INRIA

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team armor

Architectures et Modèles de Réseaux

Rennes

THEME COM

Table of contents

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, PAIR, with the University of the Republic at Montevideo, Uruguay.

Head of project-team

Gerardo Rubino [DR Inria]

Administrative assistant

Fabienne Cuyollaa [TR Inria]

Inria staff members

Bruno Sericola [DR, SINCE THE 01/10/04]
Bruno Tuffin [CR]

University of Rennes 1 staff members

Françoise André [Full professor (until 1/9/2004; with PARIS project since then)]
Ali Boudani [ATER (from 1/9/]
Bernard Cousin [Full professor]
Louis-Marie Le Ny [Associate professor]
Raymond Marie [Full professor]
César Viho [Associate professor]

Staff members of ENST Bretagne

Jean-Marie Bonnin [Associate professor]
Francis Dupont [Associate professor]
David Ros [Associate professor]
Laurent Toutain [Associate professor]

Staff member of Insa of Rennes

Miklós Molnár [Associate professor]

Project technical staff

Laurent Guillo [shared with the TEMICS project]

PhD students

Djalel Chefrour [INRIA grant]
Joël Corral [ENST grant]
Alexandra Desmoulin [MJENR grant (from 1/10/2004)]
Thierry Feuzeu [INRIA grant]
Sophie Fortin [PRAG at IUT de Valence]
Gilles Guette [INRIA grant]
Alexandre Guitton [MJENR grant]
Yézékaël Hayel [INRIA grant]
Hélène Le Guen [Cifre grant, Alitec]
Patrick Maillé [GET grant, on secondment from MINEFI]
Elizabeth Martinez [Mexican government grant]
Joanna Moulierac [MJENR grant]
Francine Ngani [Brittany region grant]
Ricardo Orozco [Mexican government grant]
Julio Orozco [Mexican government grant]
Franco Robledo [grant from the university of Montevideo, Uruguay (joint PhD between this university and Rennes 1)]
Kamal Singh [INRIA grant (from 1/10/2004)]
Martin Varela [MJENR grant]

Lucian Suciu [GET grant]

Temporary engineers

Olivier Courtay [GET, université de Rennes 1, until 31/5/04]
Annie Floch [INRIA, from 19/4/04]
David Fort [univ. Rennes 1]
Cécile Marc [junior engineer, from october 6 (shared with TEMICS)]
Samir Mohamed [INRIA, until 30/6/04)]
Frédéric Roudaut [univ. Rennes 1]
Christophe Turle [INRIA, until 30/9/04]

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 queuing 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

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

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 sub-area 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 the impact of congestion.

3.3. Stochastic modeling

The scientific foundations of our modeling activities are composed of stochastic processes theory and, in particular, Markov processes, queuing 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, queuing 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. Interoperability 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, 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 interoperability test suites generation is based on specifications (standards and/or RFCs) of network components and protocols to be tested. The model used 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

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

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 quantifying the robustness of a grid without taking into account the reliability of each component).

5. Software

5.1. Experimental platforms

Participants: Laurent Toutain, Joel Corral.

We have implemented the Saturne platform, issued for GET funded projects. This platform performs precise one-way delay (OWD) and packet loss rate measurement between two points in IPv4/IPv6 networks. Measurements are performed with a global time reference basis, implemented within GPS synchronization systems installed at each measurement point. The architecture is composed of independent functional modules (Emission, Capture and Data Management) that interact to perform the measurement process. The Saturne architecture has been used in a variety of scenarios including, but not limited to, the evaluation of IP filtering functionalities in a non-specialized router and the validation of diffserv policies in a high-speed network (VTHD Network). In the latter case, it was verified that the results computed by light-weight Saturne are equivalent to those obtained with complex passive tools. We also took advantage of IPv6 capabilities by introducing an extension header for metrology. The proposed method allows to embed metrology information in real IPv6 flow packets.

On VTHD Network we have also deployed the AGAVE platform. We defined a monitor link (extension of OSPF's virtual link) to obtain, in real time VTHD network topology. This topology is used to set up MPLS LSP (label-switched paths).

Saturne and AGAVE are now part of the Network of Excellence EuroNGI (see Section 8.2).

5.2. VISIUM platform

Participants: Laurent Guillo, Cécile Marc, Julio Orozco, Laurent Toutain.

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. This platform will be used with partner in the Cosinus RNRT project.

This protocol has been also deployed in the IRISA VISIUM platform. The TEMICS project-team uses the platform for their work on streaming video and contributes to its development. Their fine grain scalable video coder, WAVIX, can take advantage of its mechanisms allowing to correct bit errors. However, the UDP layer cannot forward data with error bits. Therefore, we are implementing UDP-lite in our platform to allow applications, such as video coders, to receive data even if bit errors still exist. That requires a new ROHC profile dedicated to UDP-lite, which is currently under study. This platform targets also studies on flow control mechanisms for multimedia flow streaming.

5.3. 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 behaviors of the modeled 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 behavior 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 standard metrics of models in equilibrium, loss probabilities, blocking probabilities, mean backlogs,...). A set of functions designed for dependability analysis is being built under the name `DependLib`.

5.4. 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 on Monte Carlo methods. We plan to increase our participation in the development of this 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 behavior of TCP. A JAVA graphical interface is being developed for the modeling and analytical analysis of networks of fluid queues. The tool will be available next year.

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 paths 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 current version of Xcast protocol and to compare it to our proposed extension GXcast. (cf. http://www.irisa.fr/prive/aboudani/research/xcast/index.htm). Xxact and GXcsat are explicit routing protocols.

We also propose a new multicast approach, called Simple Explicit Multicast (SEM). This approach uses efficiently branching nodes to build multicast trees and thus deliver multicast packets (see 6.6)

In a similar way, we have enhanced the network simulator NS2 to be able to evaluate the performance of our MMT proposition and to simulate PIM-SM in MPLS networks. MMT promotes multicasting over MPLS.

5.5. IPv6 Integration

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) and zaurus. We have also been working on securing the address allocation protocol in VPN scenarios. More details are available on http://www.dstm.info web page.

With INRIA/ARES team we have also focused on auto-configuration mechanisms. This allow the automatic deployment of complex topology networks, more precisely on Home Networking Environment. The NAP (No Administration Protocol) has been developed. DHCPv6 Prefix Delegation has also been investigated. NAP tools are available on http://nap.dstm.info.

5.6. DNSSEC platform

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

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 international 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 http://www.idsa.prd.fr

We have developed several DNSSEC pieces of software (or patches). All the software of the IDsA project is released under a BSD-like license:

- `verifperl`: 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 dig”.
- `BIND`: A patch to solve a little problem when signing NXT RRs.
- `DNSSECToolKit`: a library which allows to build DNSSEC tools and libraries.
- `Ethereal`: we have done patches for Ethereal to make it more DNSSEC aware (decoding of DS records, computing of key id, etc.). These patches are part of Ethereal since version 10.0a. A second patch, since Ethereal version 0.10.1, has provided the capability to decode RFC2535bis packets (DNSKEY, RRSIG and NSEC), NSD 2.0 and BIND 9.3 exchange such packets.

- `KROd`: a Key Roll-Over daemon tool which enables automatic roll-over of keys for DNSSEC, and automatic conversion from DNS to DNSSEC. This tool uses the DNSSECToolkit to perform all DNSSEC related operations and works with BIND 9.3. It has the following features: it handles ZSK rollover, it handles KSK rollover and it communicates securely with the parent server to ask for the keyset update, most key/signing parameters can be specified to KROd, a control channel ala zebra, and it can be used to migrate a normal DNS zone to a DNSSEC zone quite easily (KROd does nearly all the key/signing jobs for you), it can save and reload its configuration, this is useful when a crash occurs (note: at the moment KROd is not completely stateful).
- `GDS`: the BIND patch that changes the behavior of BIND when processing DS records. This includes a modification of the BIND server and a modification of the dnssec-signzone tool. Generalized DS allows to have build a DNSSEC chain of trust over a succession of secure and unsecure domains (a domain that has unsecure parents).
- `libsresolv`: it is a library built within the BIND toolkit. It comes as a patch over the BIND 9.3 sources. It contains a DNSSEC resolver and validator. The goal is to show everything that can be proved from a DNSSEC answer. The validator provides positive or negative answers (it can prove that a domain doesn't exist), it can also prove that some domains are empty non-terminal ones. `libsresolv` performs bottom-up validation, it is signature oriented.

All this software is available at http://www.idsa.prd.fr.

5.7. Network Graph and Path Computation experimental prototype

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

We are implementing a functional demonstrator 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 networks of switching nodes. A Serving Network Controller provides self-configuration and intelligent management of the switching nodes. Our demonstrator provides algorithms for the auto-configuration, data path routing and fast rerouting in case of link or node failure.

5.8. Internet Protocols Interoperability Testing Platform

Participants: César Viho, Frédéric Roudaut, Annie Floch, Francine Ngani.

We have built a platform with almost all existing IPv6 existing free stacks. We have developed a set of conformance executable test suites for IPv6 related protocols (MIPv6, 6to4, NAT-PT, RIPng, etc.) using the v6eval tool of the Japanese TAHI project. All these test suites are freely available at http://www.irisa.fr/tipi. This platform allows both conformance and interoperability testing. The test can be done remotely. We have started also to develop conformance test suites using the DANET TTCN3 based test development toolkit. This work is done in tight cooperation with the DANET company in Germany. Templates for IPv6 packets have been defined. An extended version of Ethereal has been developed allowing IPv6 stacks testing using an Ethernet layer service. We have already some TTCN3 based executable test suites for the RIPng protocol.

6. New Results

6.1. Pricing

Participants: Yézékaël Hayel, Patrick Maillé, Ricardo Orozco, 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. Our work can be decomposed into two main categories: auctioning for bandwidth, and in a general way, pricing and scheduling.

The first main category is thus auctioning for bandwidth. Our work in this field has been inspired by the progressive second price (PSP) auctions developed at Columbia University [110]. In theses auctions, there remained one degree of freedom, the reserve price representing the unit price under which the network does not accept to sell its bandwidth. In [37], we have given hints to show how this reserve price can be fixed to optimize the revenue. Nevertheless, it presents some drawbacks, such as a time and efficiency consuming convergence phase and a signaling overhead due to broadcasting the bid profile after each change of bid. These drawbacks have been tackled in [56][93][94], where the costly iterative scheme has been replaced by a one-shot multiple-bid scheme keeping the optimality and incentive compatibility properties. This scheme has been adapted to downlink CDMA power allocation in [55], and its superiority with respect to PSP illustrated in [57]. In [82], the pricing scheme, initially developed for a single link (representing the single bottleneck link of a network), has been extended to the case of a whole network, under the assumption that the backbone is not congested, and congestion can only occur at access networks, represented by trees.

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) [26]. We have also shown that, in order to increase its revenue, an ISP should use at its routers a priority scheduling mechanism rather than generalized processor sharing [44][92]. This result is also shown for in the case of TCP traffic modeled at the flow level by discriminatory processor sharing [81]. In [80], the use of passive and active measurement tools have been introduced in a pricing model. In [29], 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.

As other works on pricing, in [17], 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. In [72][85], we have developed a reliability-dependent pricing scheme assuming that the network is not congested thanks to optic fiber; end-to-end reliability is then the property of interest. In [79][46][45] a related problem, yield management, has been studied in collaboration with IBM, Yorktown Heights.

6.2. Dependability and extensions

Participants: Gerardo Rubino, Bruno Sericola, Bruno Tuffin.

We maintain a research activity in different areas related to dependability, performability, and vulnerability analysis of communication systems. In 2004 our effort has been on evaluation techniques using both the Monte Carlo and the Quasi-Monte Carlo approaches.

Monte Carlo methods represent the single tool to solve very large Markov chains. When dealing with rare events, as in the case of dependability evaluation, acceleration techniques, such as importance sampling, have to be used. In a previous work [112], we have defined the so-called Bounded Normal Approximation (BNA) property, stating that the normal approximation, and thus the confidence interval coverage is kept bounded as the rarity increases.

In [73], we have emphasized the importance of this property, by showing that if BNA is verified, then the variance of the estimator is asymptotically well-estimated. This in turn implies that the relative error is bounded, which means that the measure of interest is well-estimated. No converse implication is true in general.

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

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

(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. But this bound is proved to be useless in practice. By combining MC and QMC methods, we can benefit from the advantages of both methods: error estimation from MC and convergence speed from QMC. In [27], 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. In [76], it is also shown how by using QMC for a small amount of coordinates, and MC for the remaining ones, the accuracy of the simulation can be improved.

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 past work, 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 re-labeling of the chains at each time step of the simulation. In [19], we have illustrated the superiority of our method with other known efficient methods for Markov chains. In [49], the method is adapted to randomized QMC methods and to the case of Markov chains with random horizon (so that regenerative can also be considered). The superiority of the method with respect to those in the literature is again illustrated.

There are many methods able to evaluate asymptotic dependability measures using Monte Carlo when the system is highly reliable; less techniques have been proposed in order to estimate transient measures. In [33] a new method to evaluate the reliability function at time t for such a system is proposed. The system is modeled by a Markov process. The method is particularly efficient for small values of t (the interesting domain). This has been done in the context of the PAIR collaboration (see Section 8.4).

6.3. TCP

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

In a collaborative work with the Mistral project-team, through the TCP and PRIXNET INRIA ARCs (see Section 8.1), 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 [30][77].

We propose in [16] 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, taking into account the slow start phases whose importance is discussed.

6.4. PSQA: Pseudo-Subjective Quality Assessment

Participants: Samir Mohamed, Gerardo Rubino, Martín Varela.

This research work is part of the activities of the associated team PAIR (see 8.4).

PSQA is a methodology which allows to quantify the quality of a video or audio (or multimedia) stream at the receiving end, after said stream has passed through a packet network such as the Internet. This quantification is done automatically, and in real time if necessary. The specificity of the approach is that the evaluation obtained 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 react (from the perceived quality point of view) when receiving these flows. The tool learns and then behaves similarly to real observers. The statistical tool used to this end is the Random Neural Network model, which is an open queuing network with

positive and negative customers. In [21], we extended the approach we developed in [109] to the case of audio communications, again with excellent results.

During 2004 we started using this approach coupled with more traditional performance evaluation techniques, in order to predict the perceived QoS of a future network for certain applications, based on the predicted capacity and load of said network [69]. We also used this coupled approach to study the performance of a well known and widely used forward error correction (FEC) technique for different network conditions [70].

To the best of our knowledge, this is the only solution to the problem of assessing the quality of a multimedia stream after traveling through a packet network with the given properties: automatic, real-time if necessary or useful, and accurate (close to the evaluation performed by real human observers). In addition to being able to provide real–time assessments, this approach does very well compared to other metrics proposed in the literature [61] providing better correlation with subjective assessments.

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. In particular, we are cooperating with other members of the project in order to study the performance of different diffserv mappings on H.264 video streams. We also plan to extend our research into hi–fi audio, by continuing the work done in cooperation with France Telecom R&D [36]

6.5. Network Design

Participants: Franco Robledo, Gerardo Rubino.

This research work is part of the activities of the associated team PAIR, and is being jointly done with M. Héctor Cancela (PAIR Uruguayan project leader), from the University of the Republic of Uruguay, in Montevideo.

This team has been put in place in 2000, and its main objective is the development of techniques and tools for Wide Area Network (WAN) topology design. This problem is usually decomposed into two main phases, the design of the backbone network (usually with a meshed topology) and the design of the access network (usually with a tree-like or forest-like topology); the objectives usually taken into account is the minimization of the cost of the network topology, but we also consider other performance, dependability, or more in general user perceived quality metrics in this design process.

In the first two years, there was an important effort in the direction of studying and developing effective metaheuristics for this kind of network design problems. In particular, after exploring other alternatives (see [103][104][99] for example), we selected GRASP, the Greedy Randomized Adaptive Search Procedure heuristic, as our main optimization technique. This method gives very good results (although it does not guarantee optimality), and works as a template, within which other heuristic ideas can be incorporated. During 2003 we employed this method for the design of a backbone with reliability (connectivity) restrictions, our first results in this area were published in [101][102]. Complementary, we also developed both exact and approximate (Monte Carlo) dependability evaluation techniques, with especial emphasis on attaining good computational efficiency for networks with a large number of terminals (see e.g. [105], [106], [100]).

In 2004 we continued exploring the potential of the GRASP technique, obtaining results on a more complete test suite for the backbone problem [13], and tackling the access network design problem. For this last problem we used different heuristics as building Blocks for the GRASP method, among them the Random Neural Networks that are also being employed with good success in our technology PSQA (see paragraph 6.4). The method was tested on a large test suite with very good results, which were the object of two publications [15][14].

During 2005, we plan to use performance and dependability metrics as additional objectives within the optimization methodology being developed. In the middle term, we also plan to use the results from the PSQA work, so that the WAN design can incorporate QoS aspects from an user-centric point of view; and further, we also want to integrate pricing aspects as part of the design problem.

6.6. Low speed links

Participants: Laurent Guillo, Louis-Marie Le Ny, Cécile Marc, Elizabeth Martinez, 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) [98] 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 [108] or to study parameters impact on performances. Collaborative works with the TEMICS project-team lead us to study a new ROCH profile dedicated to UDP-lite. Always in collaboration with the INRIA project TEMICS, we will study the impact of the residual transmission error on multimedia flows, in order to evaluate the QoS perceived by the user.
  As a first result of these efforts in 2004, we present in [78] the analysis of the proposed standard ROHC deployed in an UMTS radio link and discuss different schemes to increase compression performance. The results are based on our IPv6 implementation of the ROHC header compression algorithm and on a simple and accurate analytical model used to evaluate the packet loss probability.
- **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. We have proposed a new active queue management algorithm, which we call *Adaptive RIO* (A-RIO), aimed at both easing the configuration of diffserv routers and building services with loose delay guarantees (thesis of Julio Orozco). We are currently exploring some open issues regarding A-RIO (performance aspects, implementation problems).
- **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. We are working on the sequel of Octavio Medina's PhD thesis [107], focusing in new video coding schemes like H.264, which are designed with network error resilience in mind and allow for more flexible tagging strategies.

6.7. Wireless networking

Participants: Jean-Marie Bonnin, Bernard Cousin, Hanen Idoudi, Miklos Molnar.

We study communication problems, QoS management, adaptation of flows and energy used in wireless (mainly ad hoc) networks in cooperation with the laboratory CRISTAL of ENSI, Tunisia. We proposed a model for the energy conservation, based on synchronized alternations of "on" and "off" states of network activities of the ad hoc network components. A new model of routing objectives taking into account the instabilities of ad hoc networks is also proposed.

The norm IEEE 802.11i aims the authentication and the key distribution in wireless networks. We proposed two new secure mechanisms for fast re-authentication in handover operations [48]. Several results of our investigations were presented at a workshop organized at IRISA in September (cf. Section 9).

6.8. Multicast Routing

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

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:

6.8.1. Optical Routing, Tree Construction

Construction of minimum spanning trees being NP-complete, we have proposed several heuristic polynomial time approximations taking into account some specific constraints: QoS constraint, and/or constraints in all optical networks, where some optical WDM switches can not split [62].

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, a new way of doing multicast on wavelength-routed optical networks was proposed in [43].

6.8.2. Small Group Multicast

We have enhanced ERT (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. We have proposed an extension to the Xcast protocol [32]. 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 [12]. This solution has been proposed in an IETF draft .

6.8.3. Label Switching

We propose a bridging method based on label switching. This method produces no overhead: labels are located into the Destination Address header field, but gives high flexibility. This flexibility can be used to efficiency manage QoS or multicast traffic. A prototype is developed to measure the performance of our proposition [87], [88], [38].

6.9. Security

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

Nowadays, reaching services on the Internet highly depends on the use of the DNS (Domain Name System) infrastructure, and DNS security has become strictly necessary. Moreover, such a secure infrastructure (DNSSEC) could be used to secure other applications. The goals of our project are the study and deployment of secure DNS transactions, the development of mechanisms allowing the use of the DNSSEC infrastructure to distribute keys and certificates for secure signalization of Mobile IPv6 and use of IPsec (HIP and/or opportunistic IPsec).

Last year we have analyzed the DNS threats, studied the completeness of DNSSEC and IPsec and specified the requirements for key rollover for DNSSEC [90]. A France-wide DNSSEC platform has been deployed, it is connected to the international DNSSEC, which shadows the standard DNS.

We are particularly interested by the automation of Key Roll Over process and the key management process. The DNSSEC validation process is based on the establishment of a chain of trust between zones. This chain needs a starting point called a trusted key. During the deployment phase, secure zones and unsecure zones could coexist simultaneously. Every resolver has to get a copy of the trusted key for every island of security. Currently we study the trusted keys' rollover problem and two algorithms to solve it. The first one is resistant to key-compromising and places the choice of security level in the resolver's administrator side, which is a natural way to protect a resolver [41]. The second one enables an automatic and smooth exchange of secure keys when an unsecured zone becomes secure and reduces considerably the number of trusted keys needed in a resolver [42].

The illustration and validation of our concepts, with DNSSEC patches and tools, can be found at http://www.idsa.prd.fr.

6.10. Queuing analysis

Participants: Gerardo Rubino, Bruno Sericola.

We have developed an algorithm to compute the sojourn time distribution in the processor sharing, single server queue with Poisson arrivals and phase type distributed service times. In a first step, we established the differential system governing the conditional sojourn times probability distributions in this queue, given the number of customers in the different phases of the PH distribution at the arrival instant of a customer. This differential system is then solved by using a uniformization procedure and an exponential of a matrix. The proposed algorithm precisely consists of computing this exponential with a controlled accuracy. This algorithm is then used in practical cases to investigate the impact of the variability of service times on sojourn times and the validity of the so-called reduced service rate (RSR) approximation, when service times in the different phases are highly dissymmetrical. For two-stage PH distributions, we give conjectures on the limiting behavior in terms of an $M/M/1$ PS queue and provide numerical examples to illustrate the different approximations.

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. See [18] for recent results on this approach.

We proposed a new paradigm for modeling a node in a packet communication network. It deals with the way memory is handled in such a system. The basic idea is that the usual way of modeling a store-and-forward node implicitely assumes an irrealistic memory handling algorithm. Taking this fact into account, the model becomes more complex but in some cases tractable. In [47] we explain the idea and we derive analytical expressions for the mean occupation space in such a system, when the context is of the "$M/G/1$" type. This works leads to new Pollaczec-Khintchine-like formulæ. For instance, if packets arrive according to a Poisson process with rate λ packets per sec, if packets have variable length having mean B bits and coefficient of variation C, and if the channel speed is s in bits per sec, then the classic Pollaczec-Khintchine expression for the mean occupation in bits in the node is

$$B\left(\varrho+\varrho^2\frac{1+C^2}{2(1-\varrho)}\right)$$

where the load is $\varrho=\lambda B/s<1$. Following our analysis, a more realistic expression for this mean occupation is

$$B\frac{\varrho(2-\varrho)(1+C^2)}{2(1-\varrho)}.$$

6.11. Analytical fluid models

Participant: 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 [111] fed by a Markovian queue or by an M/M/1 queue [97], we have obtained in [24] an algorithm to compute the transient distribution of a fluid queue driven by a birth and death process whose birth and death rates are suggested by a chain sequence, for which the stationary probabilities do not exist.

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 [11].

We analyzed in [25] an infinite-capacity second order fluid queue governed by a continuous-time Markov chain with linear service rate and we obtained an expression for the stationary queue level. For the first-order case we derived a simple expression of all its moments and of the Laplace transform of its distribution.

For the second-order case, we obtained its first two moments.

6.12. Interoperability Testing

Participants: Alexandra Desmoulin, Francine Ngani, César Viho.

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) that helps in generating efficient interoperability test suites. The model used here is an automata-like structure called IOLTS (Input Output Labelled 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 [63][65].

We have proposed a formal definition of the notion of interoperability, which has been considered by the testing community as one of the first real contributions in this area [96]. We also study how a distributed approach (including remote approach) can help in efficiently testing components [28]. 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, 6to4), 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. The Phase I already started with real success. The second phase is under review and will start next year, with stronger requirements.

6.13. 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 solutions 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 [75].

We are also involved in the definition of a new architecture that allows the applications to be able to adapt efficiently and timely their behaviors 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 [53], [52], [54].

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, Francis Dupont, Lucian Suciu.

Cyberté is a RNRT project, starting in January 2002, and ending in December 2004. The project leader is France Télécom R&D. ARMOR's budget is 174 k. 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 networks (such as Bluetooth, WiFi, or HiperLAN), both in home and enterprise environments.

Our main contributions to this project are: the design of a new architecture able to provide information to adaptive applications and to automatically select the best suited interface according to application needs, and 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 partnership) and ARMOR's budget is 166 k. The project spans 24 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 (2002–2005), in which ARMOR's budget is of 90 k. 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 coverage measure to the tests done during a test campaign. It also aims to find techniques to improve the effectiveness of these tests.

7.4. IDsA: Infrastructure DNSSEC et Applications

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

IDsA is being done in partnership with France Telecom and AFNIC. It spans 22 months, from September 2002 to December 2004. ARMOR's budget in this project is 218 k. 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 allow for an easier and more secure service access for nomad and mobile users (e.g. mobile IPv6 signaling, secure VPNs, etc).

7.5. 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 environment 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 18 months, from September 2002 to February 2004. ARMOR's budget was of 32 k. Our industrial partners were 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. For a global description see [74].

Web site: http://www.extra.research.philips.com/euprojects/fabric/.

7.6. NGDG: New Generation Distributed Gateway

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

NGDG is being done in association with ALCATEL Stuttgart. It spans 30 months, from June 2002 to December 04, and ARMOR's budget is of 326 k.

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).

7.7. IPv6 Interoperability Methodology

Participants: César Viho, Frédéric Roudaut, Annie Floch, Francine Ngani.

This cooperation consists of three years of research work supported by the CELAR (French army), spanning from December 2002 to November 2005. The budget is 190 k.

The project's main goal is to develop a well suited methodology and framework for IPv6 related protocols interoperability testing.

7.8. ETSI - Study on scope of IPv6 Interoperability testing

Participants: César Viho, Frédéric Roudaut.

This contract is a 3-months work supported by the ETSI, spanning from March to May 2004. The budget is of 20 k.

The project's main goal was to identify the main IPv6 related protocols that need further interoperability testing. The main requirements are listed and corresponding RFCs were also studied leading to main test groups identifications.

7.9. ETSI – IPv6 Interoperability testing

Participants: César Viho, Annie Floch, Frédéric Roudaut.

It is 2 months work supported by the ETSI Plugtest service, spanning from September to October 2004. The budget is of 15 k.

The project's main goal was to help the ETSI Plugtest service in the organization of the IPv6 interoperability event of October in Cannes. Three main tasks: identifying the main IPv6 related protocols that participants

will like to test. Providing interoperability testing expertise during tests campaigns, and giving feedbacks to the IETF.

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.

Pariod: February 2002 – February 2004.

Web site: http://www-sop.inria.fr/mistral/personnel/K.Avrachenkov/WebPage/ARC_TCP.html.

8.1.2. INRIA ARC << PRIXNET: Network Pricing >>

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

Period: January 2003 – 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. For more information, see http://www.irisa.fr/armor/Armor-Ext/RA/prixnet/ARC.htm.

Web site: http://www.irisa.fr/armor/Armor-Ext/RA/prixnet/ARC.htm.

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), IMAG (Grenoble) and PRISM (Versailles). Our group participates on the development of tools using Markov models.

Web site: http://www.lirmm.fr/~ajm/AS182/

8.1.5. G6 / IPv6 Task Force

Participants: Jean-Marie Bonnin, 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 access 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. Our group contributes to the multicast and the DNSSEC deployment activities promoted by the G6 group.

Web site: http://www.fr.ipv6tf.org/

8.1.6. GDR ARP

Participants: Bernard Cousin, Alexandre Guitton, Miklos Molnar, Joanna Moulierac, Laurent Toutain.

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

B. Cousin, A. Guitton, M. Molnar and J. Moulierac participate to the activities of TAROT, one of the poles of ARP.

Web site: http://www.arp.cnrs.fr/

8.2. European initiatives

- The project has participated to the experimentation about service differentiations performed by Renater on the network TF-NGN.
  Web site: http://www.terena.nl/tech/task-forces/tf-ngn/
- The project is an active partner of ETSI for interconnection testing in the IPv6 context. See 6.12 and 9.3 for details.
- The project is an active member of EuroNGI Network of Excellence. It has contributed to the deliverables of working packages (Joint Research Activities)

  – WP.JRA.2.2: Traffic management in a multi-provider context;
  – WP.JRA.5.4: Network optimization and control;
  – WP.JRA.5.5: Numerical, simulation and analytic methodologies;
  – WP.JRA.6.1: Quality of service from the users’ perspective and feedback mechanisms for quality control;
  – WP.JRA.6.2: Payment and cost models for NGI.

Web site: http://eurongi.enst.fr/en_accueil.html

8.3. International initiatives

- We work with Duke university (USA) on modeling aided by Petri nets.
- We work with the University of Montreal as well as Ball State University (Indiana) on the development of randomized quasi-Monte Carlo methods, with applications in telecommunications.
- We also started a collaboration with the Athens University of Economics and Business on auctions for bandwidth in telecommunication networks.
- We have a Program ECOS SUD cooperation with Uruguay, around capacity planning and pricing problems.
- We develop a partnership with the ITAM (Mexico DF) on multimedia streams quality measurement, and on 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.
- ARMOR is a partner of the STIC Asia program on IPv6. This program founded by INRIA, CNRS and MAE enhances collaboration between Asian countries (mainly South Korea, Japan and China) and French laboratories to promote research on IPv6 and related protocols. ARMOR is involved in network measurements and mobility.
- In the STIC INRIA - Universities of Tunisia program, we have a common project with ENSI, Tunisia on "Optimization of dynamic wireless networks".
- R. Marie is a member of the IFIP working groups 6.3 (Performance of Communication Systems) and 7.3 (Computer System Modelling and Performance Evaluation). G. Rubino is a member of the IFIP working group 7.3.

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, María Urquhart (Montevideo), Martín 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, with several other end-to-end aspects including performance, dependability, performability, perceived quality.

In 2004 we developed two sets of activities. They are reported in 6.4 and in 6.5.

In 2004, we have also developed a pricing scheme based on the reliability of end-to-end connections (based on the assumption that, with optic fiber, networks become not congested, so that reliability is the issue to be considered) [85][72]. See also 6.2 for results in dependability analysis of networks.

8.5. Associated team “Moca6” (or IPv6 Networks Mobility and Automatic Configuration)

Participants: Thierry Ernst (Keio University, responsible for the Nautilus Team in Japan), Jean-Marie Bonnin (responsible for France), Bernard Cousin, Francis Dupont, Thomas Noel (INRIA/ARES team), Laurent Toutain, Cesar Viho.

The MoCA6 associated team was just created in 2004 in order to help us to launch several activities around IPv6 with the WIDE/Nautilus6 project and other Japanese partners. Several members of ARMOR belong to the international Nautilus Project, so we already used to work together in this context. We have several ways to fund our collaboration with Japan and Korea so we have decided to stop the associated team after this first year. Nevertheless, the collaboration launched thanks to this team will continue to grow, especially with the Korean team (SNU/MMLab) also involved in Nautilus.

The aim of the Nautilus6 project is to prove that the Mobile IPv6 related technologies are viable. Thus, it will setup several large scale testbed to experiment Mobile IPv6 and Mobile Networks in different context: health care, school of Internet, ITS (Intelligent Transportation System, Home networking,...). This collaboration aims to apply several of our activities (multicast for small groups, interface selection, automatic network configuration, protocol validation) to the specificities of the mobile network context.

For example the works the ARMOR team have made around small group multicast will be tested in the NEMO context in collaboration with Fujitsu and Panasonic. We are also working on auto-configuration in NEMO networks and on a new protocol designed to allow router and mobile attached to a NEMO network to exchange information about interfaces and access networks available at the mobile router.

8.6. Visiting researchers

- Adje Assohoum, vice-dean of Mathematics and Computer Science at the Cocody University (Ivory Coast) sojourned during three months in our laboratory to work on new trends in information technologies and multimedia.
- Yuji Imai from Fujitsu visited our research team. A French-Asian cooperation on explicit multicasting is being developed.

- In the context of the PRIXNET ARC (cf. Section 8.1.2), we have hosted Victor Ramos for three months to work on pricing in DS-CDMA (from September to November) and Moshe Haviv (from Jerusalem) one week in November to work about pricing and decision theory.
- Patrick Maillé and Bruno Tuffin visited Athens University of Economics and Business for one week in November to work on auctions for bandwidth sharing.
- Pierre L'Ecuyer (University of Montreal) has been invited for two weeks in March-April to work on Quasi-Monte Carlo methods.
- In the context of the Moca6 project (but with STAR funding) we received the visit of Minji Nam for a two months stay. She worked with Lucian Suciu on the selection interface problem.
- Two master students of the ENSI Tunisian engineering school visited our team (for one month and for two months respectively) in the context of the STIC project. They worked on a new method of re-authentication able to speedup the re-association process in wireless LANs. They have set up a complete platform implementing the solution which was used to evaluate the performances of different methods.
- Professor Abdelfettah Belghith, head of the pole RIM at the laboratory CRISTAL of ENSI, Tunisia visited our laboratory in December 2004.
- In October, we received the visit of Hiroshi Miyata of the TAHI project, Japan (and three engineers), for one week. The goal of the visit was the preparation of our participation to the ETSI IPv6 Interoperability Plugtest event of 11-14 October in Cannes.

9. Dissemination

9.1. Animation of research activities

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 ING 2004 (Internet New Generation), Obernai, France, June 2004.
- B. Sericola has been in the PC of ASMTA'04 (11th International Conference on Analytical and Stochastic Modelling Techniques and Applications), June 13-16, Magdeburg, Germany.
- B. Sericola has been in the PC of ICETE'04 (First International Conference on E-business and TElecommunication Networks), August 24-28, Setubal, Portugal.
- B. Sericola has also been part of the PC of DSN'04 (2004 International Conference on Dependable Systems and Networks), June 28 - July 1, Florence, Italy.
- B. Cousin is a member of the Program Committee of the International Conference on Information & Communication Technology, in Cairo, Egypt.
- Bernard Cousin is a member of the Program Committee of "Securité, architecture et réseaux". This is a French workshop held every year on Network Security.

- R. Marie and G. Rubino served in the Program Committee of QEST'04 (Int. Conf. on Quantitative Evaluation of Systems, Enshede, Netherlands, Sept. 2004). QEST is the merge of three previous series: TOOLS (Int. Conf. on Modeling Techniques and Tools for Computer Performance Evaluation), PNPM (Int. Workshop on Petri Nets and Performance Models) and PAPM-ProbMIV (Joint International Workshop on Process Algebras and Performance Modeling and Probabilistic Methods In Verification). R. Marie and G. Rubino belong to the PC of QEST'05 (Riverside, California, Sept. 2005).
- G. Rubino serves in the Program Committee of DSN'05 (Int. Conf. on Dependable Systems and Networks, Yokohama, June 2005).
- G. Rubino serves in the Program Committee of EDCC-5 (European Dependable Computing Conf., Budapest, Apr. 2005).
- Bruno Tuffin has been in the Program Committee of the Fourth International Workshop on Advanced Internet Charging and QoS Technologies (ICQT'04), September 29–October 1, 2004, Barcelona, Calalunya, Spain.

9.1.3. Organisation of meetings

- The first French workshop on DNSSEC has taken place at Rennes in December 2003, organized by the ARMOR members of the IDsA project, with a strong support of the AFNIC.

9.1.4. Seminars

- A workshop was organized at IRISA in September on wireless networks with the following program.
  - Hanen Idoudi (IRISA ARMOR/ENSI): Energy conservation in ad hoc networks
  - Alain Abi Nakhoul (ENST): Power control and routing in ad hoc networks
  - Bruno Tuffin (IRISA ARMOR): Pricing and ad hoc networks
  - Imen Jemili (LABRI/ENSI): Distributed clustering in ad hoc networks
  - Miklos Molnar (IRISA ARMOR): Model for unicast and multicast routing under bandwidth constraints in ad hoc networks
  - Mohammed Kassab (ENSI), Jean-Marie Bonnin (IRISA ARMOR): Secure and fast handover in IEEE 802.11 networks.
- In the working group TAROT in October M. Molnar presented a tutorial on "QoS based multicast routing with incomplete link state information".

9.1.5. Visits

- Ali Boudani has visited research laboratories and has met with researchers from Fujitsu, Panasonic, K2, Wide consortium and KEIO university at Tokyo. Settling an XCAST6 router in Irisa to provide Xcast service by constructing a tunnel between IRISA and WIDE-X6Bone is the first one of our objectives.
- J–M. Bonnin was invited to give a lecture on IPv6 related research subjects at the SEU (South East University) of Nanjing in China.
- J–M. Bonnin and M. Molnar visited the CRISTAL Laboratory of ENSI, Tunisia.
- G. Rubino was invited to give a lecture about the PSQA technology (see 6.4) at the CRISTAL Laboratory of ENSI, Tunisia.

9.1.6. Participation in seminars, invitations

- G. Rubino was invited to make a keynote presentation at the annual Brazilian conference in computer science [67]. The talk was about the PSQA technology developed in the project (see 6.4).
- G. Rubino was invited to make an invited presentation at the annual Tunisian conference in mathematics [68]. The talk was about some mathematical problems when modeling specific aspects of the Internet.
- In October 2004, Bernard Cousin was invited to give a talk at the seminar on IPv6 security. He has presented recent developments of DNSSEC and about the interaction DNSSEC/IPv6. This workshop has been organized by the French G6 group, the Aristote group and the GIP RENATER.

9.2. Teaching

9.2.1. Local teaching activities

The team's members have a variety of responsibilities 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 network analysis and on random neural networks at the ITAM school, Mexico; L. Toutain has given another networking course at the same school (one week each).

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).

Bernard Cousin is in charge of the DESS NTIM at Cocody university (Abidjan, Ivory Coast).

J-M. Bonnin and M. Molnar participated to the master thesis formation at ENSI, Tunisia.

M. Molnar was teaching at University ENSA, Oujda, Morocco.

9.3. Standardization 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.

9.3.1. IPv6 Ready Logo Programme

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”. For details, 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.

9.3.2. RFC 3776

An important news of this year is that we have participated to a proposition that is now a RFC. It has been validated as the RFC 3776 by the IETF. It improves the security of the communications of mobiles nodes, by proposing how to use IPsec in order to guarantee the security of the network level. For the details, see the IETF site http://www.ietf.org.

10. Bibliography

Major publications by the team in recent years

[1] H. CANCELA, M. EL KHADIRI. *A recursive variance-reduction algorithm for estimating communication-network reliability*, in "IEEE Transactions on Reliability", vol. 44, n° 4, décembre 1995, p. 595-602.

[2] G. CIZAULT. *IPv6, théorie et pratique*, ouvrage collectif, avec coordination de L. Toutain, O’Reilly, 2002 (3e édition).

[3] P. LEGUESDRON, J. PELLAUMAIL, G. RUBINO, B. SERICOLA. *Transient analysis of the M/M/1 queue*, in "Advances in Applied Probability", vol. 25, n° 3, septembre 1993, p. 702-713.

[4] H. NABLI, B. SERICOLA. *Performability analysis: a new algorithm*, in "IEEE Transactions on Computers", vol. 45, n° 4, 1996, p. 491-494.

[5] G. RUBINO, B. SERICOLA. *Sojourn times in Markov processes*, in "Journal of Applied Probability", vol. 26, 1989, p. 744-756.

[6] G. RUBINO, B. SERICOLA. *A finite characterization of weak lumpable Markov processes. Part II : The continuous time case*, in "Stochastic Processes and their Applications", vol. 45, 1993, p. 115-126.

[7] G. RUBINO, B. SERICOLA. *Interval availability analysis using denumerable Markov processes. Application to multiprocessor systems subject to breakdowns and repairs*, in "IEEE Transactions on Computers", Special Issues on Fault-Tolerant Computing, vol. 44, n° 2, Février 1995, p. 286-291.

[8] L. TOUTAIN. *Réseaux locaux et Internet*, Hermès, 2003 (3e édition).

Doctoral dissertations and Habilitation theses

[9] A. BOUDANI. *Routage multicast : gestion des petits groupes et ingénierie de trafic*, Ph. D. Thesis, Université de Rennes I, July 2004.

[10] J. CORRAL. *Mesure de paramètres de qualité de service dans les réseaux IP*, Ph. D. Thesis, Université de Rennes I, November 2004.

Articles in referred journals and book chapters

[11] N. BARBOT, B. SERICOLA. *Exact Stationary Solution to Tandem Fluid Queues*, in "International Journal of Simulation: Systems, Science & Technology", vol. 4, nº 5-6, 2004.

[12] A. BOUDANI, A. GUITTON, B. COUSIN. *GXcast : une généralisation du protocole Xcast*, in "Informations, Savoirs, Décisions et Médiations (ISDM), special issue on Majecstic (To appear)", 2004.

[13] H. CANCELA, F. ROBLEDO, G. RUBINO. *A GRASP algorithm with tree based local search for designing a Wide Area Network backbone*, in "Journal of Computer Science and Technology", vol. 4, nº 1, 2004, p. 52–58.

[14] H. CANCELA, F. ROBLEDO, G. RUBINO. *A GRASP algorithm with RNN based local search for designing a WAN access network*, in "Electronic Notes in Discrete Mathematics (To appear)", 2004.

[15] H. CANCELA, F. ROBLEDO, G. RUBINO. *Finding Steiner trees with degree 1 terminal nodes*, in "IEICE Transactions (To appear)", 2004.

[16] S. FORTIN, B. SERICOLA. *A Markov model of TCP throughput, goodput and slow start*, in "Performance Evaluation (Special Issue on Distributed Systems Performance, Edited by S. Majumdar and A. Boukerche)", vol. 58, nº 2-3, 2004, p. 89-108.

[17] Y. HAYEL, B. TUFFIN. *A Mathematical Analysis of the Cumulus Pricing Scheme*, in "Computer Networks (To appear)", 2004.

[18] A. KRINIK, G. RUBINO, D. MARCUS, R. J. SWIFT, H. KASFY, H. LAM. *Dual Processes to Solve Single Server Systems*, in "Journal of Statistical Planning and Inference (To appear)", 2004.

[19] C. LÉCOT, B. TUFFIN. *Comparison of Quasi-Monte Carlo-Based Methods for the Simulation of Markov Chains*, in "Monte Carlo Methods and Applications", vol. 10, nº 3-4, 2004, p. 377-384.

[20] O. MEDINA, J. OROZCO, D. ROS. *Bandwidth Sharing under the Assured Forwarding PHB*, in "Annales des Télécommunications", vol. 59, nº 3-4, April 2004.

[21] S. MOHAMED, G. RUBINO, M. VARELA. *Performance evaluation of real-time speech through a packet network: a random neural networks-based approach*, in "Performance Evaluation", vol. 57, nº 2, 2004, p. 141–162.

[22] N. OMNÈS, A. GRAVEY, R. MARIE. *Traffic Conditioner: upper bound for the spacer overflow probability*, in "Performance Evaluation", vol. 58, nº 1, October 2004, p. 15-23.

[23] J. OROZCO, D. ROS, J. INCERA, R. CARTAS. *A Simulation Study of the Adaptive RIO (A-RIO) Queue Management Algorithm*, in "Computer Communications (to appear)", 2004.

[24] P. R. PARTHASARATHY, B. SERICOLA, K. V. VIJAYASHREE. *Transient Analysis of a Fluid Queue Driven by a Birth and Death Process Suggested by a Chain Sequence*, in "Journal of Applied Mathematics and Stochastic Analysis (To appear)", 2004.

[25] L. RABEHASAINA, B. SERICOLA. *A second order Markov modulated fluid queue with linear service rate*, in "Journal of Applied Probability", vol. 41, n° 3, 2004.

[26] D. ROS, B. TUFFIN. *A Mathematical Model of the Paris Metro Pricing Scheme for Charging Packet Networks*, in "Computer Networks", vol. 46, n° 1, September 2004.

[27] B. TUFFIN. *Randomization of Quasi-Monte Carlo Methods for Error Estimation: Survey and Normal Approximation*, in "Monte Carlo Methods and Applications", vol. 10, n° 3-4, 2004, p. 617-628.

[28] C. VIHO. *Test distribution : a solution for complex network system testing*, in "International Journal on Software Tools for Technology Transfer - Special Issue on High-Level Test of Complex Systems (To appear)", 2004.

Publications in Conferences and Workshops

[29] E. ALTMAN, D. BARMAN, R. EL AZOUZI, D. ROS, B. TUFFIN. *Pricing Differentiated Services: A Game-Theoretic Approach*, in "Networking, Athens, Greece", May 2004.

[30] E. ALTMAN, R. EL AZOUZI, D. ROS, B. TUFFIN. *Loss Strategies for Competing TCP/IP Connections*, in "3rd IFIP-TC6 Networking Conference, Athens, Greece", May 2004.

[31] F. ANDRÉ, J. BUISSON, J.-L. PAZAT. *Dynamic Adaptation of Parallel Codes: toward Self- Adaptatable Components for the Grid.*, in "Proceedings of the ICS'04 Workshop on Component Models and Systems for Grid Applications, Saint Malo, France", June 2004.

[32] A. BOUDANI, A. GUITTON, B. COUSIN. *GXcast: Generalized Explicit Multicast Routing Protocols*, in "9th IEEE Symposium on Computer and Communications (ISCC), Alexandria, Egypt", June 2004.

[33] H. CANCELA, G. RUBINO, M. URQUHART. *Pathset Based Conditioning for Transient Simulation of Highly Dependable Systems*, in "5th International Conference on Monte Carlo and quasi-Monte Carlo Methods, Juan les Pins, France", June 2004.

[34] R. CARTAS, J. OROZCO, J. INCERA, D. ROS. *A Fairness Study of the Adaptive RIO Active Queue Management Mechanism*, in "Proceedings of ENC 2004—5th Mexican International Conference on Computer Science, Colima, Mexico", IEEE Computer Society Press, September 2004.

[35] C. CASTELLUCCIA, F. DUPONT, G. MONTENEGRO. *A Simple Privacy Extension for Mobile IPv6*, in "Sixth IFIP IEE International Conference on Mobile and Wireless Communication Networks (MWCN'04), Paris, France", October 2004.

[36] C. COLOMES, M. VARELA, J.-C. GICQUEL. *Subjective Audio Tests: Quality of Some Codecs When Used in IP Networks.*, in "Proceedings of the Measurement of Speech and Audio Quality in Networks workshop (MESAQIN'04), Prague, Czech Republic", June 2004.

[37] A. DELANDA, P. MAILLÉ, B. TUFFIN. *Reserve Price in Progressive Second Price Auctions*, in "9th IEEE Symposium on Computers and Communications (ISCC), Alexandria, Egypt", June 2004.

[38] T. FEUZEU-KWENKEU, B. COUSIN. *Une nouvelle approche des VLAN basée sur Ethernet et la commutation de labels*, in "18 ème congrès DNAC : De Nouvelles Architectures pour les Communications, Paris, France", November 2004.

[39] B. GAABAB, J.-M. BONNIN, A. BELGHITH, M. WATARI. *IPv6 deployment over IPv4-only cellular networks*, in "2nd International Symposium on Image/Video Communications over fixed and mobile networks (ISIVC'04), Brest, France", July 2004.

[40] I. GOUTA, A. BELGHITH, J.-M. BONNIN. *Qualité de service Wi-Fi : Algorithme pour le support de DiffServ*, in "8th Maghrebian Conference on Software Engineering and Artificial Intelligence (MCSEAI'04), Susa, Tunisia", May 2004.

[41] G. GUETTE, B. COUSIN, D. FORT. *Algorithm for DNSSEC Trusted Key Rollover*, in "The International Conference on Information Networking (ICOIN)", 2004.

[42] G. GUETTE, B. COUSIN, D. FORT. *GDS Resource Record: Generalization of the Delegation Signer Model*, in "4th International Conference on Networking (ICN)", 2004.

[43] A. GUITTON, A. ZSIGRI. *A New Way of Doing Multicast on Wavelength-Routed Optical Networks*, in "8th IFIP Optical Network Design and Modelling (ONDM), Ghent, Belgium", February 2004.

[44] Y. HAYEL, D. ROS, B. TUFFIN. *Less-than-Best-Effort Services: Pricing and Scheduling*, in "23rd IEEE Infocom Conference, Hong-Kong, China", March 2004.

[45] Y. HAYEL, L. WYNTER, P. DUBE. *Analysis of a Yield Management Model for Internet Technology Services*, in "IFIP/World Computer Congress, Toulouse, France", August 2004.

[46] Y. HAYEL, L. WYNTER, P. DUBE. *Analysis of a Yield Management Model for On Demand IT Services*, in "4th Annual Informs Revenue Management and Pricing Conference, MIT, Boston, MA, USA", June 2004.

[47] J. INCERA, G. RUBINO. *Bit-Level and Packet-Level*, in "1st International Conference on Quantitative Evaluation of SysTems (QEST'04), University of Twente, Enschede, the Netherlands", IEEE CS Press, September 2004.

[48] M. KASSAB, A. BELGHITH, H. IDOUDI, J.-M. BONNIN. *Réalisation d'un point d'accès logiciel 802.11*, in "3rd International Conference Sciences of Electronic, Technologies of Information and Telecommunications (SETIT'2004), Susa, Tunisia", March 2004.

[49] P. L'ECUYER, P. LÉCOT, B. TUFFIN. *Quasi-Monte Carlo simulation of Markov chains with randomized copies of a two-dimensional highly-uniform point set*, in "5th International Conference on Monte Carlo and quasi-Monte Carlo Methods, Juan les Pins, France", June 2004.

[50] S. LAHOUD, G. TEXIER, L. TOUTAIN. *Classification and evaluation of constraint-based routing algorithms*

for MPLS traffic engineering, in "Rencontres francophones sur les aspects Algorithmiques des Télécommunications (Algotel), Batz-sur-Mer, France", May 2004.

[51] H. LE GUEN, R. MARIE, T. THELIN. *Reliability estimation for statistical usage testing using Markov chains*, in "ISSRE'04 - The 15th IEEE International Symposium on Software Reliability Engineering, St Malo, France", November 2004.

[52] S. LUCIAN, J.-M. BONNIN, K. GUILLOUARD, B. STÉVANT. *Achieving "Always Best Connectec" Through Extensive Profile Management*, in "9th International Conference on Personal Wireless Communications (PWC'04), Delft, Netherland", Lecture Notes in Computer Science, Springer Verlag, September 2004.

[53] S. LUCIAN, J.-M. BONNIN, K. GUILLOUARD, B. STÉVANT. *Towards a Highly Adaptable User-Centric Terminal Architecture*, in "7th International Symposium on Wireless Personal Multimedia Communications (WPMC'04), Abano Terme, Italy", September 2004.

[54] S. LUCIAN, J.-M. BONNIN. *A Survey of Multi-Criteria Network Selection Algorithms*, in "Global Mobile Congress (GMC'04), Shanghai, China", October 2004.

[55] P. MAILLÉ. *Auctioning for Downlink Transmission Power in CDMA Cellular Systems*, in "7th ACM Int. Symp. on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM'04), Venice, Italy", 2004.

[56] P. MAILLÉ, B. TUFFIN. *Multi-bid auctions for bandwidth allocation in communication networks*, in "23rd IEEE Infocom Conference, Hong-Kong, China", March 2004.

[57] P. MAILLÉ, B. TUFFIN. *Multi-bid versus Progressive Second Price Auctions in a Stochastic Environment*, in "4th International Workshop on Internet Charging and QoS Technology (ICQT'04)", Lecture Notes in Computer Science, Springer Verlag, 2004.

[58] R. MARIE, E. ARBARETIER, S. CLENET. *Approche globale d'Analyse de Niveaux de Réparation*, in "14 ème Colloque National de Maîtrise des Risques et Sûreté de Fonctionnement (Lambda-Mu 14), Bourges, France", IMdR-SdF, October 2004.

[59] R. MARIE, E. ARBARETIER. *Formules récurrentes de calcul de mesures de sûreté de fonctionnement des redondances passives de type r/n avec panne possible à la solicitation*, in "14 ème Colloque National de Maîtrise des Risques et Sûreté de Fonctionnement (Lambda-Mu 14), Bourges, France", IMdR-SdF, October 2004.

[60] A. MINABURO, K. SINGH, L. TOUTAIN, L. NUAYMI. *Proposed Behavior for Robust Header Compression over a Radio Link*, in "IEEE International Conference on Communications (ICC 2004), Paris, France", June 2004.

[61] S. MOHAMED, G. RUBINO, M. VARELA. *A method for quantitative evaluation of audio quality over packet networks and its comparison with existing techniques*, in "Proceedings of the Measurement of Speech and Audio Quality in Networks workshop (MESAQIN'04), Prague, Czech Republic", June 2004.

[62] J. MOULIERAC, J.-C. KÖNIG, M. MOLNÁR. *Diffusion contrainte dans un groupe*, in "Rencontres francophones sur les aspects Algorithmiques des Télécommunications (Algotel), Batz-sur-mer, France", May 2004,

p. 69–73.

[63] F. NGANI, C. VIHO. *Modeling and Validation of Mobile IPv6 for Automatic Test Generation purpose*, in "Position papers in The 16th IFIP International Conference on Testing of Communicating Systems (TestCom'2004), Oxford, United Kingdom", March 2004.

[64] F. NGANI, C. VIHO. *Spécification formelle et simulation du protocole de mobilité IPv6*, in "7 ème Colloque Africain sur la Recherche en Informatique (CARI'2004), Hammamet, Tunisie", November 2004.

[65] F. NGANI, C. VIHO. *Validation of the Mobile IPv6 protocol using Formal Approach*, in "The 8th World Multi-Conference on Systemics, Cybernetics and Informatics (SCI'2004), Orlando, Florida,USA", July 2004.

[66] J. OROZCO, D. ROS. *DiffServ-Aware Streaming of H.264 Video*, in "Proceedings of the 14th International Packet Video Workshop (PV2004), Irvine (CA), USA", IEEE, December 2004.

[67] G. RUBINO. *Performance evaluation using PSQA: Pseudo-Subjective Quality Assessment*, in "14th Brazilian Congress in Computer Science (SBC'04), keynote speaker, Salvador da Bahia, Brazil", August 2004.

[68] G. RUBINO. *Some research problems when modelling the Internet*, in "12th Congress of the Mathematics Tunisian Society (SMT'04), invited paper, Monastir, Tunisia", March 2004.

[69] G. RUBINO, M. VARELA. *A new approach for the prediction of end-to-end performance of multimedia streams*, in "1st International Conference on Quantitative Evaluation of Systems (QEST'04), University of Twente, Enschede, The Netherlands", IEEE CS Press, September 2004.

[70] G. RUBINO, M. VARELA. *Evaluating the utility of media–dependent FEC in VoIP flows*, in "Proceedings of the Fifth International Workshop on Quality of future Internet Services (QofIS'04), Barcelona, Spain", September 2004.

[71] L. TOUTAIN. *IPv6 - Invited Tutorial*, in "IEEE International Conference on Communications (ICC 2004), Paris, France", June 2004.

[72] B. TUFFIN, P. RODRIGUEZ, H. CANCELA. *End-To-End Reliability-Dependent Pricing of Network Services*, in "12th Latin-Ibero-American Conference on Operations Research (CLAIO'04)", 2004.

[73] B. TUFFIN. *On Numerical Problems in Simulations of Highly Reliable Markovian Systems*, in "1st International Conference on Quantitative Evaluation of SysTems (QEST'04), University of Twente, Enschede, the Netherlands", IEEE CS Press, September 2004.

[74] P. VAN DER STOK, J. BOOMGAARDT, H. BURKLIN, G. CECCHETTI, J. D. DECOTIGNIE, H. DE MEER, G. FOHLER, J. LUKKIEN, G. RUBINO. *The Fabric Project*, in "First European workshop in Software Architecture", F. OQUENDO, B. WARBOYS, R. MORRISON (editors)., LNCS, n^o 3047, Springer Verlag, May 2004, p. 272–278.

[75] R. ZAGROUBA, P. BERTIN, J.-M. BONNIN. *QoS Management in Micro-Mobility Domains, Integrating HMIPv6 and IntServ/DiffServ Schemes*, in "6th World Wireless Congress (WWC'04), San Francisco, USA",

May 2004.

[76] G. ÖKTEN, B. TUFFIN. *A Central Limit Theorem for a Hybrid-Monte Carlo Method*, in "5th International Conference on Monte Carlo and quasi-Monte Carlo Methods, Juan les Pins, France", June 2004.

Internal Reports

[77] E. ALTMAN, R. EL AZOUZI, D. ROS, B. TUFFIN. *Losses Strategies for Competing TCP/IP Connections*, (appeared also as IRISA Research report PI-1589), Technical report, n° 5100, INRIA, February 2004, http://www.inria.fr/rrrt/rr-5100.html.

[78] A. COUVREUR, A. MINABURO, L.-M. LE NY, G. RUBINO, B. SERICOLA, L. TOUTAIN. *Performance Analysis of an Header Compression Protocol: The ROHC Unidirectional Mode*, Technical report, n° 5300, INRIA, September 2004, http://www.inria.fr/rrrt/rr-5300.html.

[79] P. DUBE, Y. HAYEL, L. WYNTER. *Analysis of a Yield Management Model for On Demand Computing Centers*, Technical report, n° 1597, INRIA, 2004, http://www.inria.fr/rrrt/rr-5092.html.

[80] Y. HAYEL, M. OUARRAOU, B. TUFFIN. *Optimal Measurement-Based Pricing for an M/M/1 Queue*, Technical report, n° 1641, IRISA, July 2004.

[81] Y. HAYEL, B. TUFFIN. *Pricing for Heterogeneous Services at a Discriminatory Processor Sharing Queue*, Technical report, n° 1633, IRISA, July 2004.

[82] P. MAILLÉ, B. TUFFIN. *Pricing the Internet with Multi-Bid Auctions*, Technical report, n° 1630, IRISA, June 2004.

[83] R. MARIE. *Computation Through Stable Recurrent Expressions of the Unavailability, MTBF and Mean First Up Time for Passive r/n Redundancy with Potential Breakdowns at Activation Instants*, Technical report, n° 1626, IRISA, June 2004.

[84] J. OROZCO, D. ROS. *DiffServ-Aware Streaming of H.264 Video*, Technical report, n° 1627, IRISA, June 2004.

[85] B. TUFFIN, P. RODRIGUEZ, H. CANCELA. *End-To-End Reliability-Dependent Pricing of Network Services*, Technical report, n° 1639, IRISA, July 2004.

Miscellaneous

[86] J. BUISSON, F. ANDRÉ, J.-L. PAZAT. *Adaptation dynamique de codes parallèles*, March 2004, Journées composants.

[87] T. FEUZEU-KWENKEU, B. COUSIN. *LaidaNet : Une technique de pontage basée sur la commutation de labels*, October 2004, Manifestation des Jeunes Chercheurs STIC.

[88] T. FEUZEU-KWENKEU, B. COUSIN. *LaidaNet : Une technique de pontage basée sur la commutation de labels*, November 2004, 6ème Journées Doctorales Informatique et Réseaux (JDIR).

[89] R. GIEBEN, G. GUETTE, B. COUSIN. draft IETF: draft-gieben-resolver-application-interface-00.txt.

[90] G. GUETTE, O. COURTAY. draft IETF: draft-ietf-dnsop-key-rollover-requirements-03.txt.

[91] G. GUETTE, D. FORT, B. COUSIN. draft IETF: draft-guette-DS-generalization-01.txt.

[92] Y. HAYEL, B. TUFFIN. *Tarification des réseaux à différenciation de services*, November 2004, 6ème Journées Doctorales Informatique et Réseaux (JDIR).

[93] P. MAILLÉ, B. TUFFIN. *Enchères pour l'allocation de ressources réseaux*, November 2004, 6ème Journées Doctorales Informatique et Réseaux (JDIR).

[94] B. TUFFIN, P. MAILLÉ. *Auctioning for Bandwidth in Communication Networks*, April 2004, ERCIM News No.57, Special Theme: Games Technology.

[95] M. VARELA. *Evaluation Pseudo–subjective de la Qualité des Flux VoIP: un Approche par Réseaux de Neurones Aléatoires*, November 2004, 6ème Journées Doctorales Informatique et Réseaux (JDIR).

Bibliography in notes

[96] S. BARBIN, L. TANGUY, C. VIHO. *Towards a formal framework for interoperability testing*, in "21st IFIP WG 6.1 International Conference on Formal Techniques for Networked and Distributed Systems, Cheju Island, Korea", M. KIM, B. CHIN, S. KANG, D. LEE (editors)., August 2001, p. 53-68.

[97] N. BARBOT, B. SERICOLA. *Stationary solution to the fluid queue fed by an M/M/1 queue*, in "Journal of Applied Probability", vol. 39, n^o 2, June 2002.

[98] C. BORMANN, AL.. *RObust Header Compression (ROHC): Framework and four profiles: RTP, UDP, ESP and uncompressed*, 2001, RFC 3095.

[99] P. BURGOS, H. CANCELA, A. GODOY, L. PETINGI. *Network reliability optimization with source-terminal distance constraints*, in "International Network Optimization Conference (INOC), Évry/Paris, France", October 2003.

[100] H. CANCELA, L. PETINGI. *On the Characterization of the Source-to-all-terminal Diameter-constrained reliability domination*, in "Congreso Argentino de Ciencias de la Computación (CACIC), La Plata, Argentina", October 2003.

[101] H. CANCELA, F. ROBLEDO, G. RUBINO. *A GRASP algorithm for designing a Wide Area Network backbone*, in "International Network Optimization Conference (INOC), Évry/Paris, France", October 2003.

[102] H. CANCELA, F. ROBLEDO, G. RUBINO. *Network design with node connectivity constraints*, in "IFIP/ACM Latin America Networking Conference 2003 (LANC), La Paz, Bolivia", October 2003.

[103] H. CANCELA, F. ROBLEDO, O. VIERA. *An exact algorithm for the Steiner 2-edge-survivable network problem*, in "Proceedings of OPTIMA, Valparaiso, Chile", September 2003.

[104] H. CANCELA, F. ROBLEDO, O. VIERA. *Diseño heurístico de redes con requerimientos de conectividad (Heuristic design of networks with connectivity requirements, text in Spanish)*, in "Congreso Argentino de Ciencias de la Computación (CACIC), La Plata, Argentina", October 2003.

[105] H. CANCELA, G. RUBINO, B. TUFFIN. *MTTF estimation by Monte Carlo methods using Markov models*, in "Monte Carlo Methods and Applications", vol. 8, n° 4, 2002, p. 312-341.

[106] H. CANCELA, G. RUBINO, M. URQUHART. *An algorithm to compute the all-terminal reliability measure*, in "OPSEARCH", vol. 38, n° 6, 2001, p. 567-579.

[107] O. MEDINA. *Étude des algorithmes d'attribution de priorités dans un Internet à différentiation de services*, Ph. D. Thesis, Université de Rennes I, March 2001.

[108] A. MINABURO, L. NUAYMI, L. TOUTAIN. *Media Link Parameters for ROHC*, July 2001, draft-minaburo-parameters-00.txt, IETF.

[109] S. MOHAMED, G. RUBINO. *A Study of Real-Time Packet Video Quality Using Random Neural Networks*, in "IEEE Transactions on Circuits and Systems for Video Technology", vol. 12, n° 12, December 2002.

[110] N. SEMRET. *Market Mechanisms for Network Resource Sharing*, Ph. D. Thesis, Columbia University, 1999.

[111] B. SERICOLA. *A Finite Buffer Fluid Queue Driven by a Markovian Queue*, in "Queueing Systems", vol. 38, n° 2, 2001.

[112] B. TUFFIN. *Bounded Normal Approximation in Simulations of Highly Reliable Markovian Systems*, in "Journal of Applied Probability", 1999.