Set of Wireless norms which originated the Wifi standard. The nominal throughputs range from 1 Mbps to 54 Mbps, with radio range between 20 m to 200m. The standard is very popular nowdays.

Abstract. Analytic results from information theory provides very important insight in mobile ad hoc networking. In particular it is shown that the logical neighborhoods of nodes shrink when the local traffic load increases. This property has very important consequence on mobile routing protocol performances and on the ways of intrepreting them.

Using simulations and real-life experiment, we have thoroughly investigated the performance of OLSR protocol. This led us to greatly improve the neighbor monitoring that can experience hysterisis. We also have used analytical models for performance evaluations of mobile ad hoc protocols. Surprisingly analytical models are sometimes closer to experiment than simulations. We have used various models such as random graphs for indoor networks, unit disk graph for outdoor networks. We have also used the non-trivial wave propagation model described in the MAC layer section.

We found out that the results of Gupta and Kumar hold with the OLSR protocol. In particular we show that the hello traffic and topology control traffic imposes an upper bound on the maximum neighborhood manageable size by the protocol as predicted by Kumar and Gupta. Therefore when the density of the network increases the neighborhoods shrink and the potential number of hop inversely increase in square root.

The slotted TDMA ignores the effect of defer on signal level of 802.11. Simulations show that without an appropriate signal defer threshold level, the network can completely collapse when the density increases because nodes will always defer on defer signal if the latter is not appropriately tuned. This is the reason why the theoretical result of Gupta and Kumar is never attained in practical experiments. For example OSPF protocol collapses completely with less than 30 nodes because of its control traffic overhead in cube of its size.

6.8. Internet topology and TCP performance analysis

Keywords: *Power laws*, *asymptotic*, *long dependence*, *self-similarity experiments*.

Abstract. We provide an analytical model of power law distributions in the internet topology. We also provide analytical result on the steady state distribution of throughputs in long-lived TCP connection. We proved that power law distribution of round trip delay in the internet can introduce long range dependences in the traffic of many agregated TCP connections.

We have introduced a model that sustains the power laws that have been recently depicted in the internet topology. We call this models, the self-similar trees, and they explain the power laws in the multicast trees.

We have also provided analytic evaluation of the performance of TCP protocols in large networks which relies on the mean-field methodology. This analysis proves that throughput have log normal distributions when expanded to small values, but disproves that traffic generated by a single TCP source has long dependence.

Using this result and the result about power laws in the internet, we have proven that several TCP connections with power law distributed round trip delays generates long dependence in traffic. This result use an old result about long dependence in on/off traffics.

6.9. Multicast extension for OLSR

Keywords: *OLSR*, *group management protocol*, *multicast group*, *multicast routing protocol*.

Participants: Anis Laouiti, Philippe Jacquet, Pascale Minet, Laurent Viennot, Thomas Clausen, Georges Rodolakis, Cédric Adjih.

Abstract. We have produced a research report describing the Multicast extension for the Optimized Link State Routing protocol (MOLSR). MOLSR is in charge of building a multicast structure in order to route multicast traffic in an ad-hoc network. MOLSR is designed for mobile multicast routers, and works in a heterogenous network composed of simple unicast OLSR routers, MOLSR routers and hosts. In the last part of this document we introduce also a Wireless Internet Group Management Protocol (WIGMP). It offers the possibility for OLSR nodes (without multicast capabilities) to join multicast groups and receive multicast data. A new version of the multicast protocol called MOST for Multicast on Overlay Spanning Tree has been specified and implemented over OLSR. The main characteristic is in the use of a distributed spanning tree made of tunnels between the multicast group members. This feature is more comfortable than the multicast tree feature in MOLSR, since in MOST only the members of the multicast group implement the protocol, the other nodes are transparent, the traffic using them as tunnels. Moreover the use of unicast tunnel greatly improves the reliability of packet delivery, thanks to point to point acknowledgements.

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

6.10. OLSR and IPv6

Keywords: *IPv6*, *OLSR*, *autoconfiguration*, *neighbor discovery*, *routing protocol*.

Participants: Emmanuel Baccelli, Cédric Adjih, Thomas Clausen, Anis Laouiti, Pascale Minet, Paul Muhlethaler, Saadi Boudjit.

Abstract. The lack of addresses was one of the reasons that led to develop IPv6. But IPv6 fixes also a number of problems in IPv4 and improves other functionalities such as routing and network configuration. In order to understand how they can affect OLSR, we have first studied the features of IPv6, such as the different address formats, the neighbor discovery protocol, and the autoconfiguration procedure. We then propose changes required by OLSR to work, and to benefit from IPv6 mechanisms.

6.11. Wireless OSPF

Keywords: *wireless OSPF*.

Participants: Cedric Adjih, Dang Nguyen, Emmanuel Baccelli, Thomas Clausen, Philippe Jacquet.

Wireles OSPF

The IETF OSPF working group is focusing on the development of an OSPF standard to operate efficiently on mobile ad hoc networks: W-OSPF. Hipercom is a key participant in this task since the beginning.

Solutions are currently being experimented, one which is being elaborated at Hipercom, building on its valuable OLSR experience. The other solutions are being elaborated at Boeing Phantom Networks and Cisco Inc., with whom Hipercom interacts on this account, as Hipercom's solution, MPR-OSPF, has gained considerable visibility.

The outcome of this effort from the OSPF working group at the IETF is likely to be published as an experimental RFC. Besides, MPR-OSPF has already been subject to several IETF publications, as well as several related academic publications.

On the same time we have specified and implemented an OSPF gateway to OLSR which covers the case where the OLSR network and the OSPF network are distinct but share some routing informations.

6.12. MANET NEMO integration

Keywords: *MANET*, *NEMO*.

Participants: Emmanuel Baccelli, Thomas Clausen, Philippe Jacquet.

MANET-NEMO
Internet edge mobility has been an option for a number of years. Based on the clear division of responsibility among Internet nodes, with some being "unintelligent" edges (hosts) and others being in charge of the network maintenance (routers), protocols such as Mobile IP allows a host to change its point of attachment to the Internet. The mechanism is simple: assign a "home agent" to know the mobile host's current point of attachment to the Internet, and perform tunneling of traffic, arriving at the home agent, to the mobile host. A more general form of this is nemo, in which a group of hosts, all associated with a mobile router, move together. Symmetric to Mobile IP, a "home router" performs the tunneling of traffic to the mobile router.
Nemo allows the notion of "nested networks": a mobile network, which attaches to another mobile network to an arbitrary depth. Employing the mechanisms of informing a "home router" of points of attachment , connectivity can indeed be maintained. However since, in essence, a mobile router would signal its attachment to another (potentially mobile) router without consideration of the fact that if this router was a direct point of attachment to the internet, this approach has a vastly increased overhead (through nested encapsulations) and sub-optimal paths as the consequence. Subsequently, a number of proposals have been discussed, to what has been called "route optimization in nested nemo networks".

More specifically, this problem can be divided into two parts: route-optimization within the nemo nest (i.e. if a node in a mobile network wishes to communicate to another node in another mobile network, within the same nest), and route optimization with respect to communication to and from the Internet. Many of these proposals have suggested injecting specific nodes with specific responsibilities for "shortcutting" tunnels or construct overlay-networks for more efficiently carry traffic within and to/from nested nemo networks.

Essentially, however, the problem of "route optimization in nested nemo networks" is a routing problem: how to construct paths in a dynamic network, and how to route traffic along these paths in an efficient manner.

Hipercom has, through its involvement in the development of mobile ad-hoc routing protocols, acquired an expertise in this field, and has therefore developed a solution to this route optimization problem. The solution is unique in that it employs classic routing mechanisms, as known from OLSR, to maintain an ad-hoc network between the mobile routers in the nemo nest. This allows for, un-encapsulated, direct communication along optimal paths between any two nodes in any two mobile networks within the same nemo nest. For communication to/from the Internet, the solution proposed by Hipercom cuts away the nested tunneling and sub-optimal routing: through knowing the topology of the nemo nest, it is possible for a mobile router to apply std. mobile IP signaling for informing its home router of its point of attachment to the Internet. Specifically, rather than signaling its immediate point of attachment (which can be another mobile router – yielding nested encapsulations and dog-leg routing), a mobile router would signal its point of attachment as the point where the nemo nest actually attaches to the Internet. The yield of this approach is, that for communication to/from the Internet, only one level of encapsulation is required – which is equivalent to the encapsulation attained by standard mobile IP.

The deployment of OLSR in this context is new, and has therefore yielded academic publications as well as publications within the IETF – where a substantial interest has been shown for the approach from, among others, Cisco and Nokia.

6.13. Auto-configuration in MANET Networks

Keywords: *Auto-configuration.*

Participants: Emmanuel Baccelli, Thomas Clausen, Anis Laouiti, Paul Muhlethaler, Saadi Boudjit, Pascale Minet, Philippe Jacquet, Cedric Adjih.

Auto-configuration

A preconditioning for all routing protocols, OLSR included, is that each node is identifiable through an unique identifier – address. Address auto-configuration is as such a task orthogonal to and required for the operation of a routing protocol. Traditional measures, such as the deployment of centralized configuration servers (such as DHCP) is not well adapted to the manet domain due to the requirement that direct communication between the unconfigured nodes and the configuration server is possible. In a manet, no infrastructure is present ensuring such a communication – indeed, the task of the routing protocol is to establish and maintain a communications infrastructure, however the functioning of the routing protocol is dependent on the nodes having unique addresses.

More generally, the topic of address auto-configuration in OLSR networks is one of multi-hop auto-configuration which, while somewhat esoteric, is of relevance and interest beyond OLSR and manets.

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

We recognize that this is a partial solution to the more general problem of autoconfiguration in OLSR networks (which includes disjoint networks, merging networks and disconnected networks), however have proposed this as a pragmatic approach at solving a specific, but large, set of real-world problems.

We have developped and published a set of autoconfiguration algorithms for OLSR. This set of algorithms is based on an efficient address duplication algorithm. We have proved that this scheme works even in the case of multiple conflicts thus this algorithm can handle the case of merging networks. One of these duplication algorithms can work with multiple interfaces and we have also proved its correct operation in that case. For these autoconfiguration algorithms we have evaluated the overhead incurred by the protocol. We have proposed an Internet Draft to the MANET-Autoconf working group of IETF.

Other than an academic publication, we have also presented and discussed the larger topic of auto-configuration within the IETF. In collaboration with Telecom Italia, a publication outlining the problem-scope and potential solution space has been submitted to and discussed within the IETF, and we are core members in the IETF design-team addressing this issue.

Since the 61th IETF meeting in Washington, in november 2004, efforts have been underways to strengthen the work on MANET autoconfiguration – with the purpose of creating an IETF working group focusing on development of appropriate autoconfiguration mechanisms. This effort was chaired jointly by Thomas Heide Clausen and Shubhranshu Singh (Samsung, Seoul, Korea), and manifested itself in two BOFs (pre-working-group meetings) at the 62th IETF in Minneapolis and again at the 63th IETF in Paris before the IESG (Internet Engineering Steering Group – the IETF technical management layer) approved creation of an AUTOCONF working group immediately prior to the 64th IETF in Vancouver, november 2005. This newly created working group is chaired jointly by Thomas Heide Clausen and Shubhranshu Singh (Samsung), and is chartered to produce a number of results, including:

- a MANET architecture document, laying out the difference between a MANET and "the rest of the Internet", both in philosophical and practical terms. This document is important in that it will be the cornerstone in educating the wider IETF community on the technical aspects of MANETs

- an autoconfiguration problem statement, detailing the problem of autoconfiguring MANETs, as well as laying out the possible solution space.

- a (number of) solution(s) for standardization as the way in which nodes can be autoconfigured within a MANET.

The initial scope of this working group is 2 years.

It is worth mentioning that the process of creating the working group (i.e. nov 2004-nov 2005) has involved expending a huge effort in educating and informing members of the wider IETF (and more generally,Internet) community as to the importance of MANETs as well as the differences between MANETs and other networks. The successful creation of the AUTOCONF working group is a recognition that this effort was needed and appreciated.

6.14. Scheduling techniques for quality of service networks

In 2006, we started the French Tunisian STIC Cooperation project entitled 'Scheduling techniques for quality of service networks' with the team of Leila Saidane at ENSI (Tunisia). We have considered three types of Quality of Service (QoS) networks:

- wired QoS network,

- Bluetooth piconet,

- Mobile Ad hoc NETwork (MANET).

6.14.1. Wired QoS networks

Participants: Skander Azzaz, Leila Azouz Saidane, Inès El Korbi, Fadhel Maina, Steven Martin, Sahla Masmoudi, Pascale Minet.

In a wired QoS network, such as a DiffServ/MPLS network, several scheduling techniques have been compared: FP/FIFO, FP/DM, FP/EDF and FP/EDF*. All these techniques combine a fixed priority (FP) denoting the importance of the flow considered with a fixed (case of FP/DM) or dynamic priority (the other cases) of the considered flow packet. This second priority can be based on the flow deadline:

- Deadline Monotonic (DM) schedules packets according to their relative deadline,
- Earliest Deadline First (EDF) schedules packets according to their absolute deadline, that is equal to the arrival time at the node considered plus the relative deadline,
- a variant of EDF, called EDF*, considers the network arrival time instead of the node arrival time.

Variants have been proposed to minimize the deadline miss probability, they act on the fixed priority or on the deadline. We have also studied and compared several techniques to assign local deadlines from an end-to-end deadline.

6.14.2. Bluetooth piconets

Participants: Leila Azouz Saidane, Slim Ben Ayed, Fadi Kacem, Karima Maalaoui, Pascale Minet.

In a Bluetooth piconet, we distinguish the local scheduling used by each node to select the first message to transmit and the intra-piconet scheduling used by the master to select the next slave to be polled. We have studied 1-RR (one Round Robin) and E-RR (Exhaustive Round Robin) as intra-piconet schedulings that we have combined with FIFO and EDF local schedulings. As a further work, we will study mathematically the L-RR scheduling (i.e. a slave is not allowed to transmit more than L packets succesively), in order to determine the optimal value of L for a given configuration. The optimal value of L minimizes the deadline miss probability.

6.14.3. MANETs

Participants: Leila Azouz Saidane, [Pr. ENS Tunis], Manel Bourguiba,[ENSI, Tunis], Noor Bris, [ENSI, Tunis], Inès El Korbi, [ENSI, Tunis], Anis Laouiti, [INRIA then INT Evry], Dang Quan Nguyen [INRIA], Pascale Minet, [INRIA].

Concerning MANETs (mobile ad hoc networks), we have focused on the following topics:

- Topology modeling of a mobile radio network: we are interested in determining the probabilities to follow different routes.
- Bandwidth allocation modeling in a MANET: a mathematical model has been developed to obtain the probability to reject a new flow because of unavailable bandwidth on a node belonging to the interference area of the flow.
- QoS at the medium access control layer: a state of the art has been established for the modeling of the IEEE 802.11 protocol with its variants. New protocols have been proposed in order to take into account the flow deadlines. We are now evaluating their performances.

6.15. CBQ scheduling applied to a mobile ad-hoc network

Participants: Leila Boukhalfa, [ESIGETEL, PhD student], Pascale Minet, [INRIA], Serge Midonnet, [ESIGETEL].

We have studied the impact of WCBQ, a Wireless Class Based Queueing scheduling, on the QoS granted to flows. This scheduling policy shares the bandwidth of the node between the different flows transmitted by this node. We have compared the performances achieved by WCBQ and Priority Queueing. Simulation results show that WCBQ protects flows with low throughput. All flows receive a bandwidth proportionally to their weights. WCBQ tends to minimize the variations of the average bandwidth granted to a flow as well as the end-to-end delay. We finally propose a solution allowing the coexistence of flows with delay requirements and bandwidth requirements. This solution guarantees a low delay to low throughput flows without penalizing the bandwidth granted to other flows. We have studied different weight assignment techniques and evaluated their impact on the QoS received by the flows. For instance, the weight of a flow is set to the minimum weight

proposed by the nodes on the flow route. The gain obtained by other flows is not sufficient to justify the overhead introduced by this two-phase protocol. Hence, we locally assign the weight of a flow. This weight is equal to the fraction of the bandwidth requested by the flow considered over the sum of the bandwidth requested by all the flows present on the node considered.

We have then shown how to integrate WCBQ in a QoS support of an OLSR mobile ad hoc network. This solution encompasses five components: QoS model, admission control, QoS routing, QoS signaling, and QoS medium access control (MAC). However, a QoS MAC is not required, although it would increase the performances of the proposed solution. Interferences are taken into account by the admission control, QoS routing and QoS signaling. QoS signaling is in charge of providing the available bandwidth. QoS flows are source routed, whereas best effort flows are routed hop by hop. Simulation results show that QoS flows receive a bandwidth very close to this requested, whereas best effort flows share the available bandwidth. The performances of this solution have been evaluated by NS2 simulations. They show a good stability of the routes taken by QoS flows and an increased bandwidth with regard to native OLSR.

6.16. QoS support in an OLSR mobile ad hoc network

Participants: Dang Quan Nguyen, [INRIA], Pascale Minet, [INRIA].

In order to support multimedia applications, mobile ad hoc networks must provide quality of service (QoS). We first propose at first a simple model of QoS allowing to support flows with QoS demands in terms of bandwidth and best effort (BE) flows that have no particular QoS constraint.

QoS routing must be able to find a route that meets a QoS demand, if such a route exists. Current works are classified into two categories, one based on QoS measures (ex: bandwidth) performed at each node, the other based on reservation. Both need a QoS signaling protocol. The solution we propose is based on QoS measures performed at each node. These QoS measures (ex. local available bandwith) are then propagated by means of the QoS signaling protocol.

In his PhD thesis, Dang Nguyen proposes a QoS support taking into account the radio interferences between nodes. This support ensures that the QoS demanded is granted on the chosen route, and the acceptation of this new QoS flow does not compromise the QoS already granted to existing flows.

This thesis then shows how to extend the OLSR (Optimized Link State Routing) protocol, in order to include support for applications having QoS demands. The performances of this QoS support are evaluated by simulations to validate the conception choices (ex: source routing for QoS flows, shaping of BE flows to protect QoS flows).

Finally, the proposed QoS support is implemented on an 802.11b network in order to prove its feasibility (see the CELAR project). The gains are measured on this platform. We have observed a good accuracy of the simulation results with these measures. We have also evaluated the overhead of this solution that keeps the flooding optimization introduced by native OLSR.

As the selection of Multipoint Relays (MPRs) done in native OLSR is unable to provide QoS support, we have introduced the Multipoint Relays selected according to the available bandwith (MPRBs), in such a way that each two-hop neighbor is reached by a one-hop neighbor of maximum bandwidth. We have then compared the number of MPRs and the number of MPRBs. The higher number of MPRBs justifies the choice of keeping MPRs to optimize flooding in our QoS support based on OLSR.

6.17. Distributed real-time scheduling: the trajectory approach

Participants: Steven Martin [MdC, University of Paris-Sud 11], Pascale Minet, [INRIA].

Fixed Priority (FP) scheduling has been extensively studied in the last years. Indeed, it exhibits interesting properties:

- the fixed priority of a flow reflects its importance degree with regard to the application considered;

- The impact of a new flow τ_i is limited to flows having priorities smaller than this of τ_i;

- It is easy to implement;

- It is well adapted for service differentiation: flows with high priorities have smaller response times.

In the state of the art, the worst case analysis assumes that flows sharing the same priority are arbitrarily scheduled. However, the most widespread implementation of FP is FP/FIFO, that is packets sharing the same fixed priority are scheduled according to their arrival order in the node considered. We are interested in providing deterministic bounds on the end-to-end response times and jitters to real-time flows in a distributed system. We propose, in each node, to schedule flows according to a non-preemptive FP/FIFO scheduling. Then:

- Packets are scheduled first according to the fixed priority of the flow they belong to;

- Packets sharing the same fixed priority are scheduled according to their arrival order on the node considered.

For this worst case analysis, we use the trajectory approach. Unlike the holistic approach, the trajectory approach is based on the analysis of the worst case scenario experienced by a packet on its trajectory and not on any node visited. Then, only possible scenarios are examined. More precisely, to compute the worst case end-to-end response time of any packet m, the trajectory approach consists in moving backwards through the sequence of nodes m visits, each time identifying preceding packets and busy periods that ultimately affect the delay of m.

We show that the trajectory approach provides bounds more accurate than those provided by the holistic approach. Our bounds are reached in various configurations. We also show how to derive an admission control, based on these results. We have then applied these results to a DiffServ architecture, where the Expedited Forwarding (EF) class has the highest scheduling priority.

6.18. Coexistence of deterministic and probabilistic guarantees of quality of service

Participants: Leila Azouz Saidane,[Pr., ENSI, Tunis], Skander Azzaz, [ENSI, Tunis], Inès Korbi, [ENSI, Tunis], Fadhel Maina, [ENSI, Tunis], Steven Martin, [MdC, University of Paris-Sud 11], Sahla Masmoudi, [ENSI, Tunis], Pascale Minet, [INRIA].

We are interested in providing quantitative Quality of Service (QoS) guarantees to various types of real-time applications. We focus more particularly on the response time provided to such applications. Hard real-time applications have strong deadline requirements whereas soft real-time applications have only soft dealine requirements. We propose a solution where hard real-time applications receive a deterministic QoS guarantee whereas soft real-time applications receive a probabilistic QoS guarantee. This solution combines the advantages of the deterministic approach and the probabilistic one: the hard real-time applications have a strong guarantee of meeting their deadlines and the resource utilization is good thanks to probabilistic guarantees. The deterministic approach is based on a worst case analysis. The probabilistic approach uses a mathematical model to compute the probability density function to obtain the probability that the response time exceeds a given value. We derive from these results an admission control that allows each accepted real-time application to receive a quantitative QoS guarantee adapted to its QoS requirements. We evaluate the benefits brought by our approach.

6.19. Network Coding in wireless networks

Participants: Cédric Adjih, Song-Yen Cho, Philippe Jacquet.

In traditional communication systems, nodes exchange data through relaying by intermediate nodes: the packets are forwarded by the intermediate routers unmodified. This is true for both traditional unicast and multicast communication. Recently, the pioneering work of Ahlswede et al. have shown that *network coding*, where intermediate nodes mix information from different flows, can achieve higher throughput for multicasting over networks represented as directed graphs. The mixed is obtained via linear combination over a finite Gallois fields.

Still, it has been noted that the wireless media is inherently a broadcast media which has crucial advantage since it allows overhearing. This advantage could be exploited by wireless network coding, permitting gains by reducing the number of transmissions required to transmit the same amount information (*energy-efficiency*).

We propose a simple protocol for network coding. We describe how the packets flowing from the one source evolves in *waves*, and by studying the propagation of the waves, we are able to quantify the performance of the simple protocol. We analyze the performance of the protocol in an unit graph wireless network model in an 1 dimension model, with an asymptotic model and show that it is asymptotically close to optimal flooding obtained via MPR flooding. In 2 dimension model, we conjecture similar performance, simulations show that the protocol outperforms the MPR flooding (which is no longer optimal).

The simple network coding protocol is interesting since it does not need sophisticated network management such as neighborhood management and two-hop monitoring as it is demanded with MPR flooding. Nevertheless the asymptotic performance are obtained with rather large dimensions, which lead to non negligible information extraction cost from rather large linear combinations.

6.20. Vehicle to vehicle communication (V2V) and Vehicular Ad hoc NETworks

Participants: Cédric Adjih, Anis Laouiti, Paul Muhlethaler, Yasser Toor.

Vehicle to vehicle communication (V2V) and Vehicular Ad hoc NETworks (VANETs) are very challenging areas of research and interest in them is growing day by day. These domains are focusing an intense research activity; Yasser Toor has reviewed the state of the art of the research in these areas. He has started by giving a classification of the applications that can be used in VANETs and has identify their technical requirements . Then, he has analyzed the proposed solutions found in the literature to satisfy these requirements. The proposed solutions are at different network levels: Phy/Mac layer, routing layer, transport layer (TCP/IP), application layer (e.g. data dissemination techniques, security enforcing). He has also reviewed different simualtion tools used to evaluate the proposed solutions.

Yasser has started to work on safety applications. He is studying the scenario of an accident, in such a scenario safety packets must be quickly and reliably disseminated in the vicinity of the accident. Among the technical tools that are foreseen there are : multipoint relays, reliable broadcast, geographic routing, MAC positive or negative acknowledgment, MAC priority schemes ...

6.21. Intermittent Networks

Participants: Philippe Jacquet, Dang Quan Nguyen, Georges Rodolakis, Bernard Mans.

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*.

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.

This work is also supported by an ARC from Australia in cooperation with professor Bernard Mans of Macquarie University.

7. Contracts and Grants with Industry

7.1. COM2REACT

Participants: Cédric Adjih, Anis Laouiti, Paul Muhlethaler, Yasser Toor.

COM2REACT's overall objective is to establish the feasibility of an effective control of traffic geared to address both efficiency and safety. Its implementation will involve the deployment of two two-way communication systems: vehicle to vehicle (V2V), and vehicle to infrastructure (V2I). This structure will facilitate significant improvement in the flow of information acquired by moving vehicles and in its quality and reliability, thereby enhancing road efficiency and traffic safety on urban, intercity arterials and rural roads. A key objective of COM2REACT is the implementation of the middle control level by means of a virtual traffic control sub-centre, which manages a moving group of vehicles in close proximity. The virtual sub-centre (VSC) functions locally via the V2V communication system, it also transmits, by means of the V2I communication, selective data to an RCC (Regional Control Center) and receives, in return, instructions to distribute to the vehicles. The role of VSC is set, unnoticeable by the driver, to one of the vehicles in the group according to rules imbedded in all COM2REACT vehicles. The potential impact of the COM2REACT project consists of the developing advanced systems for vehicle cooperation that enhance both safety and information on European roads.

By proving the efficiency of such architecture, COM2REACT will contribute significantly to the introduction of V2V technologies. In COM2REACT, the V2V technology will be based on the *OLSR (Optimized Link State Routing)* protocol. This protocol is optimized for dense networks, this is particularly well suited for Vehicular Ad hoc NETworks (VANETs). Multipoint routing extension of OLSR e.g. MOLSR (Multicast OLSR) or SMOLSR (Simple Multicast OLSR) can be very useful in VANETs and should probably be used in COM2REACT. The COM2REACT project and VANETs are excellent examples of application for the OLSR technology.

7.2. CELAR

Participants: Cédric Adjih, Philippe Jacquet, Anis Laouiti, Pascale Minet, Paul Muhlethaler, Dang Nguyen, Philippe Jacquet.

The CELAR project has started in April 2004 for three years. Its aim is to enhance the demonstrator of mobile ad-hoc network MANET/OLSR, previously implemented with secured routing, quality of service (QoS), and an OLSR/OSPF gateway. This project is funded by CELAR (Centre d'Electronique de l'Armement, French MoD/DGA). 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. It is made up of 18 nodes: 10 OLSR routers and 8 terminals (VAIOs and iPAQs). Routers and terminals are equipped with 802.11b cards and measurements tools on Linux. They implement the OLSR routing protocol. Performance measurements have been done in various configurations including different traffic types, network topology and mobility (e.g., pedestrian and/or vehicle).

More precisely, this project addresses four topics :

- *secured routing*: in a mobile ad-hoc network, the use of secured tunnels is not sufficient to protect routing against potential attacks. First, we have analyzed potential attacks against OLSR routing and we have precised our security goal. In the attacks, we also consider the case of compromised nodes in the network. These nodes have a certain knowledge of the network secret keys. In the case where the network does not encompass compromised nodes, we have design a security architecture which can counter most of the identified attacks except the wormhole attack. This security architecture is base on timestamping and signing message. For the case where there is compromised nodes in the network we have proposed various scheme to mitigate the effects of attacks in such a situation.

- *QoS management*: it is more complex in mobile ad-hoc networks than in wired networks because of their high dynamicity, the presence of interferences and the limited resources. We propose an extension of OLSR conciliating both QoS support and optimized flooding. Flows having QoS requirements are source routed on the shortest path providing the requested bandwidth. Best effort flows are routed hop by hop and regulated by leaky buckets. Simulation results show that QoS flows receive a throughput close to this request and have a high delivery rate. Moreover, this extension supports node mobility : up to 20m/s with the default OLSR parameter values.

- *OLSR/OSPF gateway*: the aim is to allow exchanges of routing information between an OLSR network and an OSPF network. As both routing procols are link based, the OLSR/OSPF gateway will take advantage of this similarity.

- *up-to-date version of OLSR*: this CELAR testbed has been carried up on the OLSR version compliant with the RFC 3626.

The solution proposed for these four topics have been implemented on the testbed. Measurements made on this testbed are close to the simulations results. This MANET/OLSR testbed is frequently used in the exhibits organized by CELAR. It allows CELAR to demonstrate that MANET with OLSR routing are good candidates for tactical networks.

7.3. SAFARI

Participants: Saadi Boudjit, Philippe Jacquet, Amina Naimi, Dang Nguyen.

The partners of SAFARI are France Telecom R& D, Alcatel, INRIA, University Paris 6, University Paris 11, University of Strasbourg, INSA, IMAG, SNCF, ENST. The projects goals consists in building a protocol database (QoS, mobility, auto-configuration, security, etc) in order to deploy and manage a wireless ad hoc network connected to wired access point. The protocols will be developped above existing standards such as IPv6, multicast, application proxies, etc. Two main components will be developped:

- mobile terminals, these entities play the role of both user terminal and wireless routers in the ad hoc network;

- gateways, these entities will have two interface: a wireless interface toward the ad hoc network and a wired interface toward the wired internet.

These protocols will be deployed and experimented in two test beds: the telecom museum and a railway station. The Hipercom team is in charge of the mobile ad hoc routing (with Paris 11), the QoS management and some part of self-configuration in IPv6.

7.4. SARAH

Participants: Paul Muhlethaler, Cedric Adjih, Farid Sayah, Yasser Toor, Emmanuel Baccelli, Philippe Jacquet, Georges Rodolakis.

Follow up of SAFARI, the SARAH project, an ANR project, will focus on applications over mobile ad hoc networks such as security, indoor localization, multicast services.

7.5. OCARI

Participants: Saoucene Mahfoudh, Pascale Minet, Cedric Adjih, Farid Sayah, Philippe Jacquet.

The OCARI project, an ANR project, will focus on cross layer optimization of OLSR for sensor networks and mobile indoor communications.

7.6. Hitachi

Participants: Cedric Adjih, Emmanuel Baccelli, Thomas Clausen, Philippe Jacquet, Anis Laouiti.

Hitachi has started a long term collaboration with INRIA. Hipercom collaborates with Hitachi on mobile ad hoc routing, in particular about Quality of Service, IPv6 and mobile protocols. Hitachi has made numerous experiments of vehicular communication over OLSR. Hitachi is also an active participant in the WIDE project (Japan) with whom Hipercom has strong connections.

During 2005, we have benefited from close collaborations with Hitachi (Japan and Europe) on a number of areas: Thomas Heide Clausen's participation in IETF meetings have, in part, been sponsored directly by Hitachi Europe, as has the participation of Emmanuel Baccelli in IETF meetings during 2005 been completely supported directly by Hitachi Europe. On the technical front, Thomas Heide Clausen attended several joint meetings with Hitachi, both in France and in Japan, on the subject of security in OLSR and development and deployment of OLSRv2.

Emmanuel Baccelli spent a few months in the spring in Japan, collaborating with Hitachi SDL. Also, Hitachi Europe sponsored the 2nd OLSR Interop/Workshop, held in conjunction with the 63th IETF in Paris in August 2005.

8. Dissemination

8.1. University teaching

Philippe Jacquet taught :

- in the MPRI MASTER(Paris) class : mobile ad hoc network/PeertoPeer networks (with Laurent Viennot),
- Ecole Polytechnique, Recitation Class : Foundation of computer science
- at the EPITA school. Security in mobile and wireless networks
- Master MISIC (Polytechnique) class : Telecommunication

Pascale Minet taught :

- networks and quality of service in Master "Systèmes Electroniques et Traitement de l'Information", at INSTN (Saclay).
- routing in mobile ad-hoc networks in Master "Informatique Fondamentale et Applications" of the university of Marne-la-Vallée.

Participation of Paul Muhlethaler to Lessons "Ad hoc Networks", The 802.11 Standard and wireless Networkand for ENST B.

At the 3rd OLSR Interop Workshop in Niigata, Cedric Adih has given a kick-off presentation about security in OLSR. Dang Nguyen has given a presentation about quality of service in OLSR. These presentations launched in-depth discussion.

Thanks to the contacts created during the IETF meetings, we have started a fruitful close collaboration with Niigata University (prof. K. Mase) about mobile ad hoc networking.
T. Clausen was one of the three keynote speakers, on the 1st ad-hoc networking symposium in Japan in the spring, as well as to give a lecture at Niigata U. T. Clausen and K. Mase have submitted an IETF draft about link packet buffering in mobile networks. When a radio link fails, the packet are locally stored until the link recovers or a new route is discovered. This can be an interesting extension of mobile ad hoc network but should not be mandatory since buffer capacity might be limited on wireless routers.

Through common IETF activities with R. Wakikawa and K. Uehara, Hipercom has developed strong links with Keio University in Japan. This has recently been formalized through a "memo of understanding", between Hipercom and Keio University. Several joint academic publications as well as IETF publications have been the fruits of this collaboration on various subjects such as porting OLSR on BSD-ZEBRA, MANET-NEMO convergence, OLSR for IPv6.
This collaboration is also enabling Hipercom to take part in the WIDE consortium in Japan uniting Keio University (with J. Murai, the japanese Internet pioneer) and several industry heavy weights such as Hitachi, Mitsubishi, KDDI, NTT and other japanese universities and companies. This initiative is among other things organizing a large scale testing of OLSR on vehicles (with a prospect for testing OLSR on 1500 cars), which promises to be an extremely valuable experience for Hipercom, as no such scale study has been carried out to date.
Within the project STIC INRIA - Tunisian Universities entitled " Scheduling Techniques for Quality of Service Networks ", Professor Leila Azouz Saidane from ENSI was invited by INRIA in July and December. Her six students Slim Ben Ayed, Ines El Korbi, Manel Bourguiba, Fadi Kacem, Sahla Masmoudi and Skander Azzaz came at INRIA for a training in December. Pascale Minet was invited by ENSI in April and November and Steven Martin in April too.

Hipercom has also a STIC-ASIE Project called D.U.M.B.O, with professor Kanchana Kanchanasut (AIT Thailande). This project organized the ASIAN INTERNET ENGINEERING CONFERENCE (AINTEC) 2006. Philippe Jacquet was the Program Comittee Co-Chair. Hipercom actively participated in the design, development, and demonstration of the post-conference event, "Digital Ubiquitous Mobile Broadband OLSR". Precisely, the project demonstrated the use of mobile ad hoc networks in an environment where fixed network infrastructure is not available, such as in the case of natural disaster.

8.2. Participation to workshops, invitations

8.2.1. *Participation of Hipercom*

Philippe Jacquet was PhD adviser of Emmanuel Baccelli, January 2006 , Ecole Polytectnique , Georges Rodolakis, December 2006, Ecole Polytechnique.
He was Jury member of the PhD defense of :

- Dang Quan Nguyen, September 2006, University of Paris VI,

- Saadi Boudjit, September 2006, University of Paris XI.

- Dimitry Lebedev, September 2006, Ecole Polytechnique

- Simon Bluidze, July 2006, Ecole Polytechnique

He was Reviewer of the PhD defense of :

- Remy Badonnel , December 2006, LORIA,
- Noel Crespi, September 2006, University of Paris VI,

He was President for PhD defense committee of:

- Ines Ben Hamida, October 2006, University of Paris XI,
- Rhajar Bhaskar, Ecole Polytechnique.

Philippe Jacquet was the Chairman of the Program Committee, AINTEC 2003/2006
He also was a Program Committee member of Mathinfo 2006 and ISCIS 2006

The HIPERCOM project had the great pleasure to welcome the NATO WBWF / NBWF group in September at Rocquencourt. After a presentation of the institute by Annick Theis, Philippe Jacquet described the main research topics within the Hipercom project. Pascale Minet detailed the QoS support. Cédric Adjih, Anis Laouiti, Dang Quan Nguyen and Georgios Rodolakis were in charge of a very pedagogic demonstration of the OLSR routing protocol and of the MOST multicast protocol. All members of this NATO group were very pleased of their visit.
With regard to standardization, Pascale Minet made presentations at the following NATO WBWF/NBWF meetings:

- in Bristol, UK, February 2006, the presentation was entitled 'QoS support and OLSR routing in a MANET';
- in Rocquencourt, September 2006, the presentation title was 'MANETs at INRIA'.

Pascale Minet was reviewer of the following PhD Thesis:

- Damien Chabrol, "Etude, conception et mise en oeuvre d'un protocole de communication synchrone tolérant aux fautes et prédictible sur des composants réseaux standard", University of Paris-Sud 11, June 2006.
- Farid Jaddi,"CSR: une extension hiérarchique adaptative du protocole de routage ad hoc DSR", Institut National Polytechnique de Toulouse, October 2006.

She was also PhD adviser of:

- Dang Quan Nguyen, September 2006, University of Paris VI,
- Leila Boukhalfa, December 2006, University of Paris XII,

She was jury member of the PhD Thesis of Nicolas Pernet, "Implantation distribuée temps réel de programmes conditionnés à l'aide d'ordonnancements mixtes hors ligne en ligne de tâches périodiques avec contraintes de latence et acceptation de taches apériodiques", University of Paris 6, July 2006.
She was member of the program committee of:

- SPECTS'2006, 2005 International Symposium on Performance Evaluation of Computer and Telecommunication Systems, July 2006.
- Med-Hoc-Net'2006, 5th Mediterranean Workshop on Ad-Hoc Networks, June 2006.
- SNPD'2006, 7th International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing, June 2006.
- SAWN'2006, 2nd ACIS International Workshop on Self-Assembling Wireless Networks, June 2006.
- SERA'2006 (Int. Conf. on Software Engineering Research & Applications), August 2006.
- WCC'2006, 1st IFIP international Conference on Ad Hoc Networking, August 2006.
- RTNS'2006 (Real Time and Network Systems), Poitiers, May 2006.

Pascale Minet was member of the editorial board of the International Journal of Computer and Information Science, IJCIS and reviewer for the International Journal of Communication Systems, IJCS.

She was invited to give a presentation of the collaboration between Hipercom and CELAR during the international workshop Network Technologies for Coalition, organized by CELAR in September. In October, she also presented the Hipercom activities with regard to mobile ad hoc networks at the Journée thématique réseaux ad hoc, réseaux tactiques, organized by CELAR.

Paul Muhlethaler was the Chairman of the Wifi commission of ETNA.

Paul Muhlethaler was President for PhD defense committee of:

- Dario Vieira, "Design, Validation and Implementation of a Novel Maintenance Session Protocol", University of Evry Val d'Essonne.
- Dmitri Lebedev, "Ad Hoc Networks: Study of Protocol Behaviour", Ecole Polytechnique.

He was also PhD Reviewer of Xiaoyun Xue, "Mécanismes de Sécurité pour des Protocoles de Routage des Réseaux ad hoc", ENST.

He was PhD adviser of Saadi Boudjit, "Autoconfiguration and Security Schemes for OLSR Protocol for Mobile Ad Hoc Networks", University of Paris XI.

He was Jury member of Raghav Bhaskar, "Group Key Agreement protocols for ad hoc networks", Ecole Polytechnique.

Paul Muhlethaler was Scientist adviser for Luceor.

Cedric Adjih was jury member for the PhD thesis of Saadi Boudjit, University of Paris XI.

Cedric Adjih, Anis Laouiti and Philippe Jacquet actively contributed to the demonstration of the OLSR Routing protocol on elephants in Thailand, called DUMBO experiment.

Dang-Quan Nguyen presented his work on the extension of OLSR supporting QoS at the 3rd OLSR Interop in Japan.

8.2.2. *Workshop organized by Hipercom*

3rd OLSR Interop/Workshop

The third OLSR Interop / Workshop was organized in early october 2006, organized jointly between Hipercom@Ecole Polytechnique, Niigata University and KEIO University in Japan. As sucessfully experienced in the previous years, the event was organized as both a workshop and interop: workshop with support and at KEIO University site), followed by an interoperability event with support and at Niigata University site ; this time followed by a retreat for evaluating.

About 30 participants from all over the globe engaged in the workshop and in discussions pertaining to future developments and extensions to OLSR.

On 5 papers were selected for presentation during the morning, whereas the afternoon was dedicated to real WORKshop work, where two kick-off presentations launched in-depth discussion on QoS and OLSR Security.

We emphasize that the event was organized to encourage participation and discussion, rather than one-way communication from the speaker to the audience.

On the 3 following days, an interoperability testing was organized, where the participants would bring different implementations and hardware along and test both performance and interoperability of different OLSR implementations.

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