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Project-Team Hipercom

HIgh PERformance COMmunication

Rocquencourt

THEME 1B

Activity Report

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1. Team

Head of project-team
Philippe Jacquet [DR, Ingénieur en Chef des Mines]

Vice-head of project-team
Paul Mühlethaler [DR, Ingénieur en Chef de l'Armement]

Administrative assistant
Danielle Croisy [ITA]

Staff member Inria
Cédric Adjih [CR]
Marc Badel [CR, Ingénieur Principal de l'Armement]
Pascale Minet [CR]

Ph D student
Géraud Allard [INRIA Fellowship]
Emmanuel Baccelli [CIFRE Fellowship with Hitachi Laboratory]
Hakim Badis [INRIA Fellowship partly with LRI (Paris XI)]
Mounir Benzaïd [INRIA Fellowship partly with LRI (Paris XI)]
Saadi Boudjit [INRIA Fellowship]
Thomas Clausen [Aalborg University (Danmark) until June 2003 post-doctoral position after June 2003]
Amina Naimi [INRIA Fellowship]
Daniele Raffo [INRIA Fellowship]
Georges Rodolakis [Polytechnique Fellowship since October 2003]

Student intern
Dang-Quan Nguyen [April-June 2003]
Jean-Baptiste Piketty [April-June 2003]
Yasser Toor [March-July 2003]

Engineers
Anis Laouiti
Adokoe Plakoo

External Collaborators
Khaldoun Alagha [LRI (Paris XI)]

Long Term Visitor
Bernard Mans [Hitachi Chair Maquery University (Australia)]

Short Term Visitor
Leonidas Georgiadis [Athenes Grece]
Abdellah Najid [Rabat (Morocco)]
Wojciech Szpankowski [Purdue University (USA)]
Nikita Vvednskaya [IITP (Russia)]

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

Key words: *channel capacity, compression, predictors.*

Participants: Philippe Jacquet, Wojciech Szpankowski.

Glossary

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

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

Key words: *deterministic performance, probabilistic performance.*

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

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 [49][50][48].

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

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

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

Glossary

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

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

Key words: *Access protocols, routing, scheduling, QoS*.

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

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

Hipercom applications domains cover Wireless mobile ad hoc networks, services over mobile networks, community Network

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.

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

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

Key words: *Routing*, *Link Layer*.

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

Participants: Cédric Adjih [correspondant], Anis Laouiti, Adokoe Plakoo, Thomas Clausen.

Key words: *Internet protocol*, *routing protocol*.

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 2500 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 with multiple interfaces and tunable mobility parameters should be ready for February 2004. 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

Key words: *MAC*, *radio*, *collision resolution*, *spatial reuse*.

Glossary

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. Flooding in mobile ad hoc networks

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

Glossary

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 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.

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

Glossary

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 [24]. 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.

6.4. Quality of services in mobile ad hoc networks

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

Glossary

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.
- 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.
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.

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

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

Glossary

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.

6.6. Internet topology and TCP performance analysis

Key words: *Power laws*, *long dependence*, *asymptotic*, *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.

6.7. Multicast extension for OLSR

Key words: *multicast routing protocol*, *OLSR*, *multicast group*, *group management 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.

6.8. OLSR and IPv6

Key words: *routing protocol*, *OLSR*, *IPv6*, *autoconfiguration*, *neighbor discovery*.

Participants: Anis Laouiti, Pascale Minet, Cédric Adjih.

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.

6.9. Real-time scheduling

Real-time scheduling

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

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

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 based on the DiffServ model and more generally networks applying Fixed Priority scheduling.

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. ARCADE

Participants: Khaldhoun Al Agha, Mounir Benzaid, Saadi Boudjit, Pascale Minet.

The project ARCADE, ARchitecture de Contrôle Adaptative Des Environnements IP is an RNRT project that started in January 2001: http://www-rp.lip6.fr/arcade. It completed in January 2003 with a demonstration highlighting the developments made by each partner. Arcade partners are:

- LIP6 (main partner),
- INRIA (Rocquencourt and Sophia),
- France Télécom R&D,
- Thomson-CSF Communications,

The aim of this project is to establish a general model that allows to master IP networks. It is based on the determination of the profile of each user and client, in order to have a right resources mapping. These resources can be dynamically allocated and must be controlled according to a given policy. This control is done on security, mobility and quality of service.
In this project we show how to account for node mobility. The proposed solution is based on Mobile IP for macro-mobility (i.e. inter-domain mobility) and on OLSR for micro-mobility (i.e. intra-domain mobility). More precisely, an OLSR IP network acces constitutes an IP subdomain and allows to access Internet via a gateway OLSR. The move of a mobile within the OLSR IP network access is managed by the OLSR protocol.

The integration of Mobile IP and OLSR has been done on PCs and laptops equipped with Linux and IEEE802.11 card. It has been successfully demonstrated at the end of the ARCADE project.

7.2. CELAR

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

The CELAR project started in September 2002 for a year Its aim is to design and implement a demonstrator of mobile ad-hoc network MANET/OLSR. It 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.
This project consists in two phases:

- The first phase concerns the installation and validation of the MANET/OLSR demonstrator. This demonstrator 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. These configurations can be characterized by:
  - *network topology*,
  - *traffic types*: different traffic types have been tested such as: (i) TCP traffics with/without UDP traffics, (ii) traffics generated by a same source toward different destinations, (iii) traffics generated by different sources and converging on the same destination...
  - *node mobility*: some nodes are carried by moving pedestrians, other nodes are embeddid within vehicles moving around the building hosting the platform.

- *injection of node failures*: some nodes are switched off in order to measure the recovery time needed by OLSR to re-establish routes .
- *willingness of a node to route messages coming from other nodes* : in OLSR, this is translated by the willingness parameter.

Performances of MANET/OLSR demonstrator have been evaluated by the measurements of the following parameters:

- power of the signal received from other nodes,
- obtained throughput,
- choice of the next hop to reach a given destination,
- availability of routes,
- time needed to get a route after a failure.

- In the second phase, we study future evolutions of this demonstrator. Two extensions are proposed:
  - what are the incidences of IPv6 on the routing protocol OLSR and how OLSR can work with IPv6;
  - we also study multicast routing and the protocol allowing a terminal or a router to notify its interest in a multicast group and receive multicast data.

7.3. 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.

9. Dissemination

9.1. University teaching

Philippe Jacquet gave lessons in two Cap Geminy workshops about mobile ad hoc networks.

Pascale Minet gave lessons at INSTN (Saclay), about networks and quality of service in DEA Systèmes Electroniques et Traitement de l'Information. She also taught routing in mobile ad-hoc networks in DEA Informatique Fondamentale et Applications of the university of Marne-la-Vallée.

Participation of Paul Muhlethaler to :

- Lessons "Adhoc Networks". Mastère RSIE de l'ENST B. May 16. 2003
- "Securisation on wireless Networks". Radiocommunications Networks meeting, ETCA. Arcueil. 12 September 2003.
- Introduction to Adhoc Networks "2ème Ecole franco-mexicaine sur les systèmes répartis coopératifs" (Rennes, 29 september-4 october
- Securing OLSR. AIR&D workshop. October 7-8, 2003. Saint-Malo. France.
- The 802.11 Standard and wireless Networks. Lessons ENST B. 14 October 2003
- Review of the IST Evolute project. November 11, 12 2003. Swindon.

9.2. Participation to workshops, invitations

Philippe Jacquet participated to the AofA workshop in San Miniato (Italy).

He was reviewer of:

- Eric Fleury habilitation thesis.
- David Simplot habilitation thesis.
- Imad Aad PhD thesis
- José Ignacio Alverez-Hamelin PhD thesis
- Dominique Dhoutaut PhD thesis
- Hend Koubaa PhD thesis
- Navid Nikaein PhD thesis

Pascale Minet was:

- PhD adviser of Dana Marinca, "Conception et dimensionnement d'un système multimédia hautes performances", (Design and dimensioning of a high performance multimedia system), University of Versailles-Saint-Quentin, February 2003.
- PhD reviewer of Ahmed Jebali, "Contrôle de divergence dans des environnements faiblement connectés", University of Versailles-Saint-Quentin, November 2003.
- member of the jury that qualified Gilles Roussel in advising PhD students, "Grammaires et automates comme outils pour le développement logiciel", University of Marne-la-Vallée, December 2003.

She was member of the program committee of:

- SERA'2003 (Int. Conf. on Software Engineering Research & Applications), San Francisco, California, June 2003.
- RTS'2003 (Real Time Embedded Systems), Paris, Avril 2003.
- CFIP'2003 (Colloque Francophone sur l'Ingénierie des Protocoles), Paris, October 2003.

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