INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team hipercom

HIgh PERformance COMmunication

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THEME COM

Activity Report

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2. 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.

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, Géraud Allard, Emmanuel Baccelli, Philippe Jacquet, Paul Mühlethaler, Pascale Minet, Thomas Clausen, Dang-Quan Nguyen.

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 [67][66][39].

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, Géraud Allard, 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.

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 .

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

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 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.

4.3. Services over mobile networks

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

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 networks. This new trends now appears in Europe with many experiments in Paris, Lille and Toulouse. 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.

Hiperlan implements multihop routing at link layer

Hiperlan 1 standard proposed a forwarding scheme that performs routing at link layer. We have implemented this routing function in the driver of WiFi card and experimented it in a large scale over the INRIA Rocquencourt campus.

5.2. OLSR softwares

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

Participants: Cédric Adjih [correspondant], Anis Laouiti, Adokoe Plakoo, Marc Badel, Paul Muhlethaler, Thomas Clausen.

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.

We have implemented version 3 and version 7 of OLSR protocol for Linux daemon and for Windows. The linux daemon is very easy to install and can be downloaded from the web page. There have been more than 3000 downloads of the code which is exceptional for a routing protocol. Version 7 also contains feature adaptable to wireless driver, such as the signal power monitor. Version 7 has also be ported on Windows. Version 11 called OOLSR (for Object oriented OLSR) is IETF RFC compliant with multiple interfaces and tunable mobility parameters and has been fully tested during the OLSR Interop in San Diego, August 2004.

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. We have also implemented the MOLSR protocol (Multicast over OLSR) that forwards data to multicast group members on a mesh network 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/.

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.

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*.

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.

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 scarse 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.

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 developped 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.

6.5. Quality of services in mobile ad hoc networks

Keywords: *EDF (Earliest Deadline First)*, *PQ (Priority Queuing)*, *Quality of Service*, *bandwidth reservation*, *class*, *deadline*, *link interference*, *service differentiation*.

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.

The management of quality of service is a very hot issue in wireless networks where the radio make links more versatile than in wired networks. We can distinguish two main axes in QoS management:

- 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.
- service differentiation: we focus on Bluetooth piconet and show by means of simulation that the specified polling (round-robin) is unable to provide service differentiation. We propose a solution accounting both locally in each waiting queue and globally in the slave polling for two QoS parameters. These parameters are: the message importance and its delivery deadline.

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).

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 collison 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.
We focus on a Bluetooth piconet, analyzing its ability to support Quality of Service (QoS) requirements defined by the application. In particular, we are interested in two QoS parameters: (i) an application constraint denoting the importance degree of a message, and (ii) an end-to-end delivery deadline. The QoS perceived by the application depends on the efficiency of the scheduling schemes chosen at the medium access layer. We first show that the specified polling algorithm (roud robin) does not provide service differentiation. We then gradually introduce QoS management in the scheduling of a Bluetooth piconet. First locally, each waiting queue accounts for both QoS parameters. Finally locally and globally, our solution called Class-Based Earliest Deadline First (CB-EDF) accounts for these two QoS parameters in each waiting queue and in the polling algorithm. Simulation results show that in various scenarios CB-EDF achieves a good service differentiation and allows the coexistence of messages with different application constraints on the same link.

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

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.

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.

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*.

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, Cédric Adjih.

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.

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.

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: Emmanuel Baccelli, Thomas Clausen, Philippe Jacquet.

Wireles OSPF

Recent efforts at the IETF aim at creating W-OSPF (wireless OSPF), an extension of the OSPF standard to span on mobile ad hoc networks. This extension is based on the principles and experience of OLSR, and as part of the core IETF team appointed to design this extension, Hipercom is very much involved in this effort. This activity has also been a subject of the collaboration with Hitachi in France and in Japan (in part through the funding of Emmanuel Baccelli). Additionally, a collaboration with Boeing Phantom Works has involved designing, developing and testing the pioneer W-OSPF proposal.

Hipercom's contributions to W-OSPF have been subject to numerous academic publications, as well as several IETF publications.

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 OLSR 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.

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.

6.14. Real-time scheduling

Keywords: *DiffServ*, *FIFO*, *fixed priority scheduling*, *trajectory approach*, *worst case response time*.

Participants: Steven Martin [University of Paris 12, PhD student], Pascale Minet, Laurent George [ECE].

Real-time scheduling

With regard to real-time scheduling, we are interested in providing deterministic end-to-end guarantees to real-time flows in a network. We focus on two QoS *Quality of Service* parameters: the end-to-end response time and the end-to-end jitter, parameters of the utmost importance for such flows. Our worst case analysis allows to provide deterministic guarantees to these flows. Our new results can be applied to networks applying non-prehemptive Fixed Priority scheduling, where messages sharing the same fixed priority are scheduled either FIFO or EDF (Earliest Deadline First).

They concern:

- **A DiffServ-MPLS solution offering real-time end-to-end guarantees**
  In this study, we propose a solution, very simple to deploy, based on a combination of DiffServ and MPLS. The *Expedited Forwarding* (EF) class of the *Differentiated Services* (DiffServ) model is well adapted for real-time applications as it is designed for flows with end-to-end real-time constraints. Moreover *MultiProtocol Label Switching* (MPLS), when applied in a DiffServ architecture, is an efficient solution for providing QoS routing. The results of our worst case analysis enable to bound the worst case response time of any EF flow and to derive a simple admission control for the EF class. Resources provisioned for the EF class but not used by this class are available for the other classes.
- **Real-time end-to-end guarantees for the EF class with and without traffic shaping**
  As previously, we are interested in providing deterministic end-to-end guarantees to the Expedited Forwarding (EF) class of the Differentiated Services (DiffServ) model. As packets of any flow can experience variable network delays and sojourn times on each visited node, the inter-arrival times can be shorter than those on the source node and burst arrivals are possible. This flow distortion increases with the number of visited nodes. To cope with this distortion, traffic shaping has been introduced. We focus more particularly on two techniques of traffic shaping: jitter cancellation and token bucket. We then study the influence of traffic shaping on these two QoS parameters, independently of the scheduling policy for the EF class. In this paper, we show how to compute the worst case end-to-end response time and jitter of any flow in the EF class with and without traffic shaping, assuming that the EF class has the highest priority and packets in this class are served FIFO. We then determine when each one of the three techniques (no traffic shaping, jitter cancellation and token bucket) is the most appropriate.
- **Non-preemptive Fixed Priority scheduling with FIFO arbitration: uniprocessor and distributed cases**
  We focus on the worst case response time of flows, scheduled according to non-preemptive *Fixed Priority*, both in uniprocessor and distributed cases. On a processor, the number of available priorities is generally limited. If this number is less than the number of flows to be considered, several flows have to share the same priority. Such flows are assumed to be scheduled arbitrarily in the classical approach. We assume in this study that these flows are scheduled FIFO. This assumption lead us to revisit classical results in the uniprocessor case. As we obtain response times less than or equal to the classical results, any flow set feasible with the classical approach is feasible with our approach. The converse is false, as shown by an example. Moreover, we determine the conditions leading to shorter

response times. We then establish new results in a distributed context. We show how to compute an upper bound on the end-to-end response time of any flow. For this, we use a worst case analysis based on the trajectory approach.

7. Contracts and Grants with Industry

7.1. CELAR

Participants: Cédric Adjih, Marc Badel, Philippe Jacquet, Anis Laouiti, Pascale Minet, Paul Muhlethaler, Dang Nguyen, Adokoé Plakoo, Daniele Raffo.

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. 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. We have then designed solutions against these attacks and identified basic mechanisms for securing OLSR routing.
- *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. After a brief description of related work dealing with QoS models, QoS routing protocols and interference aware admission controls, we describe building blocks needed in QoS management. We then define the QoS requirements with regard to the MAC layer in order to get an efficient QoS management. Unfortunately no available 802.11b card meets this requirement.
- *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 will be carried up on version 11 of OLSR, the version compliant with the RFC 3626.

Each topic includes a theoretical study followed by an implementation on the testbed and performance evaluation.

7.2. FABRIC

Participants: Philippe Jacquet, Amina Naimi.

The partners of the IST project FABRIC are Philips, Thomson Multimedia,Institut National de Recherche en Informatique et en Automatique (Rennes and Rocquencourt), Technische Universiteit Eindhoven, Netherlands Organisation for Applied Scientific Research, Maelardalen Hoegskola, Scuola Superiore S.Anna, University of Passau, Centre Suisse d'Electronique et de Microtechnique. The project addresses the conception of a home network architecture that will enable the wireless access to video and internet. The Hipercom project team works on the mathematical models on traffic and architecture and contribute to the definition of the Wifi platform.

7.3. SAFARI

Participants: Géraud Allard, Saadi Boudjit, Philippe Jacquet, Amina Naimi.

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. 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.

7.5. Samsung

Participants: Cedric Adjih, Songyean Cho, Thomas Clausen, Philippe Jacquet, Anis Laouiti.

Hipercom has started a very close collaboration with Samsung electronics. The collaboration consists into developping and testing multicast protocols over OLSR. An engineer from Samsung has worked with the project team during several month in Rocquencourt. Two multicast protocols have been developped: SMOLSR (Simplified Multicast OLSR) and MOLSR (Multicast OLSR). The second one was already a draft in the IETF.

8. Dissemination

8.1. University teaching

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.

Philippe Jacquet has been invited as the first keynote speaker in the second wireless networking workshop organized by Niigata university on November 18. Cedric Adjih is spending five month as invited researcher in Niigata university . He is studying self-configuration for IPv6 Manets and is taking part to the implementation and deployment of the Niigata mobile ad hoc testbed, the largest in Japan with more than 100 nodes. Japan is the leading country in the experiments of mobile ad hoc networks for civilian use such as intelligent transportation systems.

Through common IETF activities with R. Wakikawa and K. Uehara, Hipercom has developped strong links with Keio University in Japan. This has recently been formalized through a "memo of understanding", between Hipercom and Keio University. Several joint academic publications as well as IETF publications have been the fruits of this collaboration on various subjects such as porting OLSR on BSD-ZEBRA, MANET-NEMO convergence, OLSR for IPv6.

This collaboration is also enabling Hipercom to take part in the WIDE consortium in Japan uniting Keio University (with J. Murai, the japanese Internet pioneer) and several industry heavy weights such as Hitachi, Mitsubishi, KDDI, NTT and other japanese universities and companies. This initiative is among other things organizing a large scale testing of OLSR on vehicles (with a prospect for testing OLSR on 1500 cars), which promises to be an extremely valuable experience for Hipercom, as no such scale study has been carried out to date.

Building on a strong OLSR community and on the support of different players in academia and in the industry, Hipercom has organized, over 2 days in August 2004 in San Diego (in conjunction with the IETF), an event aiming at looking forward with OLSR. With the collaboration and support of such as (among others) Hitachi, Samsung, Boeing, NRL, BAE Systems and Thales on the industry side, and UCLA, Keio University, Niigata University, LRI, CRC on the academic side, an interoperability testing session was organized where about 15 independent OLSR implementations where successfully tested as interoperating. Successful interoperability testing of independent implementations of a protocol is a valuable way of measuring a protocols maturity – and is a cornerstone within the IETF framework for progress towards standardization and wide industry acceptance.

At the same time, a workshop was held in order to gather status as well as new ideas about OLSR. 10 presentations of both academic and industrial work where given for the occasion, and as many papers published on a diverse number of topics related to OLSR. This event was seen as a great success and we've been encouraged to repeat it next year. The OLSR Interop and Workshop was kindly sponsored by Hitachi France, Boeing Phantom Works and INRIA.

Hipercom project team and LRI network team (Paris 11) have jointly organized an OLSR day which took place in Rocquencourt on April 5. With more than 100 attendees from academics, industry, operators and administrations, this day has been a memorable success (the most popular workshop organized in Rocquencourt by a single project). There were many excellent talks and presentations about wireless networking and OLSR, there was also a demo with wireless routers made in Hipercom.

Within the project STIC INRIA - Tunisian Universities entitled " Guarantee of Quality of Service in Networks ", Professor Leila Azouz Saidane from ENSI was invited by INRIA in June. Her three students Slim Ben Ayed, Dorsaf Fayech, Ines El Korbi came at INRIA for a training in December. Pascale Minet and Anis Laouiti were invited by ENSI in October.

8.2. Participation to workshops, invitations

Philippe Jacquet was :

- jury member of PhD defense of Yacine Doudane from Paris 6 university.

- president for PhD defense committee of Anelise Munaretto from Paris 6 university.
- reviewer of PhD of Guillaume Chelius from INSA Lyon.
- reviewer of PhD of Claude Chaudet from INSA Lyon.
- He also gave talks to ITW 2004 (San Antonio, USA), AofA 2004 (Berkeley, USA), ISIT 2004 (Chicago, USA), MWCN 2004 (Paris), PairaPair workshop (Arcachon, Lyon).

Pascale Minet was :

- jury member of PhD defense of Mounir Benzaid from university of Paris 11.
- jury member of PhD defense of Stevens Martin from university of Paris 12.
- jury member of PhD defense of Antoine Mercier fromuniversity of Paris 11.
- She gave lessons at INSTN (Saclay), about networks and quality of service in Master “Systèmes Electroniques et Traitement de l’Information”.
- She also taught routing in mobile ad-hoc networks in Master “Informatique Fondamentale et Applications” of the university of Marne-la-Vallée.
- She was also invited to give a presentation at Mcube (March 2004) and another presentation for the TRIO project (October 2004).

Participation of Paul Muhlethaler to :

- Review of the IST Evolute project. 29-30 January 2004. Brussel
- Lessons "Ad hoc Networks", The 802.11 Standard and wireless Networkand for ENST B.
- "Introduction aux réseaux ad hoc” Journées de la mobilité de la FING 23 Novembre 2004.
- Presentations at UPC (Barcelona) "Securing OLSR", "An Aloha Protocol for Multiple Ad Hoc Networks" 1-2 November 2004.
- PhD reviewer of Erwan Ermel, "Localisation et routage géographique dans les réseaux sans fil hétérogènes.", University of Paris VI, 2004.
- Chairman of the Wifi commission of ETNA.

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