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Project-Team DIONYSOS

Dependability Interoperability and
performance aNalYsiS Of networkS

IN COLLABORATION WITH: Institut de recherche en informatique et systèmes aléatoires (IRISA)

RESEARCH CENTER
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THEME
Networks and Telecommunications

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Project-Team DIONYSOS

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

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 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. 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 network economics 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.

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 (QoS) and Quality of Experience (QoE), since they can be seen as unifying concepts 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 (see 6.5).

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. The objectives are either to develop numerical solutions, or analytical ones, or possibly 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, queues or networks of queues) and also at the *burst level*, leading to *fluid models*.

In recent years, our work on the design of the topologies of WANs led 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.

Network 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, should 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 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 be 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. 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, César Viho.

We have built a toolkit for easing executing tests written in the standardized TTCN-3 test specification language. This toolkit is made of a C++ library together with a highly customizable CoDec generator that allows fast development of external components required to execute a test suite. 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 environments (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, Nanxing Chen, 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 tool-chain. This year we re-factored the build system using the *waf* build automation tool, which allowed us to integrate with other operating systems and tool-chains (especially MSVC on Windows). This work allowed us to study interoperability issues between tools in the TTCN-3 standard and a poster was presented at the TTCN-3 User Conference 2011. We also presented an introduction tutorial for T3DevKit at this conference [76]. A method to generate and to execute passive interoperability test suites on recorded traces has been proposed in [40].

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: Pierre Coucheney, Hai Tran Hoang, Bruno Tuffin, Jean-Marc Vigne.

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) investigating the consequences and equilibrium due to competition among providers in different contexts, iii) studying the economic aspect of interdomain relationships, iv) looking at the economics of applications, for example adword auctions for search engines, v) investigating the economics of security in telecommunications, vi) studying the network neutrality issue.

On the first item, in [70], [29], 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.

A notable part of our activity has been related to competition among telecommunication providers, mainly within the framework of the ANR CAPTURES project. The goal is to improve most of the pricing models analysis which only deal with a single provider while competition (that is observed in the telecommunication industry) can drive to totally different outcomes. A general view of some of our results is summarized in [67]. A general model of competition in loss networks is described and analyzed in [22] as a two-levels game: at the smallest time scale, users' demand is split among providers according to the Wardrop principle, depending on the access price and available QoS (depending itself on the level of demand at the provider), and at the largest time scale, providers play a pricing game, trying non-cooperatively to maximize their revenue. A striking result is that this game leads to the same outcome than if providers were cooperatively trying to maximize social welfare: the so-called *price of anarchy* is equal to one. An additional (higher) level of game is analyzed in [23] (but using another type of negative externality for users, based here on delay), at which providers play on the technologies to implement, based 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, in order to drive the resulting Nash equilibrium to a better point in terms of social or user welfare. A specific situation we have analyzed is the case for a competitive market operated by a Mobile Network Operator (MNO) and a Mobile Virtual Network Operator (MVNO) [46]. The resource that is leased by the MNO to the MVNO is spectrum. MNO and MVNO compete posting subscription prices and the mobile users may choose to subscribe to one operator, or not to subscribe. The scenario is modeled by a three-level game comprising: a bargaining game, which models the spectrum leasing by the MNO; a competition game, which models the price competition between the MNO and the MVNO, and a subscription game, which models the subscription choice by the mobile users, and the outcome of which may be either not to subscribe, to subscribe to the MNO or to subscribe to the MVNO. We assess which conditions lead to an equilibrium where the competition does take place and the amount of the spectrum that should be leased to maximize user or social welfare.

Another important activity is around interdomain issues, with 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 [33], we have described the problem, provided a state of the art and highlighted the difficulties that must be solved. In [32], we have designed a decentralized algorithm based on double-sided auctions to allocate (and charge) the resource usage.

But network economics is not only about ISPs, it also deals with the application side. In order to make money many service providers base their revenue on advertisement. Search engines for example get revenue thanks to adword auctions, where commercial links are proposed and charged to advertisers as soon as the link is clicked through. Most search engines have chosen (or switched to) a revenue-based ranking and charging scheme instead of a bid-based one. In [53] we investigate the relevance of that scheme when advertisers'

valuation comes from a random distribution, showing that depending on the search engine's click-through-rate, revenue-based does not always outperform bid-based in terms of revenue to the search engine. But in this adword auction context too, there exist very few works dealing with search engines in competition for advertisers. We have developed a two-level game where at the largest time scale search engines decide which allocation rule to implement, between revenue-based and bid-based; and at the lowest time-scale advertisers decide how to split their advertising budget between the two search engines, depending on the benefits this will bring to them. The game at the largest time scale is solved using backward induction, the search engines anticipating the reactions of advertisers [54], [52]. We describe the advertisers best strategies and show how to determine, depending on parameters, an equilibrium on the ranking rule strategy for search engines; this may explain Yahoo!'s move to switch from bid-based to revenue-based ranking to follow Google's strategy.

We similarly have looked at the competition aspects linked to security. We have reviewed the interactions and strategies of attackers and defenders [68]. But we have also looked at the economics of network security, when network users can choose among different security solutions to protect their data, offered by competitive security providers [51]. The interactions among users are modeled as a noncooperative game, with a negative externality coming from the fact that attackers target popular systems to maximize their expected gain.

A new issue we are investigating is the network neutrality debate coming from the increasing asymmetry between Internet Service Providers (ISPs), mainly due to some prominent and resource consuming content providers which are usually connected to a single ISP. We have described and analyzed in [69] the respective arguments of neutrality proponents and opponents, and are currently completing the analysis of several promising game-theoretic models on this issue.

6.2. Dependability and extensions

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

We maintain a permanent research activity in different domains related to dependability, performability and vulnerability analysis of communication systems. Our focus is on evaluation techniques using both the Monte Carlo and the Quasi-Monte Carlo approaches. Monte Carlo (and Quasi-Monte Carlo) methods often represent the only available tool to solve complex problems in the area, and rare event simulation requires a special attention, in order to be able to efficiently analyze the model, that is, to be able to use good estimators having, in particular, a sufficiently small relative variance. Novel results in simulation can be decomposed into two subsets: results on rare event simulation, and those on Randomized Quasi-Monte Carlo methods.

The effectiveness of randomized quasi-Monte Carlo (RQMC) techniques is examined in [26] to estimate the integrals that express the discrete choice probabilities in a mixed logit model, for which no closed form formula is available. These models are used extensively in travel behavior research. We consider popular RQMC constructions, but our main emphasis is on randomly-shifted lattice rules, for which we study how to select the parameters as a function of the considered class of integrands. We compare the effectiveness of all these methods and of standard Monte Carlo (MC) to reduce both the variance and the bias when estimating the log-likelihood function at a given parameter value.

The main part of our activity in this simulation area in 2011 has been on rare event simulation though. The two major simulation families for rare event estimations are importance sampling and splitting. In [63], we have provided a recent view of those methods, while in [64] we have overviewed how the zero-variance importance sampling can be approximated in classical reliability problems.

The problem of estimating the probability that a given set of nodes is connected in a graph (or network) where each link is failed with a given probability has received a lot of attention from us in 2011. We have proposed in [21] a new Monte Carlo method, based on dynamic Importance Sampling. 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. The empirical performance of the new sampling scheme is illustrated by examples. The method is even sped up in [50] by applying series-parallel reductions at each step of the algorithm.

The same problem is also analyzed in [15] by novel method that exploits a generalized splitting (GS) algorithm. We show that the proposed GS algorithm can accurately estimate extremely small unreliabilities and we exhibit large examples where it performs much better than existing approaches. Remarkably, it is also flexible enough to dispense with the frequently made assumption of independent edge failures. In [17], another splitting approach is explored for the same problem, with very good results. It consists of a standard splitting procedure applied to the so-called Creation Process that can be associated with the initial static model. The paper discusses both a method for splitting this process, and an experimental analysis of the covering of the resulting estimator, showing its good behavior on different classes of test problems. Last, in [16], always for the same static reliability problem, we proposed a new procedure belonging to the RVR family (Recursive Variance Reduction) where a new estimator based both in computed minpaths and mincuts of the graph, together with series-parallel reductions, allows to obtain very good accuracy in many rare events situations.

Finally, a versatile Monte Carlo method for estimating multidimensional integrals, with applications to rare-event probability estimation is presented in [39], [75]. The method uses two distinct and popular Monte Carlo simulation techniques, namely Markov chain Monte Carlo (MCMC) and Importance Sampling, combined into a single algorithm. We show that for some illustrative and applied numerical examples the proposed Markov Chain Importance Sampling algorithm performs better than methods based solely on Importance Sampling or solely on MCMC.

Concerning the risk on spares for life-time maintenance purposes which is due to uncertainties on the mean up time, an extended version of a presentation made in 2010 has been published in [24].

6.3. Performance evaluation

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

An important problem arising when dimensioning a P2P system is to understand the evolution of the peers' population with time. The number of units being usually large, the standard stochastic models used to represent this kind of system (e.g. a Markovian stochastic process) are difficult to use in practice. Instead, it is popular today to move to deterministic continuous-state (fluid) models whose dynamics is governed by differential equations. It is then of interest to analyze the conditions under which the latter are the limit, in some sense, of the former. We started to develop this program in [36] by focusing on some popular models of P2P systems, and analyzed when and how the deterministic model is the limit of the stochastic one when the number of peers goes to infinity.

In [60], we continued to 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 throughput and the mean response 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. In this research line, [60] opens the way for a definition of efficiency, which is currently analyzed in the team.

In [30], we expose a clear 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. We illustrate our results by a comprehensive fluid model that we solve exactly.

In [65], we analyze the transient behavior of a fluid queue driven by a general ergodic birth and death process using spectral theory in the Laplace transform domain. These results are applied to the stationary regime and to the busy period analysis of that fluid queue.

Finally, in [71] we present a global view of the performance evaluation area in computer and communication systems, an extended and reviewed version of a talk given in 2010.

6.4. Quantitative aspects of distributed systems

Participants: Bruno Sericola, Romaric Ludinard.

This work is a collaboration with the Inria team-project Asap. We proposed in [20] a fully decentralized algorithm to provide each of the nodes of a distributed system 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.

We continue our collaboration with the Inria team-projects Adept and Ipso. 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 [13] and in [35], 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 [14] and [34], 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.

6.5. QoE (Quality of Experience)

Participants: Sebastián Basterrech, Yassine Hadjadj-Aoul, Sofiene Jelassi, Adlen Ksentini, Gerardo Rubino, Kamal Singh, César Vihó.

We continue the development of the PSQA technology (Pseudo-Subjective Quality Assessment) in the area of Quality of Experience (QoE). PSQA is today a stable technology allowing 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. It provides an accurate and efficiently computed evaluation of 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 standard (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. PSQA works by analyzing the networking environment of the communication and some the technical characteristics of the latter. It works without any need to the original sequence (as such, it belongs to the family of *no-reference* techniques).

It must be pointed out that a PSQA measuring or monitoring module is network dependent and application dependent. Basically, for each specific networking technology, application, service, the module must be built from scratch. But once built, it works automatically and very efficiently, allowing if necessary to use it in real time.

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 (see [82] for a general description), but recently, we have started to explore other approaches. For instance, in the last ten years a new computational paradigm was presented under the name of *Reservoir Computing* (RC) [78] covering the main limitations in training time for recurrent neural networks while introducing no significant disadvantages. Two RC models have been developed independently and simultaneously under the name of *Liquid State Machine* (LSM) [81] and *Echo State Networks* (ESN) [78] and constitute today one of the basic paradigms for Recurrent Neural Networks modeling [79]. The main characteristic of the RC model is

that it separates two parts: a static sub-structure called *reservoir* which involves the use of cycles in order to provide dynamic memory in the network, and a parametric part composed of a function such as a multiple linear regression or a classical single layer network. The reservoir can be seen as a dynamical system that expand the input stream in a space of states. The learning part of the model is the parametric one. In a recent collaboration with the *Applied Computational Intelligence Research Unit, Artificial Neural Networks Group* of the University of the West of Scotland during the first half of the year, we developed an algorithm based on a combination of topology preserving maps such as the Self-Organising Map [80] and the Scale Invariant Map [77] to improve the performance of RC models. The obtained results are presented in two papers: [37] and [38].

In [42] we developed a PSQA version for evaluating the perceived quality in the context of SVC video coding. The tool is based on the use of the RNN model. The main difficulties in defining this tool is regarding the relation between the SVC layers, since the enhanced layers require the information of the base layer in order to be decoded.

In [61], we developed a tool for evaluating the perceived quality of an application distributing streamed video using HTTP (and thus, TCP). The difficulties here are focused around the possible playout interruptions and the quality variations due to the use of adaptive bitrate techniques. Our procedure belongs to the *no-reference* family of learning ones, and it is also based on the use of the RNN tool.

In [41] we compared PSQA used for the video evaluation to other no-reference tools as well as two objective evaluation tools. We showed that PSQA outperforms the majority of the other tools, in terms of high correlation with human evaluation. This version will be used as the main metric for evaluating the QoE in the future internet architecture proposed by the FP7 Alicante project.

We have also being developing single-ended parametric-model speech-quality assessors of VoIP conversations over future networks. To do that, a careful identification and accurate characterization of quality-degrading factors over next-generation networks has been done. The recent progress and challenges for accurate assessment of voice quality over evolving VoIP systems has been detailed in the survey paper [19]. In [18], we study the perceived effects of packet loss processes, which are the principal source of quality degradation over IP networks. In reality, the perceived effect of a given packet loss process is highly related to the distribution of missing packets. Basically, the higher the burstiness of packet loss processes, the greater the perceived quality degradation. Recently, several assessors of speech quality sensitive to packet loss burstiness have been proposed in the literature. A comprehensive comparison study of bursty-packet-loss-aware artificial assessors has been conducted in [18]. An extended and more elaborated version has been published in [47]. Moreover, novel artificial quality assessors that consider transient loss of connectivity incurred by mobile users over mobile transport system have been developed. A paper describing our developed tools and performance results is under preparation. Recently, we started to work on new analytical models of packet losses and delays of packet-based voice conversations over wireless ad-hoc networks. The developed models will be used to design specialized artificial quality assessors of multimedia services over wireless ad-hoc networks. Moreover, we are working on the enhancement of a voice quality assessor version of PSQA, by considering the features of removed speech signals.

6.6. Wireless networks

Participants: Nizar Bouabdallah, Yassine Hadjadj-Aoul, Adlen Ksentini, Raymond Marie, Bruno Sericola, César Viho.

We continue working on wireless networking. The focus mainly concerns wireless distribution of audio and video, which require strict Quality of Service (QoS) support.

In [27], we investigated the main challenges when the goal is to constitute an efficient Radio Resource Management (RRM) framework. The existing solutions of RRM were classified based on the considered decision-making technique. Moreover, we investigated in [28] how QoE can help for designing efficient RRM for wireless networks. A resource allocation mechanism is proposed in [62]. In [59] we proposed a novel network selection mechanism for heterogeneous wireless networks that take QoE into consideration for

decision-making. The main idea is to use QoE of ongoing users in candidate networks as an indicator to select the best network for connection. Besides, in order to provide efficient interworking between the different access players, we first defined some issues related to the interworking operation between the satellite and terrestrial domains. We suggested some solutions and discussed their potential in [31].

We also investigated in [74] solutions that ensure the scalability of mobile networks, which are facing a rapid increase of data traffic. We devise methods that enable User Equipments, both in idle and active mode and while being on the move, to always have optimal Packet Data Network (PDN) connections (i.e., IP addresses) in such decentralized networks. We demonstrated the effectiveness of such approach in current mobile and wireless networks. In these systems, minimizing energy consumption is becoming more and more crucial. In [66], we devised a PID (Proportional Integral Derivative)-based controller permitting to reduce the amount of wasted energy by determining an optimal schedule between the sleep and wakeup periods of the wireless interface during the VoIP communication while keeping the perceived quality at the desired level.

Based on our previous research on proactive routing for wireless ad-hoc networks, we have published a book chapter in [73], focusing on modeling the resilience of routing information for ad hoc networks where topology information is uncertain.

We continue our collaboration with the Inria team-projects Pops (Lille), D-Net (Lyon), Reso (Lyon) and the NPA (Networks and Performance Analysis) research group of LIP6 (Paris) on fast self-stabilization in large scale wireless networks. In these systems, distributed self-organization is more convenient than centralized planification. Self-stabilization protocols are a useful technique to provide self-organization but their stabilizing time is related to the size of the network. In [25], we show that a clustering algorithm, known for its good robustness properties, is actually self-stabilizing. We propose several enhancements to the scheme in order to reduce the stabilization time and thus improved the 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, Sofiane Moad.

Wireless Sensor Networks (WSNs) are composed of tiny sensor nodes, which are capable of sensing and processing data from inaccessible environments and communicating them to the end-user for further analysis. WSNs are characterized by the limited capacity of their sensor node batteries, making energy efficiency a critical issue. Once a WSN is deployed, sensor nodes must self-organize and live as long as possible, based only on their initial energy stores. Consequently, techniques minimizing energy consumption are required to improve network lifetime. Our research on WSNs [72] revolves around two main directions: 1) clustering, and 2) radio diversity. Regarding clustering, we first developed a Connectivity Degree-Based Energy Efficient Clustering Protocol for WSNs (CDEEC) [55], resulting in better topology management and decreased energy consumption compared to the well-known clustering protocol HEED. Then, we integrated a compression mechanism within a cluster-based architecture to develop a Compression Cluster-based scheme in a Spatial Correlated Region protocol (*CC_SCR*) [56], with the goal of further decreasing the energy consumption. In the direction of radio diversity, we first proposed the WETX metric [58] which uses a minimum-energy radio while routing, then we proposed the BL metric [57], on top of WETX, which allows energy-balancing inside a network in order to further extend its lifetime. The validation of our contributions was carried out with analytical analysis, and simulation using TOSSIM.

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

Participants: Majd Ghareeb, Adlen Ksentini, César Viho, Yassine Hadjadj-Aoul.

One of the multimedia market trends is audiovisual service (TV or VoD) anywhere, at any time. To support such service, a 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 optimize and enhance SVC transmission over IP and broadcast networks.

With the aim at keeping a high perceived video quality using SVC, 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 [45] and [43] 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 fluctuations by observing the changes of the available bandwidth over the multiple overlay paths, and updating the streaming strategy accordingly. In [44] we enhanced the precedent solutions by using the PSQA-SVC version [42] in order to get the end-user feedback in terms of QoE, which helps adapting the streaming strategy. In [48] we designed a new protocol optimizing the energy consumption when transmitting video streams. We propose to exploit the SVC coding to adapt dynamically the received video quality to the instantaneous wireless nodes' characteristics. This is achieved through determining the number of the transmitted/received enhancements layers of an SVC video based on the wireless node context.

In [49] we proposed to support SVC over DVBT2 networks, by associating the layering architecture of both technologies in order to tackle users mobility. This association allows mobile receivers with good physical channels to decode all the SVC layers and benefit from high video quality. Meanwhile, users with poor channel conditions can at least decode the base layer and benefit from acceptable video quality. Further, we introduced a novel QoE-based adaptive mechanism for SVC layers decoding. The proposed approach selects dynamically the number of layers to decode, at the receiver side, so as to maximize the users' perceived quality. Thus, no feedbacks or signaling messages are needed to implement the proposed algorithm. This makes it compliant with unidirectional technologies such as DVB-T2.

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 and to analyse handover between mobile providers from an economic point of view.

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. Data-aggregation for large-scale distributed networks

Participants: Bruno Sericola, Romaric Ludinard.

We started a 3-year (2011 - 2014) bilateral project with Technicolor R & D, France, on data-aggregation for large-scale distributed networks. Along with the ubiquity of data and computing devices, comes the complexity of extracting and gathering relevant information for management purposes. The very distributed nature of sources of data (be they partially local applications at user's place, or hardware as gateways), as well as their ever increasing number prohibit a systematic and exhaustive gathering on a single (or few) central server for offline analysis. In this context, collaborative data aggregation, where some computing resources collaborate securely to provide digests, appears as an interesting application for both scalability and efficiency. Moreover, collecting information at a large scale pose the problem of privacy and data aggregation may allow preserving the privacy while collecting data.

7.4. IPChronos

Participants: Yassine Hadjadj-Aoul, Adlen Ksentini, Bruno Sericola.

We are working in the 2-years (September 2011 – September 2013) FUI Project IPChronos, where the main focus is in the use of the IEEE 1588 synchronization protocol over IP. Our contribution focuses on developing analytical models to estimate, basing on the IEEE 1588 protocol, the end-to-end delay. IPChronos is led by ORALIA SPECTRACOM, and the partners are IPlabel and our team.

7.5. SVC4QoE

Participants: Adlen Ksentini, 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 led by TEAMCAST, and the partners are Thomson Grass Valley, TDF, Neotilus, IRCCYN, AccepTV, Telecom Bretagne, and our team.

7.6. ANR Captures

Participant: Bruno Tuffin.

We coordinate the ANR Verso CAPTURES: Competition Among Providers for Telecommunication Users: Rivalry and Earning Stakes.

ANR project Dec. 2008- Nov. 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/>

7.7. ANR VIPEER

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

VIPEER is a 3-year ANR project (end 2009-end 2012). VIPEER stands for 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 activities of VIPEER. Our partners are Télécom Bretagne, Eurecom, Envivio, Orange Labs and NDS Technologies.

7.8. Celtic QuEEN

Participants: Adlen Ksentini, Gerardo Rubino.

We started a 3-year Celtic project (end 2011-end 2014) called QuEEN: Quality of Experience Estimators in Networks. The project objectives are: to develop automatic QoE measure modules for Web services and applications, and to organize these measure modules as a network of cooperative agents in order to allow each member to take advantage of the measures of the others. Dionysos is involved in all the important activities of the project, and it is expected that QuEEN will benefit from our experience in developing the PSQA technology. QuEEN is a large project (22 European partners); the project leader is Orange Labs, in Sophia Antipolis.

8. Partnerships and Cooperations

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.

8.1.2. SISCom International Research Chair "Future Telecommunication Ecosystems"

Participants: Peter Reichl, Bruno Tuffin.

Cross-connecting related activities at SISCom partners (INRIA Rennes ? Bretagne Atlantique, Télécom Bretagne Rennes, and CNRS) and the Telecommunications Research Center Vienna (FTW), Austria, the main goal of the SISCom International Chair on "Future Telecommunication Ecosystems" is to develop an overall perspective of current and future research in this holistic area where user-driven research and microeconomic modeling meet the technical challenges of future telecommunications. Additionally, selected research questions in the areas of Quality of Experience, game theoretic models of cooperation and competition between users and/or providers, and future pervasive interaction will be addressed more specifically and may serve as starting points for joint follow-on activities, thus supporting the sustainability of this initiative.

The SISCom International Research Chair is funded jointly by Université Européenne de Bretagne, Région Bretagne, and the European Regional Development Fund, and is hosted by INRIA Rennes Bretagne-Atlantique for the period December 2010 through September 2011.

8.2. National Initiatives

8.2.1. ARC MENEUR

Participants: Pierre Coucheney, Peter Reichl, Bruno Tuffin.

We coordinate an INRIA cooperative research action on Network Neutralite, called MENEUR (Modélisation en Economie des réseaux et NEUtRalité du Net). This action runs over 2011-2012 in association with INRIA teams MAESTRO and MESCAL, Orange Labs, ALU-Bell Labs France, Telecom Bretagne, FTW (Austria), Columbia University and Penn State University.

The goal of this project is to study the interest of network neutrality, a topic that has recently gained a lot of attention. The project aims at elaborating mathematical models that will be analyzed to investigate its impact on users, on social welfare and on providers' investment incentives, among others, and eventually propose how (and if) network neutrality should be implemented.

See http://www.irisa.fr/dionysos/pages_perso/tuffin/MENEUR/

8.3. European Initiatives

8.3.1. NoE EuroNF

Participants: Gerardo Rubino, Bruno Tuffin.

EuroNF Euro-NF is a Network of Excellence on the Network of the Future, formed by 35 institutions (from the academia and industry) 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 June 2012 (see http://euronf.enst.fr/en_accueil.html).

Bruno Tuffin is the INRIA team leader in this project.

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.

8.3.2. 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. 2011, in collaboration with, Athens University of Economics and Business, the CWI, TELECOM Bretagne and the University of Rome.

8.3.3. Collaborations in European Programs, except FP7

Program: COST

Project acronym: ECON@TEL

Project title: Econ@Tel - A Telecommunications Economics COST Network

Duration: October 2007 - September 2011

Coordinator: B. Stiller (ETH Zurich)

Other partners: FTW (Austria), INTEC (Belgium), CUT, UniCY (Cyprus), DTU, CBS (Denmark), Institut Telecom, Inria (France), Pfh/NILC (Georgia), I-UG RUB (Germany), BME (Hungary), BRAUDE (Israel), FUB, CESPR, UniROM (Italy), RSM (The Netherlands), PUT (Poland), ASE (Romania), UniLj, CHAL, Telia (Sweden), UniLj (Slovenia), UNED, REDTEL (Spain), IC, WBC (U.K.)

Abstract: Bruno Tuffin is the French national delegate and project coordinator for the EU COST Activity IS0605. The goal of ECON@TEL is to develop a strategic research and training network linking key individuals and organizations in order to enhance European 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/>)

8.3.4. Major European Organizations with which you have followed Collaborations

Partner 1: FTW, Vienna (Austria)

We work with FTW on network economics.

Partner 2: NEC lab (Germany)

We work with NEC lab Germany on Machine Type Communication in LTE, and data offload in the context of Femto cell technologie.

8.4. International Initiatives

8.4.1. INRIA Associate Teams

8.4.1.1. MOCQUASIN

Title: Monte Carlo and Quasi-Monte Carlo for rare event simulation

INRIA principal investigator: Bruno Tuffin

International Partner:

Institution: Université de Montréal (Canada)

Laboratory: Département d'informatique et recherche opérationnelle

Researcher: Pierre L'Ecuyer

Duration: 2008 - 2013

See also: http://www.irisa.fr/dionysos/pages_perso/tuffin/MOCQUASIN/

Abstract: The goal of MOCQUASIN is to design efficient Monte Carlo and quasi-Monte Carlo simulation methods and to apply them to models in telecommunications. Simulation is indeed often the only method to analyze complex and/or large systems, but also suffers from inefficiency. Two specific situations on which we will focus are rare events, and revenue management. In the two cases, we want to deal with dependent individual events or decisions, a realistic situation requiring adapted solution techniques. The inefficiency of the standard simulation is a known issue to compute the probability of rare event since getting it only once requires in average a long simulation time, but most of the literature has up to now assumed independence in the models. The other framework, revenue management in telecommunications, is the situation of providers trying to define valid offers and capacity investments in front of complex demand models. Here too, a change in the decision of an actor has an impact on the others that has to be taken into account.

8.4.2. ECOS project with Uruguay

- Title: Mesh wireless networks and P2P multimedia applications: tools for guaranteeing Quality of Experience
- INRIA principal investigator: Gerardo Rubino
- Duration: 1 2009 - 12 2011
- International Partner:
 - Institution: University of the Republic, Montevideo, Uruguay
 - Laboratory: Institute of Computer Science (InCo)
 - Researcher: Héctor Cancela (Dean of the Faculty of Engineering, Uruguayan Responsible of the project)
- Abstract: The project consists in developing tools for QoS and QoE analysis of communication networks. We produce techniques for analyzing these structures using Monte Carlo procedures. We also develop tools allowing to reach specific levels in the Quality of Experience of transport structures for multimedia purposes, in particular when the underlying network is a mesh wireless system.

8.4.3. Visits of International Scientists

8.4.3.1. Internships

Saurabh Saurabh Saxena

Subject: Video streaming in BitTorrent (P2P) networks

Institution: IIT Kanpur (India)

8.4.4. STIC Algérie

Title: Utilisation de la plate-forme de test Senslab pour le projet irrigsense

Principal investigator: Adlen Ksentini

International Partner:

Institution: Centre de Recherche sur l'information Scientifique et Technique (CERIST)

INRIA: three teams involved: Dionysos, ASAP and Cider

Laboratory: Department of Theories and Computer engineering

Researcher: Abdelouahid Derhab

Duration: 2011 - 2013

Abstract: This collaboration aims at defining new protocols for data collecting in Wireless Sensor Networks, and evaluate them with the senslab platform. After validating the proposed protocols, CERIST intends to deploy them in the context of the project (Algerian) "Sensirrig", which aims at using sensors for agricultural irrigation.

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).
- Gerardo Rubino is a member of the Technical Committee on Multimedia Communications of IEEE.

9.1.2. Organization of conferences

- G. Rubino is a member of the Steering Committee of the international conference QEST (Quantitative Evaluation of SysTems).
- César Viho co-organized (together with Laurent Toutain from TELECOM Bretagne) an international school about "Communicating objects". The school was an initiative of the Irisa "Networks, Telecom and Services" department, and was sponsored by MATISSE doctoral school.
- Bruno Tuffin will be the co-coordinator of the "Analysis" track at the Winter Simulation Conference (WSC'12), Berlin, Germany, December 9-12, 2012. It will be the first time this event will leave North America.
- Bruno Tuffin was the TPC cho-chair for NetGCoop 2011, Oct. 12-14, Paris.

9.1.3. Program committees

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

- ASMTA 2011, 18th International Conference on Analytical and Stochastic Modelling Techniques and Applications, Venice, Italy, 20-22 June 2011.
- MAM'7, 7th International Conference on Matrix-Analytic Methods in Stochastic Models, New-York, USA, 13-16 June 2011.
- CFIP 2011, Colloque Francophone sur l'Ingénierie des Protocoles, St Maxime, France, 10-13 May 2011.

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

- ETS, 1st European Teletraffic Seminar, Poznan, Poland, 14-16 February 2011
- LANC 2011, 6th Latin America Networking Conference, in cooperation with IFIP/ACM, Quito, Ecuador, 12-14 October, 2011
- CLEI 2012, XXXVIII Conferencia Latinoamericana de Informática (Latin-American Informatics Conference), Medellín, Colombia, October 1-5, 2012.

Bruno Tuffin served as TPC member for

- Workshop on Performance Evaluation of Cognitive Radio Networks : from Theory to Reality (PE-CRN 2011), Valencia, Spain, May 13, 2011.
- IEEE International Conference on Communications (IEEE ICC 2011), June 5-9 2011, Kyoto, Japan.
- 7th Euro-NGI conference on Next Generation Internet Networks (NGI 2011), June 27-29 2011, Kaiserslautern, Germany.
- 1st International Conference on Simulation and Modeling Methodologies, Technologies and Applications (SIMULTECH), Noordwijkerhout, The Netherlands, 29-31 July 2011.
- 20th IEEE International Conference on Computer Communication Networks (ICCCN 2011), Maui, Hawaii, August 1-4, 2011.
- 8th International Workshop on Economics of Grids, Clouds, Systems and Services (GECON'2011).

Adlen Ksentini served as TPC member for

- IEEE Global Communication Conference, GLOBECOM 2011 Wireless Network Symposium, December 2011, Houston, Texas, USA
- IEEE International Conference on Communication, ICC 2011 Wireless Network Symposium, June 2011, Kyoto, Japan
- IEEE International Conference on Selected Topics in Mobile and Wireless Networking, October 2011, Shanghai, China
- IEEE International Symposium on Computer Communication, ISCC 2011, July 2011, Istanbul, Turkey.

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 in 2011.
- Adlen Ksentini is Associate Editor of Hindawi International Journal of Digital Multimedia Broadcasting

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 (and Bruno Tuffin his substitute). 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, 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 a member of the Inria Evaluation Committee which role is to assess the calibre of research conducted at Inria and to guarantee the quality of its hiring and internal promotions.
- 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 Conseil de laboratoire and of the Conseil d’Orientations scientifiques (COS) 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.
- Adlen Ksentini is the coordinator of the Special Interest Group (SIG) of the Communication Software Technical Committee (IEEE Communication Society)

9.1.6. Other activities

- B. Tuffin, Pricing in telecommunication networks: from congestion control and incentives design to competition among providers. ETICS Workshop, Versailles, France, June 2011.
- B. Tuffin. Adword auctions: impact of ranking strategies and competition on search engines revenues. INRIA, Grenoble, August 2011.
- P. Maille and B. Tuffin. Sponsored Search Engines in Competition: Advertisers Behavior and Engines Optimal Ranking Strategies. ECONTEL WG4 meeting, Vienna, Austria, September 2011.
- B. Tuffin Models for Network Provider Competition. Final Workshop, SISCom International Research Chair Future Telecommunication Ecosystems”, Rennes, September 19, 2011.
- P. Maille and B. Tuffin. Budget-limited advertising game on sponsored search engines in competition. Impact on engine ranking. ECONTEL COST Workshop, Budapest, September 2011.
- R. Marie made in November several seminar presentations in Brazil (Federal University of Minas Gerais, Federal University of Rio de Janeiro, Federal University Fluminense).
- G. Rubino gave several talks to High School students about research activity on applied mathematics and computer science. Topics were the following: rare event analysis, probabilistic tools for deterministic problems and research problems associated with Internet technologies.

9.2. Teaching

Licence L3: Introduction to networks, 20 hours, Istic/University of Rennes 1, France

Master M1: Introduction to networks, 24 hours, Esir/University of Rennes 1, France

Master M1: Wireless networking, 46 hours, Esir/University of Rennes 1, France

Master M1: Networks and protocols, 24 hours, Istic/University of Rennes 1, France

Master M1: Computer networks, 24 hours, Esir/University of Rennes 1, France
 Master M1: Algorithms and graphs, 48 hours, Esir/University of Rennes 1, France
 Master M1: Performance and dependability evaluation of computer systems, 54 hours, Istic/University of Rennes 1, France
 Master M2: Validation and tests, 6 hours, Istic/University of Rennes 1, France
 Master M2: Quality of service and multimedia, 6 hours, Istic/University of Rennes 1, France
 Master M2: Multimedia transmission, 18 hours, Istic/University of Rennes 1, France
 Master M2: Performance evaluation, 26 hours, Istic/University of Rennes 1, France
 Master M2: Network security, 14 hours, Istic/University of Rennes 1, France
 Master M2: Dependability analysis, 12 hours, Supelec, Rennes, France
 Master M2: Simulation, 5 hours, Telecom Bretagne, Rennes, France
 Master M2: Multimedia streaming over IP (MMR), 50 hours, Esir/University of Rennes 1, France
 Master M2: Multimedia services in IP networks (RSM), 29 hours, Esir/University of Rennes 1, France

PhD: Ghareeb Majd, Quality-aware multipath video-streaming in overlay networks, Université de Rennes 1, 22 September 2011, Adlen Ksentini and César Viho

9.3. Standardization activities

Participants: Anthony Baire, 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, 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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Major publications by the team in recent years

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- [11] M. GHAREEB. *Quality-aware multipath video streaming in overlay networks*, Université de Rennes 1, September 2011.
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Articles in International Peer-Reviewed Journal

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- [14] E. ANCEAUME, F. CASTELLA, R. LUDINARD, B. SERICOLA. *Markov Chains Competing for Transitions: Application to Large-Scale Distributed Systems*, in "Methodology and Computing in Applied Probability", 2011.

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