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Project-Team PLANETE

Protocoles et Applications pour l'Internet

Sophia Antipolis - Rhône-Alpes

THEME 1B

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2. Overall Objectives

Key words: *Heterogeneous networks*, *communication protocols*, *mobility*, *security*, *large scale virtual environments*, *group communication*, *transmission control*.

The Planète group, located both at INRIA Sophia Antipolis and INRIA Rhône-Alpes research units, conducts research in the domain of networking, with an emphasis on designing, implementing, and evaluating Internet protocols and applications. The main objective of the group is to propose and study new architectures, services and protocols that will enable seamless mobility, enhanced services support and multicast communication through the Internet.

Recent improvements in memory, CPU power, network bandwidth and circuitry miniaturization make the "IP everywhere" adage become a reality. Thanks to tiny sensors and efficient low power processors, it is likely that very soon, everybody will daily use multiple portable or wearable computing devices (nomadic computing). Current research problems that address mobile applications, scalable transmission protocols, and adaptive mechanisms that can handle both variable network conditions and heterogeneous applications requirements, are becoming crucial.

Our research projects span many areas, including mobile multimedia applications and protocols over the Internet; security in mobile and ad-hoc networks; impact of new transmission media on protocols performance; scalable multicast routing; quality of service over IP; scalable multi-user interactive applications; Internet measurement and traffic analysis; error control in Wireless networks; analysis of WLANs performance; inference of Internet topology.

The main research fields covered by the Planète project-team are organized in the four reaserch domains:

- Mobile Communications,
- Group Communications,
- New Transmission Media,
- Applications and Services.

Our research activities are realized in the context of French, European and international collaborations. In particular several academic (UCL, MIT, UMass, Bern University, ENS, LIP6, Eurecom, CEA-LETI, etc.) and industrial (6wind, Thomson CSF et Multimédia, FT R&D, Alcatel, CS Télécom, Bull, Motorola, Hitachi, etc.) partners.

3. Scientific Foundations

3.1. Methodology

The service provided by the Internet is expected to evolve in order to meet user needs. These evolutions are about support of mobility with the introduction of mobile IP, the support of group communication and probably the support of the quality of service.

In parallel, user needs and technological improvements lead to increased heterogeneity in both the network infrastructure and the client hosts.

- Network heterogeneity: the prevalence of principle "IP over everything" increased the heterogeneity of links and subnetworks within the Internet (ATM, satellite, high speed local area networks, wireless LANs, ADSL, telephone, GSM, etc). These different "sub-networks" are based on various technologies and provide different link level services, in terms of quality of service, cost and availability. This heterogeneity is justified by technical reasons but also by economic and political reasons.

- Heterogeneity among hosts : the machines connected to the Internet are also increasing in diversity. There are fixed and mobile hosts, PCs with very significant computing capabilities, PDAs or other hand-held devices with limited CPU resources. This heterogeneity is also due to miscellaneous reasons and motivations: commercial (the machines of the Internet come from various vendors), economic (the users of the Internet have very different budgets), and technical (the users have different needs).

This increased heterogeneity raises new research topics. In this context, our project is particularly interested in the issues related to the Internet communication protocols and applications. We thus work in the protocol engineering field. Our approach is to design new communication protocols or mechanisms, to implement and to evaluate them either by experimentation, or by simulation. On the theoretical side, we use modeling techniques (elaborated in collaboration with other INRIA projects) to evaluate the performance of the studied protocols and mechanisms. We also apply techniques of the information and queuing theories to the studied problems. On the pragmatic side, we develop applications that integrate the designed mechanisms as experimentation and demonstration tools.

We also work on the definition of new services and new network architectures. The approach we follow in this case is often based on the experimentation, and our work includes a technological component since we implement our mechanisms in pre-operational systems.

The choice of our research directions is based, on the one hand on the bet on a universal deployment of IP (already a reality!), and on the other hand on a selection of the services and protocols to study (mobility support, group communication, quality of service, etc).

The approaches followed by the industrial research groups are often targeted to specific technologies, and may result in "unoptimal" solutions. We work however in close collaboration with research and development industrial teams (Thomson, Alcatel, NEC, Motorola, 6wind and Hitachi).

In order to carry out our approach as well as possible, it is essential to attend and contribute the IETF meetings on a regular basis, in order to propose and discuss our ideas in the working groups related to our topics of interests.

3.2. Mobile Communications

It is expected that in a few years, the number of mobile phones (and other devices) connected to the Internet will be largely higher than that of computers. The phone could become a very important device to be connected to the Internet, whereas today its use on the Internet is very marginal. There are multiple reasons to use a portable phone to access the Internet : the simplicity and small dimensions, the *relatively* low cost at least as compared with computers, and the large deployment. The convergence of the wireless cellular networks and the Internet represents a major strategic and economic stake. This convergence is drastically important for Europe which plays a major role in the fields related to wireless technologies, and in particular cellular telephony. This "cellular networks-Internet" convergence is a significant technological and scientific challenge, and will undoubtedly take several years. The difficulties result from the large number of problems to be solved, and the diversity of the fields to be involved. Indeed the problems to be handled are related to network protocols, terminals, man-machine interface, billing, and many others. Our objective here is to design a network architecture allowing this convergence. Industrial bodies working in this field have significant commercial and economic constraints, that incite them to re-use their existing technologies and networks. This incremental approach leads to architectures that cannot be simultaneously optimal for voice and data. The target architecture should allow to both access real time services such as high quality telephony, and to provide low cost and high speed access to the Internet. We think an IP-based architecture is desirable. A mobility management protocol is required, to allow mobile hosts to move while preserving IP connectivity. Although this management can be done at the physical or MAC level (GSM, WLAN...), an IP-based solution seems more effective because it leads to a homogeneous system and allows for the so-called vertical handoff, i.e. passing from a network technology to another – for example a mobile passing from a WLAN to a GSM network. The IETF solution for mobility management (Mobile IP) was not developed in a context where a

mobile could be equipped with several interfaces, and where there would be more mobile hosts than fixed. This solution is not very efficient and is not suited to suit this environment. It is thus important to extend the Mobile IP protocol to cellular IP networks.

3.3. Group Communications

Beyond point to point communications, there is a clear need for communications involving a large number of entities, some of them acting as content sources, others as passive clients, or both. Many applications fall into this category: collaborative work applications, audio-video conferencing, server synchronization, content distribution (files, databases, recorded videos), live television distribution, etc. These examples show clearly:

- that scalability has several meanings and ranges from a few tens to several millions of concurrent entities, and
- that the techniques involved must address a wide range of application-specific requirements, like reliable versus timely transmissions, push versus streaming versus on-demand delivery model.

Mastering scalable communications therefore requires to master a wide range of networking components and techniques, like reliable multicast, FEC codes, multicast routing and alternative group communication techniques, audio and video coding, announcement and control protocols, end-to-end security, and routing infrastructure security. Having an expertize and making contributions in a subset of these topics is one of our goals.

3.4. New Transmission Media

The Internet is rapidly increasing in size and it is including more and more transmission media of different characteristics (satellite links, wireless links, HFC cables, ATM links, etc.). This rapid increase in the size and heterogeneity of the Internet is due to the end-to-end principle, which states that the network must be simple and must provide a simple best-effort service of packet routing and forwarding. According to that end-to-end principle, all mechanisms related to congestion and error control must be implemented in the hosts outside the network (pushing the complexity to the end users). This principle has resulted in simple routers implementing the IP layer and connecting a large number of transmission media, and has led to the worldwide connectivity we enjoy today in the Internet. But, even though connectivity is assured by this end-to-end principle, certain transmission media have some characteristics that are challenging to some Internet protocols. These challenging characteristics are caused by the physical layer that carries the data, or by some mechanisms implemented at the link layer. For example we have : the high bit error rate on wireless links; the large delay in satellite networks; the variable delay in satellite constellations and in wireless networks caused by the mobility of users and handoff; the asymmetry of bandwidth and the unidirectional characteristic of satellite and cable networks; the functions that are supported by link layers (GSM, ATM, Frame Relay) and that are redundant with those implemented at higher Internet layers.

These challenging characteristics result in different problems that we summarize as follows:

- Some Internet protocols may not work at all in presence of some transmission media, for example ARP, DVMRP and other protocols on unidirectional links.
- Other protocols continue to work but suffer from a considerable degradation of their performance, for example TCP and IGMP over links of large and/or variable delay and/or high bit error rate.
- The difficulty in designing end-to-end adaptive protocols in presence of transmission media with highly variable characteristics.
- The interference problems when congestion control mechanisms are implemented in hosts and at the link layer, e.g. TCP over ATM, TCP over wireless links implementing FEC and retransmissions.
- The difficulty to map QoS mechanisms at the IP layer to those at the link layer, e.g. Diffserv over ATM or over Frame Relay, IP over satellite.

Our work in this direction focuses on how to support "classical" Internet protocols such on top of these new transmission media, in order to get enhanced performance and full functioning of these protocols. In particular, we focus on routing and transport protocols and on QoS architectures proposed to enhance the regular best-effort service currently provided by the Internet. Such support would either require a modification to the link level control mechanisms or to the upper level (3 and above) protocols. We study in particular the split in functionalities between the layers from both functionality and performance point of views.

3.5. Applications and services

We are interested also in large scale networked multimedia applications and in new communication services (such as quality of service and security). In previous works, we have been focusing on adaptive applications that take into account both variation of network conditions and receivers heterogeneity. We have designed videoconferencing applications (ivs, FreePhone, RendezVous) that dynamically adapt their coding (compression ratio, FEC, playout delay) according to network characteristics (packet loss ratio, available bandwidth, jitter). This adaptation was possible thanks to flexibility brought by software, as compared with dedicated hardware. Today, software radio applications bring even more flexibility: the physical layer, traditionally implemented in dedicated hardware with frozen characteristics, become reconfigurable. Indeed, the fast performance improvements of processors and of digital to analog converter (DAC) allow to implement with a minimal hardware (antenna, amplifier, DAC) a whole wireless communication protocol stack. Apart from potential cost reduction, this allows to implement for example multi-standard terminals with a same processor or reconfigurable DSP. Moreover, this new approach makes it possible to further refine adaptation between all the layers of the application. For example, the type of modulation can be selected not only according to channel characteristics, but also according to the quality of service requirements of the application. This opens the way to new investigations to optimize the quality of multimedia flows for mobile and heterogeneous receivers.

We also focus on distributed interactive multimedia applications with a very large number of participants. We prefer a distributed approach rather than a centralized model for scalability reasons. Such virtual environments (VE) include massively multi-player games, Distributed Interactive Simulations (DIS), and shared virtual worlds. Today, many of these applications have to handle an increasing number of participants and deal with the difficult problem of scalability. Moreover, the real-time requirements of some of these applications make the scalability problem even more difficult to solve. The current IP multicast model has a lot of imperfections to handle LSVE applications. The use of one multicast group is not enough to handle all the traffic: the traffic received per participant would be too important and would congest both the receiver (CPU waste) and the network (bandwidth waste). In reality, in such applications, each participant is only interested in a small part of the overall traffic – typically a zone all around himself. Moreover, some participants may not be interested in, or cannot afford to receive, a particular type of flow, for example video. So, the use of different multicast groups seems a good way to address this problem. However, the distributed architecture should be modified to support new mechanisms efficient for large groups. It is important to study mechanisms to dynamically handle each participant's zone of interest, to accordingly split information into different groups, and to efficiently filter information. Moreover, IP multicast itself is not widely deployed, and alternatives such as application-level multicast will be investigated to support the multi-user virtual environment.

We are also interested in the design and evaluation of new services to be supported in Internet routers and applications. In fact, the Internet supports a large number of applications with different characteristics. However, a certain number of multimedia applications (e.g. telephony over IP) do not function "perfectly" on a best effort service.

A first approach to support multimedia applications over the Internet consists in integrating algorithms that allow the application to adapt to the variable characteristics of the network, while keeping the best effort service. However, in the case of bandwidth limitations, the adaptive applications approach does not lead to satisfactory "quality of service".

Two major approaches were proposed by the IETF to address this problem. The first approach based on a per-flow scheduling of network resources (called intserv) was abandoned because of its scalability limitations.

The second approach (within the diffserv working group), consists in defining multiple classes and avoid complex and fine grain per-flow signaling and bandwidth reservation. The basic idea is thus to apply at the level of each router the same "local" or "per hop" behavior to all flows belonging to an aggregate of traffic. The identification of such an aggregate can be done using the ToS or DSCP fields in the IP header, and thus avoiding multi-field classification.

This approach results in providing differentiated services in the network, i.e. a specific service applied to each "class" of traffic. Two Per Hop Behaviors (PHB) were defined: EF PHB (Explicit Forwarding) and AF PHB (Assured Forwarding). EF allows to provide a virtual leased line service, while AF allows to propose several classes of service with different "priorities" and drop precedence. We are interested in the evaluation of these mechanisms in general, and in a dynamic environment in particular. We would like to evaluate the complexity of such mechanisms and assess their large scale deployability in the Internet.

4. Application Domains

4.1. Architecture for hierarchical management of mobility

Mobile IP has a major drawback : it treats micro and macro-mobility the same way, which raises scalability and security problems. Indeed, with Mobile IP, a host must communicate to its correspondents its new temporary address, at every move, whatever the amplitude and the locality of this move. On the basis of a study, which showed that about 70% of the movements of a user are local, we consider it is preferable to have a hierarchical management of mobility in cellular networks. We proposed such a solution which explicitly separates the management of the local or micro mobility – within a site – from that of global or macro mobility – between sites of the Internet : when a mobile moves inside a site, its movements are managed by an internal protocol and are thus hidden to its correspondents. The results of this hierarchical architecture is to avoid sending signaling packets over the Internet in the case of local mobility. The load of the Internet is thus reduced, and the risk of attack on the hosts is minimized. It should be noted that various levels of hierarchy can be defined inside a site according to its size and the user needs. Inter-site mobility is managed by a protocol that is global to the whole Internet. We proposed the use of Mobile IP for the management of macro mobility because this solution appears well adapted to this problem. We also proposed to use Mobile IP for micro mobility. Our solution is compatible with the general Mobile IP approach. It can be deployed inside a site independently of the other sites.

Parallel to our proposal on hierarchical Mobile IPv6, other proposals for the management of the micro mobility such as Cellular IP or HAWAII were also proposed within the IETF. The multiplication of proposals for micro-mobility is likely to generate interoperability problems of interworking because a mobile will have to know the local protocols of the various visited sites.

Therefore, we evolved our proposal on hierarchical Mobile IPv6 to a hierarchical architecture that would support various micro-mobility management protocols in various parts of the Internet, in a completely transparent way to the mobile users.

4.2. Internet paging

In the networks using the Mobile IP protocol, a mobile node must signal all its movements (by sending binding updates) to its home network even if it is inactive. This results in high signaling cost, in particular in a the context of cellular IP networks, in which mobile nodes are more numerous than fixed machines. In cellular telephony networks, a mobile sends binding updates only when it is actived or if it moves across localization zones. The size of the localization zone is generally statically fixed by the operator. The network does not precisely know the exact location of the mobile, but knows the zone in which it moves. When the network needs to contact the mobile phone, it broadcasts a "paging" message in the current zone of the mobile, which answers by indicating its exact position. We are interested in developing a paging mechanism for cellular IP networks. IP paging is potentially more efficient than that carried out by the telecommunication networks.

Indeed in IP networks, the intelligence being in the terminals, one can imagine to develop individual adaptive paging systems in which each mobile permanently computes the optimal size of its localization zone. A preliminary study shows that the introduction of such paging mechanisms into Mobile IP can significantly reduce the signaling load.

4.3. Network Mobility

The IETF worked on the support of mobile terminals in the Internet but until recently did not consider network mobility. A mobile network is a network made of routers and nodes, that moves and changes its attachment point to the Internet. The possible applications of mobile networks include in particular sensor networks deployed in aircrafts, trains, cars or PAN's (Personal Area Networks), that are very popular in military research. The problems involved in the management of terminal and network mobility are relatively different. Consequently the solutions such as Mobile IP, that were developed for the mobile terminals, are not well suited to the mobile networks because they are too expensive in terms of signaling. New protocols are thus necessary. We worked on the design of protocols for network mobility management, and introduced this problem at the IETF. Our work was a basis for launching the `nemo` working group at IETF.

4.4. Efficient Large Scale Content Distribution

Large scale content distribution is one of the main domain of application of group communication services. More precisely we focuss here on several components like (partially) reliable multicast protocols, large block Forward Error Correction (FEC) codes, and scalable video streaming schemes. These components complement one another and are used to provide higher level content distribution services. These contents can largely vary, ranging from static files (e.g. a database) to live video, as well as the distribution model which can follow one of the "push", "on-demand", or "streaming" models, and the session size be limited to a few tens of participants or on the opposite be unlimited. This broad variety of application needs requires to develop appropriate mechanisms, and this is the goal of our work.

4.5. Impact of unidirectional links on unicast and multicast routing

We previously worked on the support of IP traffic over geo-stationary satellite links. In fact, we could have a low cost receive-only hardware (receiving antenna and satellite reception card). This type of connection is thus interesting to provide an asymmetrical access to the Internet : "high speed" satellite for the reception, and telephone link (fixed or GSM) for the emission. The specificity of the connection lies in its unidirectional broadcast aspect. In such environment, unicast and multicast routing protocols do not work correctly. Moreover, the multicast packets forwarding using RPF (Reverse Path Forwarding) can not be ensured by the satellite receiver which receives the data on a different connection from the one it uses to reach the source. An encapsulation mechanism was proposed and developed within the framework of the IETF unidirectional link routing working group named `udlr`. This mechanism allows to mask the unidirectionality of the satellite link, which will ensure a normal operation of the dynamic routing protocols. The udlr tunneling mechanisms became "proposed standard" RFC-3077. The udlr technology is currently industrialized by UDcast start-up[1]. We are currently interested in the scalability of the routing protocols in a udlr environment with a very large number of receivers.

On the other hand, satellite telecommunication vendors are preparing the so-called "next generation" of satellites with on board processing. The DVB-S is the de facto standard in this domain. We are interested in enhancing the support of multicast forwarding in this "multi-beam" context. In this case, the satellite will allow, with proper support of the multicast protocols, to save the bandwidth in a finer grain by duplicating the packets "on board" only towards zones with interested users.

We are also interested in studying the criteria to select the multicast tree type in the presence of a satellite link. Solutions based on a shared tree (PIM-SM) could be more efficient than the solutions based on the DVMRP "flood and prune" approach.

[1] http://www.udcast.com

4.6. Impact of new media on transmission control

We are interest in both point-to-point and reliable multicast transport protocols. Let us first consider the point-to-point protocols such as TCP. End-to-end adaptation algorithms such as *slow start* were introduced in order to perform congestion control and avoidance. However, with the increased heterogeneity of the transmission media (satellite link delays, high BER on wireless links, etc.), it becomes more and more difficult to propose efficient end-to-end adaptation algorithm adjustment.

In case of TCP, we are interested in asymmetric environments. Mechanisms such as ACK filtering and ACK reconstruction were proposed to enhance TCP's performance in such environments. We propose to study TCP performance and propose appropriate adjustments of these mechanisms.

In the area of reliable multicast protocols, we are interested in studying scalable protocols for satellite environments with a large number of receivers.

The major problem is to find a congestion control mechanism in the presence of senders/receivers with heterogeneous conditions, while ensuring reliability, preferably with a low delay. In the case of unidirectional satellite links, one should minimize the use of the terrestrial back-channel.

4.7. Implementation methodology for multimedia mobile applications

The design of multimedia mobile applications is very complex and requires multi-disciplinary expertise: software architecture, signal processing (modulation, coding, compression, error control), networking (transmission protocol, congestion control), verification and validation mechanisms, etc. There is an obvious need of development methodology to implement these applications in such a way they benefit the latest algorithms developed both in hardware (ASIC, FPGA) and in software (DSP, general purpose workstations). The new development architecture should allow to achieve the best compromise (cost, performance) between hardware and software, according to the current state of the art and the real-time requirements of the application. The main goal of this task is to make the implementation of these applications easier. Indeed, it is becoming more and more difficult to validate such a complete protocol communication stack, because of the increasing complexity and size of code generated. We have investigated the use of the formal language Esterel to implement the control part of such applications. This allows to verify properties of the application much faster.

4.8. (Re)visiting IP Quality of Service

In the late 90s, there has been a high interest in the diffserv model because it provides the ISPs (and the router manufacturers) with more billing flexibility, by supporting several classes of services. However, the evaluation of the "edge-to-edge" behavior is a difficult task and requires a lot of measurements and simulations. This is due to the complexity of the mechanisms proposed to provide the Per Hop Behaviors, and to the difficulty to parametrize these mechanisms in a scalable way for the whole network. We studied in detail the building blocks allowing to provide the quality of service (QoS) in the Internet. Our objective here was to evaluate the implementation complexity of these mechanisms, as well as the impact of the tuning parameters and the expected performance.

In addition, we worked on the dynamic provisioning of network resources in diffserv. Provisioning consists in determining and allocating the necessary resources at the various points in the network. Provisioning is a component of the so-called quality of service management. This management can be static or dynamic. In the static case, the management of QoS in the network can be carried out "manually" by the network administrator according to topology and traffic matrix changes, or "automatically" by the routers based on signaling or on measurements on the flow aggregates. Our objective here was to study both approaches in order to assess the feasibility of such QoS management mechanisms. Our study was limited to diffserv Intra-domains.

4.9. Security in wireless networks

We are also interested in wireless network security. Our objective here is to build an integrated security framework, that allows inter-domain mobility and seamless wireless services over heterogeneous wireless

networks including UWB, WiFi, Bluetooth and UMTS networks. We focus on how to efficiently accelerate the inter-domain authentication methods in terms of architecture and network protocol, as well as on how to enhance the Bluetooth security, targeted at achieving security in a public place.

4.10. Security and Group Communications

Group communications traditionally follow an open model which contradicts security requirements. These concerns is one of the reasons why multicast routing deployment is still far behind the initial expectations. Our contributions are twofold. First of all we focuss on the problem of infrastructure security from the network operator point of view: what are the threats and what kind of answers are possible ? Secondly we focuss on secure VPN environments, where several sites are connected to one another through IPSec tunnels, and see how to provide group communication services. These activities provide opposed but complementary views of the problem.

5. Software

5.1. V-EYE

V-Eye (or Virtual-Eye) (http://www-sop.inria.fr/planete/software/V-Eye/) is a 3D virtual world application over the Internet in which a large number of participants can move and interact with each others by sending and receiving multimedia flows. The aim of this tool is to experiment, on a real application, scalability of multicast transmission protocols and optimization of multimedia transmission protocols over heterogeneous environments.

5.2. MultiCast Library

MCLv3 (http://www.inrialpes.fr/planete/people/roca/mcl/) is an Open Source Implementation of the ALC and NORM Reliable Multicast Protocols.

This software is an implementation of the two major reliable multicast protocols being standardized by the RMT IETF working group: ALC/LCT and NORM. It is composed of a C/C++ library and several applications (like FLUTE, a file transfer application over unidirectional links being standardized by the IETF) built on top of it and provides an easy-to-use and integrated solution for reliable and/or highly scalable multicast delivery of data. It is used in operational, commercial environments, essentially in the satellite broadcasting area and for file delivery over the DVB system. Interoperability tests with two other ALC/FLUTE implementations are scheduled by the end of 2003. This work is done essentially by V. Roca, with contributions from J. Labouré, C. Neumann.

5.3. IGMPv3 and MLDv2

IGMPv3 et MLDv2: http://www-sop.inria.fr/planete/Hitoshi.Asaeda/igmpv3
http://www-sop.inria.fr/planete/Hitoshi.Asaeda/mldv2 IGMPv3 and MLDv2 are indispensable protocols in order to make Source-Specific Multicast (SSM). We developed IGMPv3 and MLDv2 kernel implementations for NetBSD-current which was proposed as the reference implementations, and now imported to FreeBSD, NetBSD and OpenBSD by the collaboration with KAME project.

5.4. MobiWAN

MobiWAN is a simulation tool based on NS (version ns-2.1b6) meant to simulate Mobile IPv6 under large Wide-Area Networks (both local-area mobility and global-area mobility). As such, MobiWan comprises extensions to simulate Mobile IPv6, and extensions to manipulate and configure large network topologies (TOPOMAN / TOPOGEN).

5.5. LDPC large block FEC codec

This LDPC codec is the only Open-Source, patent free, large block FEC codec for the Packet Erasure Channel (e.g. Internet) available today. It is both integrated in our MCLv3 library and distributed independently in order to be used by third parties in their own applications or libraries (we expect a large number of uses since there is a real need). This work is done essentially by J. Labouré, with contributions from V. Roca, Z. Khallouf. See (http://www.inrialpes.fr/planete/people/roca/mcl/ldpc_infos.html)

5.6. IPSEC-VPN

This software is being developed by L. Al-Chaal as part of its PhD at Netcelo S.A., a company selling IPSEC VPN solutions. The software developed will be integrated in the Netcelo commercial offer, but is not publicly available. It covers essentially two aspects: group communications within a meshed VPN environment, and a VPN based Web Service architecture.

5.7. DIAMETER Testbed

DIAMETER Testbed is a full Implementation of DIAMETER protocol including EAP, IPv6, SQL interfacing is maintained by PLANETE. The stack serves in developping new techniques for the fast handover support in wireless networks.

5.8. Prototype Software

HMIPv6 protocol an implementation of HMIPv6 under FreeBSD was performed to support our research activities.

SUCVp an implementation of the protocol SUCVp (key exchange protocol used to secure Mobile IP) was done.

Network Simulator (ns) code we performed several extension to the ns simulator.

Scalable Video Streaming over ALC (SVSoA) a Solution for the Large Scale Multicast Distribution of Videos.
This software integrates our highly scalable streaming solution for hierarchically encoded videos. It integrates a video streaming and client software, VideoLAN, an MPEG4 codec, and is built on top of our MCLv3 library. This work is done essentially by C. Neumann with contributions from V. Roca. It is not yet publicly available but may become so when it will gain stability.

An Application Level Multicast prototype. A prototype implementation of HBM, an application level multicast proposal. This work is done by A. El-Sayed as part of its PhD.

Robust Header Compression (RoHC) for wireless transmissions. This software implements the RTP/UDP/IPv4_or_v6 and UDP/IPv4_or_v6 compression profiles of the RoHC IETF standard. It is useful for wireless communications, where the potentially high loss rate and transmission delays make traditional header compression schemes useless. It is performed as part of an industrial contract with STM and is therefore not publicly available.

A Gateway for IPv6 Opportunistic Encryption. This software implements an automatic and transparent IPSEC tunneling scheme between two gateways for transmissions over the insecure Internet. It implements the SUCV proposal that has been co-developed by C. Castelluccia and SUN. This work is done by C. Neumann, in close collaboration with SUN. It is not yet publicly available but may become so when it will gain stability.

6. New Results

6.1. HMIP

Participants: Claude Castelluccia, Ludovic Bellier.

Claude Castelluccia and Ludovic Bellier are co-authors (together with Ericsson Research) of the IETF HMIPv6 protocol. HMIPv6 introduces extensions to Mobile IPv6 and IPv6 Neighbor Discovery, to allow for local mobility handling. Hierarchical mobility management for Mobile IPv6 reduces the amount of signaling between the Mobile Node, its Correspondent Nodes and its Home Agent. The Mobility Anchor Point described in this document can also be used for improving the performance of Mobile IPv6 in terms of handoff speed.

HMIPv6 is currently being standardized at the IETF and has been widely accepted. A lot of current research in IPv6 mobility relies on HMIPv6.

6.2. Paging

Participants: Claude Castelluccia, Pars Mutaf.

Mobile IP is considered as a potential candidate for 3G or 4G networks. However, Mobile IP has some limitations in terms of scalability and handoff performances. In Mobile IP, every host updates its location for each IP-layer move, which is costly in terms of bandwidth. IP paging with multiple subnets per paging area, or address resolution with large subnets, are possible solutions. IP paging and address resolution are similar, in that they rely on broadcast packets for querying unreachable destination hosts. In large IP paging areas or large IP subnets, the rate of broadcast traffic becomes excessive, and session setup delays may ocurr. We have developed a hash-based optimization using Bloom filters, that is applicable to any broadcast query technique in IPv6, for example IP paging and address resolution. We have also worked on other topics such as dynamic paging, dynamic paging area configuration algorithms, and paging security problems.

6.3. SUCV

Participants: Claude Castelluccia.

Claude Castelluccia is one of the co-authors of SUCV (with SunLabs, Europe). SUCV addresses the identifier ownership problem. It does so by using characteristics of Statistic Uniqueness and Cryptographic Verifiability (SUCV) of certain entities, which we call SUCV Identifiers (SUCV ID's). SUCV addresses are particularly suitable to solve the "address ownership" issue, that severely undermines confidence in mechanisms like Binding Updates in Mobile IP for IPv6. SUCV is currently being standardized at the IETF. It has been widely accepted and is currently applied to secure Mobile IP, Mobile Ad-hoc routing protocols, opportunistic encryption, group communications and IPv6 neighbor discovery.

6.4. Enhancements of IEEE 802.11

Participants: Qiang Ni, Thierry Turletti, Imad Aad, Chadi Barakat.

We worked on quality of service (QoS) in wireless LANs (WLAN). We started exploring the impact of differentiated services (DiffServ) on mobile networks at the IP layer. This led us to work on supporting differentiated services at the MAC layer (using IEEE 802.11). Our contribution in this field is widely known and referenced in the wireless networking community. We also explored mechanisms to enhance IEEE 802.11 in different environments (noisy and congested). We are also participating to the standardization of the IEEE 802.11e protocol that aims at enhancing the 802.11 MAC protocol by supporting Quality of Service guarantees [51]. We proposed several mechanisms, that improve performance of the Enhanced Distributed Coordination Function (EDCF) scheme when the channel is loaded [38][34]. We also proposed a new 802.11e Hybrid Coordination Function (HCF) scheduler scheme that aims at being fair for both CBR and VBR flows [42]. This work is part of the VTHD++ RNRT project.

We have also designed a media-oriented mechanism to select the transmission mode in 802.11 Wireless LANs (WLANs). The main goal is to improve performance of multimedia transmission over 802.11 by taking into account both application characteristics and physical channel conditions. In particular, this cross layer mechanism allows to benefit from robustness of multimedia coding by letting packets with corrupted payload reach the application. Basically, the application specifies its quality of service requirements (data rate, BER tolerance) and the mechanism selects the best transmission mode (PHY rate, modulation scheme, FEC scheme) also taking into account the variable channel conditions. Furthermore, by removing FEC from some standard transmission modes, we present performance of new transmission modes that could improve significantly the goodput of applications.

6.5. Communication Architecture for Large Scale Virtual Environments

Participants: Laurentiu Barza, Walid Dabbous, Thierry Turletti.

Large Scale Virtual Environment (LSVE) applications have to handle a huge number of participants and deal with the difficult problem of scalability. We have designed SCORE, a scalable multicast-based communication protocol for such applications. Our approach resides at the transport-layer, using multiple multicast groups and multiple agents. It involves the dynamic partitioning of the virtual environment into spatial areas, and the association of these areas with multicast groups [12]. The SCORE architecture is implemented within the V-Eye LSVE application, developed as part of the VTHD++ RNRT project.

6.6. Optimization of video transmission over best-effort IP networks

Participants: Thierry Turletti, Vijay Arya.

As part of the VISI RNRT project, we have addressed the problem of congestion control for video transmission in large multicast groups. We designed a mechanism for filtering **RTCP** receiver reports sent from receivers to the whole session that solves the well-known feedback implosion problem. We also investigated the problem of multimedia applications deployment over hybrid wired/wireless IP networks, as part of the VIP RNRT project. For such environments, congestion control algorithms are required to efficiently react according to the type of losses. End-to-end differentiation mechanisms proposed so far can not reliably predict the differences between congestion and wireless losses. We designed a simple window framework to explicitly and accurately differentiate these losses [18].

6.7. Support of QoS for Bluetooth Piconets

Participants: Thierry Turletti, Jean-Baptiste Lapeyrie.

The Bluetooth technology is starting to appear on the market, and there is a need to enable new applications with real time constraints to run on top of Bluetooth devices. Currently, there is no available solution to support both delay and bandwidth guarantees required by real-time applications. We designed a new polling algorithm for Bluetooth Piconet, that supports both delay and bandwidth guarantees and aims at remaining fair and efficient with asymmetric flow rates [30].

6.8. Dealing with Receiver Misbehavior in Multicast Congestion Control

Participants: Thierry Turletti, Vijay Arya.

In multicast congestion control, receivers can misbehave by maliciously causing congestion to steal network bandwidth from well behaved flows. In source driven congestion control protocols (SDCC), receivers can misbehave by sending a wrong feedback to the source. In receiver-driven congestion control protocols (RDCC), receivers may misbehave by inflating their subscriptions. We showed that when network tomography tools such as MINC are used in conjunction with SDCC protocols, they can aid in misbehavior detection. But in order to use MINC for misbehaviour detection, MINC itself must be made immune to misbehaviour. We analyzed the effect of misbehavior within MINC and proposed two techniques to detect and prevent misbehavior in MINC.

6.9. Modeling Internet backbone traffic at the flow level

Participants: Chadi Barakat.

Our goal is to design a traffic model for non-congested Internet backbone links, which is simple enough to be used in network operation, while being as general as possible. The proposed solution is to model the traffic at the flow level by a Poisson shot-noise process. In our model, a flow is a generic notion that must be able to capture the characteristics of any kind of data stream. We analyzed the accuracy of the model with real traffic traces collected on the Sprint IP backbone network. Despite its simplicity, our model provides a good approximation of the real traffic observed on this backbone and of its variation. We also discussed the application of our model to network design and dimensioning. The results related to this activity are published in [9].

6.10. A Moving Average Predictor for Playout Delay Control in VoIP

Participants: Chadi Barakat, Victor Ramos, Eitan Altman.

Our contribution in this work is the design of a Moving Average algorithm for playout delay adaptation with tunable loss percentage. Current algorithms fail to obtain a particular loss percentage. We show with trace-based simulations that, in most cases, our algorithm performs better than those implemented in popular audio tools, and this is for the range of loss rates of interest in interactive audio applications. Our algorithm is published in [36]. The work is done in collaboration with Mistral.

6.11. TCP-Friendly Multiplexing technique for VoIP

Participants: Abdel Basset Trad, Hossam Afifi.

The idea behind this contribution is to decide the number of voip connection to be multiplexed over a single stream based on TCP-Friendly decision. The goal of this decision is to reduce the overall bandwidth used by VOIP streams in a large multiplex. By this technique we let VOIP behave as TCP streams and the network transports hence homogeneous connections. When the gateway receives multiple streams for a common intermediate destination, it groups the VOIP streams into the same packet. The work has been simulated and a prototype is being tested over VTHD network.

6.12. Handling two-way TCP traffic in asymmetric bandwidth networks

Participants: Fatma Louati, Walid Dabbous, Chadi Barakat.

We proposed a new adaptive class-based queuing mechanism called ACQ for handling two-way TCP traffic over links that exhibit bandwidth asymmetry, like satellite and ADSL networks. ACQ runs at the entry of the slow return link, classifies data and ACK packets into two separate queues, then adapts the weights of the two queues based on throughput measurement in both directions in order to optimize the total satisfaction of the user. This work is validated by ns-2 simulations.

6.13. Reliable multicast protocols

Participants: Vincent Roca.

We actively participate to the RMT working group at the IETF, and in particular work on the FLUTE (File Delivery over Unidirectional Transport) document currently in "Last Call" in the IETF RMT working group.

We also contribute to the ALC, LCT, FEC information, FEC building block, and NORM building block RFC's by providing comments and suggestions. We also developed one of the reference implementations of the ALC/LCT and FLUTE standards. This implementation is widely known and is used by several groups, including in commercial applications. File delivery over satellite or DVB environments is one of its major fields of application.

6.14. Scalable Video Streaming over ALC

Participants: Vincent Roca, Christoph Neuman.

SVSoA is a major solution for the large scale streaming of video contents. It provides many advantages over more traditional approaches : massive scalability, TCP friendliness, high robustness in front of loss bursts, no QoS requirement (or other dedicated services) within the core network, and compatibility with any video encoding scheme [50]. A prototype is currently under development. This subject takes advantage of our work on ALC/LCT and MCLv3.

6.15. Group Communications in VPN environments

Participants: Lina AlChaal, Vincent Roca.

In this work we showed how to build a fully secure and efficient group communication service between several sites. This service is built on top of a VPN environment where IPSec tunnels are created, on-demand, between the various sites that need to communicate. The proposed approach is innovative and departs from the more traditional "provider provisioned" VPN solution where the same entity, namely the ISP, needs to master both the infrastructure and the VPN management. Although this approach simplifies many aspects, it requires the same ISP to manage all sites, which is too restrictive.

6.16. Large block FEC codes

Participants: Vincent Roca.

Traditional small block Forward Error Correction (FEC) codes, such as the Reed-Solomon Erasure (RSE) code, are known to raise efficiency problems, in particular when applied to the ALC reliable multicast protocol. We identified a class of large block FEC codes, LDPC, capable of operating on source blocks that are several tens of megabytes long. We designed a codec and started its performance evaluation [37]. This is currently the only Open Source, patent-free, large block FEC codec available, and we expect it to be largely used by other groups. Our work in this domain has focused on performances : raw encoding/decoding speed of a software implementation, decoding inefficiency (i.e. the number of symbols required in addition to the strict minimum). We also designed and tested several flavors of LDPC :

- LDPC(3,6), the standard LDPC code,
- LDGM, a simplified variant of LDPC, and
- a staircase LDPC, which is midway between LDPC and LDGM.

We have shown that these three FEC codes present different trade-offs between encoding speed and decoding inefficiency. It is therefore possible to perform the appropriate choice depending on the target environment. A large amount of work remains to be done on this promising class of FEC codes.

6.17. Application Level Multicast

Participants: Ayman El-Sayed, Vincent Roca.

Multicast routing is not as widely deployed as could have been expected, and offering alternative group communication services [10] has become a very active field of research. In this work we have designed and evaluated such a service, which creates and manages an overlay on which packets can be distributed to several concurrent receivers.

6.18. Supporting IP Multicast in the Next Generation of GEO Satellite Systems

Participants: Fethi Filali, Walid Dabbous.

The new generation of GEO satellites are characterized by the support of on-board switching and multiple spot beams. We proposed a new encapsulation scheme that provides an efficient segmentation of IP packets

into MPEG2-TS segments, and allows the on-board satellite processor to switch all receiving segments to the appropriate spot beams. Two approaches have been proposed and compared : (i) the self routing approach which consists in switching the incoming data segments based on a switching table maintained by the satellite, and (ii) the label switching approach which uses a label already included in each data segment by a terrestrial-satellite router to enable on-board switching. We also designed a new protocol called SMRP (Satellite Multicast Routing Protocol), that is implemented in routers connected to the satellite links and that interoperates with terrestrial PIM-SM routers. Thanks to SMRP, the system entities can make possible the management of multicast sessions, as weel as switching multicast IP packets on board a multi-spot GEO satellite. This protocol allows an efficient and transparent integration of satellite links into the Internet.

6.19. A taxonomy for fast IP address look-up schemes

Participants: Miguel Ruiz Sanchez, Walid Dabbous.

We introduced a taxonomy and a framework of reference for existing fast address lookup schemes. Our taxonomy classifies the address lookup algorithms according to the dimension of search: value or length, and also whether a linear or binary search is performed. In addition we analyze the tradeoffs of the different schemes. We compare them in terms of complexity and measured execution time on a common platform. We believe that our approach has greatly increased understanding of the relationships among the existing fast address lookup algorithms, and hence that our contribution can help to point researchers in fruitful directions in this area.

6.20. Optimization of Packet Forwarding in Best-effort Routers

Participants: Miguel Ruiz Sanchez, Walid Dabbous.

We proposed two incremental update mechanisms for address lookup engines based on the multibit-trie data structure. In our approach we have introduced two key concepts to support incremental updates : the notions of span and coverer. In particular, we propose a data structure called Prefix Nesting bit vector, or PN bit vector for short. The PN bit vector encodes a set of prefixes and their nesting structure, for this information is necessary to support incremental updates. We present performance results of a C-language implementation of our scheme. Performance results are shown in terms of time for the search, insert and delete operations. Memory requirements are also shown.

6.21. Dynamic IP QoS management

Participants: Rares Serban, Walid Dabbous.

Multimedia applications such as VoIP request QoS mechanisms in the network to ensure their good behavior. Each QoS mechanism is provisioned in function of an SLA (Service Level Agreement) established between user/application and ISPs (Internet Service Provider). The QoS management role is to preserve all specifications of the SLA during the contracts' period. The QoS management could be static or dynamic. In the static case, the network QoS management is done by the network administrator, using manual tuning work based on trial-and-error process, during a large scale of time. The dynamic QoS management is based on QoS automated and adaptable mechanisms for a flexible and efficient management of the network resources. A dynamic QoS management system is composed of the following components : signaling protocols, algorithms of resource allocation and admission control, network monitoring mechanisms and QoS trade mechanisms among multiple network domains. We proposed criteria classifications for Internet QoS signaling protocols. We also studied the impact of the service level parameters (e.g., delay, jitter, bandwidth, packet loss) and the low level parameters/network parameters of different QoS mechanisms implemented for Linux Diffserv. Using a Linux Diffserv network we demonstrate that the static QoS management in some cases is not efficient. We propose a dynamic resource allocation mechanism for the core routers that avoids the use of signaling. This protocol can be used with different bandwidth sharing rules.

6.22. SSM deployment

Participants: Hitoshi Asaeda.

We developed an IGMPv3/MLDv2 kernel implementation which was proposed as the reference implementations, and now imported to three major BSDs (FreeBSD/NetBSD/OpenBSD) by the KAME project. We have also provided several papers related to this issue [20][19].

As the next step, we start a work for new SSM channel announcement architecture called "Channel Reflector" [44]. Our work contributes the Internet-Draft of "Internet Media Guide (IMG) Framework" [58] of the `mmusic` working group.

6.23. Efficient Authentication Architecture

Participants: Hahnsang Kim, Hossam Afifi.

We developed a security framework that enhances the efficiency of the authentication architecture and the authentication and key exchange protocol by accelerating inter-domain roaming, keeping seamless mobile secured Internet services. Our security framework also provides a solution to how to distribute a pre-shared key in a public place to a pair of Bluetooth devices unknown to each other. This framework could be applied to the following scenario : at a train station, a passenger with a handset with WiFi and Bluetooth interfaces approaches the toll booth equipped with a Bluetooth payment device, and pays for a train ticket through the secure Bluetooth link with the help of our automated Bluetooth security establishment mechanism. Inside the train, the passenger can enjoy seamless mobile secured Internet services thanks to our efficient inter-domain authentication architecture covering inter-domain and our accelerated authentication and key exchange protocol as well.

7. Contracts and Grants with Industry

7.1. Industrial contracts

Hitachi There is ongoing collaboration on efficient inter-domain authentication. The activity is described in the Efficient Authentication Architecture hereabove.

Alcatel We worked with Alcatel on TCP performance in a hybrid satellite/terrestrial network, in the context of an ESA study (Transat or Transport protocol and Resource mAnagement for SATellite mobile networks) This study also included Helsinki University and ENSICA (Toulouse).

ST Microelectronics, Advanced Systems (AST), Grenoble a 3 year contract has been set up (2002-2004) between INRIA/Planète and STM. Within this framework several tasks have been performed, each of them covered by a dedicated amendment to the contract. In 2002 and 2003, development of a RoHC (Robust Header Compression) prototype. In 2003, improvement and analysis of an LDPC codec. In 2004 (prospective) follow up of the work on LDPC, and creation of a scalable video streaming prototype.

ST Microelectronics, Advanced Systems a 3 year contract has been set up (2003-2006) for Laurent Fazio's PhD on Secured Large scale virtual environments (CIFRE scholarship).

Netcelo S.A., Grenoble a 3 year contract has been set up (November 2001 to October 2004) between INRIA/Planète and Netcelo S.A. for Lina Alchaal's PhD (CIFRE).

France Telecom R&D, Lannion a 3 year contract has been set up (2003-2005) between INRIA/Planète and Netcelo S.A. for Zainab Khallouf's PhD (CIFRE).

8. Other Grants and Activities

8.1. National projects

ACI SPLASH (2003-2006):
The goal of this project is to study and develop some secure routing protocols for ad-hoc networks. The partners are Eurecom and INRIA.

VIP RNRT project (Oct 01 - Jun 04):
Video over Wireless IP. The aim of this project is to optimize quality of videoconferencing applications over wireless IP networks. Total amount is 88 Keuros.

VTHD++ RNRT project (jan 02 - jan 04):
follow-up of VTHD RNRT project.

TRANSAT An ESA project with Alcatel Space, ENSICA, and the University of Helsinki. The project will end in 2004. It aims at developing an enhanced QoS-aware link-layer for satellite access networks that mainly improves TCP traffic performance. The importance of this project for Planète is that it allows to validate in an industrial context our findings on TCP over satellite and over wireless links implementing FEC/ARQ-SR.

@IRS++ RNRT Project (Mar 01 - May 03):
Evolution of the Internet architecture. We worked on security aspects.

DIPCAST RNRT project (Sep 00 - Sep 03):
IP multicast over DVB. We worked on the support of multicast routing protocols over multi-beam satellite links.

UNIACCESS Medea+ project, (Jan 02 - Dec 03):
http://www.secuniac.org/
The project aims at designing a cheap home gateway for the large public, with all the security features and functionalities required for the current and future home networks.

9. Dissemination

9.1. Promotion of the Scientific Community

Walid Dabbous is a member of the editorial board of the IEEE Communications Surveys & Tutorials electronic journal, and of a special issue of the TSI (Techniques et Sciences Informatiques) journal on the topic "Networks and protocols" (to appear in 2003). Walid Dabbous has served in the following conferences as PC member : Med-hoc-net' 2003, NGC'(99-2003), SAINT'2001, Networking'2000, ISCC'2000, AFRICOM'98, ICCC'97, PC co-chair of PfHSN'96, tutorial chair for Sigcomm'97, WOSBIS (97-99), CFIP (97-99). He gave several presentations and tutorials at RHDM summer school, CFIP, HPN, FORTE and ECMAST. He was co-chair of the udlr working group at the IETF between 1997 and 2000. He has served several times as an expert to the European Commission to evaluate and review EC funded projects. He has also served as an expert in RNRT commission on network protocols and architecture. He gave a presentation at the "Université de tous les savoirs" in September 2000. He also gives seminars at the technical and scientific high military education society.

Claude Castelluccia is the editor of the area "Protocols for Mobility" of the ACM SIGMOBILE Mobile Computing and Communications Review (MC2R). Claude Castelluccia has served in the following conferences as PC member : IPCN2000 (Paris), ACM WoWMoW 2000 (Boston), Globecom2000 Service Portability Workshop (San Francisco), IPCN2001 (Paris), IEEE Services & Applications in the Wireless Public Infrastructure (Paris), MS3G2001 (Lyon), IEEE LCN2001 (Orlando), MobileADHOC networks (Paris), IFIP Networking 2002 (Pisa), IEEE LCN2002 (Orlando), Algotel2002, ACM/Usenix Mobisys 2003 (San Francisco), IEEE LCN2003 (Munich), IEEE Workshop on Applications and Services in Wireless Networks 2003 (Berne). Claude Castelluccia has served several times as an expert to the European Commission to evaluate and review EC funded projects.

Thierry Turletti is in the Program Committee of the following conferences/workshops: Packet Video'99-04, Saint'00, Networked Group Communication (NGC)'02, Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOpt)'03-04, Next Generation Networks (NGN)'04. He was chair of the ACM Multimedia Doctoral Symposium in December 2002. He coedited two special issues on software radios in IEEE JSAC and IEEE Communication Magazine in 1999. Since 2001, he is associated editor of the "Wireless Communications, Mobile Computing" Weslay Journal published by John Wiley & Sons. Thierry Turletti has served as an expert to the European Commission to evaluate and review EC funded projects.

Chadi Barakat

- General chair of PAM 2004.
- Technical Program Committee of GI&NGN symposium at Globecom 2004, PAM 2004, INFOCOM 2004, ASIAN 2002, ICNP 2002.
- Session chair in WiOpt 2003, ICNP 2002.
- Organizer of Mistral seminars (1999-2001), Planète seminars (2003-), and "séminaire croisé Réseau" (October 2003).

Hossam Afifi has served as a TPC member in IDMS'99, TPC Chair in Globecom 2003 and several others. He is editor of the France section in the IEEE Communications Magazine. He was the creator of ASWN (Applications and Services in Wireless Networks) with Djamal Zeghlache. ASWN is a yearly IEEE sponsored workshop.

Vincent Roca was the main technical organizer of the RHDM'02 summer school, in May 2002, which gathers most of the French academic research groups in networking area. He will also organize the next International Workshop on Multimedia Interactive Protocols and Systems (MIPS) in Grenoble in 2004. He gave several tutorials in the RHDM summer schoolds, at ICT'03 and at MIPS'03. He is part of the Program Committee of RHDM'02, ING'03, ING'04. He also serves as an expert in RNRT commission on network protocols and architecture.

9.2. University Techning

Networks and protocols: Undergraduate course at Ecole Polytechnique by W. Dabbous (36h).

Networks : course at Networks and Distributed Systems graduate studies program at University of Nice-Sophia Antipolis, by W. Dabbous (12h), H. Afifi (12h).

Multicast transmission: Optional course at the same program (24h), University of Nice-Sophia Antipolis, by W. Dabbous.

Networks: Undergraduate course at ENSIMAG (Grenoble), by Vincent Roca

Mobile Networks: course at graduate studies program at Ensimag by by C. Castelluccia (36h).

Networks: Undergraduate course at University of Nice-Sophia Antipolis, by C. Barakat (6h).

9.3. PhD Theses and Internships

9.3.1. PhD defended in 2003

1. Miguel Á. Ruiz Sánchez defended his PhD on september 5th, 2003. The topic is Optimization of Packet Forwarding in Best-effort Routers.
2. Rareş Şerban defended his PhD on September 5th, 2003. The topic is Dynamic IP QoS management.

9.3.2. Ongoing PhDs

1. Lina Al-Chaal works on “Solutions for Multicast Security”.
2. Vijay Arya works on “Multimedia transmission control algorithms for new generation mobile terminals”.
3. Laurentiu Barzu works :“Large Scale Virtual Environments”.
4. Ayman El-Sayed works on “Alternative techniques for group communications”.
5. Fatma Louati works on :“Asymetry and bidirectional traffics”.
6. Hossein Manshaei works on Multimedia Communications Protocols with cross-layering optimization”.
7. Pars Mutaf works on :“Mobility management in all-IP networks”.

9.3.3. Training activities

1. Raja Abdelmoumen worked on the Study of a link-level FEC/ARQ scheme for wireless links and short-lived TCP traffic. Duration of the stay: 18 March 2003 - 3 July 2003. Prepared degree: Diplôme d’Ingénieur en Informatique. Affiliation: ENSI, Tunisia.
2. Gion-Reto Cantieni worked on the Analysis of the MAC layer in 802.11 WLAN. Duration of the stay: 10 March 2003 - 5 September 2003. Prepared degree: EPFL Engineering Degree. Affiliation: EPFL, Switzerland.
3. Mureed Hussain worked on the Analysis of congestion control mechanisms for video transmission over hybrid (wired/wireless) IP networks. Duration of the stay: 1 March 2003 - 30 June 2003. Prepared degree: DEA Réseaux et Systèmes Distribués. Affiliation: Sophia Antipolis, France.
4. Parakram Khandpur worked on the Support of differentiated services in Bluetooth piconets. Duration of the stay: 14 May 2003 - 29 July 2003. Prepared degree: B.Tech. in Computer Science & Engineering. Affiliation: IIT Delhi - India.
5. Pierre Ansel worked on the Support of differentiated services for mutlimedia transmission over WLAN networks. Duration of the stay: 7 April 2003 - 11 July 2003. Prepared degree: Ingénieur de l’Eecole Polytechnique. Affiliation: Ecole Polytechnique, France.
6. Anne-Sophie Duserre worked on Developping a new security protocol for WiFi networks. Duration of the stay: 1 April 2003 - 30 September 2003. Prepared degree: DESS Réseaux et Applications Distribuées. Affiliation: Université de Paris VI, France.

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