INRIA

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team dionysos

Dependability Interoperability and perfOrmance aNalYsiS Of networkS

Rennes - Bretagne-Atlantique

Theme : Networks and Telecommunications

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2. Overall Objectives

2.1. Introduction

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 (QoS), Quality of Experience (QoE) and performability evaluation).

The DIONYSOS group works on different 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 their different components. 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, at different levels. Concerning the types of networks considered, we mainly work in the wireless area, in particular on sensor networks, on Content Delivery Networks for our work around measuring the perceived quality, the main component of QoE, and on some aspects of optical networks. We also work on the assessment of interoperability between specific network components, which is essential to ensure that they interact correctly before they get deployed in a real environment. As such, it is considered as a part of the standardization process. Our team contributes in providing solutions (methods, algorithms and tools) which help in obtaining efficient interoperability test suites for new generation networks. From the application point of view, we also have activities in pricing methodologies, a critical multi-disciplinary area for telecommunications providers, with many defying open problems for the near future.

For most of previous mentioned problems, our work concern their quantitative aspects. The quantitative aspects we are interested in are QoE, performance, dependability, performability, QoS, vulnerability, etc. We develop techniques for the evaluation of these different aspects of the considered systems through *models* and through *measurement techniques*. In particular, we develop techniques to measure in an automatic way the quality of a video or audio communication *as perceived by the final user*. 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.

2.2. Highlights

- The group MAPI (see 9.1.6), created by Bruno Sericola started its activities this year.
- Bruno Tuffin published book on Monte Carlo techniques [74].

3. Scientific Foundations

3.1. Introduction

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 associated 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 it can be seen as an unifying concept in our activities. Then we briefly describe the specific sub-area of models' evaluation and about the particular multidisciplinary domain of Network Economics.

3.2. Quality of Service and Quality of Experience

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, or vulnerability, in the case for instance of WAN (Wide Area Network) topologies, etc.

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 specific levels of QoS, or to improve the provided QoS, if we think of a particular system, with an optimal use of the resources available. 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 also investigate the impact of network QoS on multimedia payloads to reduce the impact of congestion.

Some important aspects of the behavior of modern communication systems 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. We are interested in analyzing these types of flows from this user-oriented point of view. We focus on the *user perceived quality*, the main component of what is nowadays called Quality of Experience (in short, QoE), to underline the fact that, in this case, we want to center the analysis on the user. In this context, we have a global project called PSQA, which stands for Pseudo-Subjective Quality Assessment, and which refers to a methodology allowing to automatically measuring the QoE.

Another special case to which we devote research efforts in the team is the analysis of qualitative properties related to interoperability assessment. 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 is the act of determining to what extent a single component conforms to the individual requirements of the standard it is based on. Our purpose is to provide such a formal framework (methods, algorithms and tools) for interoperability assessment, in order to help in obtaining efficient interoperability test suites for new generation networks, mainly around IPv6 related protocols. The interoperability test suites generation is based on specifications (standards and/or RFCs) of network components and protocols to be tested.

3.3. Stochastic modeling

The scientific foundations of our modeling activities are composed of stochastic processes theory and, in particular, Markov processes, queuing theory, stochastic graphs theory, etc., either for developing 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 systems from the classical so-called *call level*, leading to standard models (for instance, queuing ones) and also at the *burst level*, leading to *fluid models*.

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 an increasing demand (and experience has shown that demand of bandwidth has always been ahead of supply), especially now that the Internet is becoming 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 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 can help in improving the management of the network but is a costly option. These are some of the various aspects often present in the pricing problems we address in our work. More recently, we have switched to the more general field of network economics, dealing with the economic behavior of users, service providers and content providers, as well as their relations.

4. Application Domains

4.1. Panorama

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 QoE, IP mobility, ...), and on analysis and dimensioning tools: telecommunications architecture configuration, bottleneck search, resource allocation policies comparison, etc.

We can start by pointing out the PSQA technology we have been developing in the last years (PSQA stands for Pseudo-Subjective Quality Assessment) that allows an automatic and quantitative evaluation of the quality delivered to the user by a network transporting audio or video content. PSQA is accurate (which means that it provides values close to those that would have been obtained using a panel of human observers) and efficient (which means that it can work, if useful or necessary, in real time). Its main application area is in network monitoring: PSQA allows to deploy an auditing system that can continuously analyze the perceived quality (the QoE) at specific points in the network. The other main application area of PSQA is in network control, exploiting the fact that the quality assessment can been done in real time. The first applications of our technique that are currently being explored are in the monitoring and control of networks transporting video flows, with focus on IPTV applications in the context of P2P infrastructures and, more generally, of CDN (Content Delivery Networks), on networks of mobile terminals, on the properties of the SVC codec and their impact on the QoE.

In the field of traffic engineering and system dimensioning, the 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, or cellular IP, are also important application domains for our research work.

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 our 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 associated with the interoperability of network components, etc. 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 analysis, or to QoE assessment). 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 network architecture (topology) without taking into account the reliability of each component).

5. Software

5.1. T3devKit testing toolkit and IPv6 test suites

Participants: Anthony Baire, François Lerebours, César Viho.

We have built a toolkit for easing executing tests written in the standardised TTCN-3 test specification language. This toolkit is made of a C++ library together with a highly customisable CoDec generator that allows fast development of external components (that are required to execute a test suite) such as CoDec (for message Coding/Decoding), System and Platform Adapters. It also provides a framework for representing and manipulating TTCN-3 events so as to ease the production of test reports. The toolkit addresses issues that are not yet covered by ETSI standards while being fully compatible with the existing standard interfaces: TRI (Test Runtime Interfaces) and TCI (Test Control Interfaces), it has been tested with four TTCN-3 environnements (IBM, Elvior, Danet and Go4IT) and on three different platforms (Linux, Windows and Cygwin). It is publicly released under the CeCILL-C License.
All these tools with associated test suites (for RIPng, DHCPv6 and examples for DNS) are freely available at http://www.irisa.fr/tipi.

5.2. Interoperability Assessment

Participants: Anthony Baire, François Lerebours, César Viho.

In previous works we have developed a software toolkit named T3DevKit for easing the development of TTCN-3 tests. The original tool could only run on POSIX systems with the gcc toolchain. This year we refactored the build system using the *waf* build automation tool, which allowed us to integrate with other operating systems and toolchain (especially MSVC on Windows). This work allowed us to uncover interoperability issues between tools in the TTCN-3 standard and a poster was presented at the TTCN-3 User Conference 2010. We also presented an introduction tutorial for T3DevKit at this conference[79].

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`.

6. New Results

6.1. Network Economics

Participants: Hai Tran Hoang, Bruno Tuffin.

While pricing telecommunication networks was one of our main activities for the past few years, we are now dealing with the more general topic of *network economics*. We have tackled it from different sides: i) investigating how QoS or QoE can be related to users' willingness to pay, ii) pricing for telecommunication access, iii) investigating the consequences and equilibrium due competition among providers in different contexts, iv) studying the economic aspect of interdomain relationships, v) looking at the economics of applications, for example adword auctions for search engines, vi) investigating the economics of security in telecommunications.

On the first item, in [48], [26], we have studied how utility functions can be related to QoE recent research. Indeed, a logarithmic version of utility usually serves as the standard example due to its simplicity and mathematical tractability. We argue that there are much more (and better) reasons to consider logarithmic utilities as really paradigmatic, at least when it comes to characterizing user experience with specific telecommunication services. We justify this claim and demonstrate that, especially for Voice-over-IP and mobile broadband scenarios, there is increasing evidence that user experience and satisfaction follows logarithmic laws. Finally, we go even one step further and put these results into the broader context of the Weber-Fechner Law, a key principle in psychophysics describing the general relationship between the magnitude of a physical stimulus and its perceived intensity within the human sensory system.

We have continued to design efficient pricing for network access, based on congestion. As a general pricing principle, since there is usually no strict guarantee of QoS, we have designed in [30] a technique where a reimbursement is realized in case a QoS threshold is not met. We have compared it with the case without reimbursement and illustrated that it could drive to a higher revenue for a provider (because more users are likely to apply).

Our main activity has nevertheless been around competition among telecommunication providers [69]. Our main models have been reviewed in [64], [65]. While most of the previous research was focusing on price optimization for a provider in a monopoly, we believe that the same results would not be valid in the current telecommunication world, with several providers in competition for customers. This additional component is therefore a key part of our work. For example, in [20], we have studied the case of a WiFi operator against a WiMAX one, WiFi being operated in the smaller area. Using a simple model, we discuss how, for fixed prices, (elastic) demand is split among providers, and then characterize the Nash equilibria for the price war. We derive the conditions on provider capacities and coverage areas under which providers share demand on the common area. Similarly, we have studied in [43], [21] another level of game on top of the price war: providers have indeed the possibility to choose which technologies to implement, depending on the infrastructure and licence (if any) costs, anticipating what would be the resulting price war outcome and revenue for given profiles of sets of technologies. This type of study may help a regulator to decide a licence cost (for instance the last 3G licence cost) in order to drive the resulting Nash equilibrium to a better point in terms of social or user welfare.

Another important activity is around interdomain issues, a network like the Internet being made of thousands of autonomous systems. Intermediate domains need some (economic in our case) incentives for forwarding the traffic of other domains. In [29], we have described the problem, provided a state of the art and highlighted the difficulties that must be solved. In [53], we have designed a decentralized algorithm based on double-sided auctions to allocate (and charge) the resource usage.

We are also starting to look at the application side. In order to make money many service providers base their revenue on advertisement. We focus in [42] on search engine providers for which specific slots in response to keywords are assigned to advertisers depending on the amount each advertiser agrees to pay if a user clicks on its link. While auctions with a deterministic allocation rule form the pricing mechanism applied by sponsored search engine and the one getting all the attention, we illustrate that an alternative pricing scheme, selecting randomly but with a prespecified distribution the advertisers to be displayed, can bring a larger revenue.

Finally, we have looked in [73] at the competition aspects linked to security. We have reviewed the interactions and strategies of attackers and defenders, and started to investigate the economics of security service providers, an issue on which we have worked this year.

6.2. Dependability and extensions

Participants: Raymond Marie, Gerardo Rubino, Samira Saggadi, Bruno Sericola, Bruno Tuffin.

We maintain a research activity in different areas related to dependability, performability and vulnerability analysis of communication systems. In 2010 our focus has been on evaluation techniques using both the Monte Carlo and the Quasi-Monte Carlo approaches. Monte Carlo (and Quasi-Monte Carlo) methods often represent the single tool to solve complex problems, and rare event simulation requires a special attention, to accelerate the occurrence of the event and get an unbiased estimator with a sufficiently small relative variance.

Those issues are summarized in the book on Monte Carlo simulation, addressed to graduate students or practitionners, [74]. It presents all the basic notions from random number generation output analysis, variance reduction techniques and shows how they can be applied to the computation of integrals or sums, and to solve equations or optimization problems.

Novel results in simulation can be decomposed into two subsets: results on rare event simulation, and those on Randomized Quasi-Monte Carlo methods. Randomized quasi-Monte Carlo (RQMC) methods estimate the expectation of a random variable by the average of n dependent realizations of it. In general, due to the strong dependence used, the estimation error may not obey a central limit theorem. Analysis of RQMC methods have so far focused mostly on the convergence rates of asymptotic worst-case error bounds and variance bounds, when n tends to infinity, but little is known about the limiting distribution of the error. We have analyzed that asymptotic distribution in [18] for the special case of a randomly-shifted lattice rule, when the integrand is smooth. We show that for the simple case of one-dimensional integrands, the limiting error distribution is uniform over a bounded interval if the integrand is non-periodic, and has a square root form over a bounded interval if the integrand is periodic. We find that in higher dimensions, there is little hope to precisely characterize the limiting distribution in a useful way for computing confidence intervals in the general case. We nevertheless examine how this error behaves as a function of the random shift from different perspectives and on various examples. We also point out a situation where a classical central-limit theorem holds when the dimension goes to infinity, we provide guidelines on when the error distribution should not be too far from normal, and we examine how far from normal is the error distribution in examples inspired from real-life applications.

Most of our simulation activity has nevertheless been on rare event simulation. See [1], edited by G. Rubino and B. Tuffin, where a rather complete overview of the domain and a state-of-the-art about the research in most of its subfileds are presented. In [17], we have discussed the importance of designing estimators that stay efficient as the probability of the considered event decreases to zero. While robustness properties generally look at the second moment only, we discuss the importance of investigating higher order moments, and define related properties. For the adaptive estimators, for which the parameters are therefore random, one cannot strictly guarantee robustness properties, but statistical guarantees can be provided, as highlighted in [66].

The typical application of rare event simulation we have used is the evaluation of the probability that a graph is disconnected. We propose in [19] a new Monte Carlo method, based on dynamic importance sampling, to estimate this probability. The method generates the link states one by one, using a sampling strategy that approximates an ideal zero-variance importance sampling scheme. The approximation is based on minimal cuts in subgraphs. In an asymptotic rare-event regime where failure probability becomes very small, we prove that the relative error of our estimator remains bounded, and even converges to 0 under additional conditions, when the unreliability of individual links converges to 0, a property not satisfied by previous estimators. In [60], this method is combined with a Recursive Variance Reduction (RVR) estimator which approaches the unreliability by recursively reducing the graph from the random choice of the first working link on selected cuts. In [71], a conditional Monte Carlo method taking into account the expected number of samples over which a prespecified set of disjoint minpaths linking the set of nodes fails is analyzed, and combined with quasi-Monte Carlo methods. The combination with approximate zero-variance importance sampling is done in [35], where we derive asymptotic robustness properties of the resulting estimator when reliabilities of individual links go arbitrarily close to one, and we illustrate numerically the gain that can be obtained on large graphs. In [61], we explore the capability of the Importance Splitting approach to attack these static problems. Important Splitting is a generic technique designed to estimate rare event probabilities defined on stochastic processes. In [61], we adapt the method to the static context and discuss an idea for estimating network reliability metrics.

We worked on the risk on spares for life-time maintenance purposes due to uncertainties on the mean up time. More precisely, we consider the case of a mono-production of a small quantity of complex (and expensive) systems, where we have to determine, at the moment when the global system is produced, the quantity of spares we want to produce for life-time maintenance purposes. The present difficulty comes from the fact that we assume that the steady state mean up time is not known precisely but is considered as uniformly distributed

on a time interval $[a, b]$. We were able to exhibit the formal expression of the probability distribution of the spare consumption for a given duration of the life-time. A first paper was presented in a conference ([45]) and an extended version was published in [22].

Another study focuses on the case where, inside a maintenance organization, the repairman has to go to a distant operational site with a collection of spare items of different types due to lack of information. At the end of his maintenance intervention, the unused spares are put back on the shelves. Because the intervention takes a significant amount of time (the travel time is important), we show that this situation where the spares are borrowed plays a significant part in the value of the spare shortage probability. We present in [56] a detailed model that allows us to take this situation into account. An attempt to produce a simpler model has resulted in a heuristic which can be recommended as a substitution for the detailed model only when using highly time consuming iterative optimization processes.

The determination of the mission time availability when identical items share a single spare inventory has been the object of one of our studies [55] . The exchange time is neglected and the eventual unavailability is only due to the lack of spares before the end of the mission. the lifetimes of the components are supposed to follow an exponential probability distribution. First, semi-formal expressions of state probabilities of different Boolean variables are exhibited thanks to efficient recurrent procedures. Then the value of mission time availability is obtained by using graph manipulations initiated by an ordered Shannon tree (binary decision tree).

Another study [54] exposes a resolution process for the operational availability evaluation in the case when there is a commutation time for redundant system with different elements. This resolution must be analytic in order to include this solution into software which uses iterative process for optimization, like spare optimization with availability target. So far, we have been able to obtain a very satisfactory approximation for the case of redundancy $(n-1)/n$. But future work is needed for le general case k/n.

We obtained in [15] an improvement of an algorithm we developed a few years ago for the distribuition computation of the cumulative reward in Markov chains.

6.3. Performance evaluation

Participants: Laura Aspirot, Raymond Marie, Gerardo Rubino, Bruno Sericola.

We maintain a set of activities about the evaluation of the performance of specific systems, and about the development of techniques for performing these evaluations.

In [16], we proposed in a fully decentralized algorithm to provide each node with a value reflecting its connectivity quality. Comparing these values between nodes, enables to have a local approximation of a global characteristic of the graph. Our algorithm relies on an anonymous probe visiting the network in a unbiased random fashion. Each node records the time elapsed between visits of the probe which is called the return time of the random walk. Computing the standard deviation of such return times enables to approximate the conductance of the graph. Typically, this information may be used by nodes to assess their position, and therefore the fact that they are critical, in a graph exhibiting low conductance. This work is a collaboration with the Inria team-project Asap.

In [27], we expose a methodology to analyze maximum level and hitting probabilities in a Markov driven fluid queue for various initial condition scenarios and in both cases of infinite and finite buffers. Step by step we build up our argument that finally leads to matrix differential Riccati equations for which there exists a unique solution. The power of the methodology resides in the simple probabilistic argument used that permits to obtain analytic solutions of these differential equations. We illustrate our results by a fluid model that we exactly solve.

We continue our collaboration with the Inria team-projects Adept and Ipso. In [32], we present an analytic study of the impact of churn in cluster-based overlay networks and we accurately predict the frequency at which the topology of the overlay changes according to the number of join/leave operations.

It is well-known that peer-to-peer overlays networks can only survive Byzantine attacks if malicious nodes are not able to predict what will be the topology of the network for a given sequence of join and leave operations. In [76], we investigate adversarial strategies by following specific games. Our analysis demonstrates first that an adversary can very quickly subvert DHT-based overlays by simply never triggering leave operations. We then show that when all nodes (honest and malicious ones) are imposed on a limited lifetime, the system eventually reaches a stationary regime where the ratio of polluted clusters is bounded, independently from the initial amount of corruption in the system. These results have been obtained using Markov models. In [77], we consider the behavior of a stochastic system composed of several identically distributed, but non independent, discrete-time absorbing Markov chains competing at each instant for a transition. The competition consists in determining at each instant, using a given probability distribution, the only Markov chain allowed to make a transition. We analyze the first time at which one of the Markov chains reaches its absorbing state. We obtain its distribution and its expectation and we propose an algorithm to compute these quantities. We also exhibit the asymptotic behavior of the system when the number of Markov chains goes to infinity. Actually, this problem comes from the analysis of large-scale distributed systems and we show how our results apply to this domain.

In [49] we analyzed the idea of a peer-to-peer (P2P) system where some of the arriving peers are given priority over the remaining ones, based on the fact that they trend (statistically) to stay connected longer. We modeled this situation and explored the quantitative properties of the resulting system by simulation and by using deterministic models (ODEs). In the literature, this last approach is mathematically explored under the general label of mean field techniques. They are used to analyze the way, in some cases, a large Markovian model converges toward a deterministic differential one. We are exploring these convergence aspects in the case of models, focusing first on the case of P2P networks. Some preliminary results were presented in [57] and in [67]. In particular, we obtained convergence results allowing to find specific performance metrics defined in the initial large Markov model by working with the (compact) deterministic one.

Concerning the use of large Markov models and the way of analyzing them using different techniques (simulation, numerical methods, bounding procedures), we started to present the characteristics of a tool we are developing, called AF ([68]). The tool allows to describe the Markov model using a general language (`C` in our implementation) and it has been deigned to provide different facilities to researchers aiming at developing analysis techniques, belonging to the three categories described below.

In [68], we explore the concept of power of a queueing model proposed by Kleinrock in the 80s. Kleinrock's idea was to build a metric combining two "competing" ones, the mean trhoughput and the mean respnse time, for the system in equilibrium. The power is defined as the ratio of normalized versions of those metrics. We discuss different ways of adapting this concept to more general queueing systems such as queueing networks.

The paper [45] has been published under the scientific sponsoring of IFIP WG 6.3 and 7.3. Because the elements of modeling in general and of performance evaluation of discrete event systems (DES) in particular have undergone a tremendous transformation during these last four decades, the aim of this paper is to look back over all this evolution, trying to retain some particular experiences from the past together with some suggestions to preserve the quality of the expertise of the community are proposed.

Finally, we managed the publication of [75], together with two colleagues from Turin (S. Donatelli) and from Montréal (P. Panangaden), where the general topic is the performance evaluation of computer and communication systems.

6.4. QoE (Quality of Experience)

Participants: Sebastián Basterrech, Sofiene Jelassi, Adlen Ksentini, Kandaraj Piamrat, Gerardo Rubino, Kamal Singh, César Viho.

We continue the development of the PSQA technology (Pseudo-Subjective Quality Assessment) in the area of Quality of Experience (QoE). PSQA is a method to build measuring modules capable of quantifying the quality of a video or an audio sequence, as perceived by the user, when received through an IP network. PSQA provides an accurate and efficiently computed evaluation of the quality. Accuracy means that PSQA gives

values close to those than can be obtained from a panel of human observers, under a controlled subjective testing experiment, following an appropriate norm (which depends on the type of sequence or application). Efficiency means that our measuring tool can work in real time, if necessary. Observe that perceived quality is the main component of QoE.

At the heart of the PSQA approach there is the statistical learning process necessary to develop measuring modules. So far we have been using Random Neural Networks (RNNs) as our learning tool. In [58] we continue the exploration of improved versions of the main learning procedures. The general idea is to extend techniques designed for the standard Artificial Neural Network field to RNNs. In [59] we discuss how to combine the PSQA approach with the good qualities of the PESQ (Perceptual Evaluation of Speech Quality) method for assessing the quality of voice sequences. PESQ designs a set of techniques capable to evaluate the perceived quality of speech but needing access to the original signal. We follow here the "black-box" PSQA with the goal of building a PESQ-like tool but in the no-reference class, that is, no needing access to the sequence before distortion by the network. In [50] we discuss the use of PSQA-based tools in order to design new pricing techniques in the networking domain. The idea is to use the fact that PSQA allows to analyze network components and systems addressing the ultimate target from the users' point of view, the quality as they perceive it, and that way, to build pricing schemes having quality as the main target. [50] provides some preliminary ideas about this important issue for the future of networks. In [51], we explore the case of DVB-H networks with variable bit rate H-264 coding, extending our previous work in no-reference video quality assessment.

On the other hand, deployment of heterogeneous wireless networks (i.e. 4G) is spreading throughout the world, as users want to be connected anytime, anywhere, and anyhow. Meanwhile, these users are interested more and more in multimedia applications such as video streaming and Voice over IP (VoIP), which require strict Quality of Service (QoS) support. Provisioning such constraints in this kind of system is very challenging. In fact, consider the availability of various access technologies: WiFi, WiMAX, or Cellular networks; it is difficult for a network operator to find reliable criteria to select the best network that ensures users satisfaction while maximizing network utilization. Thus, designing efficient Radio Resource Management (RRM) is mandatory for tackling such constraints. In order to provide a better understanding of RRMs design, we presented in [25] a detailed investigation of key challenges that constitutes an efficient RRM framework as well as a classification of existing solutions on RRM, in term of decision-making. Moreover, we investigated in [47],[78] how QoE can help for designing efficient RRM for wireless networks. In [47] we presented a QoE-based scheduler for 3G networks. Unlike the existing solution that are based on data rate or other QoS parameters, our solution propose to use PSQA (QoE metric) in order to schedule users transmission on the uplink direction. In [78] we proposed a novel network selection mechanism for heterogonous wireless networks that takes QoE into consideration for decision-making. The main idea is to use quality of experience of ongoing users in candidate networks as an indicator to select the best network for connection.

6.5. Optical networks

Participants: Nizar Bouabdallah, Charlotte Roger.

Typical optical-based backbones are in general underutilized. This is not due to the lack of transmission needs, but to other factors, among which we underline two: the bottleneck effects at access networks, and the somehow rigid and inefficient way of using the optical infrastructure as nowadays available in the current technology. In the team, we work for providing new techniques in order to utilize efficiently the tremendous transmission capacity offered by the optical equipments. To achieve this, we propose intelligent traffic aggregation mechanisms and efficient routing algorithms [10].

Optical technology has increased significantly the transmission capacity of today's transport networks, and it is playing important roles in supporting the rapidly increasing data traffic. Meanwhile, congestion issues are definitively relieved in such core networks. Nonetheless, the rigid and large routing granularity (i.e. wavelength) entailed by such an approach could lead to bandwidth waste [10]. In this regard, increasing research interest is now focusing on the development of new concept of traffic aggregation in optical networks.

The main objective of our work is therefore eliminating both the bandwidth underutilization and the scalability concerns that are typical of all-optical wavelength-routed networks.

6.6. Wireless networks

Participants: Nizar Bouabdallah, Yassine Hadjadj Aoul, Adlen Ksentini, Bruno Sericola.

Wireless communications continues to pervade all aspects of our lives: wireless distribution of audio and video around the home, wireless solutions for logistics, wireless ticketing and access control, wireless sensors for agriculture, medical applications, etc. Meanwhile, audio/video streaming applications impose stringent requirements on communication QoS metrics and Quality of Experience (QoE). To cope with these aspects, operators are looking for efficient and cost effective solutions that ensure the scalability of their systems, the quality (QoS and QoE) of the supported services and their security. However, studies indicate that security mechanisms require extra resources at both the network and end-users, often impacting the perceived quality and sometimes degrading the overall system performance. In this line, we proposed in [52] an "agile" framework, dubbed as QoS2 (i.e., Quality of Service and Security), that protects the network from malicious usage and attacks. The proposed framework provides an adjustable level of security to ensure acceptable QoS/QoE employing a Multi Attribute Decision Model (MADM) approach. In [72], we presented a delay-based admission control algorithm in IEEE 802.11. We presented an accurate delay estimation model to adjust the contention window size in real-time basis by considering key network factors, MAC queue dynamics, and application-level QoS requirements. Based on the abovementioned delay-based CW size we introduced a fully distributed admission control protocol to guarantee QoS.

While there have been many important advances in wireless technology in recent years, there are economic challenges in providing high-speed wireless access to less populated areas. A key technology which can help is satellite communications as it can be used in areas where there is no terrestrial alternative. Two critical issues arise when considering satellite systems in this context: firstly, satellite systems are very costly in general; and secondly, there are challenges in integrating satellite and terrestrial networks, particularly when terminal mobility is necessary. In [28] we give some insights towards solving both of these problems. Specifically, we focused on interworking between the satellite part of the network and its terrestrial counterpart. Interworking related operations are performed at newly defined entities called Interworking Gateways (IGWs). We defined modules of the technological solutions that will be incorporated in IGWs and to evaluate their performances via computer simulations.

Efficient mobility management is one of the major challenges for next-generation mobile systems. Indeed, a mobile node (MN) within an access network may cause excessive signaling traffic and service disruption due to frequent handoffs. The two latter effects need to be minimized to support QoS requirements of emerging multimedia applications. In our work, we propose a new adaptive micro-mobility management scheme designed to track efficiently the mobility of nodes so as to minimize both handoff latency and total signaling cost while ensuring the MNs QoS requirements [41]. We introduce the concept of residing area. Accordingly, the micro-mobility domain is divided into virtual residing areas where the MN limits its signaling exchanges within this local region instead of communicating with the relatively far away root of the domain at each handoff occurrence. A key distinguishing feature of our solution is its adaptive nature since the virtual residing areas are constructed according to the current network state and the QoS constraints. To evaluate the efficiency of our proposal, we compared our scheme with existing solutions using both analytical and simulation approaches. Numerical and simulation results show that our proposed scheme can significantly reduce registration updates and link usage costs and provide low handoff latency and packet loss rate under various scenarios.

Multi-hop wireless networks, called also wireless mesh networks (WMNs), has gained a large interest this last decade. One of the main advantages of WMN is their ability to increase the radio coverage as regards to the one-hop wireless networks. One concern with WMN is the radio resource utilization efficiency, which can be enhanced by managing efficiently the mobility of users as well as the interference effect among neighboring links. Our main objective is therefore to route efficiently the traffic generated by mobile nodes including the signaling messages in order to optimize network radio resource utilization. In other words, we aim at

minimizing the total signaling cost by controlling the number of registration updates with the root of the domain. To achieve this, we propose new micro-mobility management schemes based on clustering techniques to track efficiently the mobility of nodes within the network. These mechanisms are conceived to minimize the total signaling cost of exchanged messages needed to manage the mobility of nodes as well as to optimize the link usage cost of the data traffic generated by each mobile user [40].

As a second alternative to increase the capacity of wireless mesh networks, we propose using the cognitive radio (CR) capabilities. The capacity of a WMN is indeed dependent on the spectrum resources it has, and the efficiency with which it uses them [13]. In our work, we considered the use of cognitive radio to improve this efficiency, by allowing networks belonging to different service providers to share both spectrum and infrastructure resources according to several different models. Using an ILP based problem formulation, this approach is demonstrated to yield significant benefits to the networks, by increasing QoS or allowing the networks to decrease their spectrum requirements.

In large scale multi-hop wireless networks, flat architectures are typically not scalable. Clustering was introduced to support self-organization and enable hierarchical routing. When dealing with multi-hop wireless networks, robustness is a crucial issue due to the dynamism of such networks. Several algorithms have been designed for clustering. In [14], we show that a clustering algorithm that previously exhibited good robustness properties, is actually self-stabilizing. We propose several enhancements to the scheme to reduce the stabilization time and thus improve stability in a dynamic environment. The key technique to these enhancements is a localized self-stabilizing algorithm for Directed Acyclic Graph (DAG) construction. We provide extensive studies (both theoretical and experimental) that show that our approach enables efficient yet adaptive clustering in wireless multi-hop networks.

On the other hand, Self-stabilization protocols are a useful technique to provide self-organization but their stabilizing time is related to the size of the network. A wide range of problems such as TDMA assignment or clustering may be solved thanks to local coloring on a graph model but with a tradeoff between the coloring time and the stabilization time of the protocol using the coloring. This stabilization time is related to the height of a directed acyclic graph induced by the colors, thus to the longest strictly ascending sequence of colors. In [24], we model this height by the longest increasing contiguous sequence of non-independent uniform random variables. Then using a Markov chain approach, we obtain a theoretical upper bound on the stabilization time. More precisely, our results show the scalability properties of such a protocol, but also that using a large number of colors does not impact its stabilization time. In [23], we show that a clustering algorithm, known for its good robustness properties, is actually self-stabilizing. We propose several enhancements to the scheme to reduce the stabilization time and thus improve stability in a dynamic environment. The key technique to these enhancements is a localized self-stabilizing algorithm for directed acyclic graph construction. We provide extensive studies (both theoretical and experimental) that show that our approach enables efficient yet adaptive clustering in wireless multihop networks.

6.7. Sensor networks

Participants: Nizar Bouabdallah, Mario Rivero, Bruno Sericola, Sofiane Moad.

Wireless sensor networks (WSNs) can be viewed as a particular case of wireless mesh networks (WMNs), where designers have to cope with the limited power, buffering and processing capacities of the sensor nodes. Despite these limitations, the growing capabilities of these tiny motes, which consist of sensing, data processing, and communicating, enables the deployment of reliable WSNs based on the cooperative effort of a large number of sensor nodes.

In contrast to the traditional networks aim to achieve high QoS levels, sensor network protocols focus primarily on power conservation, because of the limited capacity of the sensor nodes' batteries. However, this should be accomplished while respecting certain constraints on the information reliability and reporting delays. The physical phenomenon should be indeed reliably detected and estimated from the collective information provided by sensor nodes, in order to be able to initiate right actions.

Achieving these two opposite requirements, i.e., the trade-off between energy conservation and information reliability, is the key driver of our work on WSNs.

To reduce the transmission of redundant information while respecting the QoS application requirements, we proposed to profit from the natural temporal and spatial correlation among the observations of the densely deployed sensor nodes.

For instance, continuous monitoring applications require periodic refreshed data information at the sink from the sensor nodes. Profiting from spatial correlation to asleep redundant nodes or using data aggregation is usually not desired with such applications, where the network is designed to provide a continuous tracking of the individual sensor nodes' measurements. The sink node is usually interested in the separate measurements of sensor nodes, which may be used to control or test the behavior of different components of a new product. To date, this entails the need of the sensor nodes to transmit continuously in a periodic fashion to the sink, which may lead to excessive energy consumption.

To reduce the transmission of redundant information without affecting the application requirements, we proposed to profit from the natural temporal correlation among the successive observations of each sensor node. Specifically, we proposed to perform smarter data reporting by avoiding the transmission of non relevant data information [33]. By relevant data we refer to data that contains different information from the previous data transmitted by the same sensor. It has been verified that our scheme can allow for an improvement in the network lifetime while ensuring the continuous monitoring task. The gain greatly depends on the rate of variation of the phenomenon that the sensors are monitoring.

Considering continuous monitoring applications, we also proposed to further improve the network lifetime by balancing efficiently the energy consumption within the WSN [46], [70].

The routing protocols should indeed avoid the energy depletion of nodes with naturally higher load, a typical issue in conventional routing schemes such as with MTE (minimum total energy) routing. The MTE routing consists in finding the route that minimizes the total consumed energy between any pair of source and destination nodes. Nevertheless, routing always through the path with the minimum energy consumption, will deplete quickly the energy of the sensor nodes contained therein, causing thus a premature death of the WSN.

A perfect routing protocol would hence drain energy slowly and uniformly among nodes, leading to the death of all the sensors nearly at the same time. Typically, an ideal routing protocol would spread efficiently the traffic inside the network and avoid the fast drain of sensor nodes with natural high energy consumption.

To achieve this, we proposed balancing the energy consumption throughout the network by sending the traffic generated by each sensor node through multiple paths instead of forwarding always through the same path. The problem consists then in determining the set of routes to be used by each sensor node and the associated weights (i.e., the routing configuration) that maximize the network lifetime. As a main contribution of this work, we showed that by efficiently balancing the traffic inside the network, significant energy savings up to 15% can be achieved compared to the basic routing protocols.

So far, we have described different solutions to reduce the energy consumption in WSNs at different layers: physical (transmission range adjustment), MAC (sleep schedule, correlation-based schemes) and network layers (load balancing). While these protocols may achieve very high performance; in essence, they have not been jointly designed to maximize the overall network performance, specifically to minimize the energy expenditure. The main threat is that the gain achieved at one layer can be ruined at the other layers. The cross-layer design stands out thus as an attractive solution to enable further energy conservation and to cope with the relative inefficiency of traditional layered protocol architectures.

In view of this, we considered a cross layer optimization of the routing and the link layers. To do so, we extended the load balancing routing strategy to work jointly with a MAC level optimization strategy.

6.8. Scalable Video Coding (SVC) transmission over IP and Broadcast networks

Participants: Majd Ghareeb, Adlen Ksentini, César Viho.

One of the multimedia market trends is audiovisual service (TV or VoD) anywhere, at any time. To support such service, Video Service Provider has to manage, store, and distribute content towards multiple kinds and scales of terminals, and over different and transient access technologies to reach the end user. To solve such issues, video scalability seems to be the most relevant solution. It encodes the video in multiple separated layers, which enable a large number of users with heterogeneous capability to view any desired video stream, at anytime, and from anywhere. One of the most well known scalable standards is the Scalable Video Coding (SVC) extension of H.264/MPEG-4 AVC video compression. Our researches in this topic are related to how to optimise and enhance SVC transmission over IP and broadcast networks.

In the context of SVC4QoE project, we proposed in [34] an overall architecture that is able to optimize the transmission of SVC streams over DVB-T2 based broadcast network. In addition, we are developing the first complete simulation model for SVC over DVB-T2 in OPNET simulator.

With the aim at keeping a high perceived video quality, SVC video streaming over Internet still faces important challenges. Among other solutions, MultiPath Video Streaming (MPVS) over Video Distribution Network (VDN) comes as a promising solution to overcome the limitations of the classical single path and IP-level video streaming approaches. In [36] [37] we proposed different approaches that couple the three SVC scalability modes (Spatial, Temporal, SNR), with the path diversity provided by VDN. Our method adapts to both the heterogeneity of end-users using the scalable video coding as well as to network bandwidth fluctuation by observing the changes of the available bandwidth over the multiple overlay paths, and updating the streaming strategy accordingly.

7. Contracts and Grants with Industry

7.1. ADR Selfnets

Participants: Hai Tran Hoang, Bruno Tuffin.

We participate to the common lab ALU-INRIA within the “Action de Recherche” SELFNETS, on pricing issues in inter-domain. The goal is to produce economic incentives for intermediate autonomous systems to forward the traffic of concurrent providers.

7.2. Cifre contract on QoE-aware network adaptation

Participants: Adlen Ksentini, Gerardo Rubino.

This is a Cifre contract (PhD thesis supervision) with Viotech Communication, on network adaptation for multimedia traffic by using QoE metrics. This work is done in the context of the FP7 ALICANTE project.

7.3. ANR Captures

We coordinate the ANR Verso CAPTURES: Competition Among Providers for Telecommunication Users: Rivalry and Earning Stakes.
ANR project December 2008 – November 2012, in cooperation with Telecom Bretagne and France Telecom R&D.

The goal of this project is to deal with competition among providers in telecommunications. We need to study the distribution of customers among providers as a first level of game, and then to focus on a second higher level, the price and QoS war. See http://captures.inria.fr/

7.4. QoSmobile

Participants: Gerardo Rubino, Kamal Singh.

We worked in the 30-months (October 2007 – March 2010) DGE Project QoSmobile on the supervision (monitoring and control) of TV distribution systems over mobile terminals. Our contribution focused on evaluating the QoE of such an infrastructure. QoSmobile is led by ENENSYS, and the partners are Expway, Alcatel-Lucent, Siradel and our team.

7.5. SVC4QoE

Participants: Adlen Ksentini, Baptiste Marienval, Kamal Singh, Gerardo Rubino.

We are working in the 2-years (October 2009 – December 2011) DGE Project SVC4QoE, where the main focus is the SVC video coding standard and its impacts on QoE, in the context of DVB-T2 video broadcast. Our contribution focuses on evaluating through simulations and analytical models the SVC video transmission over a DVB-T2 broadcast network. SVC4QoE is leaded by TEAMCAST, and the partners are Thomson Grass Valley, TDF, Neotilus, IRCCYN, AccepTV, Telecom Bretagne, and our team.

7.6. ANR VIPEER

Participants: Yassine Hadjadj Aoul, Gerardo Rubino, Kamal Singh.

We started a 3-year ANR project (end 2009-end 2012) called VIPEER: Video Traffic Engineering in an Intra-Domain Context using Peer-to-Peer Paradigms. The VIPEER project proposes to develop a distributed Content Delivery Network (dCDN) that combines classic CDN technologies with P2P concepts. Our main application in the project is IPTV. Dionysos will mainly cover the QoE assessments in the project. Our partners are Télécom Bretagne, Eurecom, Envivio, Orange Labs and NDS Technologies.

8. Other Grants and Activities

8.1. Regional Initiatives

8.1.1. ARED Région Bretagne

Participant: Bruno Tuffin.

ARED contract (with Région Bretagne) for the PhD thesis of Sagga Samira on rare event simulation with applications in telecommunications.

8.2. European Initiatives

8.2.1. NoE EuroNF

Participants: Gerardo Rubino, Bruno Tuffin.

Euro-NF is a Network of Excellence on the Network of the Future, formed by 35 institutions (from academia and industry), coming from 16 countries. Its main target is to integrate the research effort of the partners to be a source of innovation and a think tank on possible scientific, technological and socio-economic trajectories towards the network of the future. It has started in January 2008 and is ending in 2011 (see http://euronf.enst.fr/en_accueil.html) .

Bruno Tuffin is the INRIA team leader in this project. Gerardo Rubino is the responsible of the WP SEA 7.1: "Synergic collaboration with external institutions industry, SMEs and Academy" for the whole network.

The group is contributing to the following working packages (Joint Research Activities):

- WP.JRA.2.2: Traffic Engineering, Mechanisms and Protocols for Controlled Bandwidth Sharing;
- WP.JRA.2.4: Routing and Traffic Management in a Multi-Provider Context;
- WP.JRA.2.5: Design of Optimal Highly Dependable Networks;
- WP.JRA.3.2: SLAs, Pricing, Quality of Experience;
- WP.JRA.3.3: Cost Models.
- WP SEA 7.1: Synergic collaboration with external institutions industry, SMEs and Academy

8.2.2. AMESA project

Participant: Bruno Tuffin.

We are member of AMESA project (Analysis of MEchanisms for Sponsored search Auctions) within EuroNF NoE, funded for a period of about one year Oct. 2009 and Dec. 2010, in collaboration with, Athens University of Economics and Business, the CWI, TELECOM Bretagne and the University of Rome 2.

8.2.3. COST initiative ECON@TEL

Participant: Bruno Tuffin.

Bruno Tuffin is the French national delegate and project coordinator for the EU COST Activity IS0605. The goal of ECONTEL is to develop a strategic research and training network linking key individuals and organizations in order to enhance Europe's competence in the field of telecommunications economics, to support related R&D-initiatives, and to provide guidelines and recommendations to European players (end-users, enterprises, operators, regulators, policy makers, content providers) concerning the provision to citizens and enterprises of new converged broadband and wireless content delivery networks (see http://www.cost605.org/)

8.2.4. Other initiatives

- We work with Columbia University and Stanford University on rare event simulation.
- We work with Ad Ridder, from the University of Twente, The Netherlands, on rare event simulation.
- We work with Peter Reichl (FTW, Vienna, Austria) on pricing and security issues.
- We work with Hector Cancela (Montevideo, Uruguay) on simulation issues.
- We are working with Marie-Ange Remiche from the university of Brussels (ULB) on the analysis of stationary fluid queues [27].
- We also work on fluid queues and on memory constrained queues with Miklos Telek (Technical University of Budapest,Hungary).
- We work with Alan Krinik from CalPoly, US, on transient queueing analysis.

8.3. International Initiatives

8.3.1. Associated team "MOCQUASIN"

Participants: Pierre L'Ecuyer [responsible for Canada (Montréal)], Gerardo Rubino, Bruno Tuffin [responsible for France], Samira Saggadi, Fabian Bastin, David Munger.

MOCQUASIN stands for "Monte Carlo and Quasi-Monte Carlo for rare event simulation".

The goal of this team is to develop efficient Monte Carlo methods to compute integrals, sums or to solve equations or optimization problems. They are unavoidable tools in areas such as finance, electronics, sismology, computer science, engineering, physics, transport, biloy, social sciences... Nonetheless, they have the reputation of being slow, i.e. to require a large computational time to reach a given precision. The goal of the project is to work on acceleration techniques, meaning to reach faster the targeted precision. The typical framework is that of rare event simulation for which getting even only one occurence of the event could require a very long time. There are two main acceleration techniques: importance sampling and splitting on which we work. A combination with the faster randomized quasi-Monte Carlo methods is also a challenge we want to address.

(see http://www.irisa.fr/dionysos/pages_perso/tuffin/MOCQUASIN/).

8.3.2. Associated team "OCERC"

Participants: Raouf Boutaba [responsible for Canada (Waterloo)], Nizar Bouabdallah [responsible for France], Adlen Ksentini, Gerardo Rubino, Bruno Sericola.

OCERC stands for "Optimization of the energy consumption in wireless sensor networks".

OCERC is an associated team between DIONYSOS team from INRIA and the team of Professor Boutaba of the University of Waterloo. OCERC stands for "Optimization of the energy consumption in wireless sensor networks". The collaboration aims at proposing new solutions to reduce the energy consumption in wireless sensor networks.

8.3.3. ECOS project with Uruguay

Participants: Adlen Ksentini, Gerardo Rubino.

The title of the project is "Mesh wireless networks and P2P multimedia applications: tools for guaranteeing Quality of Experience".

This is a 3-year project (2009 – 2011) between France and Uruguay. The Uruguayan partner is the Engineering School of the University of the Republic, at Montevideo. The project concerns the study of tools allowing to reach good levels in the Quality of Experience in P2P networks for multimedia purposes, when the transport infrastructure is a mesh wireless network. The French coordinator of the project is G. Rubino.

8.3.4. STIC AmSud project with Chile and Uruguay

Participants: Adlen Ksentini, Nizar Bouabdallah, Gerardo Rubino.

The title of the project is "Performance evaluation and design of optical and wireless networks".

This is a 2-year project (2009–2010) between Chile, France and Uruguay. The goal is the development of models and model analysis tools for the study of performance aspects in networks, mainly for optical and for wireless structures. The partners are: U. Técnica "Federico Santa María" and U. Adolfo Ibáñez in Chile, U. de la República en Uruguay, U. Joseph Fourier, U. de Pau et des Pays de l'Adour and INRIA in France. The global coordinator of the project is Gerardo Rubino (Dionysos, INRIA).

8.3.5. Other international activities

- Nizar Bouabdallah works with the University of Waterloo (Canada) on wireless mesh and sensor networks.
- In the STIC INRIA - DGRSRT (Universities of Tunisia) program, Nizar Bouabdallah works with SUP'COM (Tunisia) on "Resource allocation and routing in wireless mesh networks".
- Nizar Bouabdallah spent six months in SUP'COM (Tunisia) as a visitor researcher.
- We work on IPv6 interoperability testing with Prof Ma Yan and Xiaohong Huang from BUPT (Beijing University of Posts and Telecommunication), Beijing (China).
- Gerardo Rubino is a member of the Technical Committee on Multimedia Communication of IEEE.

9. Dissemination

9.1. Animation of the scientific community

9.1.1. International memberships

R. Marie and G. Rubino are members of the IFIP WG 7.3 (Working Group in Computer Performance Modeling and Analysis).

9.1.2. Organization of conferences

- G. Rubino is a member of the Steering Committee of the international conference QEST (Quantitative Evaluation of SysTems).
- Gerardo Rubino and Adlen Ksentini co-organized (together with Laurent Toutain from TELECOM Bretagne) an international school about the future of the Internet. The school was an initiative of the GIS Bretagne, and was also sponsored by EuroNF, INRIA, and the UEB. For details, see http://siscombretagne.inria.fr/index_eng.html.

9.1.3. Program committees

Nizar Bouabdallah served/serves in the Program Committee of the following conferences:

- IEEE ICC 2010, Ad Hoc, Sensor and Mesh Networking Symposium, May 2010, Cape Town, South Africa;
- IEEE GLOBECOM 2010 Ad Hoc, Sensor and Mesh Networking Symposium, December 2010, Miami, Florida, USA;

Gerardo Rubino served/serves in the Program Committee of the following conferences:

- 10th International Workshop on Computational Stochastics, Amsterdam, The Netherlands, May-June 2010.
- 1st European Teletraffic Seminar, February 14–16, Poznan, Poland

Raymond Marie served/serves in the Program Committee of the following conferences:

- 7th International Conference on the Quantitative Evaluation of SysTems (QEST) 2010, September 2010, Virginia, USA.
- French Conference on Risk Management (October 2010).

Bruno Sericola served/serves in the Program Committee of the following conferences:

- ASMTA'10, 17th International Conference on Analytical and Stochastic Modelling Techniques and Applications, Cardiff, UK, 14-16 June 2009.
- MACOM 2010, 3rd International Workshop on Multiple Access Communications, Barcelona, Spain, 13-14 September 2010.

Bruno Tuffin served/serves in the Program Committee of the following conferences:

- 3rd IFIP/IEEE International Workshop on Bandwidth on Demand and Federation Economics, April 23, 2010, Osaka, Japan.
- 6th Euro-NGI conference on Next Generation Internet Networks (NGI 2010), June 2010, Paris, France.
- 8th International Workshop on Rare Event Simulation (RESIM'10), June 21-22 2010, Cambridge, England.
- 22nd International Teletraffic Congress (ITC 22), September 2010, Amsterdam, The Netherlands.
- 3rd Workshop on Economic Traffic Management (ETM), September 2010, Amsterdam, The Netherlands.
- The 7th International Workshop on the Economics of Grids, Clouds, Systems, and Services (GECON 2010), August 30-31th, 2010, Ischia, Naples, Italy.
- 4th International Conference on Network Control and Optimization (NET-COOP'10), November 2010, Ghent, Belgium.

Adlen Ksentini served/serves in the Program Comittee of the following conferences:

- IEEE GLOBECOM 2010 Wireless Network Symposium, December 2010, Miami, Florida, USA
- IEEE ICC 2010, Wireless Communication Symposium, May 2010, Cape Town, South Africa;

9.1.4. Editorial activity

- Raymond Marie is associate Editor for Performance Evaluation.
- Bruno Sericola is a member of the Editorial Advisory Board of the Open Operational Research Journal.
- Bruno Sericola is a member of the Editorial Advisory Board of the International Journal of Stochastic Analysis.
- Bruno Tuffin is associate Editor for INFORMS Journal on Computing.
- Bruno Tuffin is associate Editor for Mathematical Methods of Operations Research.
- Bruno Tuffin is associate Editor for ACM Transactions on Modeling and Computer Simulation.
- Bruno Tuffin is a Co-guest editor of a special issue of Telecommunication Systems Journal on Socio-Economic Issues of Next Generation Networks, to appear at the beginning of 2011.
- Nizar Bouabdallah Associate Editor for the Wireless Communications and Mobile Computing journal, Wiley InterScience, since February 2009.

9.1.5. Managing research activities

- Gerardo Rubino is a member of the Research Commission of TELECOM Bretagne (advisory board for the research activities of the institution).
- Gerardo Rubino is a exterior member of the Specialist Commission of the University of Versailles Saint-Quentin-en-Yvelines, Section 27 (since 2001).
- Gerardo Rubino is a member of the CSV (Selection and Validation Committee) of the "Images et Réseaux" (Images and networks) cluster in the French Brittany Region. The cluster groups most companies and academic institutions working in networking and on image-based applications in Western France.
- Gerardo Rubino is the INRIA representative at the GIS SISCOM (and Bruno Tuffin his substitute), an association composed of the four main academic institutions in Western France in the area of information and communication sciences: the European University of Brittany-UEB, the Institut TELECOM, the CNRS and INRIA, to promote the excellence of the ICT research in Brittany.
- Bruno Sericola is responsible for the INRIA Rennes - Bretagne Atlantique budget.
- Bruno Sericola is the leader of the research group MAPI (Math Appli Pour l'Info) the goal of which is to improve the collaboration between computer scientists and mathematicians.
- César VIHO is responsible of the "Network, Telecommunication and Services" department of Irisa composed of 4 research teams. He is member of the ÒConseil de laboratoireÓ and of the ÒConseil dÕOrientations scientifiques (COS)Ó of Irisa. He is in charge of administrative issues management of PhD students of Irisa and Inria. In the context of international relations of Irisa, he is responsible of relations with Africa area universities and research centers.

9.1.6. Other activities

- Bruno Tuffin presented the following keynote talk:
  - Pricing in telecommunication networks: some issues and models. *3rd IFIP/IEEE International Workshop on Bandwidth on Demand and Federation Economics*, Osaka, Japan, April 2010.

- Gerardo Rubino supervised the team participation to the Science Party section in Rennes, in October 2010, where we presented our activities in QoE autompatic evaluation. The demonstrations were done by Kamal Singh, Sofiene Jelassi and Sebastán Basterrech.
- Bruno Tuffin made seminar presentations
  - B. Tuffin. Rare event simulation. Séminaire du département de Mathématiques de l'Université de Bretagne Occidentale, Brest, February 2010.
  - P. Maillé and B. Tuffin. Competition among wireless operators. *WINEM open seminar*, Sophia-Antipolis,France, February 2010.
  - B. Tuffin. Introduction à la simulation d'événements rares. Exemples d'application en sûreté de fonctionnement et en évaluation des performances. Journée vérification et contrôle de systèmes stochastiques, Campus Ker Lann, 6 Avril 2010.
  - B. Tuffin. Pricing in telecommunication networks: from congestion control and incentives design to competition among providers. Technicolor Lab retreat, Avril 2010.
  - B. Tuffin. A short introduction to adword auctions and the advantage of introducing randomness. Technicolor Lab retreat, Avril 2010.
  - B. Tuffin. Introducing randomness in adword auctions. ECONTEL COST Meeting, Ghent, Belgium, June 2010.
- Bruno Tuffin participated to the following summer schools:
  - B. Tuffin. Advanced methods for rare event simulation. CIMPA School: Applied Mathematics and Engineering, Solís, Uruguay, March 2010.
  - B. Tuffin. Game theory, pricing and incentives in networks, with applications. 3rd Euro-NF Summer School on Opportunistic Networking, 6h class, Valence, Spain, June 28-July 2, 2010.

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, Telecom Bretagne, Rennes Mathematics Institute). At the Bac+5 level, N. Bouabdallah, R. Marie, G. Rubino, B. Sericola, A. Ksentini, B. Tuffin, C. Viho and Y. Hadjadj, give different courses in two Masters (in Probability and in Computer science), in the 3rd year of DIIC (Engineering School) at the University of Rennes 1, at Telecom Bretagne and at Supelec. The main subjects are networking, protocols, dimensioning problems, dependability analysis, performance evaluation, etc. A. Ksentini is in charge of the 2nd year of the Master in Computer Science at the University of Rennes 1.

9.2.2. International teaching activities

- G. Rubino gave a course at the CIMPA School: Applied Mathematics and Engineering, Solís, Uruguay, March 2010. The title was "Topics in the analysis of performance, dependability and performability aspects of complex systems".

9.3. Standardization activities

Participants: Anthony Baire, François Lerebours, César Viho.

The Dionysos 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), etc. We are also 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 contributions focus today mainly on IPv6 and related protocols such as 6LowPAN and RPL.

9.3.1. IPv6 Ready Logo Program

Participants: Anthony Baire, François Lerebours, César Viho.

Dionysos 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. Dionysos 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.

In 2010 we started a collaboration with the IPSO alliance in order to address the usage of IPv6 on smart objects based on the IEEE 802.15.4 link layer (eg. sensor networks). These network have special constraints (limited power, packet loss, ...) and new protocols are designed at IETF (6LowPAN, RPL) to allow using IPv6 with these constraints.

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Articles in International Peer-Reviewed Journal

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