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INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team armor

Architectures et Modèles de Réseaux

Rennes

THEME 1B

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1. Team

ARMOR is a joint project between the following partners: INRIA, CNRS, university of Rennes 1, INSA Rennes, ENST Bretagne. It has been created in 1999. Since 2002 we have in ARMOR an associate team with the university of the Republic at Montevideo, Uruguay.

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2. Overall Objectives

The main objectives of the project are the identification, the conception and the selection of the most appropriate network architectures of a communication service, as well as the development of computing and mathematical tools for the fulfillment of these tasks. These objectives lead to two types of complementary research fields: the systems' qualitative aspects (e.g. protocols' test and design) and the quantitative aspects which are essential to the correct dimensioning of these architectures and the associated services (performance, dependability, QoS, vulnerability and performability evaluation).

The ARMOR project works on problems related to the design and the analysis of communication services. Such services require functionality specifications, decisions about where and how they must be deployed in a system, and the dimensioning of the different components of the system. The interests of the project concern not only particular classes of systems but also methodological aspects.

Concerning the communication systems themselves, we focus mainly on IP networks and our concerns go from architectural aspects to protocols, studying different aspects of the structure of networks and services: from the topological organization of nodes and links to the software techniques allowing the two current versions of the IP protocol (IPv4 and IPv6) to coexist, from the problems related to the development of architectures allowing to provide specific Quality of Service (QoS) levels, to security or mobility aspects of the IP protocol.

Interoperability testing is essential to establish that network components interact correctly before they get deployed in a real environment. As such, it is considered as a part of the standardization process. The Armor project contributes in providing solutions (methods, algorithms and tools) which help in obtaining efficient interoperability test suites for new generation networks, mainly IPv6 related protocols.

>From the application point of view, our global field is IP technology in general. We are particularly interested in the "low speed links" world where QoS aspects are very important and lead to many different and exciting problems (on architectural aspects, on routing, on the protocols themselves). We also have activities in pricing methodologies (a critical area for telecommunications providers, with many defying open problems for the near future), in many areas related to the IPv6 technology, in the integration of packet transmission techniques into the next generations of mobile networks, etc.

Related to the previous remarks are the quantitative aspects of most of those problems. We develop techniques for the evaluation of different aspects of the considered systems through *models* and through *measurement techniques*. The quantitative aspects we are interested in are performance, dependability, performability, QoS, vulnerability, etc.. The methods we work with go from discrete event simulation and Monte Carlo procedures to analytical techniques, and include numerical algorithms as well. Our main mathematical tools are

stochastic processes in general and queueing models and Markov chains in particular, optimization techniques, graph theory, combinatorics, etc. Also in the quantitative evaluation area, we develop a methodology able to quantify the quality of multimedia flows automatically and in a similar fashion as humans do.

3. Scientific Foundations

3.1. Introduction

Key words: *Resource allocation*, *congestion control*, *throughput control*, *traffic control*, *traffic engineering*, *service differentiation*, *dimensioning*, *availability*, *reliability*, *queues*, *IP*, *interconnection*, *interoperability*, *discrete event models*, *fluid flow models*, *multicast*, *multimedia*, *performability*, *metrology*, *performance*, *Markov chains*, *stochastic processes*, *protocols*, *QoS (quality of service)*, *high speed networks*, *network reliability*, *end-to-end protocols*, *security*, *simulation*, *dependability*, *pricing*, *Monte Carlo techniques*, *testing*, *header compression* .

The scientific foundations of our work are those of network design and network analysis. More specifically, this concerns the principles of packet switching and in particular of IP networks (protocol design, protocol testing, routing, scheduling techniques), and the mathematical and algorithmic aspects of the problems, on which our methods and tools are based.

These foundations are described in the following paragraphs. We begin by a subsection dedicated to Quality of Service, since this concept can be seen as a unifying concept of our activities. Then we briefly describe the specific subarea of models' evaluation and about the particular multidisciplinary domain of pricing problems.

3.2. Quality of Service

Since it is difficult to think of communication solutions dedicated to each possible application, the scientific and technological communities aim towards providing general *services* allowing to give to each application or user a set of properties nowadays called "Quality of Service" (QoS), a terminology lacking a precise definition. This QoS concept takes different forms according to the type of communication service and the aspects which matter for a given application: for performance it comes through specific metrics (delays, jitter, throughput, ...), for dependability it also comes through appropriate metrics: reliability, availability; vulnerability for instance in the case of WAN topologies, etc. Moreover, some aspects of QoS have subjective components: the quality of a video stream or an audio signal, *as perceived by the user*, is related to some of the previous mentioned parameters (packet loss, delays, ...) but in an extremely complex way, and with a strong subjective component.

QoS is at the heart of our research activities: we look for methods to obtain specific "levels" of QoS and for techniques to evaluate the associated metrics. Our ultimate goal is to provide tools (mathematical tools and/or algorithms, under appropriate software "containers" or not) allowing users and/or applications to attain some level of QoS, with an optimal use of the resources of the communications system considered. Obtaining a good QoS level is a very general objective. It leads to many different areas, depending on the systems, applications and specific goals being considered. Our team works on several of these areas. We can mention the wide family of routing problems, which in Armor go from graph algorithms to routing techniques specialized to operate in the *last mile* part of the network under extreme performance constraints, our protocol-oriented activities (header compression techniques, interaction between protocols, for instance between IPv4 and IPv6) or the research works around differentiated services. We are also concerned with specific software engineering techniques, namely with middleware technologies in order to hide as much as possible the problems related to resource sharing, scalability and heterogeneity (for instance, such software systems have been successfully used for stationary distributed systems built over fixed networks but they do not suit mobile settings). We also investigate the impact of network QoS on multimedia payloads to reduce teh impact of congestion.

3.3. Modeling

The scientific foundations of our modeling activities are composed of stochastic processes theory and, in particular, Markov processes, queueing theory, graph theory, etc., either for analytical models or for discrete

event simulation or Monte Carlo (and Quasi-Monte Carlo) techniques. We are always interested in models' evaluation techniques for dependability and performability analysis, both in static (network reliability) and dynamic contexts (depending on the fact that time plays an explicit role in the analysis or not). We look at models from the classical so-called *call level*, leading to standard models (for instance, queueing models) and also at the *burst level*, leading to *fluid models*. For this more recent research field, we work both on analytical techniques and on discrete event simulation.

Lastly, our work on the design of the topologies of WANs leads us to optimization techniques, in particular in the case of very large optimization problems, usually formulated in terms of graphs. The associated methods we are interested in are composed of simulated annealing, genetic algorithms, TABU search, etc. For the time being, we have obtained our best results with GRASP techniques.

3.4. Pricing

Pricing is a good example of a multi-disciplinary research activity half-way between applied mathematics, economy and networking. Indeed, the Internet is facing a tremendous increase of its traffic volume. As a consequence, real users complain that large data transfers take too long, without any possibility to improve this by themselves (by paying more, for instance). A possible solution to cope with congestion is to increase the link capacities; however, many authors consider that this is not a viable solution as the network must respond to increasing demand (and experience has shown that demand of bandwidth has always been ahead of supply), especially now that the Internet has become a commercial network. Furthermore, incentives for a fair utilization between customers are not included in the current Internet.

For these reasons, it has been suggested that the current flat-rate fees, where customers pay a subscription and obtain an unlimited usage, be replaced by usage-based fees. Besides, the future Internet will carry heterogeneous flows such as video, voice, email, web, file transfers and remote login among others. Each of these applications requires a different level of quality of service (QoS): for example, video needs very small delays and packet losses, voice requires small delays but can afford some packet losses, email can afford delay (within a given bound) while file transfer needs a good average throughput and remote login requires small round-trip times. Some pricing incentives should exist so that each user does not always choose the best QoS for her application and so that the final result is a fair utilization of the bandwidth. On the other hand, we need to be aware of the trade-off between engineering efficiency and economic efficiency; for example, traffic measurements help in improving the management of the network but is a costly option.

3.5. Testing

Interoperability testing is the act of determining if end-to-end functionality between (at least) two communicating systems is as required by the base standard(s) for those systems. Conformance testing is the act of determining to what extent a single component conforms to the individual requirements of the standard it is based on. In our team, we consider that conformance tests are used in order to validate single networks for interoperability purposes. As a consequence, since a couple of years ago, our research activity focuses on interoperability testing. No real formal framework exists in the interoperability testing area, contrary to conformance testing. Our purpose is to provide a formal framework (methods, algorithms and tools) for interoperability testing which helps in obtaining efficient interoperability test suites for new generation networks, mainly IPv6 related protocols.

The generation of interoperability test suites is based on specifications (standards and/or RFCs) of network components and protocols to be tested. The model we use is an automaton-like structure called IOLTS (Input Output Labelled Transition Systems). It is an LTS which distinguishes inputs, outputs and internal actions.

4. Application Domains

Key words: *Extranet*, *traffic engineering*, *Internet*, *Intranet*, *multimedia*, *providers*, *QoS*, *telecommunications*, *telephony*.

Our main application domains are those related to network design, both at the transport infrastructure level and at the service level. Our expertise currently focuses on IP technology in a variety of contexts (IP QoS, IP security, IP mobility, IP telephony,...), and on analysis and dimensioning tools: telecommunications architecture configuration, bottleneck search, resource allocation policies comparison, etc. Our works on protocols and control mechanisms are also applicable to other technologies besides IP, such as ATM.

Problems arising from the coexistence and interoperability of different technologies are also investigated: between IP and ATM, IP and WDM, IPv4 and IPv6, etc. In the field of traffic engineering and system dimensioning, technological evolution also raises a number of new performance evaluation problems. Besides these main application domains, other important subjects where quantitative analysis plays a central role are, for example, the analysis of control mechanisms, or the problems posed by pricing, which are of evident interest for operators. In the IP world, extensions such as mobile IP, cellular IP, security–related aspects, multicasting, and compression techniques (e.g. header compression) are also important application domains.

The first field in which the team's expertise is in demand is that of IP networks. The usual context is that of an industry member who wishes to develop new techniques, or that of a user who has to set up a new communications system or to upgrade (or more generally, modify) an existing one. This may involve a specific aspect of the system (e.g. the costs model which allows the development of a billing policy), or a particular kind of network (for instance, a home-network), or a family of services (for instance, a security policy).

We can also classify ARMOR's main application domains per type of services involved. Then, the past and current expertise of the team's members mainly involve the transport of multimedia flows over IP, the various network QoS management aspects, the testing techniques (interoperability tests, implementation validation tests – especially for IPv6, and test generation). In this context we find, for instance, problems related to the conception of mechanisms well adapted to specific flow types and QoS goals, both at the network access level, and at the intermediary node level.

With regard to analysis and dimensioning, we contribute to the different related methodologies (measurements, simulation, *analytical* techniques), and also to the development of new mathematical and software tools. We develop models for the collection of specific characteristics of the studied systems (e.g., those related to QoS). We also develop new simulation methodologies, in order to overcome certain limitations of the existing techniques. Finally, it should be noted that networks now offer services with a certain level of redundancy, which leads to problems of reliability. Our team has a long experience in the specific study of this systems' aspect and in related problems such as performability and vulnerability (a notion aiming at quantify the robustness of a grid without taking into account the reliability of each component).

5. Software

5.1. Experimental platforms

Participants: Bernard Cousin, Laurent Guillo, Cécile Marc, Ana Minaburo, Julio Orozco, Laurent Toutain, Miled Tezeghdanti.

We have implemented (and we mantain) an IPv6 platform which includes several recently proposed QoS mechanisms (e.g. RSVP, service differentiation, scheduling techniques). This platform is a part of the *G6-bone* (the experimental French IPv6 network). It is the current Regional Interconnection Point for the Brittany and Pays de la Loire regions. A test platform for *diffserv* architectures has also been implemented, which allows to test the different categories of service proposed by this archietcture (i.e. *Expedited Forwarding*, and *Assured Forwarding*). This platform is connected to the european TF-NGN, which tests differentiated services technology. We have also implemented an MPLS test platform. It is a local system, consisting of several machines runnning FreeBSD and Nistswitch. It serves, for instance, as a testbed for MPLS over Ethernet and RSVP signalling.

The IETF has standardized the ROHC (RObust Header Compression) protocol. This complex mechanism allows to drastically reduce the header size to increase the performance on slow and noisy links. We have

developed a full implementation of this protocol for both the IPv4 and IPv6 protocol stacks. The first testbed used PPP links. We are currently porting this code to a UMTS platform thaks to the RNRT project Cosinus. (FIXME, referencia Cosinus)

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5.2. Performance and dependability evaluation

Participants: Gerardo Rubino, Bruno Sericola, Bruno Tuffin.

We develop software tools for the evaluation of two classes of models: Markov models and reliability networks. The main objective is to quantify dependability aspects of the behaviours of the modelled systems, but other aspects of the systems can be handled (performance, performability, vulnerability). The tools are specialized libraries implementing numerical, Monte Carlo and Quasi-Monte Carlo algorithms.

One of these libraries has been developed for the Celar (DGA), and its goal is the evaluation of dependability and vulnerability metrics of wide area communication networks (WANs). The algorithms in this library can also evaluate the sensitivities of the implemented dependability measures with respect to the parameters characterizing the behaviour of the components of the networks (nodes, lines).

We are also developing tools with the objective of building Markovian models and to compute bounds of asymptotic metrics such as the asymptotic availability, of (in the context of performance evaluation) standard metrics of the models in equilibrium (loss probabilities, blocking probabilities, mean backlogs, ...). A set of functions designed for dependability analysis is being built under the name `DependLib`. Another set of procedures are being developped for the computation of various buffer level distributions of fluid queues. Its name is `FluidLib`. A JAVA graphical interface is being developed for the modeling and analytical analysis of networks of fluid queues.

5.3. Simulation

Participants: Ali Boudani, Bernard Cousin, Raymond Marie, Miklós Molnár, Gerardo Rubino, Laurent Toutain, Bruno Tuffin.

We develop different simulation tools, for specific purposes. For instance, we have made contributions to the NIST simulator for ATM networks. We have developed a discrete event simulator called SAMSON, specialized in real time problems (see http://www.rennes.enst-bretagne.fr/~toutain/samson). We have made several contributions to the QNAP language, which is currently a part of the package MODLINE, distributed by SIMULOG.

We currently participate to the design and evolution of the SPNP (*Stochastic Petri Net Package*) tool, implemented in more than 200 sites. The main designer is Duke University. Our contributions are around Monte Carlo methods. We are going to increase now our participation to the evolution of the tool.

We are now developing a simulator called `FluidSim`, working in the framework of continuous state models (or fluid models), mainly for performance evaluation of high speed communication networks. `FluidSim` has been already used to analyze ATM networks and the behaviour of TCP.

An OSPF simulator has been developed over `ns2`. This simulator was designed to allow a very fine analysis of OSPF behaviors, convergence time, amount of traffic generated,...It is very important to understand the influence of the Traffic Engineering extension on the OSPF behavior in large transit networks. Our simulator

is used to test and compare different algorithms that build pathes using the OSPF database. A pedagogic tool was built over this simulator to explain how OSPF works.

We have enhanced the network simulator `ns2` to be able to evaluate the performance of the current version of the `Xcast` protocol and to compare it to our proposed extension `GXcast` (see http://www.irisa.fr/prive/aboudani/research/xcast/index.htm).

We also proposed a new multicast approach, called Simple Explicit Multicast (SEM), which uses an efficient method to construct multicast trees and deliver multicast packets (see 6.6.3 and http://www.irisa.fr/prive/aboudani/research/sem/index.htm).

In a similar way, we have enhanced `ns2` to be able to evaluate the performance of our MMT proposition and to simultate PIM-SM in an MPLS network (see http://www.irisa.fr/prive/aboudani/research/mmt/index.htm).

5.4. Transition mechanisms

Participants: Francis Dupont, Laurent Toutain.

In collaboration with Jean-Luc Richer (IMAG), we have augmented the functionality of DSTM (Dual Stack Transition Mechanism). This mechanism aims to automatically tunnel IPv4 packets into IPv6 during the transition phase of a given network. The code has been ported to Linux (being originally developed for BSD). We have also been working on securing the address allocation protocol in VPN scenarios.

5.5. DNSsec platform

Participants: Olivier Courtay, Bernard Cousin, Francis Dupont, Gilles Guette, Olivier Peningault, David Fort.

DNSsec provides security to the DNS infrastructure. We participate to the worldwide deployment of DNSsec. Our platform is the first french DNSsec platform. It is interconnected to the internationnal DNSsec network which is shadowing the usual DNS hierarchy. Our platform offers DNSsec services provided by primary and secondary servers distributed over 4 locations in France. For more information, see the url given at the end of this section.

We are developing several DNSsec software tools (all the software associated with IDsA project is released under a BSD-like license):

- a `perl` resolver for DNSsec. This tool enables to check the chain of trust on which DNSsec is based;
- `dig-sigchase`: we have patched the well-known administrative tool `dig` to have a DNSsec-aware version;
- `DNSsecToolKit`: a library which allows to build DNSsec-aware software into a DNS client;
- `KRO`: a Key Roll-Over tool which enables automatic roll-over of key for DNSsec.

All these tools are available at http://www.idsa.prd.fr/index.php?page=code&lang=en.

5.6. Network Graph and Path Computation experimental prototype

Participants: Bernard Cousin, Thierry Feuzeu, Alexandre Guitton, Miklos Molnar, Christophe Turle.

We are implementing a functional prototype of a novel architecture for distribution area networks. The provided flexible broadband serving network adapts to the operators' topology and enables an enhanced services portfolio. The architecture is based on a non-regular mesh network of switching nodes. A Serving Network Controller provides self-configuration and intelligent management of the switching nodes. Our prototype provides algorithms for the auto-configuration, data path routing and fast rerouting in case of link or node failure.

6. New Results

6.1. Pricing

Participants: Yézékaël Hayel, Patrick Maillé, David Ros, Bruno Tuffin.

Pricing is probably one of the most efficient means to control congestion in a communication network. It is furthermore mandatory for service differentiation.

Our work has focused on pricing schemes without bandwidth reservation. We have written down a state of the art [22] emphasizing, with respect to the literature, the mathematical models involved in the methods.

We have also worked on auctioning for bandwidth. In [58][57], we have highlighted some incentivity drawbacks of a progressive second price auctions that is assumed to encourage users to truthfully submit their bids and such that converges to an optimal allocation (and the market clearing price has been determined in [81]). These drawbacks have been tackled by allowing rejected bidders to submit a sanction bid. The main tool of auctioning is game theory. Unfortunately, game theory generally involves a fixed number of players, which does not really correspond to connections behavior through time. The performance of the progressive second price auction in a random environment (i.e., users entering and leaving the network) has been investigated in [84][17]. In [83][100], the costly iterative scheme has been replaced by a one-shot multiple-bid scheme keeping the optimality and incentive compatibility propert ies.

In [55], we have studied a simple and promising pricing method called the "Cumulus Pricing Scheme", dealing with service differentiation and scalability issues. We have mathematically determined parameters optimizing the provider's revenue under the constraint that each user has an incentive to reveal his anticipated bandwidth consumption.

Multi-class pricing is also an important research topic of our group. We have obtained optimal prices for the case where the classes are logically separated (also called the Paris metro Pricing Scheme) [86][67], for priority queuing using Aumann-Shphey prices (that fairly share the total perceived cost) [80]. Optimal prices have also been found for other models, such as the Cumulus pricing scheme [108]. We have finally shown that, in order to increase its revenue, an ISP should use at its routers a priority scheduling mechanism rather than generalized processor sharing [79][99].

In [87][77], we have designed a pricing scheme for a RED buffer such that the drop probability (or more exactly the slope of the drop curve of RED) depends on the willingness to pay of the users: the more you pay, the less one of your packets is likely to be dropped. The problem is modeled as a non-cooperative game and conditions for an equilibrium to exist and to be uniquely defined are established.

6.2. Dependability and extensions

Participants: Gerardo Rubino, Bruno Sericola, Bruno Tuffin.

We maintain a research activity in different areas related to dependability, performability, vulnerability analysis of communication systems. In 2003 our effort has concentrated on evaluation techniques using the Quasi-Monte Carlo approach.

In Quasi-Monte Carlo (QMC), the error when estimating the integral

$$\int_{[0,1]^s} f(x)dx \qquad \texttt{by} \qquad \frac{1}{N}\sum_{n=1}^{N} f(\{X+\xi^{(n)}\})$$

(where $(\xi^{(n)})_{n\geq 1}$ is a low discrepancy sequence) is bounded by the product of a quantity depending on the discrepancy of the sequence and the variation of the integrand. In previous works (see for instance [113]), we had shown this bound is useless in practice and that by combining MC and QMC methods, we could to benefit of both methods: error estimation from MC and convergence speed from QMC. In [69], we have continued this work. We have especially taken care of the normal approximation, i.e., the confidence interval coverage, when using this hybrid method.

As another remark, due to the correlation structure of the sequence, necessary to "minimize" the error, the direct application of QMC methods to the analysis of Markov chains was inefficient. In [56], we have developed a QMC method analyzing the transient behavior of discrete time Markov chains using only a two-dimensional low discrepancy sequence. The main characteristic of this method is a relabeling of the chains at each time step of the simulation.

6.3. TCP

Participants: Sophie Fortin, David Ros, Bruno Sericola, Bruno Tuffin.

In a collaboration with Mistral project-team, through the TCP and PRIXNET ARCs, we have analyzed the behavior of two competing TCP connections sharing a common bottleneck link. We have analyzed several loss strategies: fixed loss probability, largest throughput loss or proportional loss. After some derivations in the general asymmetric case, we especially show that in the symmetric, surprisingly, the loss strategy has no consequence on the average throughput. We show, in contrast, that the second moment of the throughput does depend on the strategy.

We had proposed a very accurate Markovian model of TCP refining previous works on the performance evaluation of one bulk transfer TCP flow among exogenous traffic. While most of these works are mainly focused on the mean throughput evaluation, our model allows, with low cost, to study many other performance measures (see [47] and a more detailed analysis of the AIMD principle has been proposed in [48].

6.4. QQA: Quantitative Quality Assesment

Participants: Samir Mohamed, Gerardo Rubino, Martén Varela.

QQA is a methodology allowing quantifying the quality of a video or audio (or multimedia) flow by the receiver, after the flow passed through a packet network such as the Internet. This quantification is done automatically, in real time if necessary (that is, it is done very efficiently). The specificity of the approach is that the obtained evaluation is very close to the evaluation that could be done by human observers. The reason is that we use a specific statistical learning tool to capture how humans behave face to these flows. The tool learns and then behaves similarly to real observers. The statistical tool allowing this accuracy is the Random Neural Network model, that is, an open queuing network with positive and negative customers. In 2003, we extended the approach we developped in [111] to the case of audio communications, again with excellent results; see [20].

To the best of our knowledge, this is the only solution to the problem of assessing the quality of a multimedia stream after travelling through a packet network with the given properties: automatic, real-time is necessary or useful, and accurate (close to the evaluation performed by real human observers). Among other research directions, we are exploring different application of this technology in control from a general point of view, in diffserv architectures in particular, for pricing problems, etc.

6.5. Low speed links

Participants: Laurent Guillo, Louis-Marie Le Ny, Cécile Marc, Elizabeth Martinez, Ana Minaburo, Julio Orozco, David Ros, Gerardo Rubino, Bruno Sericola, Laurent Toutain.

If most of the QoS-related problems in the core network can be solved by overprovisioning, congestion may continue to arise in some specific cases: when the bandwidth is either physically limited, like in UMTS networks, or if traffic rerouting due to link failure may lead to an overload. Specific research themes and contributions of ARMOR in this context are the following:

- **Header compression techniques (ROHC protocol) in IPv6**. The performance of IPv6 in the radio link can be improved using header compression algorithms. The 3GPP (3rd Generation Partnership Project) consortium has adopted the ROHC (Robust Header Compression) algorithm of the IETF (Internet Engineering Task Force) [105] standard track for the real-time applications

using RTP/UDP/IPv6 and UDP/IPv6. We have developed one of the first IPv6 implementations of this protocol. This allowed us to propose several enhancements in order to support more efficiently IPv6 [110] or to study parameters impact on performances. See [19], [60], [59], [61], [62] for the already obtained results. Collaborative works with the TEMICS project-team lead us to study a new ROCH profile dedicated to UDP-lite.
We are now starting the behaviour of the ROHC header compression mechanism in a real UMTS platform, in the PDPC layer. It will also find the adequate parametrization of this complex protocol, in order to optimize the radio resources. In collaboration with the INRIA project TEMICS, we will study the impact of the residual tramission error on multimedia flows, in order to evaluate the QoS perceived by the user.

- **Active queue management for *diffserv***. In the context of the DiffServ architecture, active queue management (AQM) algorithms are used for the differentiated forwarding of packets; such algorithms are one of the main building blocks of the Assured Forwarding (AF) per-hop behavior. However, correctly setting the parameters of an AQM algorithm may prove difficult and error-prone. Besides, many studies have shown that the performance of AQM mechanisms is very sensitive to network conditions. We have proposed a new active queue management algorithm, which we call *Adaptive RIO* (A-RIO) [64][1], [85], aimed at both easing the configuration of DiffServ routers and building services with loose delay guarantees. A-RIO stabilizes queue occupation, without having an adverse effect on other performance parameters like packet discrimination, throughput and fairness in bandwidth sharing.
  We are currently exploring some open issues regarding the A-RIO algorithm. Since A-RIO might be used to build services with a loose bound on delay, it may be interesting to evaluate its performance when UDP traffic is used, regarding delay and jitter, as well as the influence of packet size on these quantities. We are also working on the implementation of A-RIO on the FreeBSD operating system, based on the ALT-Q framework. Finally, we intend to work on the analytical modelling of the algorithm.
- **Multimedia tagging for DiffServ** When multimedia flows are transported on an IP network, congestion may lead to a severe degradation of the perceived quality if important information of the multimedia stream is lost. The AF class defined in the DiffServ architecture introduces the notion of differentiated drop probabilities for packets belonging to the same flow aggregate. The goal of a DiffServ-aware multimedia streaming system is to use an appropriate tagging mechanism, so as to discriminate among packets when congestion arises: packets tagged as less-important ones (from the point of view of the codec) should be the first to be dropped at routers. Our current work, which can be regarded as the sequel of Octavio Medina's PhD thesis [109], focuses in new video coding schemes like H.264, which are designed with network error resilience in mind and allow for more flexible tagging strategies.

6.6. Multicast

Participants: Ali Boudani, Bernard Cousin, Thierry Feuzeu, Alexandre Guitton, Raymond Marie, Miklos Molnar.

Scalability and efficiency of routing, QoS management and tree construction have to be improved for multicast traffic. Our research on multicasting can be organized in 3 thematic axis:

6.6.1. Multicast Routing and Tree Construction.

Construction of minimum spanning tree being NP-complete, we have proposed several heuristic approximations with polynomial time taking into account some specific constraints: QoS constraint, and/or constraints in all optical networks, where some optical WDM switches can not split.

[1] Best student paper.

Generally, routing algorithms are based on static and well known information about the (link) state of the network. A new approach is needed for routing, if the state information is uncertain and/or the state of the links changes often and randomly. In the case of uncertain information on the delay of transmission, a multicast routing algorithm is proposed to diminish the end to end delay in multicast trees ([63]).

In optical networks the constraints for routing algorithms follow from the physical constraints of optical links and switches. One of the fact, which restricts well known multicast routing algorithms in WDM networks is that the splitting capability of messages is missing. In order to adapt multicast routing algorithms to WDM networks and improve their efficiency, special algorithms was proposed in [74], [75], [53], [49] and [54].

6.6.2. Multicasting over MPLS.

Using Internet over MPLS provide the efficiency and traffic engineering capability given by label switching and the flexibility given by Internet. We have presented a new approach to construct multicast trees in MPLS networks. In our approach only routers that are acting as multicast tree branching nodes for a group need to keep forwarding state for that group. All other non-branching node routers simply forward data packets over traffic engineered unicast routes using MPLS LSPs ([78]). A new simulation platform has been used to analyze the multicast traffic over MPLS ([30]).

6.6.3. Small Group Multicast.

We have enhanced Explicit routing technique, which enables routing of small groups on Internet. Our proposals decrease packet overhead, enable management of larger groups, and segment efficiently the packet (e.g. Sem: A new small group multicast routing protocol; cf. [31]).

In the same context, we have proposed an extension to the Xcast protocol [33]. Our proposition is an adaptive protocol which generalizes the Xcast forwarding method and may be parameterized to fit the size of the group. Our protocol is as efficient with small groups as the original Xcast family protocols and it can manage more efficiently larger groups. This solution is proposed in the IETF draft [90].

6.7. Security

Participants: Olivier Courtay, Bernard Cousin, Francis Dupont, David Fort, Gilles Guette, Olivier Peningault.

Nowadays, reaching services on the net highly depends on the use of the DNS (Domain Name System) infrastructure. Its secureness has become necessary. Moreover, such a secure infrastructure (DNSsec) could be used to secure other applications. The goals of the project are the study and deployment of secure DNS transactions, the development of mechanisms allowing the use of the DNSsec infrastructure to distribute keys/certificates for secure signalization of Mobile IPv6 and use of IPsec (HIP and/or opportunistic IPsec). We have analyzed DNS threats [52], studied the completeness of DNSsec and IPsec [50] and proposed requirements for key rollover for DNSsec [51][98].

6.8. Queueing analysis

Participants: Louis-Marie Le Ny, Gerardo Rubino, Bruno Sericola.

This year, our efforts focused on transient analysis of queues: on the analysis of queues fed by BMAP processes and on a new approach based on lattice path combinatorics.

The BMAP are used to represent the network traffic at the packet level. We considered queues with Batch Markovian Arrival Process and phase-type distributions for the service times. We studied in [25] the transient distribution of the buffer content of this queue. We developed an accurate algorithm to compute this distribution.

Using the concept of duality between stochastic processes as defined in “Continuous-Time Markov Chains” (W.J. Anderson, 1991, Springer-Verlag), we developed a new approach to obtain closed-form expressions of transient distribution for basic Markovian queues. The idea is to go to discrete time through uniformization, then to use duality to map the problem into transient analysis of absorbing models and then, to use combinatorial techniques to analyze these absorbing chains. Our first results are [16], [13], [15].

6.9. Analytical fluid models

Participants: Nelly Barbot, Landy Rabehasaina, Bruno Sericola.

On the basis of the simple formulae and precise algorithms that we had obtained for the distribution of the buffer content of a finite or infinite capacity fluid queue [112] fed by a Markovian queue or by an M/M/1 queue [104], we have obtained a closed form solution for tandem fluid queues fed by on-off exponential sources, with the condition that only one source is necessary to fill the first buffer, has been obtained in [29].

We have obtained the Laplace transform of the joint distribution of the buffer content of all queues in a network of fluid queues with Markov modulated input rates and linear service rates. This central result, which is a part of the thesis [10], is the basis for the analysis of more general networks of fluid queues. The transient analysis of such a single queue has been published in [66].

In [21] we have obtained the stability condition for a second order fluid queue in a general ergodic environment, with level dependent input and services rates, the local variance mapping being also level dependent. This was an open problem formulated as a conjecture. The stability of networks of such queues has been obtained in [65] where we also obtained the two first moment of the buffer levels in the case of linear service rates and in a markovian environment.

6.10. Testing

Participants: Sébastien Barbin, Hélène Leguen, Raymond Marie, Francine Ngani, César Viho.

Interoperability testing is the act of determining if end-to-end functionality between (at least) two communicating systems is as required by the base standard(s) for those systems. Conformance testing is the act of determining to what extent a single component conforms to the individual requirements of the standard it based on. We consider that conformance tests are used in order to validate single networks for interoperability purpose. As consequence since a couple of years, our research activity focuses on interoperability testing. Any real formal framework does not exist for interoperability testing area, contrary to conformance testing. Our purpose is to provide a formal framework (methods, algorithms and tools) for interoperability testing which help in obtaining efficient interoperability test suites. The model used here is an automata-like structure called IOLTS (Input Output Labeled Transition Systems). It is an LTS which distinguishes inputs, outputs and internal actions. On a pragmatic side, we try to validate our solutions for new generation network, mainly IPv6 related protocols [71].

We have proposed a formal definition of the notion of interoperability, which has been considered by the testing community as the first real contribution in this area [103]. We also study how a distributed approach (including remote approach) can help in efficiently testing components [72]. We have generated conformance and interoperability tests for significant IPv6 and 3GPP related protocols, like MIPv6 (Mobile IPv6), ROHC (Robust Header Compression), IPv4-IPv6 transition mechanisms (NAT-PT, ISATAP), RIPng (Routing Internet Protocol for IPv6), etc. These tests have been used for many interoperability events such as the ETSI/Plugtest events (since 2000), and the Japanese TAHI events (since 2001).

We are also involved in the "IPv6 Ready Logo Programme" (see http://www.ipv6ready.org) which is a world wide certification programme launched by the IPv6 Forum. We are responsible of the definition of technical requirements for the two phases of this programme.

We are also interested in the description of software behavior as probabilistic graphs. This allows for the generation of pertinent test cases by traversing the modelled graph, while producing quantitative data on the test's progress. See [24] for the obtained results (extension of [114]).

6.11. Mobile networks

Participants: Françoise André, Jean-Marie Bonnin, Djalel Chefrour, Lucian Suciu.

For two years now, the ARMOR team has launched several activities having the common key work: mobility. Some of these activities belong to other subgroups such as the TEST subgroup. Two mains theme set up the core of this new subgroup: Mobile Access Networks and Ubiquitous Terminals.

Operators are interested in the adaptation of existing micro mobility solution to their operational constraints. Hence, we have participated, in collaboration with France Telecom R&D, to the development of a new micro mobility protocol derived from HMIPv6. This protocol allows the network to take in charge the handover decision. Then the network can prepare the handover to reduce the latency time and perform load-sharing taking into account the overall situation of the network. The new protocol (NCHMIPv6: Network Controlled HMIPv6) is being improved to provide quality of service management in access network. For more detailed description of our approach, see [14].

We are also involved in the definition of a new architecture that allows the applications to be able to adapt efficiently and timely their behaviours to network condition changes. This leads us to deal with automatic interface choice and automatic configuration, as well as with the relation between the network and terminals in term of security and quality of service (on-going work). We have also defined a framework to build adaptive application and to manage network resources description thru a profile mechanism. See [26].

6.12. Network design

Participants: Héctor Cancela (Montevideo, responsible for Uruguay), Franco Robledo, Gerardo Rubino (responsible for France), Bruno Tuffin, Maréa Urquhart (Montevideo), Martén Varela.

In the framework of the associate team PAIR (8.4), we work mainly in two areas: QQA (described in 6.4) and in network design. For the results of 2003 see 8.4.

7. Contracts and Grants with Industry

7.1. Cyberté : Multiple Network Interfaces Optimized Support for an IPv6 Mobile Terminal

Participants: Françoise André, Jean-Marie Bonnin, Djalel Chefrour, Bruno Deniaud, Francis Dupont, Lucian Suciu.

Cyberté is a RNRT project, starting in January 2002, for 27 months. The project leader is France Télécom R&D. ARMOR's budget is 174 keuros. The other partners are Cisco France and the LSIIT.

This project belongs in the field of Mobile Networking, and its main goal is the improvement of QoS in heterogeneous mobile network environments. This improvement is done by a better management of inter– and intra–technology handovers in wireless netwoks (such as Bluetooth, WiFi, or HiperLAN), both in home and enterprise environments. Our main contributions to this project is the development of adaptive applications, capable of adjusting their needs according to the available resources.

7.2. Ubique : QoS Profile Management and Interface Selection

Participants: Jean-Marie Bonnin, Lucian Suciu.

Ubique is a CRE project (France Telecom funding and partnershp) and ARMOR's budget is 166 keuros. The project spans 12 months from June 2002 to June 2004.

The domain of the Ubique project is that of IP mobility, and its main goal is the design of a QoS profile management and interface selection algorithm. The growing popularity of wireless interfaces will make that mobile computers have several network (wired and wireless) interfaces. It is then likely that the system will be frequently forced to change the active interface(s), which currently implies the closing of running applications, or even a reboot. The user will then need mechanisms that allow for the selection of the most appropriate interface, following the available network access points, applications' needs, and the cost of the different connections.

7.3. Probabilistic test generation

Participants: Hélène Le Guen, Raymond Marie.

This is a CIFRE contract, in which ARMOR's budget is of 90 keuros. The goal is to develop software for testing new communication protocols. The subject of the associated PhD thesis proposed in this collaboration concerns the use of markovian models to assign a coevrage measure to the tests done during a test campaign. It also aims to find techniques to improve the effectiveness of these tests.

7.4. ASSET : Architectural Solutiuons for Services Enhancing digital television

Participants: Mathurin Body, Bernard Cousin, Miled Tezeghdanti.

Asset is a joint project with Compaq Computer (France), Thomson Broadcast Systems (France), Dalet-A.N.N GMBH (Deustchland), INESC Porto (Portugal), Institut Fuer Rundfunktechnic GMBH (Deustchland), ManageStorage International (France), SHS Multimedia (Italy). ARMOR's budget is of 141 keuros.

The aim of this project is the development of a middleware architecture for the easy integration of digital television equipment into a digital TV production system. This implies unifying both the techniques used for digital content treatment in TV production, and the interconnection procedures for the different devices which intervene in production. As a concrete goal, ASSET will develop a prototype "news room" type recording studio.

7.5. IDsA : Infrastructure DNS sec et Applications

Participants: Olivier Courtay, Bernard Cousin, Francis Dupont, Gilles Guette, Olivier Peningault.

IDsA is being done in partership with France Telecom and AFNIC. It spans 22 months, from September 2002 to July 2004. ARMOR's budget in this project is 218 keuros. The project proposes a number of improvements to the current Internet's DNS infrastructure, with a particular focus in security. In order to achieve these improvements, it is necessary to work on:

- the securization of DNS transactions, making updates secure, and
- the securization of the transmitted data, i.e. the content of DNS messages. This implies the authentication of the data origins, and its integrity.

An infrastructure such as DNSsec, which covers almost completely the Internet, may also be used for other purposes, such as the distribution of public keys, and/or certificates associated to an IP address or a domain name. Besides this, the new architecture should allwo for an esaier and more secure service access for nomad and mobile users (e.g mobile IPv6 signalling, secure VPNs, etc).

7.6. HADES: high–speed networks and security

Participants: Bruno Sericola, Bruno Tuffin.

This 24–month project (September 2001 to September 2003) is a PEA (Plan d'Etude Amont) project on securing high speed networks, supported by the CELAR (French army). It is being done in cooperation with industrial (AQL, SAGEM, SILICOMP Réseaux, SOREP) and academic (R2D2 INRIA project, INT Evry) partners. ARMOR's budget is of 60 keuros.

HADES aims at designing security devices for gigabit networks and at identifying research directions for securing terabit networks. ARMOR's goal is to model and evaluate the performances of the architectures and protocols proposed by the partners [102].

7.7. IPv4–IPv6 transition studies

Participants: Francis Dupont, Laurent Toutain.

This is a CRE (*Contrat de Recherche Externe*) with France Telecom, spanning 12 months from March 2002 to March 2003. ARMOR's budget is of 100 keuros.

The project's main goal is to study the performance aspects of the DSTM transition mechanism and the size of the IPv4 address pool needed in production networks.

7.8. FABRIC: Federated Applications Based on Real-time Interacting Components

Participants: Samir Mohamed, Gerardo Rubino, Martin Varela.

The FABRIC consortium wants to fulfill the Ambient Intelligence promise in the home by concentrating on a computing- and network- infrastructure. FABRIC aims at developing an architecture in which several standards and technologies in the home networking context can be integrated. The project lasted 6 months, from September 2002 to February 2003. ARMOR's budget was of 32 keuros. Our industrial partners are Philips (Netherlands) and Thomson (France), and our academic ones are Eindhoven Univ. of Technology (Netherlands), TNO Physics and Electronics Lab. (Netherlands), Maelarden Univ. (Sweden), Scuola Superiore S. Anna (Italy), Univ. College (UK) and CSEM (Switzerland).

The main goals of the project were the identification of user needs, the development of middleware for the integration of different technologies, and the performance evaluation of home networks. As an additional goal, there is the preparation of a second project (STREPS class; code: STRUCTURE) about home networking for 2004–2007. ARMOR in FABRIC: modeling activities; in STRUCTURE: IPv6 issues, modeling, reservation techniques, QQA, etc.

7.9. NGDG: New Generation Distributed Gateway

Participants: Bernard Cousin, Thierry Feuzeu, Alexandre Guitton, Raymond Marie, Miklos Molnar, Christophe Turle.

NGDG is being fone in association with ALCATEL Stuttgart. It spans 24 months, from June 2002 to July 04, and ARMOR's budget is of 326 keuros.

This project belongs in the field of high performance access networks. Its goals are the design of optimized architectures and protocols for the control of a versatile, dependable access multi-gigabit network (auto-configuration, topology and resource discovery process, fast rerouting, route optimization, and route protection).

8. Other Grants and Activities

8.1. National initiatives

8.1.1. INRIA ARC "Models and Algorithms for TCP/IP Networks"

Participants: Sophie Fortin, David Ros, Bruno Sericola, Bruno Tuffin.

This ARC (cooperative research action) regroups the INRIA projects MISTRAL (coordinator), ARMOR, PLANETE, TREC, RAP, the LIRMM (at Montpellier), France Telecom R&D (Lannion, Sophia Antipolis and Issy-les-Mlx) and the EPFL (Lausanne). We work mainly on the modeling of TCP transfers, on active queue management for congestion control, and on the evaluation of service differentiation mechanisms.

8.1.2. INRIA ARC « PRIXNET: Network Pricing »

Participants: Yézékaël Hayel, Patrick Maillé, David Ros, Bruno Tuffin.

Period: January 2002 – December 2004.

Armor project-team coordinates this ARC project grouping the french laboratories interested in pricing. Our partners are INRIA's Mistral project-team, PRiSM laboratory at the University of Versailles-St Quentin, France Telecom and also IBM (Watson Research Center). The goal is to design, implement and test pricing schemes to cope with congestion and to allow service differentiation.

8.1.3. ACI "SURE-PATHS"

Participants: Gerardo Rubino, Bruno Sericola, Bruno Tuffin.

We started the work at the ACI "SURE-PATHS" whose objective is to provide dependability analysis tools (see http://www-id.imag.fr/Laboratoire/Membres/Sbeity_Ihab/Sure-Paths/firstpage.html). This project spans over three years, starting in August 2003.

8.1.4. CNRS AS "Random Models and Performance Evaluation of Distributed Systems"

Participants: Gerardo Rubino, Bruno Sericola.

This is a one year AS (from November 2003 to November 2004), which regroups several labs, namely IRCCyN (Nantes), LAG (Grenoble), LIRMM (Montpellier), INRIA, LT2I (Paris), ENST (Paris), FIXME (Grenoble) and PRSIM (Versailles).

8.1.5. G6 / IPv6 Task Force

Participants: Bernard Cousin, Francis Dupont, Laurent Toutain, César Viho.

ARMOR actively participates at the G6 (French–speaking IPv6 users group), and on several topics: autoconfiguration, IPv6-IPv4 relations, security (DNSsec). The G6 project benefits from the regional acess point to Renater's IPv6 pilot and to the VTHD network. ARMOR is also very active in the G6test group, which defines tests for IPv6.

8.2. European initiatives

- The project has participated to the experimentation about service differentiations performed by Renater on the network TF-NGN.
- The project is an active partner of ETSI for interconnection testing in the IPv6 context. See 6.10 and 9.3 for details.

8.3. International initiatives

- We work with Duke university (USA) on modeling aided by Petri nets, with the Lebanese University on multicast networking and with Cocody University on new information technology and multimedia.
- We develop a partnership with and with the ITAM (Mexixo DF) on multimedia streams quality measurement, and simulation methods.
- We are currently working with the university of Arizona (M. F. Neuts), with the Indian Institute of Technology, Madras (P. R. Parthasarathy) and AT&T Labs Research (V. Ramaswami) on the analysis of fluid models.
- R. Marie is a member of the IFIP working groups 6.3 (Performance of Communication Systems) and 7.3 (Computer System Modeling and Performance Evaluation). G. Rubino is a member of the IFIP working group 7.3.
- L. Toutain, F. Dupont and C. Viho have been to the ETRI (Korea) for the first French-Korean joint IT workshop.
- In the context of the LAFMI French-Mexican cooperation program, ARMOR co-organised on September-October 2003 the Second French-Mexican School on Cooperative Distributed Systems. This School, partially funded by INRIA, was aimed at PhD students and junior researchers from Mexico and France working on the areas of distributed systems and networking. For more details, see the web site of the School: http://www.irisa.fr/manifestations/2003/ESRC/.

8.4. Associated team "PAIR" (or PAWN: Planning of the Architecture and the infrastructure of a Wide area Network)

Participants: Héctor Cancela (Montevideo, responsible for Uruguay), Franco Robledo, Gerardo Rubino (responsible for France), Bruno Tuffin, Maréa Urquhart (Montevideo), Martén Varela.

PAIR is an associated team, that is, a formal cooperation between two teams, with mainly INRIA funding.It has been started at the end of 2001. PAIR formalizes the cooperation between a subgroup of ARMOR and a subgroup of the Operations Research Team at the Computer Science Department of the Faculty of Engineering, University of the Republic, Montevideo, Uruguay. PAIR also helps in developing our partnership with the ITAM institution at Mexico. The goal of the team is to develop techniques for the design of a WAN (Wide Area Network). From the scientific point of view, this means very complex high-dimensional optimization problems set in terms of graphs. One of the goals of the team is to integrate modern performance evaluation techniques and dependability analysis methods in the optimization process. A second goal is to provide the developed algorithms as a tool. This cooperation also helped in developing two other themes in ARMOR: the QQA one (through the participation of M. Varela) and the PRICING one, through the participations of B. Tuffin and E. Accinelli, from Montevideo, invited by PAIR in 2002.

During the first year of work of this team, the emphasis was on developing computationally efficient dependability evaluation techniques. Networks with a large number of terminals deserved special study; this work resulted in the proposal of both exact and approximate (Monte Carlo) algorithms, for different network operation rules (see e.g. [106], [107]). This year, some new results in this direction are [34][35][36]. Part of these works have a software development side, done jointly with the effort coded `DependLib` in 5.2.

In 2003, we made a significant effort on network design problems using combinatorial optimization heuristics. The design of a WAN is usually decomposed in two main phases, the design of the core network (usually with a meshed topology) and the design of the access network (usually a tree-like or forest-like topology). The heuristics employed allow integrating performance objectives into the optimization process. In particular, we developed a variant of the Greedy Randomized Adaptive Search Procedure heuristic for the design of a core network with reliability (connectivity) restrictions (see [37][38] and also [39][40] for the associated publications).

For the QQA results, see 6.4.

8.5. Visiting researchers

- In the context of the associated team PAIR, we have twice been visited by the uruguayan head of the team, Héctor Cancela, in June (for a month) and from November to December.
- In the same context of the PAIR project but with uruguayen fundings mainly, we received the visit of Pablo Rodréguez (MSc. student at the University of the Republic, Uruguay), from September to November, to work on network pricing and dependability. We also received Franco Robledo, uruguayan PhD student, from October to December, funded by the University of the Republic, Uruguay.
- In October we received the visit of Thierry Ernst, from the WIDE consortium, Japan, for a week. The goal of the visit was the preparation of our participation to the NAUTILUS project (on the development and deployment of MobileIPv6).
- C. Lécot (Université de Savoie) has visited for one week Armor project-team in July, to work on the quasi-Monte Carlo simulation of Markov chains.
- R. Márquez (Univ. De Los Andes, Venezuela) has been invited one week in September (supported by the TCP ARC) to work on control theory applied to the pricing of TCP/RED buffers.
- As part of the IDsA project, we received he visit of Mick Gieben from NLnetLabs (NL). The goal of the visit was the preparation of an IETF draft on DNSsec.

- Adje Assohaum, vice-dean of Mathematics and Computer Science at the Cocody University (Ivoiry Coast) sojourned during three months in our laboratory to work on new trends in information technologies and multimedia.

9. Dissemination

9.1. Other grants

B. Cousin and L. Toutain participate in the "High-Speed Networks" group of the GDR ARP (Architecture, Networks and Parallelim) of the CNRS.

9.1.1. Editorial activities

- R. Marie is co–editor of the *Performance Evaluation* journal.

9.1.2. Program committees

- Jean-Marie Bonnin served at the PC of MedHoc 2003 (International Mediteranean Workshop on AdHoc Networking), Maadia, Tunisia, June 2003.
- B. Sericola has been in the PC of ASMTA'03 (10th International Conferences on Analytical and Stochastic Modelling Techniques and Applications) conference, June 9-11, Nottingham, UK.
- B. Cousin is a member of the PC of the International Conference on Information & Communication Technology, in Cairo, Egypt.
- R. Marie was a member of the Program Committee of MASCOTS 2003, the 11th IEEE/ACM Symposium on Modeling, Analysis and Simulation of Computer and Telcommunication Systems, Orlando, Florida, October 2003.
- R. Marie and G. Rubino served in the PC of Performance and Tools' 2003, the 13th International Conference on Modelling Techniques and Tools for Performance Evaluation.

9.1.3. Organisation of meetings

- The first french workshop on DNSsec has tken place at Rennes in december, organized by the ARMOR members of the IDsA project.

9.1.4. Visits

- J.-M. Bonnin was invited to give a tutorial on security in 802.11 networks at MedHoc'2003 (Maadia, Tuinisia, June 2003).
- J.-M. Bonnin visited twice for a week the ENSI at Tunis, in the context of a collaboration with the CRISTAL Laboratory, to work on IP mobility and on 802.11 networks.
- B. Cousin was invited by the Lebanese University to develop scientific cooperations in the area of networking and computer science.
- G. Rubino was invited by the ITAM in July to work on traffic analysis, to give seminars about performance evaluation of communication networks and to develop cooperations with the PAIR associated team (see 8.4).
- G. Rubino visited three times (one week in February, April and September) the University of the Republic in Montevideo, Uruguay, to work with the uruguayan members of PAIR (see 8.4).
- B. Tuffin has been invited one week in May at the University of Montréal by P. L'Ecuyer. Their common work is on quasi-Monte Carlo methods and their applications to queuing problems.
- B. Tuffin has visited Ball State University (Muncie, IN) for one week in december, to work on theoretical results for hybrid Monte Carlo/quasi-Monte Carlo methods.

9.1.5. Participation in seminars, invitations

- G. Rubino was invited to talk at the seminar on telecommunications and dependability organized by the ISDF (Dependability Institute) in January 9, ENST, Paris, about network reliability and related topics.
- G. Rubino was invited to talk at the LAFMI (France–Mexico cooperation) meeting at Mexico, in July, about research projects on networking involving academia and industry.

9.2. Teaching

9.2.1. Local teaching activities

The team's members have a variety of responsabilities concerning teaching in the local environment (Ifsic, Cnam Rennes, Rennes IUT, Insa, ENST Bretagne, Rennes Mathematics Institute). At the Bac+5 level, B. Cousin, R. Marie, G. Rubino, B. Sericola, C. Viho, L. Toutain, J-M. Bonnin, and D. Ros give different courses in two DEAs (probability and computer science), in the 3rd year of DIIC, and in the ISA DESS, at the Rennes 1 university, at the ENST Bretagne, and at the ENSAI. The main subjects are networking, protocols, dimensioning problems, dependability analysis, etc. C. Viho is in charge of the ISA (computer science and its applications) DESS at the Rennes 1 university. L. Toutain is in charge of the RSIE (networking and information systems for enterprises) master's degree at ENST Bretagne; he also gives networking courses at the ISIA, at Sophia Antipolis.

9.2.2. International teaching activities

G. Rubino has given a course on telecommunication networks performance evaluation in the Modeling and Engineering of Scientific Software DEA, at the Lebanese University of Beyrouth, in April. This DEA is organized by the Lebanese University of Beyrouth, EPFL, Reims university and IRISA.

G. Rubino has given a course on network analysis at the ITAM school, Mexico.

J-M. Bonnin is in charge of a DEA (computer science and networking) course on mobile data networks at the Tunis ENSI. He also dictates a course on routing in the NTIM DESS at Cocody university (Abidjan, Ivory Coast).

L. Toutain has given a networking course at the ITAM school, Mexico.

9.3. Standardisation activities

Participants: Francis Dupont, Laurent Toutain, César Viho, Bernard Cousin, Jean-Marie Bonnin.

The Armor team dedicates a significant effort toward standardization and certification in the telecommunications area. We participate in several working groups of the main telecommunication standardization institutes like the IETF (Internet Engineering Task Force), ETSI (European Telecommunication Standardization Institute), 3GPP (3rd Generation Partnership Project), etc. We are also very active in the main mailing-lists treating new generation networks and protocols. Several proposals of drafts and contributions to the definition of standards and RFCs (Request For Comments) have been published. Our research concerns mainly the IPv6 related protocols, IPv6 mobility (MIPv6), IPv4–IPv6 transition mechanisms such as DSTM (Dual Stack Transition Mechanism), small group multicasting, and "Universal Mobile Telecommunications System" (UMTS). We have a long term activity on security issues of network layer mobility: security mechanisms of mobile IPv6, interactions between mobile IPv6 and IPsec/IKE, modern network access control (based on AAA) in a mobile environment, security of the DNS (DNSsec) and its usage as a large scope PKI, secure two-space solutions for mobility and multi-homing, etc. The Armor team has also a major role in the world-wide certification process for IPv6 products launched by the IPv6 Forum, the "IPv6 Ready Logo Programme" (see http://www.ipv6ready.org). This project aims to provide the means needed to test existing IPv6 products to be deployed in the market. The Armor team leads the technical part of this Programme by defining the certification process itself, specifying required tests, and developing some of the interoperability tests needed.

This work is done together with the IPv6 Forum, the ETSI in Europe, the WIDE-project in Japan and the TTA (Telecommunications Technology Association) in Korea.

This year we published the drafts [98][90][89][95][94][93][88][96][92][91][97].

We also have contributed to the improvement of other several RFCs and drafts. As such, we appear in acknowledgement of:

- RFC 2402 “IP Authentication Header”
- RFC 3519 “Mobile IP Traversal of Network Address Translation (NAT)”
- draft-ietf-dhc-dhcpv6
- draft-ietf-mobileip-hmipv6
- draft-ietf-mobileip-ipv6
- draft-ietf-pana-threats-eval
- draft-ietf-pana-usage-scenarios
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