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INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team armor

Architectures et Modèles de Réseaux

Rennes

THEME COM

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1. Team

ARMOR is a joint project between the following partners: INRIA, university of Rennes 1, INSA Rennes, CNRS. 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.

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2. Overall Objectives

2.1. 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, Quality of Service, 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 QoS levels, to security or mobility aspects of the IP protocol.

Interoperability testing is essential to ensure 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 enabled 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. In view of this, 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*, *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. 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 develop as many communication solutions as possible applications, 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 (Wide Area Network) 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 (for instance, header compression techniques), 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. We can also mention our interest in *user perceived quality* when the transmitted flows are audio, video or multimedia ones.

Another special case to which we devote research efforts in the team is the assessment of qualitative properties around interoperability testing. This refers to the act of determining if end-to-end functionality between at least two communicating systems is as required by the base standards 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. 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, even though we still have to deal with some issues that apply also for conformance 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 Labeled Transition Systems). It is an LTS which distinguishes inputs, outputs and internal actions.

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.

Pricing is a good example of a multi-disciplinary research activity half-way between applied mathematics, economy and networking, centered on stochastic modeling issues. 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.

4. Application Domains

4.1. Panorama

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

Our main application domains are those related to network design, at both the transport infrastructure and the service levels. 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 requested is the area 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. Internet Protocols Interoperability Testing Platform

Participants: César Viho, Annie Floch, Anthony Baire, Frédéric Roudaut, Ariel Sabiguero.

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 also developed 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 and the OSPFv3 protocols. This test suites are also available at http://www.point6.net.

5.2. Performance and dependability evaluation

Participants: Gerardo Rubino, Bruno Sericola, Bruno Tuffin.

We develop software tools for the evaluation of two classes of models: Markov models and reliability networks. The main objective is to quantify dependability aspects of the 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`.

5.3. Simulation

Participants: Bernard Cousin, Raymond Marie, Miklós Molnár, Gerardo Rubino, 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 [95], 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.

In wireless network simulation domain the open source simulator JSIM (cf. http://chief.cs.uga.edu/~jam/jsim) has several extensions to simulate 802.11 based network functionalities. To compare power save mechanisms in wireless networks modules implementing the Power Save Mode (PSM) of the 802.11 standard have been added to JSIM. The extensions permit to test other power saving mechanisms related to recent works (see the associated page).

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. 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.

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.

5.4. DNSSEC platform

Participants: Bernard Cousin, 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.

5.5. Network Graph and Path Computation experimental prototype

Participants: Bernard Cousin, Thierry Feuzeu, Miklós Molnár.

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.

6. New Results

6.1. Pricing

Participants: Yézékaël Hayel, 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 [12]. 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 [96]. Nevertheless, this pricing scheme 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, the costly iterative scheme has been replaced by a one-shot multiple-bid scheme keeping the optimality and incentive compatibility properties. We have proposed in [32] to extend this scheme to the case of a network, by using the properties/assumptions that the backbone network is over-provisioned and the access networks have a tree structure. This last assumption is relevant in many access networks.

Multi-class pricing is also an important research topic of our group. We have had a special focus on third Generation (3G) wireless systems where Direct-sequence code-division multiple-access (DS-CDMA) is implemented but where, due to a limited radio spectrum and the growing number of demanding applications, it seems likely that congestion will still remain an issue. In [51], we have studied the impact of a per-packet static pricing scheme on the use of the reverse-link in a cell. Since DS-CDMA supports integrated services, we also deal with pricing of multiple classes. We have also dealt in general with priority pricing in [26], where Aumann-Shaphey prices (that fairly share the total perceived cost) optimizing the social welfare are determined. In [13], 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, we have designed a pricing scheme that allows to control the number of parallel TCP sockets a user should open [84], this approach being used to improve throughput performance of bulk data transfers (e.g. gridFTP). Also, in [25], the use of passive and active measurement tools (for throughput and delay respectively) and their uncertainties have been introduced in a pricing model. In [52], we have also replaced the usually arbitrarily chosen utility functions that represent the behavior of users by an estimation/approximation coming from tests and analyzed through the PSQA tool.

6.2. Dependability and extensions

Participants: Gerardo Rubino, Bruno Sericola, Bruno Tuffin.

We maintain a research activity in different areas related to dependability, performability, vulnerability analysis of communication systems. In 2006 our effort has been on evaluation techniques using both the Monte Carlo and the Quasi-Monte Carlo approaches, especially through the cooperative research action (ARC) RARE.

Monte Carlo methods represent the most powerful tool to analyze very large Markov chains. In the context of rare-event simulation, splitting and importance sampling (IS) are the primary approaches to make important rare events happen more frequently in a simulation and yet recover an unbiased estimator of the target performance measure, with much smaller variance than a straightforward Monte Carlo (MC) estimator. In a previous work [97], 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 rarity increases. In [85], we discuss and relate all robustness measures of rare event estimators. We also introduce three properties named bounded relative error of empirical variance (BREEV), bounded relative efficiency of empirical variance (BREffEV), and asymptotic optimality of empirical variance (AOEV), which state that the empirical variance has itself the BRE, BREff and AO property, respectively, as an estimator of the true variance. We then study the hierarchy between all these different characterizations for a model of highly-reliable Markovian systems (HRMS) where the goal is to estimate the failure probability of the system. In [29], [54], [46], we provide a guided tour of splitting and Russian roulette techniques, introducing along the way some improvements in the implementation of the multilevel splitting. We also propose in [55] a combination of importance sampling and splitting. The basic idea is to Reducing the variance of the likelihood ratio introduced in importance sampling by trying to keep it in a desired window through splitting and Russian roulette.

Another successful approach to deal with large Markov chains is to compute bounds of the interesting metrics. This is extremely useful in case of very large models, and it is an alternative to Monte Carlo estimations. Recently, we developed a technique that is able to bound the most basic dependability metric, the Mean Time To Failure (MTTF), when it is defined on a Markov model of a highly reliable system. The technique can handle very large models and provide very tight upper and lower bound of the MTTF. It is based on a classification of the transitions in the model into fast and slow ones, leading to an associated classification of the states, on the stochastic complement of a chain with respect to a subset of its state space, and on a path-based exploration procedure. It has been published in [45].

In Quasi-Monte Carlo (QMC), the error when estimating an integral uses a deterministic sequence (instead of a random one) called a low discrepancy sequence and having the property to spread quickly over the integration domain. The estimation error 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 [35], it is also shown how, by using QMC (or its randomized version) for a small amount of coordinates, and MC for the remaining ones, the accuracy of the simulation can be improved. The gain is theoretically proved, as well as illustrated on finance problems. Randomized quasi-Monte Carlo (RQMC) is another class of methods for reducing the noise of simulation estimators, by sampling more evenly than with standard MC. In [29], we show how the *array-RQMC* technique, a randomized QMC method we have previously designed and devoted to the simulation of Markov chains, can be used jointly with splitting and/or IS to construct better estimators than those obtained by either of these methods alone. A study of cross-entropy technique that adaptively learns the optimal importance sampling parameters has also been studied in [86].

Finally, we worked also on some general concerns in dependability analysis. In [64] we discuss about some basic issues when evaluation standard dependability metrics such as MUT and MDT. In [63] we worked on the validation of algorithms for the analysis of different repair levels.

6.3. TCP

Participant: Bruno Tuffin.

As a consequence of a previous collaboration with Maestro project-team through the TCP and PRIXNET ARCs, we have analyzed the behavior of two competing TCP connections sharing a common bottleneck link. We have analyzed several loss strategies: fixed loss probability, largest throughput loss or proportional loss. After some derivations in the general asymmetric case, we especially show that in the symmetric, surprisingly, the loss strategy has no consequence on the average throughput. We show, in contrast, that the second moment of the throughput does depend on the strategy [14]. This invariance result has been extended in [37] to more than two connections in competition. This is shown to be of practical importance as it elucidates the throughput of parallel TCP sockets, an approach used widely to improve throughput performance of bulk data transfers (e.g. gridFTP). The validity of the result has also been illustrated through ns simulations. In [84], we have designed a pricing scheme that allows to limit the number of sessions each user should open.

6.4. Low speed links

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

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. The contribution of ARMOR in this context concerns the 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). We present in [21] 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.

6.5. Core persistence in P2P systems

Participant: Bruno Sericola.

Distributed systems are now both very large and highly dynamic. Peer to peer overlay networks have been proved efficient to cope with this new deal that traditional approaches can no longer accommodate. While the challenge of organizing peers in an overlay network has generated a lot of interest leading to a large number of solutions, maintaining critical data in such a network remains an open issue. In [48], which has been done in collaboration with the Inria Asap team, we obtained results concerning the portion of nodes and frequency one has to probe, given the churn observed in the system, in order to achieve a given probability of maintaining the persistence of some critical data.

6.6. Self-stabilizing wireless networks

Participant: Bruno Sericola.

Wireless multi-hop networks (such as ad hoc or sensor networks) consist of sets of independent mobile wireless nodes that operate without the support of a pre-existing fixed infrastructure. They offer unique benefits for certain environments and applications as they can be quickly deployed. Nodes are self-contained, battery-powered computers with radio links that enable the entities to self-organize into a network, communicate with each other and exchange data. The advent of large-scale wireless networks highlights problems of fault tolerance and scale in distributed system, motivating designs that autonomously recover from transient faults and spontaneous reconfiguration. Resuming correct behavior after a fault occurs can be very costly: the whole network may have to be shut down and globally reset in a good initial state. While this approach is feasible for small networks, it is far from practical in large networks such as forecast sensor networks. Self-stabilization is an attractive approach for such problems. It provides a way to recover from faults without the cost and inconvenience of a generalized human intervention: after a fault is diagnosed, one simply has to remove, repair, or reinitialize the faulty components, and the system, by itself, will return to a good global state within a relatively short amount of time.

Distributed self-stabilizing algorithms may thus be used for organizing and/or managing wireless networks. For example, the self-stabilizing distributed vertex coloring algorithm can be used for resource allocation or distributed local organization. The vertex coloring problem, issued from classical graph theory, consists in choosing different colors for any two neighboring nodes in a graph. This problem can easily be generalized to distance k, requiring that any two nodes that are up to k hops away must have different colors. Intuitively, the vertex coloring algorithm runs as follows: every node repetitively collects colors chosen by its neighbors, and if it detects a conflict with its own color, randomly chooses a fresh color (not taken by its distance-k neighborhood).

Such algorithms in sensor networks do not try to minimize the number of used colors, but when the graph degree is bounded by a small constant (as it is the case in sensor networks), the expected local stabilization time (i.e. the stabilization time in any neighborhood) of the algorithm is also constant. This makes the algorithm independent on n and thus scalable to large networks. While this distance-k coloring algorithm has proven fast local stabilization time, the influence of system parameters remains unknown. In [66] and [67], which have been done in collaboration with the Inria Grand-Large and Ares teams, we studied its stabilization time in various settings that are relevant to sensor networks. We provide a theoretical study in synchronous networks. Using simulations, we consider various topologies (grids and random graphs) and different kinds of scheduling hypothesis (synchronous and probabilistically asynchronous).

6.7. Analytical fluid models

Participant: Bruno Sericola.

Motivated by queuing systems playing a key role in the performance evaluation of telecommunication networks, we analyzed in [24] the stationary behavior of a fluid queue, when the instantaneous input rate is driven by a continuous-time Markov chain with finite or infinite state space. In the case of an infinite state space and for particular classes of Markov chains with a countable state space, such as quasi birth and death processes or Markov chains of the G/M/1 type, we developed an algorithm to compute the stationary probability distribution function of the buffer level in the fluid queue. This algorithm relies on simple recurrence relations satisfied by key characteristics of an auxiliary queuing system with normalized input rates.

6.8. Interoperability Testing

Participants: Alexandra Desmoulin, Francine Ngani, Ariel Sabiguero, César Viho.

To our knowledge, so far a 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 Labeled Transition Systems). It is an LTS which distinguishes inputs, outputs and internal actions.

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 [94]. This year we have studied the problem of quiescence management in interoperability testing. We prove that by taking into account potential quiescence of implementations, we can improve interoperability testing. Based on these results we developed algorithms that generate more accurate interoperability tests [47].

We have also developed methods and algorithms using formal methods for automatic conformance and interoperability tests generation for mobility protocols. The Mobile IPv6 (MIPv6) has been used to validate these algorithms [11].

We have proposed some solutions for some issues regarding the last step of testing activity, where abstract test suites are translated to obtain executable test suites that are executed against real implementations. The new standardized TTCN3 language and the RIPng protocol have been used for this purpose [78].

We have also proposed some solutions that deal with test management and trace analysis issues during interoperability testing. We provided a tool that interacts directly with target and reference devices involved in the test for running the scenarios and manages the interconnection between the devices using IEEE 802.1Q VLANs. Depending on resources and needs, test control can be centralized in one single console or done separately on each device [34]. Another tool [79] helps in analyzing traces of TTCN3 based test suites.

On a pragmatic side, we try to validate our solutions for new generation network, mainly IPv6 related protocols. We have generated conformance and interoperability tests for significant IPv6 and 3GPP related protocols, like MIPv6 (Mobile IPv6), 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 Program" (see http://www.ipv6ready.org), a world wide certification program launched by the IPv6 Forum where we are the only representative for Europe. We are responsible of the definition of technical requirements for the two phases of this program. The Phase I started two years ago with real success. The second phase started last year, with stronger requirements.

6.9. Optical networks

6.9.1. Dimensioning and traffic grooming in optical networks

Participant: Nizar Bouabdallah.

Optical fiber communication is now ubiquitous in the telecommunications infrastructure. Fiber optics and wavelength-division multiplexing (WDM) technology have increased significantly the transmission capacity of today's transport networks, and they are playing important roles in supporting the rapidly increasing data traffic. Nonetheless, the rigid and large routing granularity (i.e. wavelength) entailed by such an approach could lead to bandwidth waste [19]. Yet, as WDM technology keeps maturing, there is a bandwidth gap between a wavelength channel's transmission speed (over a Gbit/s) and the capacity requirement of customers' connections. In this regard, increasing research interest is now focusing on the development of new concept of traffic aggregation in optical networks. The objective is eliminating both the bandwidth underutilization and the scalability concerns that are typical of all-optical wavelength-routed networks.

To achieve this, we proposed and evaluated a new concept of traffic aggregation in WDM optical networks based on the distribution of the aggregation process [40]. Unlike traditional all-optical networks, which limit the access to a lightpath capacity at the ingress node, we allow lightpath channel sharing among several access nodes. Our objective is to reduce the network cost while preserving the benefits of all-optical wavelength-routed networks. In order to assess the efficiency of our proposal, all underlying network costs are compared. These costs include that of the transceivers required at node level, as well as the number of wavelengths. In other words, the network dimensioning is achieved by evaluating the cross-connect and IP router dimensions as well as the number of wavelengths. To date, it lacks a real methodology to dimension such high-speed networks. In this regard, we developed in [39] a new model to dimension optical networks. Our results show that our proposed aggregation technique can significantly improve the network throughput while reducing its cost.

Moreover, as the distributed aggregation concept relies on the lightpath sharing, efficient partition of the lightpath capacity among competing access nodes must be ensured. We proved in [18], through analytical models based on the queuing theory, that fairness issues are likely to arise in such shared medium networks. We demonstrated also the limitations of the token bucket access rate-based algorithm to resolve the aforementioned issues. In this context, we devised a new strategy called TCARD (Traffic Control Architecture using Remote Descriptors) to alleviate the fairness problems. We exhibited, through simulations and analytical models, the TCARD ability to achieve fairness and to improve the network performances.

6.9.2. Optical networks survivability

Participants: Nizar Bouabdallah, Bruno Sericola.

One of the major challenges of optical network operators is ensuring the stringent levels of availability required by their highest-class clients. Indeed, in such environment, the cut of a fiber link can lead to a tremendous traffic loss. In this regard, network survivability becomes a critical concern for operators. To alleviate this, backup resources are used to restore failed connections. These resources are usually shared among several primary connections to improve the network utilization. Generally, the primary connections are considered as equally important when contending for the use of the backup resources. However, this solution is unsuitable from service perspective. Indeed, the quality of service (QoS) required by different clients can be very different because of their diverse services' characteristics. To meet this requirement, we introduce relative priorities among the different primary connections contending for access to the shared-protection paths. We developed an analytical model for the proposed priority-enabled scheme [20]. As a key distinguishing feature from existing literature, we derived explicit analytic expressions for the average availability and service disruption rate for the different priority classes. Based on the elaborated model, we also provided a comprehensive study of the impact of the backup sharability on the network reliability when using the backup reprovisioning scheme.

6.10. Wireless communications

Participants: Fatma Bouabdallah-Othman, Nizar Bouabdallah, Hanen Idoudi, Adlen Ksentini, Miklós Molnár.

6.10.1. Mobility management in wireless networks

Participant: Nizar Bouabdallah.

The last few years have seen tremendous growth in the installation of IEEE 802.11 wireless local area networks (WLAN) access points as hotspots in public places to support data communications in general and Internet access in particular. WLAN technology has become widely deployed thanks to its simple and robust contention-based MAC protocol. In view of this, wireless communication is now firmly established as the preferred means of communication for signals over a few megabits per second over distances more than a few hundred meters.

Future wireless networks are expected to provide IP-based coverage and efficient mobility support with end-to-end Quality of Service (QoS) requirements. In our work, we propose a new architecture that supports both mobility and QoS management in wireless MPLS networks [31]. To achieve this, we suggest a new micro-mobility management scheme called Micro Mobile MPLS [61]. Our proposal includes two protocol variants. In the first variant called FH-Micro Mobile MPLS, we consider the fast handoff mechanism, which anticipates the LSP procedure setup with an adjacent neighbor subnet that a mobile node (MN) is likely to visit. This mechanism is proposed to reduce service disruption by using the link-layer (L2) functionalities [60]. In the second variant called FC-Micro Mobile MPLS, the forwarding chain concept, which is a set of forwarding path, is provided to track efficiently the host mobility within a domain. This concept can significantly reduce the registration updates cost and provide low handoff latency as demonstrated in [30]. The performance of the proposed protocols are evaluated using both simulation and analytical approaches in [57] [56]. Finally, comparisons with the existing solution are conducted in [58] [59].

6.10.2. The wireless sensor networks

Participants: Fatma Bouabdallah-Othman, Nizar Bouabdallah.

The above-mentioned advances in wireless communication and embedded computing technologies have lead to the emergence of wireless sensor nodes technology. These pill-sized nodes can be deployed in many domains including health, environment and battlefield monitoring. The major concern is such networks is energy-efficiency is due to the limited capacity of the sensor nodes' batteries. Indeed, once a wireless sensor networks (WSNs) is in place, its lifetime must last as long as possible based on the initially provided amount of energy. In view of this, techniques minimizing energy consumption are required to improve the network lifetime. In order to minimize the energy consumption in WSNs, most previous works focused on energy-aware MAC or routing protocols without paying attention to the impact of the density of reporting nodes on the WSN performances. Indeed, we need to study how the network lifetime evolves with respect to the number of deployed reporting nodes. Moreover, previous works focused mainly on the energy minimization problems. Whereas, minimizing the energy consumption must be achieved while respecting the specific QoS requirements of sensor applications, such as the maximum tolerable time to report an event, and the required event reliability, etc. To tackle these issues, a new Ph. D has been started since October 2006 in armor team.

6.10.3. Power saving in wireless and sensor networks

Participants: Miklós Molnár, Hanen Idoudi, Adlen Ksentini.

We study communication problems, QoS management, adaptation of flows and energy saving in wireless (mainly ad hoc) networks in cooperation with the laboratory CRISTAL of ENSI, Tunisia. The IEEE 802.11 standard proposes an efficient Power Save Mode (PSM) to spare battery energy in wireless network component. One of the drawbacks of the PSM manifests in the latency implicated by missing nodes in the case of routing. An improvement of PSM for infrastructure 802.11 networks was proposed in [15]. In order to decrease the latency, we proposed also a model for the energy conservation, based on synchronized alternations of "doze" and "awake" states of network activities of the ad hoc network components [89]. The performance analysis of the proposition can be found in [53]. The results show that the new proposition can be advantageous in ad hoc sensor networks.

Besides providing services as well as connectivity for users, wireless networks are actually involved in monitoring specific phenomena through sensors networks. Thereby, we were interested in the issue concerning the energy saving en sensor networks. In [73] we proposed to use a clustering procedure aiming at portioning the sensors networks in different clusters allowing thus an important energy saving.

6.10.4. QoS in Wireless Networks

Participant: Adlen Ksentini.

With the recent dramatic growth in wireless communication and access, together with adoption rates of the Internet, wireless and Internet communications undergone enormous development with the goal of delivering multimedia applications and services, at anytime, anywhere and on any devices. However, the intrinsic nature of wireless and Internet networks present many challenges on quality of service (QoS). We are exploring several issues in wireless multimedia communications and networking. It includes quality of service (QoS) support, resource allocation [28]. Among different media as well as presenting a novel solutions multimedia adaptation to networks under varying conditions. Another important aspect of our works is in the introduction of novel concepts aiming at enhancing video transmission over WLAN. In fact in [27] we have proposed a cross-layer architecture involving the application and 802.11e MAC layer.

6.11. Trafic Enginneering

Participants: Bernard Cousin, Miklós Molnár, Joanna Moulierac, Imène Chaieb, Wojtek Bigos, Shadi Jawhar, Thomas Legrand.

Dependability and efficiency in routing and QoS management have to be improved for high speed networks. Our research on this domain is focused on the management of Optical Networks. Some of these works are connected to other works described in the multicast chapter.

Backbone data networks evolve towards all-Optical Networks. In such networks IP routers are interconnected by re-configurable optical cross-connects (OXC) managed by an automatic control plane. This architecture, on the one hand, improves the overall network performances by providing advanced functionalities such as optical by-pass, traffic engineering and fault protection mechanisms but, on the other hand, introduces an additional switching layer which increases the overall network cost.

In previous works, we have proposed several heuristic for multicast tree construction. These polynomial time approximations take into account some specific constraints of optical networks: QoS constraint, lightwave constraint and/or constraints on specific resources from optical switches (i.e., limited availability of light splitters, light amplifiers, light swappers, etc.).

6.11.1. Optimization of IP over MPLS in optical networks

Participants: Bernard Cousin, Hanen Idoudi, Adlen Ksentini, Miklós Molnár.

Moreover, we have previously proposed to use an enhanced architecture which introduces an intermediate layer based on MPLS. This architecture introduces some independence and flexibility in the network management. This multi-layer architecture have lead us to consider modeling techniques which enable us formulate and to solve various design problems, including multi-layer modeling of networks comprising different technologies and incorporating network recovery mechanisms [16], [9].

6.11.2. Classification of MPLS-TE routing

Participants: Bernard Cousin, Hanen Idoudi, Adlen Ksentini, Miklós Molnár.

MPLS-TE is being deployed by network operators to better optimize their network resources. The routing in MPLS-TE networks is a large and open issue. Studies aimed to improve MPLS-TE routing in terms of scalability, stability, robustness, optimality and survivability. Various (MPLS-TE) Routing Systems have been proposed in the literature to achieve optimization of resources utilization, Quality-of-Service (QoS) and Fast Recovery. We have proposed a generic architecture for for MPLS-TE Routing Systems, that combines MPLS-TE functional blocks such as TE-Trunk Computation, TE-Trunk utilization and TE-Trunk Adaptation, [42], [43]. This generic architecture is proposed to facilitate the classification of MPLS-TE Routing solutions, to improve existing mechanisms and to propose new solutions. By relying on this architecture, we can identify and evaluate a set of MPLS-TE Routing approaches using several evaluation metrics. We have showed that some TE criteria, either alone or combined, can influence the performances of a MPLS-TE Routing System. The combination of these criteria leads to the identification of main families of MPLS-TE Routing Systems which are finally compared and qualitatively evaluated according to a set of metrics, [44].

6.12. Multicast Routing

Participants: Mohand Saidi, Bernard Cousin, Miklós Molnár, Joanna Moulierac.

Scalability and efficiency of routing, QoS management, communication protection and tree construction have to be improved for multicast traffic. Our research on multicasting can be organized in several thematic axis and can found application on several types of networks : Internet v6, MPLS, optical networks. Thus, some of these works are connected to works described in other chapters, for instance the Traffic Engineering and Optical Network chapter.

6.12.1. Optimized tree construction for enhanced communication protection

To provide fault-tolerance for multicast connections, different techniques of protection are developed. These techniques can be classed into reactive and pro-active approaches. Reactive approaches can have long recovery latency which is undesirable for many types of applications such as the real time ones. In our work, we focus on the multicast pro-active fault-tolerance schemes. One of the promising protection techniques is the dual-tree protection which is efficient to cope with single link failure but which cannot deal with node failures suitably. In a first work, we have presented an improved solution using a dual-forest for multicast protection [81]. Our proposition provides three improvements to traditional dual-tree protection. The first one concerns the capability to bypass both single link and node failures in a suitable and quick manner. The second increases the level of protection with the use of a forest as backup instead of a tree. The last permits the cost optimization of the dual-forest and of the delivery tree after recovery. Simulation experiments show that the improved dual-forest scheme has better protection rate and causes less tree cost increase after recovery than the path protection scheme. In a second work, we proposed an upstream way to compute the backup paths use for the protection of a multicast tree. Our evaluation demonstrates that protection rate is improved when the network topology have a low connectivity rate, [82].

6.12.2. Multicast Tree Aggregation

Multicast is not scalable in IP due to the number of forwarding states needed in routers. The aggregation of the used multicast trees is a recent proposition to decrease the number of used trees and so the number of forwarding states in the routers. The previously proposed algorithms for tree aggregation need important computation capacities and time. Generally, the aggregation algorithms do not handle the QoS needs of multicast communication requests. To simplify the tree aggregation and deal with the scalability and the QoS problem several propositions were formulated in [10].

One of the most efficient solution to aggregate multicast trees in a routing domain is the pre-configuration of potential trees. Our studies show that the number of trees using a shortest path tree construction algorithm is very limited and so the pre-configuration is possible (cf. [70], [72].

If the number of routers having multicast members in the domain becomes large then the aggregation of mainly independent groups becomes weak. So solution are needed for large domain tree aggregation. In [33] and [69] simple and robust solution for multicast tree aggregation in large routing domains was proposed.

6.12.3. Multi-constrained Multicast Communications

The major part of the multicast communications needs quality of service (QoS) specification. Often, the QoS is given as a set of QoS criteria and the computation of feasible or optimal routes corresponds to a multi-constrained optimization. Find the multicast sub-graph respecting the defined QoS requirement and minimizing network resources is a NP-difficult optimization task. Exhaustive search algorithms are not supported in real networks. Greedy algorithms as MAMCRA was proposed to find good multicast sub-graphs. The local decisions of greedy algorithms can be lead to solutions which can be easily ameliorated. Meta-heuristics are good candidates to find better solutions using a controlled execution time. For multi-constrained multicast routing problems, we proposed a Taboo Search based algorithm to improve the multicast sub-graph computed by the greedy algorithm MAMCRA (cf. [38]).

6.13. Security

Participant: Gilles Guette.

Nowadays, reaching services on the Internet highly depends on the use of DNS (Domain Name System). DNSSEC [22] is the secure successor of DNS, providing to this protocol the security services needed. After having studied the automation of the key management in DNSSEC last year, we have explore another theme in the management of this protocol: the key revocation. We have first analyzed the consequences of a compromised key in DNSSEC [50], [88]. This publication have shown a security flow in certain cases. We have proposed a novel and complete revocation mechanism as a solution, this proposition is under submission yet. This approach is a new one in this protocol because there is no revocation service in DNSSEC. The designer of the protocol claims that every key is under the responsibility of the zone owner and then there is no need for a global revocation system. If a key is compromised, the zone owner must take the appropriate counter measure. We have proved that this is impossible and that this point of view is inefficient.

7. Contracts and Grants with Industry

7.1. IST-Go4IT

Participants: César Viho, Anthony Baire, Annie Floch, Ariel Sabiguero.

We are an active member of the IST-Go4IT project. IST-Go4IT is a project co-financed by the European Commission under the 6th Framework Program of the European Research Area. The project has started in November 2005 and is ending in April 2008. The project partners are made of 11 organizations coming from Europe, China and Brazil. The objectives of Go4IT are:

- Promote and foster conformance testing oriented validation approach as well as associated technologies such as TTCN3.
- Develop the users community of such an approach
- Supply a range of executable and freely accessible test services
- Supply the associated range of support services on a free basis
- Supply complementary commercial services such as certification, consulting
- Set-up the environment required to develop a low cost, open and generic solution

7.2. Anemone

Participants: César Viho, Gerardo Rubino, Nizar Bouabdallah, Kamal Singh, Antoine Boutet.

The Anemone project (Advanced Next gEneration Mobile Open NEtwork) is a IST-STREP (Specific Targeted Research Project) project that started from June 1st, 2006 for a duration of 2 years. The objectives of ANEMONE are:

- To gather and integrate in a single place all the components (i.e. latest standards in wireless access technologies, communication protocols, and applications) necessary to conduct research, development and study the feasibility of deployment of the IPv6 mobility technologies.
- To share the partial experiences the partners of the project have on IPv6 mobility deployment in order to leverage the European IPv6 experience.
- To provide a pan-European IPv6 mobility testbed open to the research and developer communities so that they could test and validate their new applications and services.
- To define procedures and tools to conduct experiments, to gather results, to evaluate the performance and to validate the compliance with IETF standards.
- To gather together a significant number of “real users” coming from different cultural and social populations (students, teachers, ISP customers...).

The Armor team is an active member of this project. We are the leader of the WP3: Testbed integration and Validation.

7.3. Fast reroute

Participants: Bernard Cousin, Miklós Molnár, Yazid Saidi.

Fast reroute is a CRE project (France Telecom funding and partnership). The project spans 24 months.

MPLS-TE technology enables the establishment of efficient point to point or multipoint connections which should offer strict QoS guarantee. MPLS Fast Reroute proposes pro-active protection of the network connections based on pre-established backup paths. The main goal of our project is, first, to select the best paths for the backups (each backup could be shared between several connections), second to evaluate the bandwidth which should be allocated to each backup.

8. Other Grants and Activities

8.1. Regional Initiatives

Bruno Sericola continues its collaboration with Fabrice Guillemin from France Telecom (Lannion) on the analysis of standard and fluid queues [24].

8.2. National initiatives

8.2.1. ARC RARE

Participants: Gerardo Rubino, Bruno Tuffin.

We coordinate an INRIA cooperative research action on rare event simulation and its various applications. The partners are at INRIA, the project-teams Aspi, Mathfi, Omega and Mescal, abroad the CWI (The Netherlands), Bamberg University (Germany), and industrials EDF and the DGAC (see http://www.irisa.fr/armor/Rare/). This project spans over two years, starting in January 2006.

8.2.2. ACI "SURE-PATHS"

Participants: Gerardo Rubino, Bruno Sericola, Bruno Tuffin.

We worked at the ACI "SURE-PATHS" whose objective was to develop dependability analysis tools (see http://www-id.imag.fr/Laboratoire/Membres/Sbeity_Ihab/Sure-Paths/firstpage.html). We contributed on Monte Carlo analysis of Markov models, on the study of the efficiency of Monte Carlo estimators and on bounding techniques also in the context of Markov chains. This project went over three years (2003–2006).

8.2.3. ARC IFFANY

Participant: Bruno Tuffin.

We are part of the INRIA cooperative research action on InFormAtioN theorY: New challenges and new interdisciplinary tools. The partners are at INRIA, the project-teams Maestro, Trec, Hypercom, Temics, POPS, as well as France Telecom, the University of Avignon, the GET/INT, GET/ENST Bretagne, Eurecom, EPFL and the University of Cyprus (see http://www-sop.inria.fr/mistral/personnel/Eitan.Altman/ifany/). This project spans over two years, starting in January 2006.

8.2.4. Point6: IPv6 Skill Cluster

Participant: César Viho.

Point6 has the ambition to bring a support for the various public or industry actors around IPv6 technologies. Point6 could help them in progressive deployment of IPv6 in their networks which currently work very largely in IPv4, and/or in development of new applications which could draw part of IPv6 technologies, in very diverse fields such as mobile telephony and the personal assistants, house automation, car and intelligent transportation systems, or maybe in unspecified distributed industrial systems for which a better communication between the various parts is required in order to gain in effectiveness or reliability, of the new services of assistance to be brought to residence to the people to reduced capacities, etc.

Period: February 2005 - June 2006

Web site: http://www.point6.net/

8.2.5. G6 / IPv6 Task Force

Participants: Jean-Marie Bonnin, Bernard Cousin, 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 also to the multicast and the DNSSEC deployment activities promoted by the G6 group.

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

8.2.6. GDR ASR

Participants: Bernard Cousin, Miklós Molnár, Joanna Moulierac, Mohand Saidi.

B. Cousin , M. Molnár, J. Moulierac and M. Saidi participate in the ResCom group of the GDR ASR ("Architectures, Systems and Networks") of the CNRS.

8.3. European initiatives

8.3.1. NoE EuroNGI

Participants: Yézékaël Hayel, Gerardo Rubino, Bruno Tuffin.

The project is an active member of EuroNGI Network of Excellence. G. Rubino belongs to the Steering Board of NGI.

We have contributed to the deliverables of the following working packages (Joint Research Activities):

- 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.

8.3.1.1. Sub-project AUCTION of EuroNGI

Participant: Bruno Tuffin.

We coordinate the AUCTION project funded for 2005 by the network of excellence EuroNGI, to work on inter-domain pricing by means of auctions. We aim at defining the way different ISPs could negotiate exchanges to transport their own traffic (e.g. through a redefinition or generalization of BGP, the Border Gateway Protocol). This work is in collaboration with Prism laboratory (Université de Versailles-St Quentin), The University of Cantalabria, Athens University of Economics and Business, and the University of Roma 2.

8.3.1.2. NoE EuroFGI

Participants: Gerardo Rubino, Bruno Tuffin.

EuroFGI is the follow-up of EUroNGI, starting in December 2006. Bruno Tuffin becomes the INRIA team leader in this project.

8.3.2. Other European collaborations

Participant: Bruno Sericola.

- We are currently working with the Marie-Ange Remiche and Guy Latouche from the university of Brussels (ULB) on the analysis of stationary fluid queues.
- We also work on second order fluid queues with Miklos Telek (Technical University of Budapest, Ungary), Marco Gribaudo and Daniele Manini (University of Torino, Italy).

8.4. International initiatives

8.4.1. 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 (Montevideo), Gerardo Rubino (responsible for France), Bruno Tuffin, María Urquhart (Montevideo).

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.

For PAIR activities, see the Web pages: http://www.irisa.fr/armor/PAIR.

8.4.2. Other international activities

- We work with Duke university (USA) on modeling aided by Petri nets.
- We work with the University of Montreal on the development of randomized quasi-Monte Carlo methods, with applications in telecommunications.
- We participated at an ECOS project with Uruguay, with ARMOR involved in pricing and capacity planning activities.
- We work with Florida State University on quasi-Monte Carlo methods and their randomizations, with applications in finance and telecommunications.
- Program FQNRT Québec/INRIA 2006: on rare event simulation with the University of Montréal and HEC Montréal.
- *ISAT bilateral collaboration with the University of Auckland (New-Zealand) 2006-2007*. Work on pricing methods in a competitive market.
- In the STIC INRIA - DGRSRT (Universities of Tunisia) program, we have a common project with ENSI and its Cristal research laboratory, Tunisia on "Optimization of dynamic wireless networks".

8.5. Visiting researchers

- Pierre L'Ecuyer, professor at the University of Montreal, visited us for several months. He will stay at our group from February 2007 until July 2007. His main research area is simulation.
- Marie-Ange Remiche, professor at the university of Brussels, visited our laboratory in May 2006. Her main research area is on the analysis of queuing models.

9. Dissemination

9.1. Animation of research activities

9.1.1. Organization of conferences

- In 2006, we received SIGMETRICS/PERFORMANCE'06 (ACM 22th International Conference on Measurement and Modeling of Computer Systems and IFIP 7.3 25th International Symposium on Computer Performance, Modeling, Measurements, and Evaluation), at St Malo, France, June; R. Marie was the General Chair; G. Rubino was the Proceedings Chair.

  We also organized some satellite activities associated with this conference: MAMA 2006 (8th Workshop on MAthematical performance Modeling and Analysis), SysML 2006 (1st Workshop on Tackling Computer Systems Problems with Machine Learning Techniques), JSSPP 2006 (12th Workshop on Job Scheduling Strategies for Parallel Processing), ICQT'06 (5th International Workshop on Advanced Internet Charging and QoS Technologies).
- Bruno Tuffin was General Chair of ICQT'06 (see previous item), which had the subtitle "Performance has its price" (June 27, 2006, St Malo, France).
- G. Rubino organized the summer IFIP 7.3 Workshop at ST Malo, France, in June 2006, as a joint activity with SIGMETRICS/PERFORMANCE 2006.

9.1.2. Program committees

G. Rubino was Co-PC Chair of QEST'06 (International Conference on Quantitative Evaluation of Systems), Riverside, USA, September 2006.

We also served at different PC:

- Nizar Bouabdallah was PC member of IEEE GLOBECOM 2006, IEEE Global Telecommunications Conference, World Class Solutions: Networking the Globe Symposium, December 2006, San Francisco, USA.
- Bruno Tuffin was PC member of i-Society 2006, International Conference of Information Society, August 2006, Miami, USA.
- Bruno Tuffin was PC member of "European Simulation and Modelling Conference" (ESM2006), October 2006, LAAS-CNRS Toulouse, France.
- Bruno Tuffin was PC member of the 6th IEEE International Symposium on Signal Processing and Information Technology (ISSPIT'06), August 2006, Vancouver, Canada.
- Bruno Tuffin was PC member of the First International Conference on Performance Evaluation Methodologies and Tools (VALUETOOLS'06), October 2006, Pisa, Italy.
- Gerardo Rubino was PC member of SIGMETRICS/PERFORMANCE'06 (ACM 22th International Conference on Measurement and Modeling of Computer Systems and IFIP 7.3 25th International Symposium on Computer Performance, Modeling, Measurements, and Evaluation) St Malo, France, June 2006.
- Gerardo Rubino was PC member of ISAS'06 (3rd International Service Availability Symposium); Helsinki, Finland, May 2006.
- Gerardo Rubino was PC member of ICIL'06 (International Conference on Industrial Logistics), Kaunas, Lithuania, June 2006.
- Gerardo Rubino was PC member of EDDC–6 (6th European Dependable Computing Conference, IEEE et IFIP), Coimbra, Portugal, October 2006.
- Gerardo Rubino was PC member of CLAIO'06 (13th Latin-american and Spain congress in operations research), Montevideo, Uruguay, November 2006.
- Gerardo Rubino was PC member of HET-NETs'06 (4th International Conference in Performance Modelling and Evaluation of Heterogeneous Networks), Ilkley, West Yorkshire, UK, September 2006.

- Gerardo Rubino was PC member of WCIT'06 (Wireless Communications and Information Technology in Developing Countries, IFIP WG 6.9 meeting), Santiago, Chile, August 2006.
- Bruno Sericola was PC member of ASMTA'06, 13th International Conference on Analytical and Stochastic Modelling Techniques and Applications, Bonn, Germany, May 2006.
- Bruno Sericola was PC member of AlgoTel'06, 8ème rencontres francophones sur les aspects Algorithmiques des Télécommunications, Trégastel, France, May 2006.
- Bruno Sericola was PC member of CFIP'06, Colloque Francophone sur l'Ingénierie des Protocoles, Tozeur, Tunisie, 30 October – 3 November 2006.
- Raymond Marie was PC member of QEST'06 (International Conference on Quantitative Evaluation of Systems), Riverside, USA, September 2006.
- Bernard Cousin was a member of the Review Committee of MajecSTIC 2006. This is a French conference for young researchers.
- Bernard Cousin was PC member of DNAC 2006 (De Nouvelles Architectures pour les Réseaux).

9.1.3. Managing research activities

- B. Tuffin is a member of the "Comité des actions incitatives" for the "Conseil d'Orientation Scientifique et Technologique de l'INRIA" (COST).
- G. Rubino was the President of the Scientific Committee of the UR Rennes until 31/08/07 and as a consequence, a member of the Laboratory Committee of the UR and of the Evaluation Commission of INRIA.
- G. Rubino is a member of the Specialists Commission (Computer Science) at the University of Versailles.

9.2. Participations in seminars, invitations

- B. Tuffin gave a lecture "A decentralized learning algorithm when pricing a RED buffer" at the Internet Economics Dagstuhl seminar, Dagstuhl, Germany, March 2006.
- B. Tuffin and G. Rubino gave two talks at the IFIP WG7.3 meeting, St Malo, June 2006.
- G. Rubino was invited speaker at CLAIO'06 (talk about PSQA) and at ERPEM'06 about transient analysis of Markovian queues.
- B. Cousin, and M. Molnár visited the CRISTAL Laboratory of Ecole Nationale Supérieure d'Informatique (ENSI) in Tunis.
- B. Cousin was invited to visit the Dublin City University and its Research Institute in Networks and Communications Engineering (RINCE) in September 2006.
- M. Molnár visited the Department MIT of the Technical University at Budapest.

9.3. Teaching

9.3.1. 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, N. Bouabdallah, B. Cousin, R. Marie, G. Rubino, B. Sericola, C. Viho, give different courses in thwo Masters (in Probability and in Computer science), in the 3rd year of DIIC at the Rennes 1 university, at the ENST Bretagne, the INSA and at the ENSAI. The main subjects are networking, protocols, dimensioning problems, dependability analysis, etc. C. Viho is in charge of the 2nd year of the Master in Computer Science at the Rennes 1 university. B. Cousin gave a course on Network Security in June 2006 at Institut National des Télécommunications (INT).

9.3.2. International teaching activities (NB)

- N. Bouabdallah gave a course on computer networks at the Institute of management Gabes Tunisia (February 2006).
- G. Rubino gave a course on performance evaluation at the Lebanese University of Beyrouth, in the context of a joint doctoral program between this university and other European institutions (February 2006).
- B. Cousin gave a course multicasting at the university of Bucharest (April 2006).
- B. Cousin is in charge of the coordination of the french side for the DESS NTIM at Cocody university (Abidjan, Ivory Coast). He is currently helping to create an Doctorate School in computer science in Ivory Coast. This "Ecole Doctorale" regroups the Cocody university and the polytechnic institute Felix Houphouet Boigny (INPHB).
- M. Molnár participated to the master thesis formation at ENSI, Tunisia.
- M. Molnár gave a course at the University ENSA, Oujda, Morocco.

9.4. Editorial activities

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

9.5. Standardization activities

Participants: Bernard Cousin, Gilles Guette, César Viho.

The Armor team dedicates a significant effort towards 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. We also participated to the RFC 4033 on DNS security.

9.5.1. IPv6 Ready Logo Program

Participant: César Viho.

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 Program". 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 Program 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.

9.6. Participation to the evaluation of research

Raymond Marie was the leader that President of the Evaluation Committee of the Institut National des Télécommunications (INT).

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