Activity Report 2014

Project-Team DIONYSOS

Dependability Interoperability and perfOrmance aNalYsiS Of networkS

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Keywords: Quality Of Experience, Monte Carlo Methods, Wireless Networks, Markovian Model, Rare Events

Creation of the Project-Team: 2009 January 01.

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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 for 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. protocol testing 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 range 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. Research Program

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 model 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, etc.), 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 measure 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. 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 model 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. New Software and Platforms

4.1. T3devKit testing toolkit and IPv6 test suites
Participant: 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 (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 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.

4.2. Interoperability Assessment
Participant: César Viho.

Our experience in interoperability assessment (since 1996) and in using the TTCN-3 standard allowed us to develop a tool (called `ttproto`) that helps in: (i) experimenting new concepts for long term evolution of the TTCN-3 standard and (ii) facilitating new approaches and methods for interoperability assessment. For instance, new passive approaches that we developed have been implemented and validated using `ttproto`. This tool `ttproto` has been used to develop test suites for 6LoWPAN-ND (IPv6 for Low Power Networks) and CoAP (Constrained Application Protocol). The CoAP test suites have been successfully used for two Plugtest interoperability events organized by ETSI, IPSO Alliance and the FP7 PROBE-IT project. The tool `ttproto` and the test suites indicated above are freely available at http://www.irisa.fr/tipi.

4.3. 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, etc. A set of functions designed for dependability analysis is being built under the name `DependLib`.

Pierre L'Ecuyer is also developing in Montreal a library, *Stochastic Simulation in Java* (SSJ), providing facilities for generating uniform and nonuniform random variates, computing different measures related to probability distributions, performing goodness-of-fit tests, applying quasi-Monte Carlo methods, collecting (elementary) statistics, and programming discrete-event simulations with both events and processes.

5. New Results

5.1. Highlights of the Year

Pierre L'Ecuyer received the Award of Merit from the Canadian Operational Research Society, 2014.

We had one best paper award in 2014 on a novel architecture for resilient networks (see 5.8).
BEST PAPER AWARD :
[50] **LOCARN: Low Opex Capex Architecture for Resilient Networks in IEEE International Conference on Innovations for Community Services**. D. LEQUÉRÉ, C. BETOULE, G. THOUENON, Y. HADJADJ-AOUL, A. KSENTINI, R. CLAVIER.

5.2. Quality of Experience

Participants: Yassine Hadjadj-Aoul, Adlen Ksentini, Gerardo Rubino, Bruno Sericola, Pantelis Frangoudis, César Viho, Quang Pham Tran Anh.

PSQA. We continue the development of the PSQA technology (Pseudo-Subjective Quality Assessment) in the area of Quality of Experience (QoE). PSQA is today a mature 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 that 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. Observe that perceived quality is, in general, the main component of QoE when the application or service involves video and audio, or voice. 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, and for any application or service, the module must be built from scratch. But once built, it works automatically and efficiently, allowing if necessary its use in real time, typically for controlling purposes.

QoE and SLA. On the applications side, we focused this year on using QoE estimates to drive service/application-level decisions. As a first use case, we proposed a multi-objective optimization framework for the problem of optimally selecting among a set of available hosting and network connectivity Service-Level Agreements (SLAs) for the migration of enterprise communication services (such as teleconferencing) to the Cloud [59]. Our framework captures the tradeoff between user experience and deployment cost, and offers a service provider the opportunity to weight these two conflicting criteria based on its preferences. Our approach is generic and can be applied to various application settings by appropriately selecting application-specific user experience models. For example, for enterprise voice teleconferencing we used the E-model for estimating user experience under a specific selection of hosting and network SLAs and a specific amount of resources (virtual machines) to deploy.

QoE and collaborative projects. We then considered QoE-aware content delivery, targeting in particular an environment where web and multimedia content is disseminated by over-the-top (OTT) providers, but assuming a level of cooperation between the content provider and the ISP (a trend which has started to become commonplace) [46]. We built on the outcome of our prior work [1], where we designed and implemented a network load estimation methodology and tool which operates by observing the delay behavior of the Precision Time Protocol (PTP) for network clock synchronization. After quantitatively establishing the link between network load and user experience, we proposed an architecture for OTT content delivery where user requests are redirected to the data centers expected to offer optimal QoE, taking into account, among others, information about network load in the media path offered by our load estimation service (LES) in real time. In the same context, we developed a demonstrator where the LES is integrated as an additional network probe with the QoE monitoring architecture developed in the Celtic QuEEN project (see 7.2.1.1). Using a simple video QoE model which takes into account network load and video information (quality/resolution, bitrate), we implemented [2] an adaptation scheme for DASH video delivery which switches among video qualities based on QoE estimates received by the QuEEN software agent.

QoE and PTPv2. In [46], we make the case for an alternative use of the PTPv2 protocol: Adopting a learning approach, we observe its delay behavior during the protocol message exchange, derive models of its dependence on network load and build a real-time load estimation service. Then, as an application scenario of this service, we turn our attention to the provision of Over-the-Top (OTT) services. In such an environment, and assuming a level of cooperation between the ISP and the OTT provider, we demonstrate how our service can be used for estimating the QoE for web applications. To this end, we establish quantitatively the link between network load and user experience using a state-of-the-art web QoE monitoring framework, and show how our PTPv2-based load estimation scheme can integrated in an OTT service architecture and be utilized for load-aware, QoE-optimized content delivery decisions.

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[1]P.A. Frangoudis, A. Ksentini, Y. Hadjadj-Aoul, and G. Boime, "PTPv2-based network load estimation," Proc. IEEE ISPCS 2013. (This work was carried out in the context of the FUI project IPChronos, see 6.10.)

[2]Our video adaptation scheme is implemented in the VLC open-source media player.

QoE and reneging. We consider in [45] an important Quality of Experience (QoE) indicator in mobile networks that is reneging of users due to impatience. We specifically consider a cell under heavy load conditions and compute the reneging probability by using a fluid limit analysis. By solving the fixed point equation, we obtain a new QoE perturbation metric quantifying the impact of reneging on the performance of the system. This metric is then used to devise a new pricing scheme accounting for reneging. We specifically propose several flavors of this pricing around the idea of having a flat rate for accessing the network and an elastic price related to the level of QoE perturbation induced by the communications.

QoE-aware OLSR for Video Streaming over Wireless Multihop Networks. Multi-hop environments can impact significantly ad-hoc network performance. In [57], we propose a routing algorithm based on optimized link state routing (OLSR), aimed at guaranteeing the quality of experience (QoE) of users in these types of networks. PSQA (see above in this same section) is used to estimate a mean opinion score (MOS), and then this MOS value is exploited by the source for selecting the appropriate path in the network. Moreover, an event- triggered based on the MOS value is used to provide more relevant information in selecting the best path by the source. The performance of this proposed mechanism was validated through intensive simulation under different scenarios. The results in [57] show that the proposed scheme outperforms other OLSR-based routing protocols particularly in a heavy load and high mobility scenario.

QoE-Aware Routing for Video Streaming over VANETs. In-vehicle multimedia applications are gaining interest since recent years. However, the high loss rate caused by high mobility in vehicular networks (VANETs) imposes several challenges in multimedia transmission. Moreover, in the context of multimedia, the quality of service (QoS)-based approaches assess the quality of streaming services through network-oriented metrics while the concept of quality of experience (QoE) is built upon the perception of users. In [58], a QoE-based routing protocol for video streaming over VANETs is proposed. By taking the mean opinion score (MOS) into account for path selection, good performance levels can be achieved, as shown by our simulation results.

5.3. Analytic models

Participants: Bruno Sericola, Gerardo Rubino, Raymond Marie.

New book about Dependability Theory. Dependability metrics are omnipresent in every engineering field, from simple ones through to more complex measures combining performance and dependability aspects of systems. The new book [69] written in the team, entitled "Markov Chains and Dependability Theory" and published in 2014 by Cambridge University Press (see also http://www.amazon.fr/Markov-Chains-Dependability-Theory-Gerardo/dp/1107007577/), presents the mathematical basis of the analysis of these metrics. The modelling context corresponds to the most used framework, Markov models. The book describes both basic results and specialised techniques. The authors first present discrete and continuous time Markov chains before focusing on dependability measures, which necessitate the study of Markov chains on a subset of states representing different user satisfaction levels for the modelled system. Topics covered include Markovian state lumping, analysis of sojourns on subset of states of Markov chains, analysis of most dependability metrics, fundamentals of performability analysis, and bounding and simulation techniques designed to evaluate dependability measures. As stated in its abstract, the book is of interest to graduate students and researchers in all areas of engineering where the concepts of lifetime, repair duration, availability, reliability and risk are important.

Fluid models. In [77] we study congestion periods in a finite fluid buffer when the input rate depends upon a recurrent Markov process; congestion occurs when the buffer content is equal to the buffer capacity. We consider the duration of congestion periods as well as the associated volume of lost information. We derive their distributions in a typical stationary busy period of the buffer. Our goal is to compute the exact expression of the loss probability in the system, which is usually approximated by the probability that the occupancy of the infinite buffer is greater than the buffer capacity under consideration. Moreover, by using general results of the theory of Markovian arrival processes, we show that the duration of congestion and the volume of lost information have phase-type distributions.

Industrial Logistic Aspects. Motivated by the consideration of clauses of penalty, we worked again on the determination of the probability distributions of the delays of unavailability of systems on the operational sites. By considering in particular a given type of spare, we show the important role played by the possible waiting time of the change during the occurrence of a breakdown. In particular we verify that the cumulative probability distribution of the delay of unavailability possesses a relatively low tail diminution as well as a high square of cœfficient of variation. Upper and lower bounds are highlighted in the simplest case. These results allow to calculate the risk inferred by the use of clauses of penalty; for example, by proposing an expression of the expectation of the cost of penalty imposed by unit of time if any unavailability exceeding a certain threshold is penalized [62]. If the possible waiting time of the change is the obsession of the specialists of the maintenance, the consideration of stock shortages in supply chains is often underestimated when these events are rare events. A related work consisted in showing that a low probability of break can be associated with a high coefficient of variation can have a very significant consequence [54].

We also studied the extension of our analytical method of calculation of the operational availability of a fleet of consequent systems deployed on a site and maintained by exchanges on the site of subsets (the LRU for *line repaired unit*) in the specific case where a policy of cannibalization is implemented. We propose an approximated method which is particularly adapted to the case of systems with strong operational availability because in this case the error inferred by the approximation remains low. The developed method consists in determining the expectation of the number of blocked systems due to the lack of change, in the presence of a policy of cannibalization. This expectation is directly associated with a loss of operational availability. At present, in the presence of a policy of cannibalization, the proposed solution concerns only the systems constituted by a series of LRU but the policy of cannibalization can be applied to all or part of the types of LRU [63].

5.4. Performance Evaluation

Participants: Pierre L'Ecuyer, Bruno Sericola, Romaric Ludinard.

Network Monitoring and Fault Detection. Monitoring a system consists in collecting and analyzing relevant information provided by the monitored devices, so as to be continuously aware of the system state (situational awareness). However, the ever growing complexity and scale of systems makes both real time monitoring and fault detection a quite tedious task. Thus the usually adopted option is to focus solely on a subset of information states, so as to provide coarse-grained indicators. As a consequence, detecting isolated failures or anomalies is a quite challenging issue. We propose in [39], [61] to address this issue by pushing the monitoring task at the edge of the network. We present a peer-to-peer based architecture, which enables nodes to adaptively and efficiently self-organize according to their "health" indicators. By exploiting both temporal and spatial correlations that exist between a device and its vicinity, our approach guarantees that only isolated anomalies (an anomaly is isolated if it impacts solely a monitored device) are reported on the fly to the network operator. We show that the end-to-end detection process, *i.e.*, from the local detection to the management operator reporting, requires a logarithmic number of messages in the size of the network.

Robustness Analysis of Large Scale Distributed Systems. In the continuation of [81] which proposed an in-depth study of the dynamicity and robustness properties of large-scale distributed systems, we analyze in [13], 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. When the number of Markov chains goes to infinity, we analyze the asymptotic behavior of the system for an arbitrary probability mass function governing the competition. We give conditions for the existence of the asymptotic distribution and we show how these results apply to cluster-based distributed systems when the competition between the Markov chains is handled by using a geometric distribution.

Detection of distributed deny of service attacks A Deny of Service (DoS) attack tries to progressively take down an Internet resource by flooding it with more requests than it is capable to handle. A Distributed Deny of Service (DDoS) attack is a DoS attack triggered by thousands of machines that have been infected by a

malicious software, with as immediate consequence the total shut down of targeted web resources (*e.g.*, e-commerce websites). A solution to detect and to mitigate DDoS attacks it to monitor network traffic at routers and to look for highly frequent signatures that might suggest ongoing attacks. A recent strategy followed by the attackers is to hide their massive flow of requests over a multitude of routes, so that locally, these flows do not appear as frequent, while globally they represent a significant portion of the network traffic. The term "iceberg" has been recently introduced to describe such an attack as only a very small part of the iceberg can be observed from each single router. The approach adopted to defend against such new attacks is to rely on multiple routers that locally monitor their network traffic, and upon detection of potential icebergs, to inform a monitoring server that aggregates all the monitored information to accurately detect icebergs. Now, to prevent the server from being overloaded by all the monitored information, routers continuously keep track of the c (among n) most recent high flows (called items) prior to sending them to the server, and throw away all the items that appear with a small probability. Parameter c is dimensioned so that the frequency at which all the routers send their c last frequent items is low enough to enable the server to aggregate all of them and to trigger a DDoS alarm when needed. This amounts to compute the time needed to collect c distinct items among n frequent ones. A thorough analysis of the time needed to collect c distinct items appears in [71].

Randomized Message-Passing Test-and-Set. In [74], we present a solution to the well-known Test&Set operation in an asynchronous system prone to process crashes. Test&Set is a synchronization operation that, when invoked by a set of processes, returns yes to a unique process and returns no to all the others. Recently, many advances in implementing Test&Set objects have been achieved, but all of them target the shared memory model. In this paper we propose an implementation of a Test&Set object in the message passing model. This implementation can be invoked by any number $p \leq n$ of processes where n is the total number of processes in the system. It has an expected individual step complexity in $O(\log p)$ against an oblivious adversary, and an expected individual message complexity in $O(n)$. The proposed Test&Set object is built atop a new basic building block, called selector, that allows to select a winning group among two groups of processes. We propose a message-passing implementation of the selector whose step complexity is constant. We are not aware of any other implementation of the Test&Set operation in the message passing model.

Call centers. We develop research activities around the analysis and design of call centers, from a performance perspective. In [56], we focus on the scheduling problem (which task must be done by which worker at each period of time). We show that a Constraint Programming model can be used to solve large instances of this type of optimization work. In [21], we study call routing policies for call centers with multiple call types and multiple agent groups, focusing on the case of small and medium size centers, whose behavior may differ from those obtained in heavy-traffic regimes, and for which non-work-conserving policies can perform better. We propose a routing policy based on weights, expressed as linear functions of the call waiting times and agent idle times, or number of idle agents, following a simulation-based optimization approach.

5.5. Network Economics

Participants: Bruno Tuffin, Pierre L'Ecuyer.

The general field of network economics, analyzing the relationships between all acts of the digital economy, has been an important subject for years in the team. The whole problem of network economics, from theory to practice, describing all issues and challenges, is described in our book [67].

Among the topics we have particularly focused on, the network neutrality debate was a major concern in 2014. In the position paper [79], Bruno Tuffin and his co-author Patrick Maillé discuss for a large audience the issues and challenges of network neutrality in response to the European parliament text voted in April 2014. A related (and often forgotten) issue, the recently raised search neutrality debate questions the ranking methods implemented by search engines: when a search is performed, do they (or should they) display the web pages ordered according to the quality-of-experience (relevance) of the content? In [22], we analyze that question in a setting when content is offered for free, content providers making revenue through advertising. For content providers, determining the amount of advertising to add to their content is a crucial strategic decision. Modeling the trade-off between the revenue per visit and the attractiveness, we investigate the interactions among competing content providers as a non-cooperative game, and consider the equilibrium

situations to compare the different ranking policies. Our results indicate that when the search engine is not involved with any high-quality content provider, then it is in its best interest to implement a neutral ranking, which also maximizes user perceived quality-of-experience and favors innovation. On the other hand, if the search engine controls some high-quality content, then favoring it in its ranking and adding more advertisement yields a larger revenue. This is not necessarily at the expense of user perceived quality, but drastically reduces the advertising revenues of the other content providers, hence reducing their chances to innovate.

But while ISPs and search engines are almost the only Internet actors being pointed out as potentially non neutral, we investigate the economic impact and strategies of Content Delivery Networks (CDNs), Internet actors that reduce the capacity needs in the backbone network and improve the quality perceived by users. The growing importance of Content Delivery Network (CDN) in the value chain of content delivery raises concerns about the neutrality of these players. We consider in [52] the so-called push and pull models where the traffic is paid by the sender or the receiver, respectively, as well as the situation where the CDN is (vertically) integrated to, i.e., owned by, an Internet Service Provider (ISP). We then discuss the implication of CDNs into the network neutrality debate, another issue forgotten by researchers and regulators. We also propose in [53] a model to analyze the impact of revenue-oriented CDN management policies on the fairness of the competition among two content providers that use CDN services to deliver contents. We show that there exists a unique optimal revenue maximizing policy for a CDN actor –the dimensioning and allocation of its storage capacity– that depends on prices for service/transport/storage, and on the distribution of content popularity. Using data from the analysis of traces from two major content providers (YouTube Live and justin.tv), we remark that a CDN remains a relatively neutral actor even when one of the content providers it serves tries to monopolize the CDN storage space by implementing an aggressive policy to harm its competitors.

Finally, when a customer searches for a keyword at a classified ads website, at an online retailer, or at a search engine (SE), the platform has exponentially many choices in how to sort the output to the query. The two extremes are (a) to consider a ranking based on relevance only, which attracts more customers in the long run because of perceived quality, and (b) to consider a ranking based on the expected revenue to be generated by immediate conversions, which maximizes short-term revenue. Typically, these two objectives are not perfectly positively correlated and hence the main question is what middle ground between them should be chosen. We introduce in [78] stochastic models and propose effective solution methods that can be used to optimize the ranking considering long-term revenues. A key feature of our model is that customers are quality-sensitive and are attracted to the platform or driven away depending on the average relevance of the output. The proposed methods are of crucial importance in e-business and encompass: (i) classified ad websites which can favor paid ads by ranking them higher, (ii) online retailers which can rank products they sell according to buyers' interests and/or the margins these products have, (iii) SEs which can position the content that they serve higher in the output page than third-party content to keep users in their platforms for longer and earn more. This goes in detriment of just offering rankings based on relevance only and is directly linked to the current search neutrality debate.

5.6. Monte Carlo

Participants: Bruno Tuffin, Gerardo Rubino, Pierre L'Ecuyer.

We maintain a research activity in different areas related to dependability, performability and vulnerability analysis of communication systems, using both the Monte Carlo and the Quasi-Monte Carlo approaches to evaluate the relevant metrics. Monte Carlo (and Quasi-Monte Carlo) methods often represent the only tool able to solve complex problems of these types. A review of Monte Carlo, Quasi-Monte Carlo and pseudo-random generation can be found in [66]. In [27], we examine some properties of the points produced by certain classes of long-period linear multiple recursive random number generators. These generators have their parameters selected in special ways to make the implementation faster. We show that as a result, the points produced by these generators have a poor lattice structure, and a poor initialization of the state can have long-lasting impact, because of the limited diffusion capacity of the recurrence.

However, when the events of interest are rare, simulation requires a special attention, to accelerate the occurrence of the event and get unbiased estimators of the event of interest with a sufficiently small relative variance. This is the main problem in the area. Dionysos' work focuses then on dealing with the rare event situation. In [20], we present several state-of-the-art Monte Carlo methods for simulating and estimating rare events. Among variance reduction methods, the most prominent ones for this purpose are Importance Sampling (IS) and Multilevel Splitting, also known as Subset Simulation. Some recent results on both aspects are described, motivated by theoretical issues as well as by applied problems.

A non-negligible part of our activity on the application of rare event simulation was about the evaluation of static network reliability models, with links subject to failures. Exact evaluation of static network reliability parameters belongs to the NP-hard family and Monte Carlo simulation is therefore a relevant tool to provide their estimations. In [34], we propose an adaptive parameterized method to approximate the zero-variance change of measure. The method uses two rough approximations of the unreliability function, conditional on the states of any subset of links being fixed. One of these approximations, based on mincuts, under-estimates the true unknown unreliability, whereas the other one, based on minpaths, over-estimates it. Our proposed change of measure takes a convex linear combination of the two, estimates the optimal (graph-dependent) coefficient in this combination from pilot runs, and uses the resulting conditional unreliability approximation at each step of a dynamic importance sampling algorithm. This new scheme is more general and more flexible than a previously-proposed zero-variance approximation one, based on mincuts only, and which was shown to be robust asymptotically when unreliabilities of individual links decrease toward zero. Our numerical examples show that the new scheme is often more efficient when low unreliability comes from a large number of possible paths connecting the considered nodes rather than from small failure probabilities of the links. Another paper, reference [18], focuses on another technique, known as 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. This previously known method is shown to not verify the bounded relative error (BRE) property as reliability of individual links goes to one, i.e., the estimator is not robust in general to high reliability of links. We then propose to use the decomposition ideas of the RVR estimator in conjunction with the IS technique. Two new estimators are presented: the first one, called Balanced Recursive Decomposition estimator, chooses the first working link on cuts uniformly, while the second, called Zero-Variance Approximation Recursive Decomposition estimator, combines RVR and our zero-variance IS approximation. We show that in both cases BRE property is verified and, moreover, that a vanishing relative error (VRE) property can be obtained for the Zero-Variance Approximation RVR under specific sufficient conditions. A numerical illustration of the power of the methods is provided on several benchmark networks. Continuing the analysis of existing method, we have described in [44] a necessary and sufficient condition for a well known technique called Fishman's method to verify BRE and have realized a deep analysis of the technique.

But in the literature and the previously described static network reliability models one typically assumes that the failures of the components of the network are independent. This simplifying assumption makes it possible to estimate the network reliability efficiently via specialized Monte Carlo algorithms. Hence, a natural question to consider is whether this independence assumption can be relaxed, while still attaining an elegant and tractable model that permits an efficient Monte Carlo algorithm for unreliability estimation. In [75], we provide one possible answer by considering a static network reliability model with dependent link failures, based on a Marshall-Olkin copula, which models the dependence via shocks that take down subsets of components at exponential times, and propose a collection of adapted versions of permutation Monte Carlo (PMC, a conditional Monte Carlo method), its refinement called the turnip method, and generalized splitting (GS) methods, to estimate very small unreliabilities accurately under this model. The PMC and turnip estimators have bounded relative error when the network topology is fixed while the link failure probabilities converge to 0. When the network (or the number of shocks) becomes too large, PMC and turnip eventually fail, but GS works nicely for very large networks, with over 5000 shocks in our examples. [65] focuses on the application of our zero-variance approximation IS estimator to this same type of model.

Another family of models of interest in the group are the highly reliable Markovian systems, made of components subject to failures and repairs. We describe in [60] how importance sampling can be applied

to efficiently estimate the average interval availability of those models. We provide a methodology for approximating the zero-variance change of measure. The method is illustrated to be very efficient on a small example, compared with standard importance sampling strategies developed in the literature.

Finally, in Quasi-Monte Carlo (QMC), the error when estimating an integral uses a deterministic sequence (instead of a random one) called a low discrepancy sequence and having the property to spread quickly over the integration domain. The estimation error is bounded by the product of a quantity depending on the discrepancy of the sequence and the variation of the integrand. But this bound is proved to be useless in practice. By combining MC and QMC methods, we can benefit from the advantages of both approaches: error estimation from MC and convergence speed from QMC. Randomized quasi-Monte Carlo (RQMC) is another class of methods for reducing the noise of simulation estimators, by sampling more evenly than with standard MC. In [37], we analyze the convergence rate of the *array-RQMC* technique, a randomized QMC method we have previously designed and devoted to the simulation of Markov chains.

In [19], we propose a method for estimating performability metrics built upon non-binary network states, determined by the hop distances between distinguished nodes. In other words, we explore the analysis of a generalization of network reliability, particularly relevant for instance in telecommunications. The estimation is performed by a Monte Carlo simulation method where the sampling space is reduced using edge sets known as d-pathsets and d-cutsets. Numerical experiments over two mesh-like networks are presented. They show significant efficiency improvements relative to the crude Monte Carlo method, in particular as link failures become rare events, which is usually the case in most real communication networks.

5.7. Wireless Networks

Participants: Osama Arouk, Btissam Er-Rahmadi, Adlen Ksentini, Yassine Hadjadj-Aoul, Quang Pham Tran Anh, Hyunhee Park, César Viho.

We continue our activities around wireless and mobile networks, where we focus particularly on 4G/5G networks as well as on a new mobile architecture known as mobile cloud.

LTE improvements. In [35], we investigated, at both the core network (EPC) and Radio Access Network (RAN), the impact of caching the shared content among users. We reviewed the different locations were data could be cached and their impacts on user QoS/QoE. In [33], we proposed several new mechanisms to handle the gateway relocation in the context of highly decentralized mobile network. To evaluate these mechanisms, we proposed an analytical model based on Markov Chains, whereby we captured the randomness of user mobility and its impact on the user QoS in terms of the probability to be connected to the optimal gateway, the drop rate, etc. In [32], we devised an agile admission control mechanism that anticipates QoS/QoE degradation and proactively defines policies for admitting UEs handing-in from the macro network to the small cell network. It also enables IP flow mobility between small cells and macro networks. We provided an analytical model to the admission control mechanism based on Markov Decision Processes (MDP). The ultimate objective of the proposed model is to derive the optimal policy (i.e., reject or accept flows in the macro or the small cell) which maximizes users' QoE under different load scenarios (low and high load user traffic). Another work regarding small cells in LTE was proposed in [76], where we used the small cell principle to extend the mobile network coverage in emerging countries that not include a wired infrastructure. The proposed framework aims to backhaul the small cell with the less costly connection, while ensuring minimal QoS to users. In this vein, we formulated this problem through an Integer Linear Program (ILP), and solve it for small network sizes. For large instances of the network size, we proposed two new heuristics. In [30], we investigated network decentralization in conjunction with the Selective IP Traffic Offload (SIPTO) approaches to handle the mobile increased data traffic. We first devised different approaches based on a per destination domain name basis, which offer operators a fine-grained control to determine whether a new IP connection should be offloaded or accommodated via the core network. Two of our solutions are based on Network Address Translation (NAT) named simple-NATing and twice-NATing, while a third one employs simple tunneling and a forth proposal adopts multiple Access Point Names (APNs). We also proposed methods enabling User Equipment (UEs), both in idle and active modes and while being on the move, to always have efficient Packet Data Network (PDN) connections. A qualitative analysis and a simulation

study compared the different approaches with respect to cost, complexity, service continuity and network performance, demonstrating the significance of the proposed schemes for multimedia applications.

M2M. We addressed another type of traffic that appeared these last years, namely Machine to Machine (M2M) communication or Machine Type Communication (MTC). Such traffic is known by its intensity and its impact on increasing congestion in both parts of 4G networks, the Radio Access Network (RAN) and the core network. The main spirit of the proposed solutions is to proactively anticipate system overload by reducing the amount of MTC signaling messages exchanged in normal network operations. In [49] we introduced a solution that operates at the core network. We proposed that the Mobility Management Entity (MME), or an alike core network node, computes the device trigger rate that alleviates congestion, and communicates this value to the MTC-Interworking Function (MTC-IWF) element that enforces MTC traffic control, via admission control or data aggregation, on the device trigger request rate received from the different MTC servers.

As mentioned earlier, the MTC would impact not only the EPC part, but also the RAN. Group paging is currently considered as one of the most efficient mechanisms proposed to alleviate the problem of the RAN overload. In [42] we introduced a new solution to improve the performance of the current group paging method and overcome its disadvantages. The proposed solution is intended for MTC devices in connected mode state, in which they have an RRC context without being synchronized with the network. In [41] we devised a novel algorithm which estimates the network status (the number of active devices), thus better controlling the RAN access. Unlike most existing methods that consider only one channel, the proposed solution uses the statistics of all the channels in order to estimate the number of arrivals (UE and MTC devices) in each RA (Random Access) slot.

Most of the above-proposed solutions are basically incremental ones. In [31], we devised a complete new architectural vision to support MTC in mobile networks. This vision relies on the marriage of mobile networks and the cloud, specifically based on Network Function Virtualization (NFV). The proposed solution simplifies the network attach procedure for MTC devices by creating only one NFV MTC function that groups all the usual procedures. By doing so, the proposed solution is able to create and scale instances of NFV MTC functions on demand and in an elastic manner to cope with any sudden increase in traffic generated by MTC devices.

Wireless Sensor Networks (WSN). WSNs are complex systems that are mainly limited by the battery life of the nodes in order to have an adequate performance. In most cases, it is possible to have a re-deployment of new nodes in order to prolong the systems lifetime. This leads to a situation where some nodes have a low energy level while other nodes (the majority of nodes a few instants after the re-deployment procedure) have high energy levels. In these environments, it is clear that ancient nodes, those with low energy levels, have to contend for the shared medium against the majority of high energy nodes. As such, the remaining battery life of low energy nodes would be rapidly consumed. In [64], we propose to extend the battery life of low energy nodes by means of assigning prioritized access to the shared channel to those nodes. The goal is to content among a low population of such nodes, while delaying the contention access of high energy nodes which can support higher number of collisions before energy depletion. This is done by studying two different transmission strategies referred to as "hard" and "soft" transmission probabilities. Results show that a soft transmission strategy achieves better results in terms of reduced energy consumption than both the conventional protocol or a hard transmission assignment.

The communication between nodes is the greedy factor to the energy consumption. One important mechanism to reduce the energy consumption is the in-network data aggregation. This mechanism removes repeated and unnecessary data readings and thus cuts on the energy used in communications. In [14] we reviewed the state of art on this topic. Then, we proposed a classification of the available solutions according to the way the aggregation is done. In [15], we addressed the reliable minimum data aggregation scheduling problem in wireless sensor networks under multi-channel frequency use. The proposed solution ensures the collection reliability and reduces the latency in disseminating aggregated data to the base-station over multi-frequency radio links. Another mechanism to improve energy efficiency is to optimize link scheduling when using TDMA-based techniques and data fragmentation when using slotted CSMA/CA access methods. In this line, we proposed a protocol, named DLSP, with the objective of achieving both low energy consumption and low

latency in Wireless Sensor Networks. DLSP takes advantage of the spatial reuse of interference-free time slots by means of conflicts graphs. Unlike the previous studies that often consider saturated nodes, we propose to relax the saturation assumption in order to maintain good performance when some of the nodes have no data to send citemouloud:hal-01101396. In [55], we noticed that the standardized slotted CSMA/CA may lead to a wastage of the bandwidth utilization and an additional transmission delay. This drawback is mainly caused by Deferred Transmission in the CSMA/CA algorithm at the end of the superframe, when there is not sufficient time to complete the frame transmission. Thus, we proposed to fragment a data frame into a short frame and attempt its transmission in the current frame and transmit the remaining frame in the next superframe. The data fragmentation mechanism was modeled using a Markov chain. A non-saturated traffic and acknowledgement transmission are considered in our analysis.

High data rate WiFi networks. The IEEE 802.11ac Task Group (TGac) is actively working on an amendment that allows WLAN to reach a maximum aggregate network throughput up to 7 Gbps on bands below 6 GHz. In particular, the standard envisions a maximum Medium Access Control (MAC) throughput of at least 500 Mbps for a single user, and at least 1 Gbps in case of multiple users. In [36] we proposed an analysis of the IEEE 802.11ac TXOP Sharing mechanism, which was recently introduced by the 802.11ac group, by providing a Markov chain-based model. Based on the proposed Markov chain, we provided an analytical model of the achievable throughput for each AC. Accordingly, we can analyze the impact of the TXOP Sharing on the throughput of each AC, hence highlighting the improvement achieved in terms of bandwidth utilization and channel access fairness among the different ACs.

Mobile cloud. One of the 5G-architecture visions considers the usage of clouds to build mobile networks and help in decentralizing mobile networks on demand, elastically, and in the most cost-efficient way. This concept of carrier cloud becomes of vital importance knowing that several cloud providers are distributing their cloud/network, globally deploying more regional data centers, to meet their ever-increasing business demands. As an important enabler of the carrier cloud concept, network function virtualization (NFV) is gaining great momentum among industries. NFV aims for decoupling the software part from the hardware part of a carrier network node, traditionally referring to a dedicated hardware, single service and single-tenant box, that is using virtual hardware abstraction. Network functions become thus a mere code, runnable on a particular, preferably any, operating system and on top of a dedicated hardware platform. The ultimate objective is to run network functions as software in standard virtual machines (VMs) on top of a virtualization platform in a general-purpose multi-service multi-tenant node (e.g., Carrier Grade Blade Server) put into the cloud. In [26], we presented a LISP-based implementation of the Follow Me Cloud (FMC) concept, whereby mobile services hosted in federated clouds follow mobile users as they move and according to their needs. This implementation clearly demonstrates the feasibility of the FMC concept. On the other hand, service migration in FMC may be an expensive operation given the incurred cost in terms of signaling messages and data transferred between DCs. Indeed, decision on service migration defines therefore a tradeoff between cost and user perceived quality. In [48] we addressed this tradeoff by modeling the service migration procedure using a Markov Decision Process (MDP). The aim was to formulate a decision policy that determines whether to migrate a service or not when the concerned User Equipment (UE) is at a certain distance from the source DC.

In order to meet the general needs of mobile operators, efficient mobile cloud must give high importance to the placement/instantiation of mobile network functions (such as data anchor gateways) in the federated cloud. In [43] we argued the need of using service/application type and requirements as metrics for efficiently: (i) create virtual instance of the Packet Data Network Gateway (PDN-GW); (ii) select the virtual PDN-GW for UEs with specific application type. After modeling this procedure though a nonlinear Optimization Problem (OP) and proving it as a NP-hard problem, we proposed three solutions to solve this issue.

Wireless Local Area Networks. User-centric networking has emerged as a disruptive new communication paradigm. We particularly focused on its expressions in *wireless* networking and the challenges it brings about [23]. In this context, by means of testbed experiments and simple analytic models, we quantified the upper bounds on VoIP capacity of a purely user-centric secure VoIP communications scheme that we designed, identifying the major quality degradation factors. Our results have shown that typical user Wi-Fi equipment can

sustain a satisfactory number of concurrent secure VoIP sessions with acceptable QoE and, at the same time, protection from malicious user activity can be offered to access providers, while a level of roaming privacy can be guaranteed [24]. We then studied the role of users in wireless network management tasks. In particular, we proposed a scheme where monitoring the topology of Wi-Fi deployments is crowdsourced to roaming users, who submit reports on wireless coverage in their vicinity [25]. Topology information can then be used as input to reconfiguration mechanisms, such as channel assignment schemes. Users cannot be assumed trustworthy, though. They can engage in fraudulent reporting, which, unless specific countermeasures are in place, can severely impact one's view of the network topology. To this end, we designed and implemented an architecture for accurate Wi-Fi topology discovery, devising a reputation-based mechanism to tackle realistic and simple to implement attacks. We have shown analytically and via simulation that, even in the presence of large numbers of attackers, our user-centric scheme significantly outperforms pure infrastructure-based approaches, where monitoring is carried out only by trusted Access Points.

In another line of research, we focused on efficiently integrating wireless users in an Information-Centric Network (ICN) architecture. In ICN, multicast content delivery is the norm. At the same time, wireless multicast is problematic. To address this issue, we took advantage of the content awareness inherent in ICN and proposed a relay-based approach for local wireless multicasting: ICN information *scoping* mechanisms assist in expressing content semantics and, in turn, encoding the heterogeneous performance requirements of different content/application types. Under this premise, we proposed a multiobjective optimization approach for relay selection and multicast transmission rate assignment which allows to optimize for reliability, delivery time, or energy cost on a per content basis [47].

Energy saving. Another part of our activities in wireless network are related to energy saving. Indeed, one of the biggest problem today in the wireless world is that wireless devices are battery-driven, which reduce their operating lifetime. The experimental measurements we have achieved in [16] and [17] revealed that operating system overhead causes a drop in performance and energy consumption properties as compared to the GPP in case of certain low video qualities. We propose, thus, a new approach for energy-aware processor switching (GPP or DSP) which takes into consideration video quality. We show the pertinence of our solution in the context of adaptive video decoding and implement it on an embedded Linux operating system.

Adaptive Beam Scheduling for Scalable Video Multicast in Wireless Networks. Design of efficient multicast for a scalable video coding (SVC) streaming combined with directional beamforming is a challenging issue. In [29], we propose a QoE-aware directional beam scheduling (QBS) scheme which optimizes overall quality of experience (QoE) for multirate multicast of SVC, with beamforming in wireless networks. We optimally schedule different SVC layers to different beams and rate modulations. We provide a mixed integer linear programing (MILP) formulation of the problem, and then propose a heuristic algorithm. Extensive simulation results demonstrate that QBS can increase the overall QoE and can satisfy a minimum expected QoE for all users.

5.8. Future networks and architectures

Participants: Damien Le Quéré, Adlen Ksentini, Yassine Hadjadj-Aoul, Jean-Michel Sanner.

LOCARN. LOCARN (i.e. Low Opex & Capex Architecture for Resilient Networks) is a flat, dynamic and very simple packet architecture that focuses on plug-and-play guidance to provide flexibility and resiliency on the transport of client data traffics. To that end, the counterpart of the solution is a significant overhead due to the generation of control plane packets. In [50], we proved that in typical meshed operators transport networks applications, (i.e. infrastructures having high data-rates and high resiliency requirements), the LOCARN overhead is acceptable up to thousands of communications. In [51], we introduced two proposals that permit to increase the amount of simultaneous communications while maintaining the good properties of the initial design.

SDN. We started an activity on Software Defined Networking (SDN), a recent idea proposed to handle network management problems. SDN are becoming an important issue with the ever-increasing network complexity. They are proposed as an alternative to the current architecture of the Internet, which cannot meet the supported

services requirements such as Quality of Service/Experience (Qos/QoE), security and energy consumption. We particularly address the scalability issue by proposing an automated hierarchical controller-based architecture handling the whole control chain.

6. Bilateral Contracts and Grants with Industry

6.1. Bilateral Contract with Industry: ALSTOM-Inria Common Lab

Participants: Bruno Tuffin, Gerardo Rubino.

Bruno Tuffin is the co-director of ALSTOM-Inria common Lab.

The group currently manages a project with ALSTOM on system availability simulation taking into account logistic constraints. Current ALSTOM Transport and Power contracts, especially service-level agreements, impose stringent system availability objectives. Non-adherence to the required performance levels often leads to penalties, and it is therefore critical to assess corresponding risk already at a tender stage. The challenge is to achieve accurate results in a reasonable amount of time. Monte Carlo simulation provides estimates of the quantities it is desired to predict (e.g., availability). Since we deal with rare events, variance reduction techniques, specifically Importance Sampling (IS) here, is used. The goal of the project is to establish the feasibility of IS for solving problems relevant to ALSTOM and to develop the corresponding mathematical tools.

6.2. Bilateral Contract with Industry: Participation in a CRE with Orange

Participant: Bruno Tuffin.

We are participating to a CRE (managed by Telecom Bretagne) with Orange on the strategies of Content Delivery Networks (CDNs) and their impact on the overall Internet economy and regulation. In this study, we focus on the CDN as an economic actor. The goals are 1) to analyze CDNs' caching strategies from an economic point of view, 2) to study the strategies of an integrated CDN actor, and 3) to study the impact of CDNs in the net neutrality debate.

6.3. Bilateral Contract with Industry: Data-aggregation for large-scale distributed networks

Participants: Bruno Sericola, Romaric Ludinard.

This was 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.

6.4. Cifre contract on LOCARN: Low Opex and Capex Architecture for Resilient Networks

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

This is a Cifre contract (2012-2015) including a PhD thesis supervision, done with Orange Labs, on evaluating and developing a new plug-and-play routing protocol (called Low Opex and Capex Architecture for Resilient Networks, or LOCARN), which do not require any network management or configuration.

6.5. Cifre contract on Small Cell Networks

Participants: Btissam Er-Rahmadi, Adlen Ksentini, César Viho.

This is a Cifre contract (2013-2016) including a PhD thesis supervision, done with Orange Labs, on cooperation and self-* small cell networks. The aim is to define architectures and protocols for deploying small cell networks in AMEA (Africa, Middle East and Asia) countries.

6.6. Cifre contract on a dynamic adaptive service-driven SDN architecture

Participants: Jean-Michel Sanner, Yassine Hadjadj-Aoul, Gerardo Rubino.

This is a Cifre contract (2013-2016) including a PhD thesis supervision, done with Orange Labs, on defining a dynamic adaptive service-driven network architecture based on the SDN concept.

6.7. Cifre contract on defining an open, a flexible and a unified network architecture

Participants: Yue Li, Yassine Hadjadj-Aoul, Gerardo Rubino.

This is a Cifre contract (2013-2016) including a PhD thesis supervision, done with Orange Labs, on designing an open, flexible and unified network architecture.

6.8. DGA Grant

Participant: Adlen Ksentini.

This DGA grant, with Cidre Inria team, is for the PhD supervision of Florient Grandhomme. The aim of the PhD program is to study a new routing protocol for MANET.

6.9. DVD2C

Participant: Adlen Ksentini.

We are working in the 3-year (September 2014 to September 2017) FUI Project DVD2C, which aims to virtualize CDN through the Cloud and Network Function Virtualization concept. DVD2C is leaded by Orange Labs, and the partners are two SMEs (Viotech and Resonate) and two academics (our team and Télécom Paris Sud).

6.10. IPChronos

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

The 3-year (September 2011 – September 2014) FUI Project IPChronos, where the main focus is in the use of the IEEE 1588 synchronization protocol over IP, ended. Our contribution focused on developing analytical models to estimate, based on the IEEE 1588 protocol, the end-to-end delay. IPChronos was leaded by ORALIA SPECTRACOM, and the partners are IPlabel and our team.

6.11. Camion

Participants: Yassine Hadjadj-Aoul, César Viho, Raymond Marie, Pantelis Frangoudis.

We are working in the 2-year (October 2014 to October 2016) Eurostars European Project Camion, which aims at offering cost-efficient, QoE-optimized content delivery, allowing for faster content access, as well as offline operation, while improving wireless network capacity and coverage. Camion is leaded by JCP-Connect, and the partners are a SME (FON) and our team.

7. Partnerships and Cooperations

7.1. National Initiatives

7.1.1. ANR

- Adlen Ksentini is participating at 20% of his time to the IRT BCOM granted by the ANR.
- Yassine Hadjadj-Aoul is participating at 20% of his time to the IRT BCOM granted by the ANR.

7.2. European Initiatives

7.2.1. *Collaborations in European Programs, except FP7 & H2020*

7.2.1.1. QuEEN project

Program: CELTIC

Project acronym: QuEEN

Project title: Quality of Experience Estimators in Networks

Duration: October 2011 - January 2015

Coordinator: Orange Labs

Other partners: 24 partners in many European partners

Abstract: QuEEN is a large 3-year Celtic project going from end 2011 to January 2015. Its objectives are to develop automatic QoE measurement modules for Web services and applications, and to organize these measurement modules as a network of cooperative agents in order to allow each agent to take advantage of the measurements done by the others. Dionysos was involved in most of the activities of the project, and QuEEN partners have benefit from our experience in developing the PSQA technology. QuEEN involved many companies and academic institutions (24 European partners); the project leader was Orange Labs, in Sophia Antipolis.

For more details, visit http://celtic-queen.inria.fr/dokuwiki/doku.php?id=start

7.2.1.2. DPDM1

Program: IT for Knowledge Management, IT4 Innovations, National Supercomputing Center, Ostrava, Czech Republic

Project acronym: DPDM1

Project title: Database of Performance and Dependability Models 1

Duration: October 2014 – March 2015

Coordinator: Technical University of Ostrava

Other partners: Inria (G. Rubino, Dionysos)

Abstract: the project consists in using the supercomputing facilities at Ostrava to build very large models with known numerical solutions, that will serve as a benchmark to many types of techniques designed to compute numerically exact values, bounds, estimations, etc., under research efforts all over the world (areas: Markovian models, rare event problems, neural networks, etc.).

7.2.2. *Collaborations with Major European Organizations*

Partner 1: FTW, Vienna (Austria)

We work with FTW on network economics.

Partner 2: VTT, Oulu, Finland

We work with VTT on Quality of Experience estimation and use.

7.3. International Initiatives

7.3.1. *Inria International Labs*

7.3.1.1. CIRIC

In the context of CIRIC, we cooperate with the team of Reinaldo Vallejos, professor at the UTFSM, Valparaíso, Chile, on different topics related to networking and modeling issues. Specifically, these activities are organized around two collaborative projects, 7.3.2.1 and 7.3.4.1, where one can find the scientific details. We start to work also with Javiera Barrera's team at the University Adolfo Ibañez, Santiago de Chile, on stochastic optimization problems.

7.3.2. Inria Associate Teams

7.3.2.1. MANAP

Title: MANAP (Markovian ANalysis and APplications)

International Partner (Institution - Laboratory - Researcher):

Universidad Técnica Federico Santa María (Valparaíso, Chile)

Duration: 2013 - · · ·

See also: http://people.rennes.inria.fr/Gerardo.Rubino/RESEARCH/MANAP/manap.html

This project has two goals. The main one is to develop techniques allowing to accelerate solving techniques for Markov models, both in equilibrium and in their transient phases. The applications behind these efforts are the evaluation of performance, dependability and performability properties of complex communication systems. The second goal is to apply these solving techniques to specific problems in networking, concerning optical and wireless infrastructures. On both cases there is some emphasis on dependability aspects: fault tolerance routing schemes in the first case, complex dependability characteristics and their analysis in the second one. A third explicit objective is to produce a software tool implementing the techniques coming from the main research direction of the project, designed to be used both by engineers and researchers.

7.3.3. Inria International Partners

7.3.3.1. MOCQUASIN

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

International Partner (Institution - Laboratory - Researcher):

University of Montreal (Canada)

Duration: 2013 - · · ·

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

The goal of this team is to compute integrals, sums or to solve equations or optimization problems by means of Monte Carlo methods, which are statistical tools used when the models have a high complexity (for instance a large dimension). They are unavoidable tools in areas such as finance, electronics, seismology, computer science, engineering, physics, transport, biology, 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 methods allowing to reach the targeted precision in a shorter computational time. A typical framework is that of rare event simulation for which getting even only one occurrence of the event could require a very long time. In this case, there are two main acceleration techniques: importance sampling and splitting, on which we work.

7.3.4. Participation In other International Programs

7.3.4.1. Stic AmSud with UDELAR, Uruguay, and UTFSM, Chile

Program: Stic AmSud

Title: Accelerating Markov Models for analysis and design of dynamic WDM optical networks (AMMA)

Inria principal investigator: Gerardo Rubino

International Partners (Institution - Laboratory - Researcher):

University of the Republic (UDELAR), Montevideo, Uruguay – Computer Science at the Engineering Faculty – prof. Héctor Cancela

Technical University Federico Santa María (UTFSM), Valparaíso, Chile – Electronics Department – Prof. Reinaldo Vallejos

Duration: 2 years, Jan. 2013 – Dec. 2014

This project has two main scientific goals: (i) to develop methods capable of solving Markov models faster than with state-of-the-art techniques, and (ii) to apply these techniques to the design of fault-tolerant optical networks. The rationale behind (i) is that the group has ideas and some preliminary promising unpublished results that makes it expect that its approach will be effective in producing new nice solving procedures. Concerning (ii), we have already produced results in simpler cases (without taking into account failures), and we also have results on all the associated areas (dependability analysis, combinatorial optimization, etc.). These main research lines are completed with other goals all concerned with the quantitative analysis of such complex communication systems.

7.3.4.2. Math AmSud with UDELAR, Uruguay, and UV, Chile

Program: Math AmSud

Title: Stochastic Analysis, Statistics Inference, Numerical Analysiss (SIN)

Inria principal investigator: Gerardo Rubino

Main International Partners (Institution - Laboratory - Researcher):

University of the Republic (UDELAR), Montevideo, Uruguay – Computer Science at the Engineering Faculty – prof. Paola Bermolen

University of Valparaíso, Chile — Prof. Soledad Torres

Duration: 2 years, Jan. 2013 – Dec. 2014

Stochastic calculus with respect to the standard Brownian motion or more generally with respect to semi-martingales is currently one of the most important components of international research in probability theory. The applications of this theory largely exceed the original probabilistic framework and have repercussions in various fields, including differential geometry, differential partial equations, theoretical physics, modeling in finance, hydrology, telecommunications and biology. Recently, many authors have been interested in developing a stochastic calculus with respect to Gaussian processes which are not necessarily semi-martingales, as for instance the well known fractional Brownian motion. This research project is articulated around the analysis and the applications of stochastic differential equations driven by long memory processes.

SIN is a large project with many partners. Our team participates in looking at differential equations and stocastic differential equations as limits of discrete Markov processes.

7.4. International Research Visitors

7.4.1. Visits of International Scientists

- Professor Héctor Cancela

    Subject: network reliability (see 7.3.4.1, 7.3.2.1)

    Institution: UDELAR, Montevideo, Uruguay

    Duration: December 14 to December 31

- Professors Reinaldo Vallejos and Marta Barría

    Subject: network modeling and Markov chain analysis (see 7.3.4.1, 7.3.2.1, 7.3.1.1)

    Institutions: UTFSM and UV, Valparaíso, Chile

    Duration: October 17 to October 27

- Leslie Murray

    Subject: Monte Carlo methods (see 5.6)

    Institution: University of Rosario, Argentina

    Duration: November 21 to December 19

- Assistant Professor Pablo Romero

Subject: network modeling and network reliability (see 7.3.4.1, 7.3.2.1)

Institutions: UDELAR, Montevideo, Uruguay

Duration: September 4 to November 14

- Luis Gutiérrez Begovich

    Subject: neural networks

    Institution: IPN (Instituto Politécnico Nacional), Mexico DF, Mexico

    Duration: December 6, 2013, to February 28, 2014

- Assistant Professor Jorge Graneri

    Subject: neural networks and human memory modeling (preparation for a future PhD work)

    Institutions: UDELAR, Montevideo, Uruguay

    Duration: October 1 to November 21

7.4.2. Visits to International Teams

7.4.2.1. Research stays abroad

Gerardo Rubino

Date: Jan 6 - Jan 10

Institution: Kaust, Saudi Arabia

G. Rubino visited the Center for Uncertainty Quantification in Computational Science and Engineering, Kaust, Saudi Arabia, one week in January, where he gave a seminar. He also served at the international Advisory Board of this Center

Gerardo Rubino

Date: Jun 25 - Jun 28

Institution: National Supercomputing Center, Technical University of Ostrava, Czech Republic

This was a research visit, which included a tutorial on rare event analysis using Monte Carlo techniques, and the preparation of a project

8. Dissemination

8.1. Promoting Scientific Activities

8.1.1. Scientific events organisation

8.1.1.1. Member of the organizing committee

Pierre L'Ecuyer was a member of the following groups:

- Steering Committee for the IMACS Seminar on Monte Carlo Methods (biennial conference), since 2009.
- Steering Committee for the International Conference on Monte Carlo and Quasi-Monte Carlo Methods in Scientific Computing, since 2006.
- Selection committee for the INFORMS Simulation Society Distinguished Service Award, 2012-2015.

G. Rubino and B. Tuffin are members of the Steering Committee of the International Workshop on Rare Event Simulation (RESIM).

8.1.2. *Scientific events selection*

8.1.2.1. *Chair of conference program committee*

- Bruno Sericola served as Program Chair of ASMTA 2014, 21th International Conference on Analytical and Stochastic Modelling Techniques and Applications, Budapest, Hungary, July 2014.
- Adlen Ksentini served as Technical Program Committee Chair of the 3rd IEEE Workshop on Telecommunication Standards: From Research to Standards, hold in conjunction with IEEE Globecom 2014.

8.1.2.2. *Member of the conference program committee*

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

- MACOM 2014, 7th International Workshop on Multiple Access Communications, Halmstad, Sweden, 27-28 August 2014.
- ACCESS 2014, 5th International Conference on Access Networks, Seville, Spain, 22-26 June 2014.

Pierre L'Ecuyer was a member of the program committee of the following events:

- SIMULTECH'2014: International Conference on Simulation and Modeling Methodologies, Technologies and Applications, Vienna, Austria, Aug. 2014.
- MCQMC'2014: Eleventh International Conference on Monte Carlo and Quasi-Monte Carlo Methods in Scientific Computing, Leuven, Belgium, April 2014.
- ICORES'2014: International Conference on Operations Research and Enterprise Systems, Angers, France, March 2014.

Adlen Ksentini was a member of the program committee of the following events:

- IEEE ICC 2014 Adhoc and Sensors and Wireless Networks Symposium, Sydney, Australia 2014.
- IEEE Globecom 2014 Adhoc and Sensors Symposium, Austin, USA 2014.
- IEEE WCNC 2014, Istanbul, Turkey 2014.

Yassine Hadjadj-Aoul was a member of the program committee of the following events:

- IEEE ICC 2014, Adhoc and Sensor Networking Symposium, Sydney, Australia 2014.
- IEEE Globecom 2014, Wireless networking Symposium, Austin, USA 2014.
- IEEE WCNC 2014, Mobile and Wireless Networks track, Istanbul, Turkey 2014.
- IEEE ICNC 2014, Wireless Ad hoc and sensor networks symposium, Honolulu, Hawaii, USA

Bruno Tuffin was a member of the program committee of the following events:

- 3rd Workshop on Smart Data Pricing (SDP 2014), Workshop of IEEE INFOCOM 2014, Toronto, Canada, May 2, 2014.
- 2014 ACM SIGSIM Conference on Principles of Advanced Discrete Simulation (ACM SIGSIM PADS 2014), Denver, Colorado, USA, May 18-21, 2014.
- RAWNET/WNC3 2014 - 10th International Workshop on Resource Allocation, Cooperation and Competition in Wireless Networks, Hammamet, Tunisia, June 2014.
- W-PIN+NetEcon 2014: The joint Workshop on Pricing and Incentives in Networks and Systems, Austin, TX, USA, in conjunction with ACM SIGMETRICS.
- Workshop on QoE-centric Network and Application Management (QoENAM 2014), co-located with the IEEE ICC 2014 conference, Sydney, Australia, June 2014.
- 10eme Atelier de performance, Sophia Antipolis, France, 11-13 Juin 2014.
- 10th International Workshop on Rare Event Simulation (RESIM 2014), August 27-29, 2014, Amsterdam, Netherlands.
- 4th International Conference on Simulation and Modeling Methodologies, Technologies and Applications (SIMULTECH), Vienna, Austria, 2-4 September 2014.

Gerardo Rubino was a member of the program committee of the following events:

- Networking 2014: IFIP Networking 2014 Conference, Trondheim, Norway, Jun 2–4
- Resim 2014: 10th International Workshop on Rare Event Simulation, Amsterdam, Netherlands, Aug 27–29, 2014.
- QEST 2014: 11th International Conference on Quantitative Evaluation of SysTems, Florence, Italy, Sep 8–12, 2014.
- CLEI 2014: XL Conferencia Latinoamericana de Informática (Latin-American Informatics Conference), Montevideo, Uruguay, Sep 15–19, 2014.

8.1.3. Journal

8.1.3.1. Member of the editorial board

Adlen Ksentini was guest editor for the Special Issue in IEEE Wireless Communication Magazine on Research & Standards: Leading the Evolution of Telecom Network Architectures.
Bruno Sericola is an associate editor for the following journals:

- Open Operational Research Journal.
- International Journal of Stochastic Analysis.
- IISRN Probability and Statistics.

Bruno Tuffin is an associate editor for the following journals:

- INFORMS Journal on Computing, since 2007.
- Mathematical Methods of Operations Research, since November 2008.
- ACM Transactions on Modeling and Computer Simulation, since July 2009.

Pierre L'Ecuyer is an associate editor for the following journals:

- ACM Transactions on Mathematical Software, since August 2004.
- Statistics and Computing (Springer-Verlag), since June 2003.
- International Transactions in Operational Research, since May 2007.
- Cryptography and Communications - Discrete Structures, Boolean Functions and Sequences (Springer-Verlag), since December 2006.

8.1.3.2. Reviewer

Bruno Tuffin has reviewed papers in 2014 for Operations Research, Telecommunication Systems, IEEE Transaction on Reliability, IEEE/ACM Transaction on Networking, Annals of Telecoms, International Transaction in Operational Research, etc. Bruno Tuffin was also a reviewer in 2014 for the Natural Sciences and Engineering Research Council of Canada (NSERC) and for CIFRE contracts (France).

César Viho has reviewed project proposals for the ANR and for CIFRE contracts for the ANRT. He has reviewed papers for the journals IEEE Transaction on Wireless Communication, IEEE Transactions on Vehicular Communications, IEEE Communications Magazine, and for the following international conferences: IWCNC'14, Globecom'14, ICTSS'14, VTC Fall 2014.

Adlen Ksentini has reviewed papers in 2014 for Transaction Paralel Distributed Systems-TPDS, Transaction on Wireless Communication - TWC, Transaction on Vehicular Technology - TVT, Wireless Communication Magazine, Elsevier Computer Communication.

Yassine Hadjadj-Aoul has reviewed papers in 2014 for Transaction on Vehicular Technology-TVT, Wireless Communication Magazine, Elsevier Computer Communication and for the following international conferences: Globecom'14, ICC'14, WCNC'14.

Gerardo Rubino has reviewed papers for IEEE Wireless Communications Magazine, Neural Computation, Journal of Applied Probability, Networking 2014, XL Latin American Computing Conference (CLEI 2014), Latin American Symposium on Computing and Society, 11th International Conference on Quantitative Evaluation of SysTems (QEST 2014).

8.1.4. Seminar and talks

- W. Chan, G. Koole, and P. L'Ecuyer, "Dynamic Call Routing Policies Using Call Waiting Times and Agent Idle Times", The Optimization Days, Montreal, May 2014.

- N. Chapados and P. L'Ecuyer, "Hierarchical Bayesian State-Space Model for Call Center Arrival Rate Forecasting", The Optimization Days, Montreal, May 2014.

- R. Ibrahim, P. L'Ecuyer, H. Shen, "Service Times in Call Centers: A Data-Based Perspective", INFORMS Annual Meeting, San Francisco, Nov. 2014.

- P. L'Ecuyer, "Challenges in Stochastic Modeling of Service Systems: Illustrations with Call Centers", Rotman School of Management, University of Toronto, Nov. 2014.

- P. L'Ecuyer, Discussion of 2014 Markov Lecture of Peter W. Glynn: "Perspectives on Traffic Modeling", INFORMS Annual Meeting, San Francisco, Nov. 2014.

- P. L'Ecuyer, "Challenges in Stochastic Modeling of Call Centers", Ecole Centrale de Paris, Châtenay-Malabry, France, June 2014.

- P. L'Ecuyer, "Multiple Streams of Random Numbers for Parallel Computers: Design and Implementation", Centre d'Energie Atomique (CEA), Saclay, France, June 2014.

- P. L'Ecuyer, "Challenges in Stochastic Modeling of Service Systems: Illustrations with Call Centers", invited plenary talk, 10th Workshop on Performance Evaluation (AEP 2014), Inria Sophia-Antipolis, France, June 2014.

- P. L'Ecuyer, "On the Distribution of Integration Error with Randomly-Shifted Lattice Rules", invited talk, Latrobe University, Melbourne, Australia, Feb. 2014.

- P. L'Ecuyer, "Static Network Reliability Estimation Under the Marshall-Olkin Copula", School of Mathematics, University of New South Wales, Sydney, Feb. 2014.

- M. Pelleau, L.-M, Rousseau, P. L'Ecuyer, and L. Delorme, "Agent Scheduling from Forecasts of Future Call Arrivals at Hydro-Quebec Call Centers", The Optimization Days, Montreal, May 2014.

- G. Rubino and B. Tuffin. "Introduction to Monte Carlo methods". One-day course/seminar at ALSTOM, France, May 2014.

- N. Stier-Moses, P. L'Ecuyer, P. Maillé, and B. Tuffin, "Revenue-Maximizing Rankings for Online Platforms with Quality-Sensitive Consumers", Yahoo Inc., June 2014.

- T. A. Ta, P. L'Ecuyer, and F. Bastin, "Staffing Optimization with Chance Constraints in Call Centers", The Optimization Days, Montreal, May 2014.

- M. Thiongane and P. L'Ecuyer, "Waiting Time Prediction in Multiskill Call Centers with Callback Options", The Optimization Days, Montreal, May 2014.

- B. Tuffin. "La neutralité du Net." Tr@nspolo: transparence politique et organisationnelle dans les sociétés numériques, Avignon, July 2014.

- B. Tuffin. "Importance Sampling and variance reduction techniques". Summer school on Modeling and Numerical Methods for Uncertainty Quantification (MNMUQ 2014), Porquerolles Island, France, 1-5 September 2014.

- A. Ksentini, "Quand les réseaux mobiles rencontrent le Cloud", au Laboratoire LIF de Marseille, Mars 2014.

- G. Rubino, "Analyzing rare events with Monte Carlo: advanced methods", Center for Uncertainty Quantification, Annual Workshop, Kaust, Saudi-Arabia, January 8, 2014.

- G. Rubino, "New developments around PSQA", at the Applied Science and Technology Research Institute, Hong Kong, June 17, 2014

- G. Rubino, "Discrete Event Simulation: generalities and the particular case of rare event analysis", in CSS'2014: the 3rd International Cybernetics Summer School, Ostrava, Czech Republic, June 2014.

- G. Rubino, "Automatic measuring of perceptual quality on the Internet", plenary talk at the First International Congress on Telematics, Computing and Communications (CITELC 2014), Mexico DF, Mexico, August 23, 2014.
- G. Rubino, "Monte Carlo y los eventos raros (Monte Carlo and rare events)", in the 3rd International AMMA Workshop, Technical University Federico Santa María, Valparaíso, Chile, December 2, 2014.

8.1.5. *Managing research activities*

- 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.
- Adlen Ksentini was elected as secretary of the IEEE ComSoc Technical Committee on Software.
- Adlen Ksentini was elected as secretary of the IEEE ComSoc France Section.
- 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.
- G. Rubino has been appointed as the Inria representative at the Scientific Committee of the IFCAM (Indo-French Center for Applied Mathematics), a joint international unit between Indian Ministry of Science and Technology and several French institutions including CNRS, Inria, École Polytechnique, École Normale Supéieure, Inria, Nice Sophia Antipolis University and University of Toulouse III.
- 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 member of the CSV (Selection and Validation Committee) of the "Images et Réseaux" (Images and networks) cluster in the French Brittany Region. The cluster includes most companies and academic institutions working in networking and in image-based applications in Western France.
- César Viho is deputy director of the MATISSE (Mathematics, Electronics and Computer Sciences) doctoral school in charge of managing the recruitment of PhD students and their activities during their doctorate, in all the concerned areas of the doctoral school.

8.2. Teaching - Supervision - Juries

8.2.1. *Teaching*

Licence L2: Probability and Statistics, 40 hours, University of Science and Technology, Hanoi, Vietnam

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

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

Master M1: Simulation, 18 hours, Université de Rennes 1, France

Master M1: Wireless Networks, 48 hours, Esir/University of Rennes 1, France

Master M1: Performance and dependability evaluation of computer systems, 54 hours M1, Istic/University of Rennes 1, France

Master M1: Introduction to graph theory, 14 hours, Esir/University of Rennes 1, France

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

Master M2: Simulation, 5 hours, Telecom Bretagne, France

Master M2: Logistic and performance, 8 hours, Faculté de Sciences économiques/University of Rennes 1, France

Master M2: Multimedia transmission, 36 hours, Istic/University of Rennes 1, 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

Master M2: Software Defined Networks, 4 hours, Istic/University of Rennes 1, France

Master M2: Performance evaluation, 26 hours, ESIR/University of Rennes 1, France

Master M2: Performance Evaluation, 9 hours, M2, Université de Rennes 1, France

Master M2: Algorithms on graphs, 40 hours, Istic/University of Rennes 1, France

Master M2: Multimedia Networking, 8 hours, Istic/University of Rennes 1, France

8.2.2. *Supervision*

Master: Thuy Dung Mai, Economics of CDNs, Université de Rennes 1, 2014, supervised by Bruno Tuffin.

PhD: Romaric Ludinard, "Caractérisation locale de fautes dans les systèmes large échelle", Université de Rennes 1, 2/10/2014; advisors: Bruno Sericola and Emmanuelle Anceaume. See [10].

PhD: Leslie Murray, "New variance reduction methods in Monte Carlo rare event simulation", University of the Republic (UDELAR), Uruguay, 17/9/2014; advisors: Héctor Cancela (UDELAR) and Gerardo Rubino. See [11].

PhD: Claudio Risso, "Using GRASP and GA to design resilient and cost-effective IP/MPLS networks", University of the Republic (UDELAR), Uruguay, 5/5/2014; advisors: Franco Robledo (UDELAR) and Gerardo Rubino. See [12].

PhD in progress: Laura Aspirot, "Fluid Approximations for Stochastic Telecommunication Models", University of the Republic (UDELAR), Uruguay, started in December 2011; advisors: Ernesto Mordecki (UDELAR) and Gerardo Rubino.

PhD in progress: Damien Le Quéré, "Conception et étude des performances d'une solution auto-configurable pour les réseaux de transport du futur", started in January 2012; advisors: B. Sericola and A. Ksentini.

PhD in progress: Btissam Er-Rahmadi, Cifre Grant, Orange Labs, "Coopération et auto-* dans un réseau de small cells network", started on January 2013; advisors: C. Viho and A. Ksentini, University Rennes 1.

PhD in progress: Osama Arouk, "Cellular-based M2M communication: congestion control", started on December 2012; advisors: C. Viho and A. Ksentini, University Rennes 1.

PhD in progress: Farouk Messaoudi, "Orchestration et la virtualisation des ressources de terminaux, la vision Global OS", started on October 2014; advisor: A. Ksentini, University Rennes 1.

PhD in progress: Florient Grandhomme, "Etudes de protocoles de routage dynamique externe de type BGP dans un environnement réseaux tactiques adhoc mobiles : faisabilité, performances, qualité de service, et passage à l'échelle", started on October 2014; advisors: A. Ksentini, G. Guette, University Rennes 1.

PhD in progress: Jean-Michel Sanner, Cifre Grant, Orange Labs, "SDN technologies for network services performances adaptation of carriers networks"; started on January 2013; Advisors: Y. Hadjadj-Aoul and G. Rubino, University Rennes 1.

PhD in progress, Yue Li; Cifre Grant, Orange Labs; title: "Elaboration d'une architecture réseau unifiée, ouverte et flexible", started on October 2013; Advisors: Y. Hadjadj-Aoul and G. Rubino.

PhD in progress: Quang Pham Anh Tran, "QoE-based adaptive algorithms for wireless sensor networks", started on October 2013; advisors: C. Viho, University Rennes 1.

8.2.3. Juries

- B. Sericola was a member of the juries for the recruitment of young graduate scientists and senior researchers at Inria.

Bruno Tuffin was a member of the following PhD defense committees:

- Mariem Krichen, "Modèle technico-économique pour le déploiement d'un réseau femto avec partage de ressources", Université de Versailles Saint-Quentin, 2014, rapporteur.
- Luca Rose, "Decisional Process for Ad Hoc Networks", SUPELEC, Gif-sur-Yvette, January 2014, rapporteur.
- Tim Bereton, "Monte Carlo Methods for Complex Stochastic Models", The University of Queensland, Australia, 2014, rapporteur.
- Mohamed Lamine Lamali, "Qualité de Service et calcul de chemins dans les réseaux inter-domaine et multicouches", Université de Versailles Saint-Quentin, Septembre 2014, president.
- Vladimir Fux, "Game-theory approaches to study and influence interactions among self-interested agents in wireless networks", TELECOM Bretagne, November 2014, president.

Adlen Ksentini was a member of the following PhD defense committees:

- Malik Mubashir Hassan, "Gestion de la qualité de service dans les réseaux maillés IEEE 802.11s", Université de Versailles Saint-Quentin, Juin 2014, rapporteur.
- Shengyang Chen, "A Cross-layer Content-aware Energy-efficient Rich Media Application Delivery Scheme in Heterogeneous Wireless Networks", DCU, Dublin, Irlande, Octobre 2014, rapporteur.
- Petros Anapliotis, "Content-Aware Networking in Virtualised Environments for Optimised Resource Exploitation", Université de Bordeaux, December 2014, rapporteur.

Cesar Viho was a member of the following PhD defense committees:

- Hassan Ali Ahmad, "Design and Analysis of Distributed Mobility Management in IPv6 Mobile Networks", Telecom Bretagne, January 2014, president.
- Arnab Sinha, "Self-describing objects with tangible data structures", IRISA/Université Rennes 1, May 2014.
- Hamza Samih, "Test basé sur les modèles appliqué aux lignes de produits", IRISA/Université Rennes 1, December 2014, president.
- Siwar Ben Hadj Said, "Contextual Connectivity in Multi-Access Architectures", Telecom Bretagne, December 2014, president.

Gerardo Rubino was a member of the following PhD defense committees:

- José-Manuel Martínez, "Modelos Markovianos de Sistemas Computacionales y de Telecomunicaciones: Métodos Matemáticos y Algoritmos de Implementación", UFTSM (Universidad Técnica Federico Santa María), Valparaíso, Chile, November 11, rapporteur.
- Benoît Barbot, "Accélération pour le Model Checking Statistique", École Normale Supérieure de Cachan, November 20, rapporteur.
- Ait Solaht, "Chaînes de Markov incomplètement spécifiées : analyse par comparaison stochastique et application à l'évaluation de performance des réseaux", Université de Versailles Saint-Quentin, October 3, rapporteur.

8.3. Popularization

- In their position paper [79], Bruno Tuffin and his co-author Patrick Maillé discuss for a large audience the issues and challenges of network neutrality in response to the European parliament text voted in April 2014.
- G. Rubino makes regular presentations to high school students about the research work in general, and specific technical topics in particular. Current talks:

– Randomness as a tool
– Internet as a research problem
– Great challenges in maths: the Riemann Hypothesis
– Great challenges in math/computer science: the "P versus NP" problem

9. Bibliography

Major publications by the team in recent years

[1] G. RUBINO, B. TUFFIN (editors). *Rare Event Simulation using Monte Carlo Methods*, John Wiley & Sons, 2009

[2] N. BOUABDALLAH, A.-L. BEYLOT, E. DOTARO, G. PUJOLLE. *Resolving the Fairness Issues in Bus-Based Optical Access Networks*, in "IEEE Journal on Selected Areas in Communications", 2005, vol. 23, n⁰ 8, pp. 1444–1457

[3] Y. HADJADJ-AOUL, T. TALEB. *An adaptive fuzzy-based CAC scheme for uplink and downlink congestion control in converged IP and DVB-S2 networks*, in "IEEE Transactions on Wireless Communications", Feb. 2009, vol. 8, n⁰ 2, pp. 816–825

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

[5] P. LEGUESDRON, J. PELLAUMAIL, G. RUBINO, B. SERICOLA. *Transient analysis of the M/M/1 queue*, in "Advances in Applied Probability", September 1993, vol. 25, n⁰ 3, pp. 702–713

[6] H. NABLI, B. SERICOLA. *Performability analysis: a new algorithm*, in "IEEE Transactions on Computers", 1996, vol. 45, n⁰ 4, pp. 491–494

[7] A. NAFAA, A. KSENTINI. *On Sustained QoS Guarantees in Operated IEEE 802.11 Wireless LANs*, in "IEEE Transactions on Parallel and Distributed Systems", 2008, vol. 19, n⁰ 8, pp. 1020–1033

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

[9] B. TUFFIN. *Bounded Normal Approximation in Highly Reliable Markovian Systems*, in "Journal of Applied Probability", 1999, vol. 36, n⁰ 4

Publications of the year

Doctoral Dissertations and Habilitation Theses

[10] R. LUDINARD. *Local fault caracterization in large scale systems*, Université de Rennes 1, October 2014, https://hal.inria.fr/tel-01094191

[11] L. MURRAY. *New variance reduction methods in Monte Carlo rare event simulation*, University of the Republic, Uruguay, August 2014, https://hal.inria.fr/tel-01112957

[12] C. RISSO. *Using GRASP and GA to design resilient and cost-effective IP/MPLS networks*, University of the Republic, Uruguay, May 2014, https://hal.inria.fr/tel-01112958

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