

INRIA, Evaluation of Theme Networks and Telecommunications

Project-team DIONYSOS

March 21-22, 2012

Project-team title: DIONYSOS

Scientific leader: Gerardo Rubino

Research center: INRIA Rennes – Bretagne Atlantique

Common project-team with: University of Rennes 1

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1 Personnel

Personnel (Q4 of 2008, project creation)

	Misc.	INRIA	CNRS	University	Total
DR (1) / Professors		2		2	4
CR (2) / Assistant Professors		2		2	4
Permanent Engineers (3)				1	1
Temporary Engineers (4)		4			4
PhD Students	2	5		4	11
Post-Doc.		2			
Total	2	15		9	
External Collaborators					
Visitors (> 1 month)		1			

- (1) “Senior Research Scientist (Directeur de Recherche)”
- (2) “Junior Research Scientist (Chargé de Recherche)”
- (3) “Civil servant (CNRS, INRIA, ...)”

(4) “Associated with a contract (Ingénieur Expert or Ingénieur Associé)”

Personnel (March 21-22, 2012)

	Misc.	INRIA	CNRS	University	Total
DR / Professors		2		2	4
CR / Assistant Professor		2		2	4
Permanent Engineer				1	1
Temporary Engineer		2			2
PhD Students		7		3	10
Post-Doc.		2			
Total		15		8	
External Collaborators					
Visitors (> 1 month)		1			

Changes in staff

DR / Professors	Misc.	INRIA	CNRS	University	total
CR / Assistant Professors					
Arrival				1	1
Leaving				1	1

Comments: Arrivals: Yassine Hadjadj, Assistant Professor (University of Rennes 1, end 2009). Departures: Alexandra Desmoulin, end 2008, to the company SOGETI High Tech, an Orange service provider.

Current composition of the project-team (March 21-22, 2012):

Permanent positions

- Gerardo Rubino, INRIA, DR
- Bruno Sericola, INRIA, DR
- Bruno Tuffin, INRIA, CR
- Nizar Bouabdallah, INRIA, CR (on leave from Jan 2011 to Dec 2014)
- César Viho, U. of Rennes 1, prof.
- Adlen Ksentini, U. of Rennes 1, ass. prof.
- Yassine Hadjadj, U. of Rennes 1, ass. prof.
- Raymond Marie, U. of Rennes 1, prof., emeritus from end 2011
- Anthony Baire, U. of Rennes 1, permanent engineer

Temporary positions

- Sofiene Jelassi, INRIA, temporary engineer
- Sofiane Moad, INRIA, temporary engineer
- Pierre Coucheney, INRIA, post-doc

PhD students

- Samira Saggadi, On rare event analysis through simulation for static problems
- Wael Cherif, On context-Adaptation based on Quality of Experience (QoE) in Next Generation Networks (NGN)
- Hai Tran Hoang, On auctions for competitive network providers
- Sebastián Basterrech, On improving the statistical learning techniques used in our PSQA methodology
- Romaric Ludinard, On data aggregation in large scale distributed systems
- Nanxing Chen, On passive approaches for interoperability testing
- Jean-Marc Vigne, On the analysis of competition between telecommunication network providers
- Laura Aspirot, On the analysis of large Markovian models
- Damien Le Quéré, On auto-configurable solutions for future transportation networks
- Pablo Sartor, On diameter-constrained network reliability evaluation

Current position of former project-team members (including PhD students during the 2008–2012 period):

- Sofiane Moad, Research Engineer, INRIA, Rennes, France (former PhD)
- Majd Ghareeb, Post-doc, IRCCYN, University of Nantes, France (former PhD)
- Kandaraaj Piamrat, Post-doc, Technicolor, Rennes, France (former PhD)
- Alexandra Desmoulin, Research Engineer, SOGETI High Tech/Orange, Sophia-Antipolis, France (former PhD)
- Fatma Bouabdallah, Post-doc at the University of Waterloo, Canada (former PhD)
- Pablo Rodríguez-Bocca, Engineer in Antel (Uruguayan operator), Uruguay, and Assistant Profesor, Engineering School of UDELAR, Uruguay (former PhD)
- Arnaud Delenda, Consulting Manager at PROS Pricing, Paris, France (former PhD)
- Hélène Le Cadre, Temporary Researcher, CEA, France (former PhD)
- Charlotte Roger, Research Engineer, Orange Labs, France (former PhD)
- Mario Rivero, Assistant Professor at the National Polytechnic Institute (IPN), Mexico (former post-doc, until July 2010)
- Mohammad Abdul Azim, Post-doc at the Masdar Institute, UAE (former post-doc, 1 year, 2009)
- Baptiste Marienval, Engineer at Alyotech, France (former temporary engineer, Nov 2009 – Oct 2010)
- Kamal Singh, Research Engineer, Telecom Bretagne, France (former temporary engineer, until end 2011)

- Antoine Boutet, PhD student, INRIA, Rennes (ASAP team), France (former temporary engineer, 6 months in 2008)
- Katy Paroux, Assistant Professor, U. Paul Sabatier, Toulouse, France (former visiting scientist, until Aug 2009)
- Peter Reichl, Full Professor, from FTW, Vienna, Austria (former temporary engineer, 10 months, Dec 2010 – Sep 2011)

Last INRIA enlistments

None in the evaluation period.

2 Work progress

2.1 Keywords

Our main keywords are, as reported in our activity reports: Monte Carlo Methods; Performance; Reliability; Quality of Service; Markovian Model; Quality of Experience; Network Economics.

To these, we can add the following ones, that help clarifying our skills and activities: Monte Carlo and Quasi-Monte Carlo techniques; Rare Event analysis; Dependability Analysis (including Reliability and Availability aspects); Queues and Networks of Queues; Fluid Models; Wireless Networks; Sensor Networks.

2.2 Context and overall goal of the project

Dionysos works on “the identification, the conception and the selection of the most appropriate network architectures of a communication service, as well as the development of computing and mathematical tools for the fulfillment of these tasks”. These objectives lead to two types of complementary research fields: the systems’ qualitative aspects (mainly, interoperability assessment of network’s components) 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).

More specifically, Dionysos has a strong research direction on the evaluation of the *perceptual quality* of an application or service built around audio/voice and/or video transportation over an IP network. We are the authors of the PSQA technology (Pseudo-Subjective Quality Assessment), a tool allowing to automatically measuring this perceptual quality, that federates today our activities in this quality evaluation field (see 2.4). Another strong direction is on the analysis of dependability properties of complex systems, mainly using Monte Carlo techniques, but also through the use of analytical and numerical ones. Both research fields involve many of Dionysos members, working in strong cooperation with external partners.

We have a long trajectory on the analysis of stochastic models thought for performance evaluation purposes, and we continue today in this research direction, focusing on distributed systems, on continuous-state models and on transient analysis of Markovian systems. Here again, our activities are developed in cooperation with different partners outside the team.

On the network mechanisms and protocols point of view, we study how to make use of QoE for resource management in wireless networks. The QoE evaluation tool is also used to define protocols for content (mainly video) delivery over different kinds of networks (P2P,

Overlay Networks, Wireless Networks). Regarding Wireless Sensor Networks (WSN), we continue developing routing protocols and techniques for minimizing energy consumption. In parallel, we continue our activities on methods and tools for interoperability assessment.

2.3 Objectives for the evaluation period

When Dionysos was created, at the end of 2008, we presented our objectives in two sets, the application-driven ones and those organized around methodological issues. We also underlined the directions where a strong synergy inside the team was expected. It must be observed that the team is composed of members with an applied mathematics profile and members coming from the networking area.

2.3.1 Application-driven activities

Perceptual quality analysis This was expected to be and was our main research activity during the period, around our PSQA (Pseudo-Subjective Quality Assessment) technology that was designed to allow the automatic evaluation of the perceived quality of an audio or video transmission over an IP network (see first Section 2.4 for a short description). In the evaluation period, we mainly focused on two objectives. One was to look at the flows at a lower level than the packet one, the level used in the original version of PSQA. The second one was to go into a deeper testing phase of the methodology, through its use in large size cases and in quite different contexts. The idea was to use PSQA in different projects developed with partners from industry. The goal of the first objective was to improve the robustness¹ of the technology in the case of video flows, by looking the video sequences at the frame level. We wanted also to look at signal-based inputs, both for voice and for video and to see if they allowed some increase in the robustness of the approach. The challenges here were related to the fact that PSQA is a very general approach, but it must be “customized” to each new network or service or application, or even to new versions of a same environment. Was the methodology robust enough to support this, given its very good accuracy and efficiency in measuring?

Concerning the evolution of these objectives, as we will see in Section 2.4.3, the challenge of improving the quality of our measuring modules by adding data measured at lower levels could only be done for video, inside the QoSmobile project (see Page 46). Since the result was negative (the packet level has enough information, and adding signal-based data could not improve the performance of the approach), we limited this objective to that study. The second objective remained unchanged during the period, because we could test the approach in many contexts (see 2.4.3) with great success.

There was a third objective, put at a second level, concerning the coupling between PSQA and classical probabilistic (e.g. queueing) models. Several years ago^{2 3}, we showed how to couple PSQA with standard modeling techniques. We wanted to develop this promising direction further during the evaluation period, but the importance that took the second objective mentioned above and the resulting lack of time for other things, made that this objective was abandoned. It is being examined today, and we will probably try to recruit a PhD on the issue during next period. In a nutshell, the goal is the following:

¹As we stated in our original work, we don’t believe that we can expect a significant improvement in accuracy, PSQA has the same accuracy as an individual human observer, measured with respect to the average coming out of a subjective testing session.

²G. Rubino and M. Varela. Evaluating the utility of media-dependent FEC in VoIP flows. In *QoFIS’04*, pages 31–43, 2004.

³G. Rubino and M. Varela. A new approach for the prediction of end-to-end performance of multimedia streams. In *QEST’04*, pages 110–119, 2004.

instead of saying “the packet-loss probability is $p = (1 - \varrho)\varrho^N/(1 - \varrho^{N+1})$ in your multimedia system S ” (or the mean response time, etc.), and then look for ϱ such that $p < p_0$, PSQA allows us to say “the final quality as seen by the user of S is $Q =$ some implicit or explicit function of the input model parameters”, and then look for ϱ (and probably other inputs) such that $Q \geq Q_0$. As explained briefly in Section 2.4, PSQA provides a function mapping QoS and application-based parameters (that are by construction, easy to measure) into quality, and the mapping is done by a nice mathematical function allowing several post-processing including analytical results.

Wireless networks: objectives concerning networks of sensors Considering the fact that one key challenge in sensor nodes’ technology is to maximize the WSN (Wireless Sensor Network) lifetime, and given the past research track of some of the team’s members, we proposed to attack the problem of reducing energy consumption in these systems. In this context, most previous works focused mainly on proposing energy-efficient MAC and routing protocols. We rather aimed at avoiding the transmission of redundant information regarding the detected event. That is, we wanted to limit the reporting tasks of a detected event to a small subset of reporting nodes, when possible. To summarize, our main objective here was ensuring energy efficiency in sensor networks, by using reporting node selection techniques, while considering the energy-latency-reliability tradeoff.

Objectives in interoperability testing Interoperability is one of the key feature of networks. In the future, as observed for IPv6, there will be an increasing number of protocols that will need to work together. One of the associated challenges is to provide accurate test methodologies, together with associated test suites and tools that allow to verify the network components interoperate correctly while providing the expected services. Those testing methodologies have to deal with the heterogeneous, mobile, complex and distributed nature of network components. The testing languages will include necessary features that allow to specify test suites in abstract way and derive easily executable test suites.

At the creation of the team, we observed that an important amount of work had been done regarding conformance testing but an efficient and general methodology for interoperability testing was still missing. Our purpose was then to provide a formal framework (methods, algorithms and tools) for interoperability testing which helps in obtaining efficient interoperability test suites for new generation networks, based on our past successes in the case of one-to-one interoperability testing architectures composed of two equipments.

Optical infrastructures Optical fiber communication is now ubiquitous in the telecommunications infrastructure, with the well-known benefits regarding capacity and congestion problems. One of the main focus then was the development of the recent concept of traffic aggregation in those infra-structures. At Dionysos, we decided to attack the specific problem of eliminating both the bandwidth underutilization and the scalability concerns that are typical of all-optical wavelength-routed networks. The specific goal was to study the possible use of multiple-access lightpaths (i.e., optical circuits) instead of the traditional point-to-point lightpaths, leading to the subproblem of designing new medium access and sharing mechanisms adapted to such very high speed networks.

These objectives concerned work to be done jointly with a team of France Telecom R&D, at Lannion. The objective remained as it was, because the cooperation was established and lasted during the evaluation period (it concerned the PhD of [Charlotte Roger](#), see [10]).

Network economics The main challenges we addressed in our activities on pricing (the community used this term at the time) were the following: First, designing an efficient pricing scheme reaching at the same time the objective of providing incentives for users while keeping a good trade-off between economic efficiency and engineering simplicity and while satisfying simultaneously customers and provider interests is still open. The typical networks of interest are access networks which have to cope with the *last mile* problem. A second important challenge was to properly model socially-conditioned users. Third, observe that in pricing, there is not only a relation between customers and providers, but also a competition among providers, and this aspect needs to be integrated in the models and proposals. A typical example is the competition for access points at a WiFi hotspot, or the choice between different access media (WiFi, WiMax, UMTS, etc.). Finally, how will providers charge each other to exchange their traffic? This point was also still in its infancy, in 2008, and its understanding belonged to our scientific objectives.

These objectives were addressed with the Telecom Institute through our strong cooperation with Patrick Maillé from Télécom Bretagne (a former PhD student of the team, and a regular collaborator since Dionysos’ creation).

2.3.2 Methodological issues

Monte Carlo In the Monte Carlo field, our priority was rare event analysis. There are many approaches that have been followed in the area, basically either changing the underlying measures to approach the zero-variance estimator (the *importance sampling* approach), or by “early killing” the bad trajectories and by “cloning” the good ones (the *importance splitting* approach). In both cases there were families of problems or great importance for which there was no robust estimator available (that is, an estimator keeping the relative error bounded when the event of interest becomes more and more rare). Some work had been done in queuing analysis in this direction (for instance, it is now understood that no static change of measure exist leading to a robust estimation), but less had been done in the dependability area. Looking for efficient methods in this field and understanding the way robustness appear were our priorities for the evaluation period. Two examples announced as objectives for us: to explore the use of dynamic (i.e., state-dependent) changes of measure in dependability analysis (that is, when estimating dependability metrics) and the possibility of approaching the zero-variance estimator in the case of splitting procedures.

Numerical schemes, analytical techniques The main measures on which we announced to focus were standard dependability metrics and those known as performability measures. The latter combine dependability and performance aspects of systems, by using reward rates associated with states of the model and/or with transitions between states. Under Markovian assumptions, the evaluation of such measures exhibit a high complexity and the use of techniques based on Laplace transforms may lead to severe numerical problems. In the past, we proposed techniques based on probabilistic arguments which led to simple and stable algorithms for which the precision can be specified in advance. When creating the team, we proposed to extend these methods to more general performability measures and to more general mathematical models such as semi-Markov processes. A first reason for this is that some of the work already done on fluid models’ analysis can provide inspiration for developing new techniques in the performability area. A second one is that there is an increasing interest in these types of metrics, which in turn is explained by the complexity of the new systems and the fact that, in some cases, dependability becomes the main criteria (in the backbone, for instance). Performability allows to address these

aspects while still taking into account the performance aspects. Last, the evolution of networking makes that dependability aspects (alone or inside performability approaches) are becoming more important than before. In some situations dependability is the critical dimensioning criteria (for instance, in backbones where performance does not appear as an immediate problem). Moreover, emerging network areas such as sensor networks bring to the first plane dependability properties of the systems, because the systems are composed by many units with weak capacities, and work using basic redundancy approaches.

This objective evolved because of the technical difficulty in obtaining stable procedures when dealing with semi-Markov processes. The usual transform-based approaches suffer from many numerical problems, and we moved towards PH distributions instead, to capture non-exponential cases, where we had already worked in the past (see Section 2.7.3).

2.3.3 Increasing synergy inside the team

At the creation of Dionysos, an explicit objective of the proposal was to reach some degree of synergy inside the team. The presentation of the objectives as separate topics was intended to give some detail on the technical side about the challenges associated with the different goals, but it somehow hides the interconnection between them in our activities. In a nutshell, the links between members of the team come firstly from the fact that in many networking problems, we need both the skills in the technical aspects of the architectures or the protocols and those regarding the quantitative sides through model analysis (this is clearly visible in the output of the period, in most of our research topics). In other cases, the links are made through the targets (for instance, we addressed P2P networks as an example of system designed around the concept of perceptual quality, then it appeared as an example of managed network (network of an operator) and the research work involved other members of the team, and they appear again in modeling work at least in two different lines (represented by papers [159, 104], for instance). Last, we expected a strong synergy on the measuring of perceptual quality using PSQA and on the use of these measures basically for controlling purposes. That was underlined when Dionysos was created and it is one of the main characteristics of the team today.

About the evolution of these objectives, some were reached and some were not. From the point of view of the topic of this section, the largest success is clearly on the last point: measuring perceptual quality is the first federating theme in Dionysos today, from more than one viewpoint. To provide an example of an objective that looked (and still looks) interesting and reachable, but that was left aside, we intended to use our joint experience on dependability analysis and on Monte Carlo techniques, and in interoperability testing, to analyze the possibility of a probabilistic testing of these properties in particularly complex context. We could not go in this direction, because of lack of resources to do so. It is still a topic deserving some thoughts, but we didn't really work on that in the last period.

Coming back to the evolution of the objectives, excepting the expected and observed increase in the work on perceptual quality, we observed an important development of the activities on network economics. That is why the next two subsections describing the work performed in the evaluation period concerns these two axis of our research. We grouped in a third section the activities concerning the hot topics related to the future of networking where our members work, namely on wireless systems and on interoperability properties of heterogeneous networks, and last, we describe our work on the last main domain we cover, simulation and analytical methods, where important developments scale out the evaluation period.

2.4 First objective: The PSQA project – Executive summary

In the evaluation period we consolidated a first generation of tools for the automatic assessment of the perceived quality of a video/audio/voice communication over the Internet, which is the main component of the so-called Quality of Experience (QoE) of the considered service/application. Our methodology has the name Pseudo- Subjective Quality Assessment (PSQA).

PSQA allows to measure in an automatic way the instantaneous perceived quality, providing a number (for instance, a MOS-like (Mean Opinion Score) value) at time t , that is close enough to the average quality of the received flow as it would come out of a subjective testing session. This means two things: first, PSQA provides a value of the *instantaneous* perceived quality; second, this value is close to the value that would be obtained following a standardized evaluation by a panel of human observers, under controlled experimental conditions, and following an appropriate norm (depending on the type of flow that is being measured). PSQA works by building a mapping from Quality of Service (QoS) technical parameters together with parameters characterizing the flow, into *perceptual quality* (typically in a MOS-like form). This is done following a statistical learning approach, so far using a specific learning tool called a Random Neural Network (a particular type of open queueing network but seen as a network of artificial neurons), in a black-box manner. Observe that PSQA belongs to the measuring tools that do not need access to the original sequence, that is, the sequence before its transmission through the network (for that reason, they are called no-reference methods). It works for both unidirectional transmissions (e.g. streaming applications) or for bidirectional ones (e.g., IP telephony), and it has already been tested in different contexts and for different applications and services. The reader should go to the foundational bibliography on the technique⁴ and to some global description of the procedure⁵, if necessary.

As a by-product of the type of statistical learning tool used, the way PSQA works produces a nice mathematical function (a specific type of rational function actually) mapping several QoS parameters plus some other input variables related to the connection between source and destination. This leads to supplementary possibilities: to optimize objective functions (easy handling of derivatives), evaluation inverses, etc.

2.4.1 Personnel

Team permanent members: Gerardo Rubino (project leader and author of the PSQA technology), César Viho, Adlen Ksentini and Yassine Hadjadj-Aoul. Engineers: Kamal Singh, Sofiene Jelassi. PhD students: Sebastián Basterrech, Pablo Rodríguez-Bocca.

2.4.2 Project-team positioning

The main competitors of PSQA are products of the industrial world, but none today performs similarly for the same targets (no-reference methods for real-time assessment).

To the best of our knowledge, no INRIA team works on measuring perceptual quality of network applications or services. Geographically, we have, in France, the IVC group at IRCCyN in the U. of Nantes, mainly for their subjective testing work, and several companies strongly interested in this area (Orange Labs, Alcatel-Lucent, Nokia, Ericsson,

⁴S. Mohamed and G. Rubino. A Study of Real-Time Packet Video Quality Using Random Neural Networks. In IEEE Transactions on Circuits and Systems for Video Technology, 12(12), December 2002.

⁵G. Rubino. Quantifying the Quality of Audio and Video Transmissions over the Internet: the PSQA Approach. In *Design and Operations of Communication Networks: A Review of Wired and Wireless Modelling and Management Challenges*, Imperial College Press, Edited by J. Barria, 2005.

British Telecom, Deutsch Telecom, IPlabel, just to mention a few). Abroad, we mainly have Peter Reichl at FTW, Vienna, or Markus Fiedler, at BTH, Karlskrona, Sweden. Both know very well our proposal and work today on similar things, focusing on specific aspects and working with less “input variables” as we do in PSQA. Of course, almost every operator is strongly interested in measuring the quality of voice, audio and video applications. The same can be said about the companies that build telecommunication equipments.

Up to quite recent times, research on perceptual quality was the fact of industry, with a few exceptions (like our group, or the mentioned colleagues above, or some other people like Shelley Buchinger at the university of Vienna, a group at the U. of Ghent, Belgium, Lingfen Sun, at Plymouth U.). Today, under the more global umbrella called Quality of Experience, we are witnessing an explosion of papers and projects addressing this user-centric view of the performance, or more generally, the quality of an application or a service. For an example of this trend see the very large starting European project QuEEN (Page 43, completely dedicated to this concept and how to measure it. We are strongly involved in this project (see Section 5.1), and the list of partners provide examples of industrial partners investing in the field: most of the 22 partners of QuEEN come from industry. A problem with the topic of QoE is its broad spectrum and very wide covering area. We will come back on this in Section 5.1.

2.4.3 Scientific achievements

The two objectives of our work were to explore the robustness of our PSQA approach by including data coming from lower levels in the stack, or from the transported signal itself, and to test the approach on different types of systems, for different applications or services, for also different classes of media.

Concerning the first point, we analyzed in the QoSmobile project (see Page 46) the possibility of adding more information coming from low level components in the flow. The project was on developing diagnosis techniques for networks of TV channels dedicated to mobile terminals. The result was something we had already found when developing PSQA: *given the richness of the inputs we are taking into account*, the new “low-level variables” or “signal-based” variables add little more. This doesn’t mean that they have no impact on quality in absolute terms, but the problem here is a conditional one. Some results are given in [164].

But most of our effort was on the second challenge: testing PSQA in a rich set of conditions.

- A first set of results come from P2P networks for the distribution of live video. In a number of steps, we developed new techniques for the design of such a system, that finished with the PhD [14]. Following a multi-path approach, we proposed a quality-oriented control system for managing the network architecture around the goal of optimizing the ultimate target, the quality as perceived by the user. Since the design was based on the possibility provided by PSQA of measuring the perceived quality in real-time, we also developed a monitoring system, whose first prototype won a couple of awards⁶ in the period. See also [88] where the system awarded at SIGMETRICS is described. Other papers related to this project in the period are [174], [175]. A related optimization problem concerning the quality-oriented design problem is addressed in [237]. In [218] there is a discussion on using perceived quality for

⁶One at ACM SIGMETRIC 2008 (Best Demonstration Award), one at the NEM Summit 2009 (Best Demonstration Award) also, here mainly for an industrial audience.

dimensioning purpose. As a by-product of this work, our design has been deployed in Uruguay, as an extension of the network of the traditional operator Antel for distributing TV contents, and its at the heart of the GoalBit open source project⁷. A last word on this P2P project: the multi-path developed approach has almost no signaling associated cost, and this comes from our skills in modeling, because the procedure is based on the properties of pseudo-random number generators⁸.

- Globally, PSQA has been used in other collaborative projects where it has always been the central tool for monitoring and, when relevant, for control purposes. Still on P2P design, we have been part of one of the largest industrial projects in the domain and in the period, P2Pim@ges (see Page 46), where many aspects of P2P systems were analyzed. P2Pim@ges was the main financial support for all our P2P studies. In [243] there is a short discussion on one of the main aspects of the work, the interest of P2P techniques for operator networks. This led to the preparation of the VIPEER project, who was accepted and is running now (see 46).
- In the still running project ViPEER (Page 46), we explore the use of the boxes of an operator for extending its video distribution network. At the same time, the technological choices done in VIPEER led u to explore the use of TCP (because of HTTP) instead of UDP and its impact on quality. For that purpose, we designed new versions of PSQA where input variables related to these choices, quite dominant today, were successfully introduced to the general methodology. These solutions to the problem are described in [99].
- Another area where PSQA has been extended and successfully tested is Scalable Video Coding (SVC) through the project SVC4QOE (Page 47). Even if the extension is somehow straightforward, all the steps associated with PSQA were followed (identification of the right input variables, creation of a data base of sequences, statistical learning preparation and execution phases, etc.). The results are the object of [111, 112]. See also [119] where the DVB-T2 technology is taken into consideration. For a global view on the project see [133].
- Being able to measure the perceptual quality accurately and in real time immediately leads to the exploration of its use as feedback information for multimedia networking purpose. This was done in the distributed world for P2P systems as described in the first item of this list and for evaluating multipath video streaming schemes in overlay networks. In a set of works around a PhD [9], different multi-path mechanisms were explored, taking into account quality and available bandwidth. See the PhD for the details and the initial guidelines given in [208]. See also [112, 113, 142]. PSQA has also been used successfully for defining several QoE-based mechanisms for resource management (access control, rate adaptation, scheduling, network selection, etc.) in heterogeneous wireless networks. The results of this axis can be found in the PhD document [11], and, for instance, in [36, 37, 125, 127, 156, 195, 196, 197, 233, 234].

Last, quality analysis led to other works. Connected to the objective 2 on network economics, the concerned Dionysos member, Bruno Tuffin, together with Peter Reichl from FTW, Austria, analyzed some connections between both areas in [157, 38].

⁷See <http://goalbit.sourceforge.net/research.html> for details.

⁸The deterministic nature of pseudo-random numbers' generators allows to provide deterministic guarantees on the control system and the strong law of large numbers they satisfy deals to probabilistic ones on other aspects of the managing system.

All the preceeding descriptions concern mainly video (that is to say, video plus audio). We also worked on voice applications, more specifically on VoIP flows. In [28], we present a state-of-the-art on the techniques used to assess the perceptual quality of VoIP applications. We identify areas where research has been weak so far, in spite of the high impact they are on the final goal, in many cases (temporal impairments, lack of interoperability of the developed techniques, lack of analysis of the codec dependency of those techniques). In [29] (extended version of [116]), we focus on the impact of bursts of losses on quality, and show the problems of the techniques that handle this issue at least partially. In [143], we analyze the impact of frequency bandwidth changeover, always in the context of VoIP applications. Finally, in [87], we analyze the use of PSQA in the case of interactive voice-based applications.

As a side effect of the success of statistical learning techniques for perceptual quality assessment, we started to explore other mathematical tools in the area. The idea is to apply the same type of methodology to traffic prediction. For this purpose, we recently analyzed the possibilities of a new technique that has given pretty good results in time series analysis, called *reservoir computing*. This is being done through a new collaboration with the U. of the West of Scotland. See [106], where a new algorithm of initialization of the Echo State Network, a main component of the reservoir, is proposed. Another contribution to statistical learning concerning our main tool, the Random Neural Network, is [52], where a new learning procedure (that is, dedicated optimization method) is proposed and evaluated.

2.4.4 Collaborations

Some of our collaborators in the period are from the industrial work (see projects P2Pim@ges, QoSmobile, VIPEER, SVC4QOE, and QuEEN). We can underline Orange Labs (Frédéric Guyard, on the design of the QuEEN project), VTT (Martín Varela, on the design of the QuEEN project and also on papers [87, 172], Gilles Straub, from Technicolor (for the management of the P2Pim@ges project), the R&D of ENESYS in the QoSmobile project, for the preparation of paper [164].

From the academic side, E. De Souza e Silva in the exploration of the perceptual quality of VoIP interactive applications [87], Peter Reichl, from FTW, Vienna, mainly in the design of the QuEEN project, and also in collaborative research joining Objectives 1 and 2 [38, 157], Jean-Marie Bonnin, from Telecom Bretagne (Telecom Institute), for many papers in the area, some related to the PhD of Kandaraj Piamrat, Colin Fyfe, from the University of Scotland, on statistical learning issues (Sebastián Basterrech visited him for some months in 2011, [106, 105]).

2.4.5 External support

Industrial projects P2Pim@ges, QoSmobile, VIPEER, SVS4QOE, Anemone (Page 46), and academic project MWN-P2P-QOE in Page 44.

We also had the support of the Antel Uruguayan operator through its partial support to the PhD thesis of Pablo Rodríguez-Bocca, and for the support of large scale experiments of our P2P video transporting prototype network.

2.4.6 Self assessment

The PSQA technology has an increasing success shown by our participation (under request) to many collaborative projects with industry (see Section 2.4.5). Concerning the visibility of our approach, it was the object of several keynote talks in the period: [239],

2.5.3 Scientific achievements

During the evaluation period, we have slowly but clearly switched our activity from telecommunication network pricing to network economics in general. The idea is not only to look at the way a single provider should charge its access in order to limit congestion and/or to maximize its revenue, but rather to look at the many economic issues arising in telecommunications. We have investigated the following main topics, on which we have obtained significative publications:

- A notable part of our activity has been related to competition among telecommunication providers, mainly within the framework of the ANR CAPTURES project. The motivation comes from the fact that most of the pricing models analysis only deal with a single provider, while competition (that is observed in the telecommunication industry) can drive to totally different outcomes. We have published a sequence of papers on this issue (see also [193, 190, 97]), where the models decompose the problem in a two or three levels game: at the smaller time scale, the users choose their provider and at the larger one, the providers compete on prices, and even at a larger one, they compete on the technologies they implement. The games are solved by backward induction. We have analyzed many such contexts: non exhaustively, but for illustration purpose, a direct competition among providers [230, 58], a competition between a WiFi and a WiMAX provider (the last one operating on a larger domain) [31], the case when providers share bandwidth (illustrating that licensing the bandwidth is good for operators [193], but sharing it is better for users), the relation between a Mobile Network Operator (MNO) and a Mobile Virtual Network Operator (MVNO) [115], assessing under which conditions lead to an equilibrium where the competition does take place and the amount of the spectrum that should be leased to maximize user or social welfare, and different scenarios of investment in infrastructure and license for operators in a competitive context, as for the fourth 3G license in France to determine its price [32].
- Another activity is around inter-domain issues, with a network like the Internet being made of thousands of autonomous systems. Intermediate domains need some (economic in our case) incentives for forwarding the traffic of other domains. We have described the problem, provided a state of the art and highlighted the difficulties that must be solved [40]. We have designed a decentralized algorithm based on double-sided auctions to allocate (and charge) the resource usage [41].
- But network economics is not only about ISPs, it also deals with the application side. In order to make money many service providers base their revenue on advertisement. Search engines for example get revenue thanks to adword auctions, where commercial links are proposed and charged to advertisers as soon as the link is clicked through. We have conducted several works in this context: dealing with a random allocation of slots because the same users may recombine the same keyword several times [129], showing that depending on the search engine's click-through-rate, revenue-based does not always outperform bid-based in terms of revenue to the search engine [122], and designing models of competition of search engines for advertisers, something neglected in the literature [123, 124].

2.5.4 Collaborations

- Our main collaboration is definitely with Patrick Maillé (Telecom Bretagne), co-author of most of our papers on the topic;

- Peter Reichl’s group at FTW (Vienna, Austria), with whom we have had several exchanges and who has come to Rennes in 2011 for 9 months on an international Chair;
- Athens University of Economics and Business and the University of Rome Tor Vergata, through a network of excellence;
- France Telecom, through two PhD thesis and a collaboration within an ANR project;
- Alcatel-Lucent (within the common Lab with Inria) on inter-domain issues.

2.5.5 External support

We have led or participated in several French or European initiatives, and partnerships with French industrial partners. We can mention two ANR projects (one as leader), one INRIA ARC (on network neutrality, still in progress) as leader, member of European Network of Excellence, within which we have specific joint research projects on network economics issues have been funded, the participation to a EU COST activity, a contract with France Telecom and a participation to the INRIA/Alcatel-Lucent common Lab.

2.5.6 Self assessment

We have acquired a visibility on network economics thanks to the following points:

- A strong implication into French and European projects (2 ANRs, 1 ARC, 2 NoEs with 4 specific projects, 1 EU COST, collaborations with Orange and Alcatel-Lucent, etc.)
- numerous publications (10 journal papers, 5 book chapters, 23 conference papers)
- organization of conferences (TPC-chair of NetGcoop; ICQT; steering committee of ICQT; special issue of journals; numerous TPC programs), all in the area of this scientific objective
- two keynote talks: ‘Pricing in telecommunication networks: from congestion control and incentives design to competition among providers’, 5th Lati-American Networking Conference, LANC 2009, Keynote talk, Pelotas, Brazil, September 2009, and ‘Pricing in telecommunication networks : some issues and models’, in 3rd IFIP/IEEE International Workshop on Bandwidth on Demand and Federation Economics, Keynote talk, Osaka, Japan, April 2010.

Our works around competition between providers is a noticeable part of this work, and an original one.

We have also consolidated the strong cooperation with the Telecom Institute through this joint work of many years between **Bruno Tuffin**, INRIA, and Patricke Maillé, from Telecom Bretagne.

We must underline the difficulty of getting support and implication of small companies in this subject. The usual explanation is their urgency in solving less complex and more critical (and short-term) issues instead of the mid-long term ones related to finding the right economic models and analyzing them. Large companies are more active in the field and we cooperate with them (Orange, Alcatel-Lucent).

2.6 Third objective: New generation networks research – Executive summary

During the evaluation period, our activities in networking aimed at proposing solutions to improve the overall quality of service (QoS) and quality of experience of new generation networks while ensuring interoperability of associated protocols and components. We consider mainly wireless networks (including sensors) and the new version of the Internet protocol IPv6 (including related protocols). In the wireless domain with the limited bandwidth and the variable network conditions, one of the main challenges is to cope with the rapid increase of data traffic and to support multimedia applications while increasing the wireless devices' lifetime. In this context, our work aimed at solving issues related to the optimization of wireless resources and to the reduction of energy consumption. These issues were addressed from different perspectives and for different network architectures.

Besides, since future networks will continue to be heterogeneous, the risk of non-interoperability will increase. This may lead to the unavailability of some critical network services like emergency, etc. It is important to ensure that network components will still interoperate. One important way among others is to provide efficient testing methodology that help in guaranteeing interoperability of the underlying protocols. In this context, we concentrated on the new IPv6 related protocols and we developed new interoperability-assessment solutions (methods and tools).

2.6.1 Personnel

Team permanent members: César Viho, Nizar Bouabdallah, Adlen Ksentini, Bruno Sericola and Yassine Hadjadj-Aoul. Engineers: Kamal Singh. PhD students: Nanxing Chen, Madj Ghareeb, Kandaraj Piamrat, Fatma Bouabdallah, Sofiane Moad. Post-docs: Mario Rivero.

2.6.2 Project-team positioning

Resource management in wireless networks has attracted large amount of activities throughout the world. Both academics and industrials participated to resolve issues related to this topic. In we [36] established a detailed survey on the existing solutions and open issues in this topic. Clearly, resource management in wireless network covers a very large spectrum, such as resource optimization, QoS support, network dimensioning. In addition, this topic is closely related to the industrial world as Network operators are very interested by solutions to maximize their revenues while ensuring QoS to their consumers. Thus, there are a strong efforts from industry to standardize solutions at the IEEE (for instance, 802.11e for QoS and 802.21 for mobility) as well as the 3GPP for 3G and 4G. Meanwhile, academics was interested by more theoretical issues such as using game theory for network selection (particularly in heterogenous networks) and Markov model to capture the behavior of specific wireless network such as WLAN or WiMax.

At the national level, and more specifically at INRIA, Planete project at Sophia-Antipolis has worked specifically on defining new protocols and architectures to efficiently support QoS (guarantees on delays, throughput...) in WLAN and WiMax. They worked mainly on the MAC protocol, where they introduced the concept of Traffic Class in WLAN. The main difference with our proposed solutions, is the fact that we used QoE as metric and criteria for designing efficient radio resource management rather than QoS. To the best of our knowledge, we are the first team at INRIA as well as the international level who explored the use of QoE as metric for designing resource management procedures in wireless networks.

In the context of IPv6 (and related) protocols interoperability testing, we are the only research team in Europe that contributes to the worldwide IPv6 Ready Logo certification Program (v6LC). Until 2008, only two other teams were recognized by the IPv6 Forum as a v6LC certification lab: IOL-UNH (USA) and the TAHI-group (Japan). Now five other labs, mainly in Asia (BII, Infoweapon, CHT-TL, TTA, JATE) have joined the v6LC but Dionysos still remains the only European research team.

2.6.3 Scientific achievements

Supporting QoS/QoE in wireless networks is becoming increasingly important nowadays. Indeed, wireless and mobile users are more and more interested in using multimedia applications, such as video streaming and Voice over IP (VoIP), over wireless devices. These applications clearly require strict Quality of Service (QoS) support. Provisioning such constraints in this system is very challenging, due the lack of wireless resources. Therefore designing efficient radio resource management (such as admission control, network selection, network scheduling, spectrum utilization) is mandatory for tackling such constraints. Thus, we addressed several issues related to QoS/QoE enforcement and energy saving in wireless networks, during the evaluation period. The focus was firstly dedicated to radio resource management.

In [36] we presented a detailed survey on radio resource management, and related issues and challenges. We proposed, in [95], an admission control mechanism for Wireless Local Area Network (WLAN), which prevents from degrading QoS of admitted flows while ensuring QoS for the new connections. This admission control protocol is based on an analytical model of 802.11e standard in order to derive a reject factor that ensures a bounded end-to-end delays for admitted and arriving flows. Since QoS metrics are not efficient to predict user QoE, we used PSQA in order to consider QoE rather than QoS as a main criteria for radio resources management in wireless networks. In this regard, we proposed in [234] [233] [196] [156] [125] a number of solutions considering users' QoE as a main metric in WLAN/3G networks, for: (i) admission control; (ii) network selection; (iii) rate adaptation for multicast flows; (iv) resource scheduling.

Furthermore, we considered radio resource management in Wireless Mesh Networks (WMN), which represent another way for deploying wireless networks. These networks clearly suffer from high interferences and the scarcity of available bandwidth. Thereby, we presented solutions for: (i) managing more efficiently the users' mobility [54]; (ii) routing more efficiently packets inside the network by using new routing metrics better adapted to WMN environments [94] [74]; (iii) Using more efficiently the spectrum utilization through the cognitive radio technology [53].

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. We addressed the energy issue in wireless network for two different contexts: (i) rich media (such as VoIP) delivery in Wireless LAN; (ii) Wireless Sensor Network (WSN).

In WLAN, mobile stations conserve energy by maximizing the sleep mode periods of the wireless interfaces. Despite of its efficiency, this mode is incompatible with real-time applications and media streaming, like VoIP. In fact, maximizing the sleep mode periods is directly translated into an increased delay, which induces packets losses when exceeding certain thresholds (e.g. buffer overflow and late packet loss), and may severely degrade the perceived user's QoE. In [21], [100], we showed the relation between user QoE and the sleep period in the context of Voice over Wireless Lan (VoWLAN). The system was modelled and controlled using a Proportional Interatal Derivative (PID) controller, which

computes the sleep period enabling to reach a QoE reference value. Thus, we achieved the trade-off between energy consumption and QoE.

On the other hand, WSN protocols focus primarily on power conservation, because of the limited capacity of the sensor nodes' batteries. However, this should be accomplished while respecting certain constraints on the reporting delays and the reliability of the delivered data. Achieving these two opposite requirements, i.e., finding a good trade-off between energy conservation and information reliability, is the key driver of our work on WSNs. According to the particular reporting requirements, three major classes of applications can be indeed identified: continuous monitoring, event-driven and on-demand reporting applications. Such applications with different properties impose different challenges. In our work, we considered the above three categories of applications. For each category of WSNs with its corresponding challenges, we proposed new solutions to improve the energy-reliability efficiency. Observe that unlike conventional networking paradigms, WSNs are deployed with a specific sensing application objective, which influences the network design, and consequently, our research work.

New interoperability-assessment solutions include formal characterization of interoperability of two components [72]. A method that helps in testing interoperability without disturbing the real operational interactions of tested components has been proposed [109]. Together with those methods, we provided lot of contributions to the improvement of a test description language called TTCN3 standardized by ETSI (see Section 3.3) and we develop tools that ease the test execution phase (see T3DevKit in Section 3.2). These methods and tools have been used to develop IPv6 related protocol test suites (see Section 3.3) that have been successfully experimented in the context of the Anemone testbed [215] and are still used in the worldwide IPv6 Ready Logo certification programme (see Section 3.3).

2.6.4 Collaborations

- We collaborate with Abdelhamid Nafaa from the University College of Dublin (UCD) on QoS in WLAN.
- We collaborate with Jean-Marie Bonnin from Télécom Bretagne on QoE-based resource management in heterogeneous network, mainly in the context of Kandaraj Piamrat's Phd.
- The work on sensor networks was done with the collaboration of the University of Waterloo, more specifically with Raouf Boutaba's team. This collaboration was enriched with the establishment of the INRIA associated team OCERC.
- We work with Tarik Taleb from NEC Europe research, on Machine Type Communication in LTE.
- The work on IPv6 interoperability testing has been done in tight collaboration with the TAHI Japanese group, and the UNH-IOL (University of New Hampshire – Interoperability Laboratory).

2.6.5 External support

We participated in the FP7 Anemone (see Page 43), where we deployed WiFi-based cells in order to cover the University of Rennes 1's campus and to propose internet connectivity to students. Our platform was connected with the partner platforms (composed by 3G and WiMax) which allowed us to make experiments in the context of heterogeneous wireless networks. Note that Anemone platforms are IPv6 native and support user mobility. We

established an INRIA associated team with the University of Waterloo on saving energy in WSN. Also, two INRIA STIC collaboration with Supcom (Tunisia) and with CERIST (Algeria) was launched on WSN.

2.6.6 Self assessment

We have come up with many solutions for QoS/QoE-aware resources managements in wireless networks. We believe that considering the QoE as a metric is a key element in future wireless networks to really support rich media delivery. Besides, resource management in wireless heterogeneous networks is a permanent research area as new wireless technologies are developed and will be developed in the future. Considering the new advances in wireless technologies like MIMO will be considered in the next years. On the other hand, the cognitive radio technology will be deeply considered in future works. We believe we have now valuable assets to address such issues.

Our participation to the IPv6 Ready Logo Certification Program helped us to develop new approaches for testing. This work has to be continued as it brings new research challenges in interoperability testing. On the other hand, this work obliges to some administrative and engineering tasks (like applications examination, help in using test tools, etc.) that have to be stopped. This process has already started in September 2011.

A merge of positive and negative point is the fact that **Nizar Bouabdallah**, who headed our work on sensor networks, left INRIA to spend 4 years in Tunisia. This is a strong loss for the institution and for our group, and at the same time a mobility move and a positive one for the individual projects of Nizar.

2.7 Fourth objective: Methodological contributions to the analysis of models – Executive summary

Several members of Dionysos have been involved in modeling and in models' solving techniques for years. In the evaluation period, we have been working on Monte Carlo techniques, for rare event analysis, one of the strong expertise of the team. This was done for classical stochastic models, such as Markov chains, and also for static ones, around the concept of *network reliability* for dependability applications in both cases. We have been also active on the analysis of fluid queueing models, and on the analysis of distributed systems.

Concerning the evolution of the objectives announced when the team was created in 2008, the promising area of bounding techniques specially effective when the goal is the analysis of a rare event were left for the future, due to the activity level reached in the work on Monte Carlo techniques.

2.7.1 Personnel

Permanent researchers: **Bruno Tuffin**, **Bruno Sericola**, **Gerardo Rubino**, **Raymond Marie**;
Students: **Laura Aspirot**, **Samira Saggadi**, **Pablo Sartor** (just starting).

2.7.2 Project-team positioning

On simulation, a specificity of Dionysos is that we are the only ones within Inria to work on dependability aspects and their generalizations or extensions (performability, vulnerability,...). We are also the only ones to work on quasi-Monte Carlo and Randomized Quasi-Monte Carlo techniques. A simulation activity already exists at Inria (OMEGA Project), but their approach focuses on problems involving stochastic differential equations, with

application mainly in finance, whereas we are more concerned with the simulation of rare events with dependability and performance evaluation applications. In Rennes, there is also the ASPI group working on rare event simulation techniques (with whom we have collaborated within the ARC RARE and co-published book chapters), but they essentially focus on the development of splitting techniques, while we use a broader range of methods. Observe that our combination of Monte Carlo and Quasi-Monte Carlo methods is also specific in France, the only notable other researcher being Christian Lécot of the University of Savoie, with whom we collaborate.

Outside Inria and France, the most active players in rare event simulation can be found in North America (with the exception of S. Asmussen in Denmark and S. Juneja in India), but here too they do not have the same intensity of work on dependability models, working more on applications in queues and finance. As key leaders, we can mention P.W. Glynn, J. Blanchet, P. L'Ecuyer, with whom we have collaborated in the evaluation period and continue to do so.

2.7.3 Scientific achievements

Simulation techniques The analysis technique needing the less assumptions is (Monte Carlo) *simulation*. Improving the efficiency of a simulator can be a requirement such as in the case of rare events. Indeed, if we wish to validate a loss probability of 10^{-9} for a system, we will need in average a sample of size 10^9 to get the event once, and much more to get a confidence interval. Several “acceleration” methods, meaning improving the efficiency, exist in the literature. We have worked on the two main techniques for rare event simulation, *importance sampling* which modifies the probability laws of the sample, introducing a bias that is counterbalanced by the introduction of the likelihood ratio, and *splitting* which basically decomposes the rare event into a succession of less rare events, which probabilities are estimated in a classic way: as soon as an intermediate event is reached, the “trajectory” is split in several new ones trying to reach the next events. The proportion of successful trajectories at the end gives the estimation. On importance sampling, we have been leaders in the development of approximations of zero-variance estimators, with applications to dependability analysis; our estimators are proved to outperform the best ones up to now [226, 51, 63, 30]. We have similarly developed new splitting estimators [25]. We have also been interested in robustness properties of simulation methods as the probability of the event goes to zero; we have shown the importance of defining new properties that an estimator needs to satisfy to guarantee its accuracy and the relative error of the produced confidence interval [56]. It has also to be noted that we have published two books on simulation, one general in French explaining the basic use of Monte Carlo and including numerous examples [3], and a book in English (as editors) on rare event simulation (with six co-written chapters), which is the only one in the literature explaining all the different available methods and application areas (from experts in each field) [6].

Another technique, allowing here to improve the *convergence speed* of a Monte Carlo estimator is quasi-Monte Carlo (QMC). Here, instead of using random numbers, we use a sequence of points that distributes itself “very well” on the considered domain (a so-called low-discrepancy sequence). But this attractive method suffers from two drawbacks: the lack of *practical* error bounds and a limited application range. We are historical leaders on *randomization* methods which allow to get a confidence interval (hence an estimation of the error) from independent copies of the randomization, but such that each randomization keeps the low discrepancy of the sequence. During the evaluation period, we have especially worked on a method specific to Markov chains [93], which drastically reduces the

mathematical dimension and yields very good results and improvements when the states can be properly ordered. We have also determined limit distributions of the randomized methods to discuss the necessary trade-off between length of the low-discrepancy sequence and number of randomizations [144, 50]. In all those directions we are leading the research activities.

Dependability models We started a collaboration with the Inria project-team Ipso, in Rennes, on the evaluation of the moments of cumulative reward in Markov models [55]. We studied the convergence of the normalized moments and, based on this convergence, we developed a new algorithm to compute them. We also analyzed these moments and gave a probabilistic interpretation of the quantities arising in the algorithm. We also obtained in [71] an improvement of an algorithm we developed a few years ago for the distribution computation of the cumulative reward in Markov chains.

Fluid queues We analyzed in [235] the sequence of the successive sojourn times spent by a fluid queue, driven by a homogeneous Markov chain, in various levels of its state space. These fluid flows models are widely used in the performance analysis of telecommunication systems. The analysis is carried out in the Laplace-Stieljes transform domain and we study the limiting behavior of this sequence of sojourn times.

A crucial property of second order fluid models is the behavior of the fluid level at the boundaries. In [91], two cases have been considered: the reflecting and the absorbing boundary. This paper presents an approach for the stationary analysis of second order fluid models with any combination of boundary behaviors. The proposed approach is based on the solution of a linear system whose coefficients are obtained from a matrix exponent. A practical example demonstrates the suitability of the technique in performance modeling.

In [39], we expose a clear methodology to analyze maximum level and hitting probabilities in a Markov driven fluid queue for various initial condition scenarios and in both cases of infinite and finite buffers. Step by step we build up our argument that finally leads to matrix differential Riccati equations for which there exists a unique solution. The power of the methodology resides in the simple probabilistic argument used that permits to obtain analytic solutions of these differential equations. We illustrate our results by a comprehensive fluid model that we exactly solve.

In [20], we analyze the transient behavior of a fluid queue driven by a general ergodic birth and death process using spectral theory in the Laplace transform domain. These results are applied to the stationary regime and to the busy period analysis of that fluid queue.

The MAPI group Bruno Sericola is the leader of the research group MAPI (Applied Mathematics for Computer Science) the goal of which is to improve the collaboration between computer scientists and mathematicians at INRIA.

See the page http://www.irisa.fr/dionysos/pages_perso/sericola/MAPI.html where the name of the collaborators can also be found in the list of publications. Note that we didn't include in this page the multiple collaborations of MAPI with Dionysos and Ipso teams since some members of these teams belong to the group.

Such collaborations were sporadic in the past, but since 2006 there has been an increasing demand from Inria computer scientists to use probabilistic models to evaluate computer and communication systems. Moreover the visiting committee gave in his report in 2009, as a main recommendation, to reinforce the synergy between computer science and applied mathematics. From these observations, Bruno Sericola decided to create the MAPI group, which has been validated by the Inria Rennes project committee in January

2010. Since 2006, the group has worked with several Inria teams as Asap, Adept, Ipso (Rennes), Pops (Lille), Grand-Large (Saclay), D-Net (Lyon) and Reso(Lyon). The group has now an industrial contract with Technicolor (see Page 48), a PhD student and several other teams have required the group for collaboration.

2.7.4 Collaborations

We are collaborating (and publishing) with the world-leading personalities in simulation:

- Pierre L’Ecuyer at the University of Montreal (with whom we have an Inria associated team), Canada
- Peter Glynn (Stanford University, USA)
- José Blanchet (Columbia University, USA)
- Héctor Cancela (University of the Republic, Uruguay)

The MAPI group is by construction based on the collaboration with researchers of other teams at INRIA. A current list of teams together with the involved researchers is: Asap, Inria-Rennes (A.-M. Kermarrec, A. Mostefaoui, M. Raynal, E. Le Merrer, G. Trédan, V. Gramoli); Cider, Irista-Rennes (E. Anceaume), Ipso, Inria-Rennes (F. Castella, G. Du-jardin); Cidre, Inria-Rennes (F. Tronel); Pops, Inria-Lille (N. Mitton); Grand-Large, Inria-Saclay (S. Tixeuil); D-Net, Inria-Grenoble (G. Chelius, E. Fleury); Reso, Inria-Grenoble (I. Guérin-Lassous).

Other major collaborators of the team in these topics are:

- Alan Krinick, CalPoly, US, on transient analysis of Markovian queues
- Fabrice Guillemin, Orange Labs and RAP Inria team, on queueing systems’ analysis
- Miklos Telek, TUB, Hungary, and Marie-Ange Remiche, FUNDP, Namur, Belgium, on Markovian analytical techniques
- Juan Carrasco, UPC, Barcelona, Spain, Hedi Nabli, Sfax University, Tunisia, Daniel Manini, University of Torino, Italy, and Marco Gribaudo, University of Torino, Italy, on Markovian analysis

2.7.5 External support

- Associated-team MOCQUASIN: INRIA associated team with the University of Montréal. 2008-2010, extended to period 2011-2013. Main topic: Monte Carlo and quasi-Monte Carlo simulation techniques. Application to rare event simulation. See http://www.irisa.fr/dionysos/pages_perso/tuffin/MOCQUASIN/.
- Région Bretagne: project ARED SIMERTEL (rare event simulation with applications in telecommunications) (2008-2011).
- Contract with Technicolor (see Page 48).

2.7.6 Self assessment

Our strengths on simulation are our international visibility and the fact that we collaborate with the world-leading people. This translated into several positive actions and results in the period:

- We ([Gerardo Rubino](#), [Bruno Tuffin](#)) edited a book on rare event analysis using Monte Carlo [6]. In that book, we are co-authors in 6 over 11 chapters, and some of our main collaborators contributed as well (L’Ecuyer, Glynn, Blanchet, Cancela, plus Michel Mandjes (CWI), Thomas Booth (Los Alamos), etc.
- [Bruno Tuffin](#) published a book on Monte Carlo, [3]
- In 2012, two more books will be published by the group. The first one, [1], is based on past work of the authors in the analysis of Markov models including topics such as weak lumpability, sojourn times, cumulative dependability and performability metrics, bounding and simulation techniques, and more. The second one, [2], covers more standard material about Markov chains and different applications.
- We have an associated team with Pierre L’Ecuyer, that was quite active during the period (see 44)
- Globally, one of our strong points in the area is the high number of collaborations and the visibility of our partners. We also have a high number of collaborations inside INRIA through the MAPI group.
- We received the conference QEST in 2008 (5th issue), where classical performance evaluation is put together with formal techniques such as probabilistic model checking; [Gerardo Rubino](#) was the General Chairman.
- We received the workshop RESIM in 2008 (7th issue), the only one exclusively dedicated to rare event analysis using Monte Carlo techniques; [Gerardo Rubino](#) was the General Chair and [Bruno Tuffin](#) was the Committee Program Chair. Both Dionysos members serve at RESIM Steering Committee.
- We are starting a new collaboration phase with South America through our involvement in the new center INRIA has launched with several Chilean universities (CIRIC). The topic are part of the ones covered by the objective described in this section.

On the weaknesses side now:

- In the simulation area, we must point out our lack of cooperation with industrial partners (and lack of contracts), while our academic collaborations are very strong. We are currently working on that issue, and a first opportunity for the new period appears from a company working on architectural problems (memory chips) in Grenoble, France. But it seems difficult, in general, to motivate industry to invest in research in the field, or we didn’t find the right angle to do that.
- We have also difficulties in recruiting good students in the area, even if this is more a problem in our ecosystem in Brittany rather than a weakness of the team. It is partly related to the needed background both in applied mathematics and in computer science and the way educational institutions are structured in our region. We try to solve this by recruiting abroad, with variable success so far.

- The MAPI group also needs more visibility. It is a recent initiative, and perhaps an idea to develop it further is to make it become a scientific service.

3 Knowledge dissemination

3.1 Publications

	2008	2009	2010	2011
PhD Thesis	2	0	2	2
H.D.R (*)	0	1	0	0
Journals	13	9	13	26
Conference proceedings (**)	35	41	39	33
Book chapter	0	9	5	9
Book (written)	0	0	1	2
Book (edited)	0	2	0	0
Patents	–	–	–	–
General audience papers	0	0	0	0
Technical reports	–	–	–	2
Deliverables (***)	–	–	–	–

(*) HDR Habilitation à diriger des Recherches

(**) Conference with a program committee

(***) An average of 4 per industrial project, with many co-authors. Not included in the bibliography at the end of the report.

Indicate the major journals in the field and, for each, indicate the number of papers coauthored by members of the project-team that have been accepted during the evaluation period.

Starred journal underlined.

1. Annals of Operations Research* 4
2. Methodology and Computing in Applied Probability* 4
3. Computer Networks* 4
4. Performance Evaluation* 4
5. Computer Communications* 3
6. International Journal of Network Management* 3
7. Annals of Telecommunications 2
8. IEEE Transactions on Mobile Computing* 2
9. IEEE Transactions on Vehicular Technology* 2
10. IEEE Transactions on Wireless Communications* 2
11. IEEE/ACM Transactions on Networking* 2
12. Int. J. Logistics Systems and Management 2
13. ACM Performance Evaluation Review* 2

14. ACM Transactions on Modeling and Computer Simulation* 1
15. Ad Hoc & Sensor Wireless Networks* 1
16. The Computer Journal 1
17. Electronic Commerce Research Journal 1
18. Electronic Journal of Statistics 1
19. EURASIP Journal on Image and Video Processing 1
20. IEEE Communications Surveys and Tutorials* 1
21. IEEE Transaction On Parallel and Distributed Systems* 1
22. IEEE Transactions on Computers* 1
23. IEEE Transactions on Reliability* 1
24. IIE Transactions 1
25. INFORMS Journal on Computing* 1
26. International Journal of Security and Networks 1
27. International Journal on Software Tools for Technology Transfer 1
28. Journal of Communication 1
29. International Journal of Foundations of Computer Science* 1
30. Netnomics 1
31. Simulation Modeling, Practice and Theory 1
32. Telecommunication Systems 1
33. Transportation Research Part B 1
34. Security and Communication networks 1
35. Operations Research* 1
36. IEEE Wireless Communications Magazine* 1

Indicate the major conferences in the field and, for each, indicate the number of papers coauthored by members of the project-team that have been accepted during the evaluation period.

Starred conferences underlined.

1. IEEE Globecom* 14
2. The IEEE International Conference on Communications (ICC)* 10
3. Winter Simulation Conference* 5
4. International Workshop on Rare Event Simulation (RESIM)* 4
5. The IEEE Wireless Communications and Networking Conference (WCNC)* 3

6. IEEE Symposium on Computers and Communications (ISCC) 3
7. International Teletraffic Congress (ITC)* 3
8. IEEE Consumer Communications and Networking Conference (CCNC)* 3
9. IEEE Vehicular Technology Conference (VTC) 2
10. QUEST* 2
11. International Conference on Network and Service Management (CNSM) 2
12. IEEE International Conference on Multimedia and Expo (ICME)* 2
13. MASCOTS* 2
14. St Petersburg Workshop in Computer Simulation 2
15. International Workshop on Advanced Internet Charging and QoS technologies (ICQT) 2
16. International Workshop on Applied Probability (IWAP) 2
17. International Conference on COMMunication Systems and NETworks (COMSNETS) 1
18. IEEE/IFIP International Conference on Dependable Systems and Networks (DSN)* 1
19. IFIP International Conference on Testing Software and Systems 1
20. Conference on Decision and Game Theory for Security (GameSec) 1
21. IEEE International Wireless Communications and Mobile Computing Conference (IWCMC) 1
22. International Conference on Multimedia Information Networking and Security (MINES) 1
23. ETSI Workshop on QoS / QoE / User Experience 1
24. International Packet Video Workshop* 1
25. IFIP/IEEE International Workshop on Bandwidth on Demand and Federation Economics 1
26. IEEE Personal, Indoor and Mobile Radio Communications (PIMRC)* 1
27. International Symposium on Stabilization, Safety, and Security of Distributed Systems (SSS)* 1
28. Mesaqin 1
29. International Workshop on Reliability, Availability and Security (WRAS) 1
30. Conference of the International Association for Travel Behaviour Research 1
31. Conference on Ultra Modern Telecommunications (ICUMT) 1

32. International Workshop on Future Multimedia Networking 1
33. IEEE WONS (International Conference on Wireless On-demand Network Systems and Services) 1
34. International Conference on Broadband Communications, Networks, and Systems (Broadnets) 1
35. International Conference on Broadband Network & Multimedia Technology 1
36. International Conference on ITS Telecommunications 1
37. International Conference on Monte Carlo and quasi-Monte Carlo Methods 1
38. International Conference on Networking (ICN) 1
39. IEEE INFOCOM, Mini-Conference 1
40. International Symposium on Distributed Computing (DISC)* 1
41. ACM International Workshop on Mobility Management and Wireless Access 1
42. IEEE INFOCOM* 1
43. TTCN-3 User Conference 1
44. International Conference on Operations Research 1

3.2 Software

- T3devKit testing toolkit and IPv6 test suites 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, OSPFv3, etc.) are freely available at <http://www.irisa.fr/tipi>.

3.3 Valorization and technology transfert

- Thanks to the Point6 initiative (an IPv6 skill center of Brittany region, supported by the Regional Council of Brittany (Conseil Régional de Bretagne)), Dionysos and Silicomp AQL were partners for IPv6 testing activities. In order to anticipate predictable growth of the needs for IPv6 testing demands, we wished to outsource related services and engineering activities towards an industrial partner, so as to concentrate on the research side (network testing methods) while maintaining the certification role (IPv6 Ready Logo Committee). This strategic partnership led to

the elaboration of our test methodology (and associated tools: see T3DevKit in Section 3.2). It allowed the transfer to Silicomp AQL of testing expertise in using these tools for the development of additional test suites as well as certification applications' examination.

- On the perceptual quality assessment problems, we underline here the fact that many companies have integrated part of our PSQA methodology as parts of the various collaborative projects where we participated in the field (see Section 4).

3.4 Teaching

- **César Viho** is a Full Professor at the University of Rennes 1. As such, he has at least 192 hours per year of teaching and related tasks, each year in the computer science department (ISTIC) of the University of Rennes 1. He teaches mainly Computer Networks and Protocols (92hours), Validation and Interoperability testing (12hours), Quality of service and multimedia (12hours) in 1st and specifically in the 2nd year of Master degree. He also teaches Algorithms and graphs (24 hours) at the Engineering school (ESIR) of University of Rennes 1. In May 2011, he co-organized (together with Laurent Toutain from TELECOM Bretagne) an international 3 days summer-school on "Communicating objects".
- **Adlen Ksentini** is an Associate Professor at the University of Rennes 1. As such, he teaches around 192 h per year, mainly at the undergraduate and Master levels, in computer science. He taught "Introduction to network and Internet" to the Licence 3 (3rd year of Licence on computer science), "Multimedia transmission over network" and "Performance evaluation of networks" to the Master 2 (2nd year of master on computer science). Since 2008, Adlen Ksentini is in charge of the 2nd year of the master on computer science at the University of Rennes 1.
- **Yassine Hadjadj-Aoul** is an Associate Professor at the University of Rennes 1. As such he has at least 192 hours per year of teaching, particularly at the Engineering school of Rennes 1, which is named ESIR. He teaches "Algorithms and graphs" (36 hours) to the students of the first year, "Introduction to networks and to the Internet" (24 hours) and "Wireless networking" (46 hours) to the to the students of the second year, and "Multimedia services in IP networks" (35 hours) to the students of the third year.
- **Raymond Marie** is a Full Professor at the University of Rennes 1. As such, he has at least 192 hours per year of teaching and related tasks, each year in the computer science department (ISTIC) of the University of Rennes 1. He teaches mainly the following topics: introductory courses on probability, on statistics, performance evaluation and dependability analysis.
- **Gerardo Rubino**:
 - 2008: "Performance Evaluation" (14h, Master level, U. of Rennes 1), "Dependability Analysis" (20h, 3rd year Eng. School DIIC, U. of Rennes 1), "Probability and Simulation" (8h, 3rd year Eng. School Telecom Bretagne), "Performance Evaluation using Queueing Models", (20h, Master level, U. Lebanese, Beirut)
 - 2009: "Performance Evaluation" (14h, Master level, U. of Rennes 1), "Dependability Analysis" (20h, 3rd year Eng. School DIIC, U. of Rennes 1), "Probability and Simulation" (8h, 3rd year Eng. School Telecom Bretagne), "Dependability Theory" (15h, 3rd year Eng. School SUPELEC)

- 2010: as in 2009, plus a 3-hour tutorial on Monte Carlo techniques done with Bruno Tuffin at QEST’09, Budapest, Hungary, plus a mini-course (6h) entitled “Topics in the analysis of performance, dependability and performability aspects of complex systems”, at the CIMPA School in Applied Mathematics and Engineering, organized in Solís, Uruguay
- 2011: as in 2009, plus a 3-hour tutorial on Monte Carlo techniques at DEPEND’09, Venezia, Italy
- **Bruno Sericola:**
 - Master M1 (2008,2009,2010,2011): “Performance and dependability evaluation of computer systems”, University of Rennes 1, Computer Science (36 hours)
 - Master M2 (2008,2009,2010,2011): “Queueing systems and performance evaluation”, University of Rennes 1, Engineering School in Computer Science (20 hours)
- **Bruno Tuffin** taught at the master level: 4 times 18 hours of simulation in Master 1 of computer science, as well as 4 times 6 hours in Master 2 (simulation output analysis and game theory). He was also the co-chair of Networks and Systems track of Computer Science Master in Rennes: 2007-2008. He also taught a course “Advanced methods for rare event simulation” at the CIMPA School Applied Mathematics and Engineering, Solís, Uruguay, in March 2010. Finally, together with Gerardo Rubino, he gave a tutorial entitled “An Introduction to Monte Carlo Methods and Rare Event Simulation” at the 5th International Conference on Quantitative Evaluation of SysTems (QEST), IEEE CS Press, Budapest, Hungary, September 2009.

All the activities at the Master level are associated with the Doctoral Program of the University of Rennes 1.

3.5 General Audience Actions

- Talks to High-School students for introducing them to research work. Titles so far: “Rare event analysis”, “Long tails and some great successes in the Internet”, “Game theory and applications”, “Using randomness to solve deterministic problems” (**Gerardo Rubino**)
- Some interviews (radio, newspapers) associated to the Summer School organized by the team in July 2010, Rennes, together with the keynotes John Day (U. of Boston) and Andrew Odlyzko (U. of Minnesota) (**Adlen Ksentini** and **Gerardo Rubino**).
- On March 2011, a visit of Inria for an 11th year class of a Rennes’ school, and a talk on the researcher work (**Bruno Sericola**).
- Different demos (5) built around the PSQA project. Some already mentioned since they won international process (ACM SIGMETRICS 2008 and NEM Summit 2008). Others done in general audience meetings (like the “Fête de la science”) or at industrial audiences (e.g. for visitors at INRIA, or associated to conferences, such as QEST’2008). Responsible: **Gerardo Rubino**.
- Interviews by economic journals (“Les Echos”) concerning some aspects of the future of the Internet (**Gerardo Rubino**).

3.6 Visibility

Organization of conferences

- Bruno Tuffin was the local organization Chair, 5th International Conference on the Quantitative Evaluation of SysTems (QEST'08), Saint-Malo, September 2008.
- Bruno Tuffin was Scientific Committee Chair, 7th International Workshop on Rare Event Simulation (RESIM'08), Rennes, September 2008.
- Bruno Tuffin was co-chair for the sixth International Workshop on Advanced Internet Charging and QoS technologies (ICQT'09), Aachen, Germany, May 2009.
- Bruno Tuffin was the TPC co-chair for NetGCoop 2011, Oct. 12-14, Paris.
- Gerardo Rubino is a member of the Steering Committee of the international conference QEST (Quantitative Evaluation of SysTems).
- Gerardo Rubino was the General Chair of the following conferences: 5th International Conference on the Quantitative Evaluation of SysTems (QEST'08), Saint-Malo, September 2008 and the 7th International Workshop on Rare Event Simulation (RESIM'08), Rennes, September 2008.
- Nizar Bouabdallah was the TPC Co-Chair for the IEEE GLOBECOM 2009 Ad Hoc and Sensor Networks Symposium, Honolulu, Hawaii, USA.
- Adlen Ksentini was the PHD Forum Chair for the ICST Mobile Lightweight Wireless Systems (MOBILIGHT) 2009
- Gerardo Rubino and Adlen Ksentini co-organized in 2010 (together with Laurent Toutain from TELECOM Bretagne) an international school about the future of the Internet. The school was an initiative of the GIS Bretagne, and was also sponsored by EuroNF, INRIA, and the UEB.
- César Viho co-organized (together with Laurent Toutain from TELECOM Bretagne) an international school about "Communicating objects". The school was an initiative of the Irista "Networks, Telecom and Services" department, and was sponsored by MATISSE doctoral school.
- Bruno Tuffin will be the co-coordinator of the "Analysis" track at the Winter Simulation Conference (WSC'12), Berlin, Germany, December 9-12, 2012. It will be the first time this event will leave North America.

Program committees Nizar Bouabdallah served in the Program Committee of the following conferences:

- IEEE GLOBECOM 2008, Ad Hoc, Sensor and Mesh Networking Symposium, December 2008, New Orleans, LA, USA.
- IWCMC 2008, Wireless LANs and Wireless PANs Symposium, August 2008, Chania, Crete Island, Greece.
- IEEE PIMRC 2008, Mobile and Wireless Networks Track, September 2008, Cannes, France.
- IEEE WCNC 2008, Networking Track, April 2008, Las Vegas, USA.

- Radio Resource Management in Wireless Mesh Networks (RRMinMesh'08) Workshop held in conjunction with AICCSA'08 conference, April 2008, Doha, Qatar.
- IEEE ICC 2009, Ad-Hoc and Sensor Networking Symposium, June 2009, Dresden, Germany.
- IEEE ICC 2010, Ad Hoc, Sensor and Mesh Networking Symposium, May 2010, Cape Town, South Africa;
- IEEE GLOBECOM 2010 Ad Hoc, Sensor and Mesh Networking Symposium, December 2010, Miami, Florida, USA;

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

- 8th ICIL (International Conference on Industrial Logistics), March 2008, Neguev, Israel;
- 4th Euro-NGI (Next Generation Internet Networks Design and Engineering for Heterogeneity), April 28–30, 2008, Krakow, Poland, 2008.
- SMCtools 2008: International Workshop on Tools for solving Structured Markov Chains, Athens, Greece, October 2008;
- 8th ICOR (International Conference on Operations Research), February 2008, La Habana, Cuba;
- IEEE INFOCOM 2009 (The 28th Conference on Computer Communications), Rio de Janeiro, Brazil, April 2009.
- IFIP/ACM (SIGCOMM) LANC'09 (5th Latin America Networking Conference 2009, Pelotas, Brazil, September 2009.
- 10th International Workshop on Computational Stochastics, Amsterdam, The Netherlands, May-June 2010.
- 10th International Workshop on Computational Stochastics, Amsterdam, The Netherlands, May-June 2010.
- ETS, 1st European Teletraffic Seminar, Poznan, Poland, 14-16 February 2011
- LANC 2011, 6th Latin America Networking Conference, in cooperation with IFIP/ACM, Quito, Ecuador, 12–14 October, 2011
- CLEI 2012, XXXVIII Conferencia Latinoamericana de Informática (Latin-American Informatics Conference), Medellín, Colombia, October 1–5, 2012.

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

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

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

- ASMTA'08, 15th International Conference on Analytical and Stochastic Modelling Techniques and Applications, Nicosia, Cyprus, 4-6 June 2008.

- MAM6, 6th International Conference on Matrix Analytic Methods in Stochastic Models, Beijing, P. R. China, June 11-14, 2008.
- CFIP'08, Colloque francophone sur l'ingénierie des protocoles, Les Arcs, France, 25-28 mars 2008.
- ASMTA'09, 16th International Conference on Analytical and Stochastic Modelling Techniques and Applications, Madrid, Spain, 9-12 June 2009.
- SMCTools'09, 4th International Workshop on Tools for Solving Structured Markov Chains. Pisa, Italy, October 20-22, 2009.
- CFIP'09, 14ème Colloque francophone sur l'ingénierie des protocoles, Strasbourg, France, 12-15 October 2009.
- ASMTA'10, 17th International Conference on Analytical and Stochastic Modelling Techniques and Applications, Cardiff, UK, 14-16 June 2009.
- MACOM 2010, 3rd International Workshop on Multiple Access Communications, Barcelona, Spain, 13-14 September 2010.
- ASMTA 2011, 18th International Conference on Analytical and Stochastic Modelling Techniques and Applications, Venice, Italy, 20-22 June 2011.
- MAM'7, 7th International Conference on Matrix-Analytic Methods in Stochastic Models, New-York, USA, 13-16 June 2011.
- CFIP 2011, Colloque Francophone sur l'ingénierie des protocoles, St Maxime, France, 10-13 May 2011.

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

- 2nd IEEE International Workshop on Bandwidth on Demand (BoD 2008) April 11, 2008, Salvador da Bahia, Brazil.
- 4th EURO-NGI Conference on Next Generation Internet Networks Design and Engineering for Heterogeneity (NGI'08), April 28-30, Krakow, Poland.
- 9ème Atelier en Évaluation de Performances, 1-4 Juin 2008, Aussois, France.
- 8th International Conference on Monte Carlo and Quasi-Monte Carlo Methods in Scientific Computing (MCQMC'08), July 7-11, 2008, Montréal, Canada.
- 17th International Conference on Computer Communications and Networks (ICCCN'08), August 4 - 7, 2008 St. Thomas U.S. Virgin Islands.
- The 5th International Workshop on Grid Economics and Business Models (GECON 2008), August 25-26, 2008, Las Palmas, Gran Canaria, Spain.
- 3rd International Conference on Performance Evaluation Methodologies and Tools (VALUETOOLS'08), October 13-18, 2008, Athens, Greece.
- European Simulation and Modelling Conference (ESM2008), October 27-28, 2008, Le Havre, France.
- 2nd IFAC Workshop on Dependable Control of Discrete Systems (DCDS'09), June 10-12, 2009, Bari, Italy.

- 5th EURO-NGI Conference on Next Generation Internet (NGI 2009). Aveiro, Portugal, June 22-24, 2009.
- The 6th International Workshop on Grid Economics and Business Models (GECON 2009), August 24, 2009, Delft, The Netherlands.
- 6th International Conference on the Quantitative Evaluation of SysTems (QEST) 2009, September 2009, Budapest, Hungary.
- 21st International Teletraffic Congress (ITC 21), September 15,17, 2009, Paris, France.
- Co-organizer of the invited session “Game theory in communication networks” at the Roadf Conference, Clermont Ferrand, February 25-27, 2008.
- 3rd IFIP/IEEE International Workshop on Bandwidth on Demand and Federation Economics, April 23, 2010, Osaka, Japan.
- 6th Euro-NGI conference on Next Generation Internet Networks (NGI 2010), June 2010, Paris, France.
- 8th International Workshop on Rare Event Simulation (RESIM’10), June 21-22 2010, Cambridge, England.
- 22nd International Teletraffic Congress (ITC 22), September 2010, Amsterdam, The Netherlands.
- 3rd Workshop on Economic Traffic Management (ETM), September 2010, Amsterdam, The Netherlands.
- The 7th International Workshop on the Economics of Grids, Clouds, Systems, and Services (GECON 2010), August 30–31, 2010, Ischia, Naples, Italy.
- 4th International Conference on Network Control and Optimization (NET-COOP’10), November 2010, Ghent, Belgium. Workshop on Performance Evaluation of Cognitive Radio Networks : from Theory to Reality (PE-CRN 2011), Valencia, Spain, May 13, 2011.
- IEEE International Conference on Communications (IEEE ICC 2011), June 5-9 2011, Kyoto, Japan.
- 7th Euro-NGI conference on Next Generation Internet Networks (NGI 2011), June 27-29 2011, Kaiserslautern, Germany.
- 1st International Conference on Simulation and Modeling Methodologies, Technologies and Applications (SIMULTECH), Noordwijkerhout, The Netherlands, 29-31 July 2011.
- 20th IEEE International Conference on Computer Communication Networks (ICCCN 2011), Maui, Hawaii, August 1-4, 2011.
- 8th International Workshop on Economics of Grids, Clouds, Systems and Services (GECON’2011).

Adlen Ksentini served in the Program Committee of the following conferences:

- The IEEE 22nd International Conference on Advanced Information Networking and Applications (AINA 2008), GinoWan, Okinawa, Japan, March 2008.
- 3rd ACM International Workshop on Performance Monitoring, Measurement, and Evaluation of Heterogeneous Wireless and Wired Networks (PM2HW2N 2008), Vancouver, British Columbia, Canada, October 2008.
- 3rd Workshop on multiMedia Applications over Wireless Networks (MediaWiN 2008), Marrakech, Morocco, July 6th, 2008.
- IEEE GLOBECOM 2009 Wireless Network Symposium, December 2009, Hononulu, Hawaii, USA
- IEEE GLOBECOM 2010 Wireless Network Symposium, December 2010, Miami, Florida, USA
- IEEE ICC 2010, Wireless Communication Symposium, May 2010, Cape Town, South Africa;
- IEEE Global Communication Conference, GLOBECOM 2011 Wireless Network Symposium, December 2011, Houston, Texas, USA
- IEEE International Conference on Communication, ICC 2011 Wireless Network Symposium, June 2011, Kyoto, Japan
- IEEE International Conference on Selected Topics in Mobile and Wireless Networking (iCost), October 2011, Shangai, China
- IEEE International Symposium on Computer Communication, ISCC 2011, July 2011, Istanbul, Turkey.

Editorial activity

- Raymond Marie is associate Editor for Performance Evaluation.
- Bruno Sericola is a member of the Editorial Advisory Board of the Open Operational Research Journal.
- Bruno Sericola is a member of the Editorial Advisory Board of the International Journal of Stochastic Analysis.
- Bruno Tuffin is associate Editor for INFORMS Journal on Computing.
- Bruno Tuffin is associate Editor for Mathematical Methods of Operations Research.
- Bruno Tuffin is associate Editor for ACM Transactions on Modeling and Computer Simulation.
- Bruno Tuffin is a Co-guest editor of a special issue of Telecommunication Systems Journal on Socio-Economic Issues of Next Generation Networks, 2011.
- Gerardo Rubino was a co-editor of a special issue of Performance Evaluation, 2010.
- Nizar Bouabdallah Associate Editor for the Wireless Communications and Mobile Computing journal, Wiley InterScience, since February 2009.
- Adlen Ksentini is Associate Editor of Hindawei International Journal of Digital Multimedia Broadcasting

Standardization activities The Dionysos team dedicates a significant effort towards standardization and certification in the telecommunications area. We participate in several working groups of the main telecommunication standardization institutes like the IETF (Internet Engineering Task Force), ETSI (European Telecommunication Standardization Institute), etc. We are also active in the main mailing-lists treating new generation networks and protocols. Several proposals of drafts and contributions to the definition of standards and RFCs (Request For Comments) have been published. Our contributions focused mainly on IPv6 and related protocols such as IPv6 mobility.

IPv6 Ready Logo Program Dionysos team has also a major role in the world-wide certification process for IPv6 products launched by the IPv6 Forum, the “IPv6 Ready Logo Program”. For details, see <http://www.ipv6ready.org>. This project aims to provide the means needed to test existing IPv6 products to be deployed in the market. The Dionysos team leads the technical part of this Program by defining the certification process itself, specifying required tests, and developing some of the interoperability tests needed. This work is done together with the IPv6 Forum, the ETSI in Europe, the WIDE-project in Japan and the TTA (Telecommunications Technology Association) in Korea. César Viho has been nominated as *IPv6 Forum Fellow* for his work in this world-wide IPv6 Ready Logo Program.

Other memberships and responsibilities

- Raymond Marie and Gerardo Rubino are members of the IFIP WG 7.3 on Computer Performance Modeling and Analysis
- Gerardo Rubino is a member of the Advisory Scientific Board of the Engineering School Telecom Bretagne
- Gerardo Rubino has been a member of the Specialist Commission of the University of Versailles
- Gerardo Rubino is a member of the Selection and Validation Committee of the Images and Network cluster in Brittany, that groups most companies and academic institutions working on networking and image processing and synthesis in Western France
- Gerardo Rubino is the INRIA representative at the GIS SISCO, an association composed of the four main academic institutions in Western France in the area of information and communication sciences: the European University of Brittany-UEB, the Institut TELECOM, the CNRS and INRIA; the goal is to promote the excellence of the ICT research in Brittany.
- César Viho is responsible of the “Network, Telecommunication and Services” department of Irisa composed of 4 research teams. He is member of the Conseil de laboratoire and of the Conseil d’Orientations scientifiques (COS) of Irisa. He is in charge of administrative issues management of PhD students of Irisa and Inria. In the context of international relations of Irisa, he is responsible of relations with Africa area universities and research centers.
- Adlen Ksentini is the coordinator of the Special Interest Group (SIG) of the Communication Software Technical Committee (IEEE Communication Society)
- Gerardo Rubino belongs to the Technical Committee on Multimedia Communication of the IEEE Communication Society

- Gerardo Rubino belongs to the Scientific Committee of the Indo-French Centre for the Promotion of Advanced Research (IFCPAR), created by the Department of Science and Technology of India and the CNRS, France.

4 External Funding

Budget in keuros.

(k euros)	2008	2009	2010	2011
INRIA Research Initiatives				
ARC [†] <i>MENEUR</i>				8.5
National initiatives				
ANR <i>WINEM</i>	10.2	10.2		
ANR <i>CAPTURES</i>		17.5	17.5	17.5
ARED <i>SIMERTEL</i>		29.5	29.5	29.5
European projects				
IST <i>Anemone</i>	122.4	61.2		
NoE <i>EuroFGI</i>	7.6	7.6		
NoE <i>EuroNF</i>		23.8	23.8	23.8
EuroNF <i>CAP</i>	8.6			
EuroNF <i>PRECO</i>		8.0		
EuroNF <i>AMESA</i>			10.0	
EuroNF <i>INNIS</i>				2.0
STREP <i>GO4IT</i>	22.6			
CELTIC <i>QuEEN</i>				20.0
UEB Chair				129.0
Associated teams (AT), international projects				
AT <i>MOCQUASIN</i>		18.2	10.0	10.0
AT <i>OCERC</i>		20.0	20.0	
ECOS <i>MWN-P2P-QOE</i>		5.0	5.0	5.0
STIC <i>PED-OWN</i>		8.0	3.0	
STIC <i>USPS</i>				5.0
STIC <i>CLOH</i>	3.0	5.0		
Industrial contracts				
FUI <i>P2Pim@ges</i>	20.0	130.8	130.8	30.0
FUI <i>QoSmobile</i>		105.5	105.5	30.0
FUI <i>ViPEER</i>			60.0	60.0
FUI <i>SVC4QoE</i>		10.0	50.0	42.8
FUI <i>IPChronos</i>				23.0
CELAR (DGA) <i>IA</i>	120.0	120.0	60.0	
Scholarships				
PhD*				38.5
Post Doc*		46.8		46.8
Total	314.4	627.1	525.1	498.4

[†] INRIA Cooperative Research Initiatives

[‡] Large-scale Initiative Actions

* other than those supported by one of the above projects

+ junior engineer supported by INRIA

engineer supported by INRIA

Remark: Some activities (ARC FRACAS, COST action ECON@TEL) has external support under the form of traveling fees, mainly.

ARCs

INRIA's cooperative research action "MENEUR"

MENEUR stands for "Modélisation en Economie des réseaux et NEUtralité du Net" (Network Economics and Net Neutrality Modeling).

Participants from Dionysos: **Bruno Tuffin** (responsible), **Pierre Coucheney** (Post-doc), **Hai Tran Hoang** (PhD student), **Jean-Marc Vigne** (PhD student), Francois Boussion (Intern)

Funding: 17 000 euros

Action coordinated by Dionysos. Leader of MENEUR: **Bruno Tuffin**

INRIA's cooperative research action (ARC) 2011-2012 with INRIA teams MAESTRO, MESCAL, plus Orange Labs, ALU-Bell Labs France, Telecom Bretagne, FTW (Austria), Columbia University and Penn State University

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

INRIA's cooperative research action "FRACAS"

FRACAS stands for "Fiabilité des Réseaux Autonomes de Capteurs et Applications à la Sécurité" (Autonomous Sensor Networks' Reliability and Security Applications).

Participants from Dionysos: **Bruno Sericola** (responsible), **Katy Paroux**

Funding: external budget

INRIA's cooperative research action 2006–2008 with INRIA teams ARES, REGAL and Grand-Large, and the LRI (Paris).

The goal of this project was to study sensor networks from the reliability viewpoint and some aspects of their security properties.

National initiatives

ANR "WINEM"

WINEM stands for "WIMAX Network Engineering and Multihoming".

Participant from Dionysos: **Bruno Tuffin**

Funding: 30 840 euros

This is a 3-year ANR Télécommunications project (2007-2009), in cooperation with Motorola, the GET (INT and ENST Bretagne), MAESTRO project-team at INRIA Sophia-Antipolis, the University of Avignon, the Eurecom institute and France Telecom R&D. The project aimed at working on the open issues of the IEEE 802.16 norm. The role of Dionysos was to make use of game theory modeling and analysis.

ANR "CAPTURES"

CAPTURES stands for "Competition Among Providers for Telecommunication Users: Rivalry and Earning Stakes".

Participants from Dionysos: **Bruno Tuffin** (responsible), **Jean-Marc Vigne**

Funding: 69 936 euros

Global project leaded by Dionysos. Project leader: [Bruno Tuffin](#)

This is a four years ANR VERSO project (2009-2012) in collaboration with France Telecom and TELECOM Bretagne. Our goal in this project is to introduce and analyze pricing models dealing with competition in the context of constantly evolving telecommunication networks and services. We provide models and analysis of direct competition among providers operating on the same or different technologies (being WiFi, WiMAX, 3G, ADSL, etc.) and the dynamics of those models. We also deal with competition at the content level and between network access and content providers. See <http://captures.inria.fr/>.

INRIA- Alcatel Lucent project “SELFNETS”

SELFNETS stands for “SELF OPTIMIZING WIRELESS NETWORKS”.

Participants from Dionysos: [Bruno Tuffin](#) (responsible), [Hai Tran Hoang](#)

Funding: 137 775 euros

SELFNETS is an “action de recherche” in the framework of the joint laboratory INRIA- Alcatel Lucent. Our contribution is a collaboration through a PhD thesis titled “Evolution towards auto-configuration of pricing and resource planning” (2008–2011) whose goal is to produce economic incentives for intermediate autonomous systems to forward the traffic of concurrent providers.

ARED project “SIMERTEL”

SIMERTEL stands for “Simulation d’événements rares en télécommunications” rare event simulation with applications in telecommunications.

Participants from Dionysos: [Bruno Tuffin](#) (responsible), [Gerardo Rubino](#), [Samira Saggadi](#)

Funding: 88 500 euros

SIMERTEL is a Région Bretagne ARED project (2008–2011), to fund the PhD thesis of [Samira Saggadi](#) on the design of efficient Monte Carlo estimator for the analysis of network dependability, based on the approximation of the zero-variance importance sampling estimator.

GDR CNRS action “ROTJER”

Participant from Dionysos: [Bruno Tuffin](#)

Funding: external budget.

ROTJER was a CNRS funded group of discussion on Operations Research and Game Theory for communication networks, in the period 2007–2008.

European projects

Network of Excellence “EuroFGI”

EuroFGI stands for “European Future Generation Internet”.

Participants from Dionysos: [Gerardo Rubino](#) and [Bruno Tuffin](#).

Funding: 30 313 euros

EuroFGI was an European Network of Excellence on the future of networking, going from 2006 to Dec. 2009. Its goal was to create and maintain the most prominent

European centre of excellence in Next Generation Internet design and engineering, leading towards a leadership in this domain.

Bruno Tuffin was the leader for the participation of INRIA teams in this project.

Gerardo Rubino was a member of the project Steering Committee.

The project has contributed to the deliverables of the following working packages (Joint Research Activities):

- WP.JRA.5.4: Network optimization and control
- WP.JRA.5.5: Numerical, simulation and analytic methodologies
- WP.JRA.6.1: Quality of service from the users' perspective and feedback mechanisms for quality control
- WP.JRA.6.2: Payment and cost models

Network of Excellence “Euro-NF”

Euro-NF stands for “European Network of the Future”.

Participants from Dionysos: Gerardo Rubino and Bruno Tuffin

Funding: 83 158 euros

Euro-NF is a Network of Excellence on many aspects of future networks, integrating 35 institutions (from academia and industry), coming from 16 countries. Its main target is to integrate the research effort of the partners to be a source of innovation and a think tank on possible scientific, technological and socio-economic trajectories towards the network of the future. It has started in January 2008 and is ending in June 2012 (see http://euronf.enst.fr/en_accueil.html) and is a follow-up of Euro-FGI.

Bruno Tuffin is the leader for the participation of INRIA teams in this project.

Gerardo Rubino is the leader of the relationships with other academic projects in Europe, and with European industry.

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

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

EuroNF internal project “CAP”

CAP stands for “Competition Among Providers in the access network”.

Participant from Dionysos: Bruno Tuffin

Funding: 8 650 euros

CAP was a Specific Joint Research Project within EuroNF NoE, funded for a period of about one year between 2007 and 2008, in collaboration with GET/ENST Bretagne, the University of Rome 2 and the University of Cantalabria.

The goal of this project was to study the behavior of competitive network access providers.

EuroNF internal project “PRECO”

PRECO stands for “Pricing and Regulation in Competitive Telecommunication Networks”.

Participant from Dionysos: [Bruno Tuffin](#)

Funding: 8 000 euros

PRECO was a Specific Joint Research Project within EuroNF NoE, funded for a period of about one year between Sept. 2008 and Sept. 2009, in collaboration with TELECOM Bretagne and the University of Rome 2.

The project’s goal was to analyze the competition between telecommunication providers, study their retention schemes to prevent customers from churning, and to propose associated regulation procedures.

EuroNF internal project “AMESA”

AMESA stands for “Analysis of MEchanisms for Sponsored search Auctions”.

Participant from Dionysos: [Bruno Tuffin](#)

Funding: 10 000 euros

AMESA was a Specific Joint Research Project within EuroNF NoE, funded for a period of about one year between Oct. 2009 and Dec. 2010, in collaboration with, Athens University of Economics and Business, the CWI, TELECOM Bretagne and the University of Rome 2.

The project’s goal was to study adword auctions mechanisms, mainly thanks to game theory.

EuroNF internal project “INNIS”

INNIS stand for “Impacts of Network Neutrality on the Internet Stakeholders”.

Participants from Dionysos: [Bruno Tuffin](#) (responsible), [Pierre Coucheney](#)

Funding: 7 000 euros

Global project leaded by Dionysos. Project leader: [Bruno Tuffin](#)

INNIS is a Specific Joint Research Project within EuroNF NoE, funded between November 2011 and June 2012 on network neutrality analysis. This is a project in collaboration with TELECOM Bretagne, the polytechnic University of Valencia (Spain), the University of Rome 2, and the Italian Data Protection Authority.

European COST Activity “ECON@TEL”

Participant from Dionysos: [Bruno Tuffin](#).

Funding: external (COST)

Bruno Tuffin is the French national delegate and project coordinator for the EU COST Activity IS0605 called ECON@TEL. The goal of ECON@TEL is to develop a strategic research and training network linking key individuals and organizations in order to enhance Europe’s competence in the field of telecommunications economics, to support related R&D-initiatives, and to provide guidelines and recommendations to European players (end-users, enterprises, operators, regulators, policy makers, content providers) concerning the provision to citizens and

enterprises of new converged broadband and wireless content delivery networks (see <http://www.cost605.org/>).

European STREP project “IST-Go4IT”.

Participants from Dionysos: César Viho (responsible), Anthony Baire.

Funding: 113 082 euros

We were an active member of the IST-Go4IT project co-financed by the European Commission under the 6th Framework Programme of the European Research Area. The project has started in November 2005 and ended in April 2008. The project partners are made of 11 organizations coming from Europe, China and Brazil. The objectives of Go4IT were (i) Promote and foster conformance testing oriented validation approach as well as associated technologies, (ii) Supply a range of executable and freely accessible test services (iii) Set-up the environment required to develop a low cost, open and generic solution.

The Dionysos team was the main contributor in this project. Its contribution led to an open-source platform for an IPv6 test suite development.

European IST project Anemone.

Participants: César Viho (responsible), Anthony Baire, Kandaraj Piamrat, Adlen Ksentini

Funding: 367 338 euros

The Anemone project (Advanced Next generation Mobile Open Network) is an IST-STREP (Specific Targeted Research Project) project started from June 2006 and ended in November 2008. The main objectives of ANEMONE were: (i) To gather and integrate in a single place all the components (i.e. latest standards in wireless access technologies, communication protocols, and applications) necessary to conduct research, development and to study the feasibility of deployment of the IPv6 mobility technologies, (ii) To provide a pan-European IPv6 mobility testbed open to the research and developer communities so that they could test and validate their new applications and services.

The Dionysos team was the leader of the WP3: Testbed integration and Validation. This testbed is still used for experimenting different aspects of MIPv6.

European CELTIC project “QuEEN”.

QuEEN stands for “QQuality of Experience Estimators in Networks”.

Participants from Dionysos: Gerardo Rubino (responsible), Sofiene Jelassi.

Funding: 193 940 euros

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

Dionysos belongs to the 6-member QuEEN’s Board (member: G. Rubino).

UEB chair.

Participants from Dionysos: **Bruno Tuffin** (responsible), **Gerardo Rubino**

Funding: 129 000 euros

This chair was obtained by Peter Reichl from TFW, Vienna, Austria. The funding supported 10 months of Professor Reichl as a visiting scientist in 2011, together with visits of members of his team at FFW and the organization of two scientific events.

Associated teams and other international projects

We had two associated teams in the period, both with Canadian teams. The oldest and still active project is with the group of a world leader in Monte Carlo techniques, Pierre L’Ecuyer, from the University of Montréal. The other one was with a world leader on sensor network research, Raouf Boutaba, from the University of Waterloo.

Associated team “MOCQUASIN”.

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

Partners: INRIA and the University of Montréal, Canada.

Participants: prof. Pierre L’Ecuyer, U. of Montréal, Canadian leader, **Bruno Tuffin**, INRIA leader, plus Fabian Bastin, Zravko Botev and David Munger, from U. of Montréal, together with **Samira Saggadi** and **Gerardo Rubino**, from Dionysos.

Funding: 38 200 euros

The goal of this team is to develop efficient Monte Carlo methods to compute integrals, sums or to solve equations or optimization problems. The team works on acceleration techniques, meaning reaching faster the targeted precision. The typical framework is that of rare event simulation for which getting even only one occurrence of the event could require a very long time. A combination with the faster randomized quasi-Monte Carlo methods is also a challenge we address in the group.

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

Associated team “OCERC”.

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

Partners: INRIA and the University of Waterloo, Canada.

Participants: prof. Professor Raouf Boutaba, U. of Waterloo, Canadian leader, **Nizar Bouabdallah**, INRIA leader, plus **Adlen Ksentini** and **Bruno Sericola**, from Dionysos.

Funding: 40 000 euros

This collaboration aims at proposing new solutions to reduce the energy consumption in wireless sensor networks. The associated team OCERC, created in 2009, was stopped at the end of the evaluation period, 2011, because of the departure of the leader at the INRIA side, Nizar Bouabdallah, on leave for 3 years (2012 – 2014).

ECOS project “MWN-P2P-QOE”.

MWN-P2P-QOE stands for “Mesh Wireless Networks and P2P multimedia applications: tools for guaranteeing Quality Of Experience”.

Partners: INRIA and the University of the Republic, Uruguay.

Participants: prof. Héctor Cancela, U. of the Republic, Uruguayan leader, **Gerardo Rubino**, INRIA leader, plus several members from the Uruguayan university, together with **Adlen Ksentini** from Dionysos.

Funding: 15 000 euros

This is a 3-year project (2009 – 2011) between France and Uruguay. The project concerns the study of tools allowing to reach good levels in the Quality of Experience in P2P networks for multimedia purposes, when the transport infrastructure is a mesh wireless network.

STIC AmSud project “PED-OWN”.

PED-OWN stands for “Performance Evaluation and Design of Optical and Wireless Networks”.

Participants: **Gerardo Rubino** (leader of the whole project), **Nizar Bouabdallah**, **Sebastián Basterrech**, **Laura Aspirot**

Funding: 11 000 euros

This is a 2-year project (2009–2010) between Chile, France and Uruguay. The goal is the development of models and analysis tools for the study of performance aspects in networks, mainly for optical and for wireless structures. The partners are: U. Técnica “Federico Santa María” and U. Adolfo Ibáñez in Chile, U. de la República en Uruguay, U. Joseph Fourier, U. de Pau et des Pays de l’Adour and INRIA in France. This project had also the goal of contributing to prepare the future cooperation between INRIA and Chilean universities through the common CIRIC center (starting in 2012).

STIC Algeria project “USPS”.

Project’s title: “Use of the Senslab platform for the project Sensirrig”

Participants: **Adlen Ksentini** for Dionysos and Abdelouahid Derhab from the CERIST (Centre de Recherche sur l’information Scientifique et Technique) at Alger, Algeria. The ASAP and CIDER teams at INRIA Rennes also participate.

Funding: 5 000 euros in 2011.

This collaboration (2011–2013) aims at defining new protocols for data collecting in Wireless Sensor Networks, and evaluate them with the Senslab platform. After validating the proposed protocols, CERIST intends to deploy them in the context of the project (Algerian) “Sensirrig”, which aims at using sensors for agricultural irrigation.

STIC Tunisia project “CLOH”.

Title: “Cross layer optimization of Handover procedures and radio resource management on WIMAX mobile networks (norm IEEE 802.16e/m)”

Participants for Dionysos: **Nizar Bouabdallah** (responsible), **Fatma Bouabdallah**

Funding: 8 000 euros

The goal of this collaboration (2007–2008) between INRIA and Sup’Com (École supérieure des communications, Tunis) was to study QoS aspects in WiMAX mobile networks. Specifically, we proposed a cross-layer solution that enables efficient management of the handoff operations and allows at the same time an efficient resource allocation.

Industrial contracts

FUI project “P2Pim@ges”.

Participants from Dionysos: **Gerardo Rubino** (responsible), **Adlen Ksentini** and **Kamal Singh**.

Dionysis was in the Board of the project. Member: **Gerardo Rubino**

Funding: 311 609 euros

This was a large 2-year project (end 2008 – end 2010). The project was leaded by Thomson, with the participation of Orange, TMG, Devoteam, IPdiva, and the academics Telecom Bretagne, M@rsouin, University of Rennes 1, and 3 teams of INRIA, including Dionysos. We were the coordinators for INRIA’s participation. G. Rubino was also member of the Board of P2Pim@ges.

The project’s goal was to analyze the technical characteristics pf P2P distribution of audiovisual content, both in controlled and uncontrolled (open Internet) environments. Our contribution mainly focused on evaluating the perceptual quality of P2P applications, using our PSQA technology. We also developed performance evaluation analysis of P2P solutions, in the context of a managed network (for instance, the network of a telecommunications operator).

One of the prototypes developed in the project for the demonstrations part of the obtained results got the special prize of the NEM Summit 2009 Best Exhibition Award. It was developed by Devoteam, Telecom Bretagne and our team. In the prototype, our PSQA technology (see 6.10) was used to evaluate the perceived quality distributed by a P2P network and to provide feedback for controlling purposes. The demonstration allows to see the network adapting its structure as a function of the QoE delivered, in order to optimize that QoE, thanks to our PSQA module.

FUI project “QOSMOBILE”.

Participants from Dionysos: **Gerardo Rubino** (responsible), and **Kamal Singh**.

Funding: 263 764 euros

This was a 30-months project (October 2007 – March 2010), whose domain was the supervision (monitoring and control) of TV distribution systems over mobile terminals. Our contribution focused on evaluating the perceptual quality of such an infrastructure using our PSQA technology. QoSmobile was headed by ENENSYS, and the partners were Expway, Alcatel-Lucent, Siradel and our team.

ANR project “VIPEER”.

The extended title of VIPEER is “Video Traffic Engineering in an Intra-Domain Context using Peer-to-Peer Paradigms”.

Participants from Dionysos: **Yassine Hadjadj-Aoul** (responsible), **Gerardo Rubino** and **Kamal Singh**.

Funding: 143 712 euros

This is a 3-year ANR project (end 2009-end 2012). It proposes to develop a distributed Content Delivery Network (dCDN) that combines classic CDN technologies with P2P concepts. Dionysos will mainly cover the QoE assessments in the project. Our partners are Télécom Bretagne (project leader), Eurecom, Envivio, Orange Labs and NDS Technologies.

FUI project “SVC4QOE”.

The extended title of SVC4QOE is “Scalable Video Coding for Quality Of Experience”.

Participants from Dionysos: **Adlen Ksentini** (responsible) and **Baptiste Marienval**.

Funding: 102 792 euros

This is a 2-year (October 2009 – December 2011) FUI Project. The main focus is the SVC video coding standard and its impacts on QoE, in the context of DVB-T2 video broadcast. Our contribution focuses on evaluating through simulations and analytical models the performance of SVC video transmissions over a DVB-T2 broadcast network. SVC4QoE is headed by TEAMCAST, and the partners are Thomson Grass Valley, TDF, Neotilus, IRCCYN, AccepTV, Telecom Bretagne, and Dionysos for INRIA.

FUI project “IPChronos”.

Participants from Dionysos: **Yassine Hadjadj-Aoul** (responsible), **Adlen Ksentini** and **Bruno Sericola**.

Funding: 137 800 euros

This is a 2-year French FUI project (September 2011 – September 2013), whose main focus is in the analysis of the use of the IEEE 1588 synchronization protocol over IP. Our contribution focuses on developing analytical models to estimate, basing on the IEEE 1588 protocol, the end-to-end delay. IPChronos is headed by ORALIA SPECTRACOM, and the other partners are IPlabel and our team.

CELAR contract IA (interoperability assessment).

Participants: **César Viho** (responsible), **Anthony Baire**, **Nanxing Chen**.

In the context of our work on interoperability assessment, we continued the cooperation with the CELAR (Centre d’Électronique de l’Armement), a research laboratory of the French Army. Our work was to provide a new framework for interoperability testing, with applications to routing protocols such as OSPFv3 and MTR (Multi-Topology Routing). IA was a 30-months project, Oct 2005 – April 2008.

CIFRE scholarships.

These are PhD thesis funding coming from industry. The funding covers the thesis and 10 000 euros per year for the team’s budget.

- CIFRE with Orange Labs for the PhD of **Hélène Le Cadre** (2007–2010). Topic: pricing and revenue and resource management for an integrated telecommunication provider in the context of competition and convergence of services. Advisor: **Bruno Tuffin**
- CIFRE with Viotech for the PhD of **Wael Cherif** (started in 2009) . Topic: QoE-aware network adaptation. Advisors: **Adlen Ksentini** and **Gerardo Rubino**
- CIFRE with Orange Labs for the PhD of **Charlotte Roger** (2008–2011). Topic: data aggregation in passive optical networks (resource management and sharing). Advisors: **Nizar Bouabdallah** and **Gerardo Rubino**
- CIFRE with Orange Labs for the PhD of **Damien Le Quéré** (started in Jan 2012). Advisors: **Adlen Ksentini** and **Bruno Sericola**.

Direct PhD scholarship from Technicolor

This is a project with Technicolor, on the PhD work of **Romaric Ludinard** (started in 2011). Technicolor provides the thesis funding. The work is shared with team CIDRE (Emanuel Anceaume, CNRS researcher). From Dionysos, the participant is **Bruno Sericola**.

Other funding,

- The PhD of **Laura Aspirot** and the starting PhD of **Pablo Sartor** benefit from external funding for traveling to France and for their sojourns here, and for participating to conferences (French Ministry of Foreign Affairs and the corresponding Uruguayan universities)

5 Objectives for the next four years

5.1 From perceptual quality to Quality of Experience

In many areas of the networking field, the trend today is to focus on the human user (as we can see at the application level with the social network paradigm, with the so-called Web 2.0, etc.). The qualification of *user-centric* appears nowadays in a increasing number of fields. We pretend that this must also happen when we consider dimensioning tasks, or even control schemes. Instead of optimizing the network design using classical QoS metrics such as loss rates, jitter, mean delays, etc., our thesis is that we can do it by working with the ultimate target, quality (of the application, of the service,...) as perceived by the end (human) user. For instance, with the increasing number of new wireless networks, it will become more and more possible for a user to have several access networks. What is the best one to choose is a question that we think can be answered using our techniques. Observe that admission control and network selection have been studied separately. What happen when they are combined in a context of wireless heterogeneous networks? Basing the approach on the quality delivered to the end user, we believe that this analysis can be led successfully. We have already shown that our technology PSQA is able to allow this paradigm, and one of our goals in the next period is to explore this in deep. This objective was prepared by the numerous extensions and then, validations, of our approach in various contexts (networks based on DVB-H, on DVB-T2, on SVC, using HTTP, etc.). We also did some steps on control applications, represented by the three PhD [14, 11, 9] and the associated papers.

A second goal is to succeed in putting PSQA as a monitoring tool in the industrial world. For this purpose, we have three subgoals. (i) Firstly, we will try to increase the robustness of PSQA (not the accuracy) by moving from our initial black box approach into a “grey” one in which the parametric models used to learn how the users react face to the flow, from the quality point of view, will include now some previous knowledge of the perceived quality assessment field. This can be considered today because we cumulated several years of experience in measuring quality in different contexts. Related to these improvements, we also have now ideas of how to improve the efficiency of the learning processes associated with our methodology. (ii) Secondly, we will continue the exploration of the extension of PSQA to new communication conditions, for instance, to the case of applications using other kinds of video scalable coding, such as MDC (Multiple Description Coding), to 3D video applications, etc. Related to this effort, we will evaluate the impact on quality of the fact that a flow travels through different networks based on very different technologies (fixed, wireless, low and high speed ones, etc.) in the same application; the

same can be considered when looking at the characteristics of different terminals, and the way these differences impact on the perceived quality (some preliminary work was done in the QoSmobile project, has already described). (iii) Thirdly, we have the idea of exploring a new approach in which we avoid (at least partially) to use panels of human observers (that is, subjective testing), in building our measuring modules. The idea is to replace them by signal-based procedures, that are in many cases (while not in all of them) quite accurate, but of course very expensive and unable to work in real time (and for some of them, needing the original flow, before going through the network, called the *reference*). This comes from some initial ideas given in our paper [172].

For this goal of industrial transfer, we have started the process by means of our relations with the starting French Perceptiva Labs company, www.perceptiva-labs.com/.

A special effort will be done towards the quality of voice-based applications, building on three ideas we intend to explore: (i) the first one consists of taking into account the interruptions in the voice flow that typically happen, for instance, when the transmission infrastructure is of the wireless type; (ii) we want to explore the possibility of shunting the use of panel of humans during the statistical learning phase, replacing them by signal-based procedures (this is part of the foundations of the starting collaboration with the Perceptiva Labs company, in order to transfer PSQA to industry; (iii) we want to explore the use of the semantics of the sequence to assess its quality, that is, to integrate the fact that the perception of the user is also related to how much she understands the transmitted message⁹.

The last topic we want to explore is to extend the idea of the assessment of perceptual quality to other services than the transmission of video, audio or voice flows. We want to explore the possibility of automatically measuring the so-called Quality of Experience related to other services, and a first step in this direction is a new project proposal in the Celtic project QuEEN. The idea is to explore the capability of an automatic device in providing an estimation of the quality of a Web service, for instance, as seen by the user. The QuEEN project will explore the ability of a parametric approach such as ours, to handle such a more complex situation. QuEEN has a second goal: to be able to build a network of cooperative agents measuring QoE and exchanging information between them, in particular for improving their initial measuring capabilities.

5.2 Simulation

The development and application of simulation techniques have a potential for improvement that cannot be neglected. The goal is each time to get the fastest possible estimator to reach a targeted accuracy. This is important for users needing an answer in a reasonable or very short time. We can decompose our future work in several tasks. We can notice a transverse line of research on the notion of robustness of estimators and of the returned confidence interval in terms of parameters for a fixed sample size. The considered parameters can be related to the rarity for rare event simulation, the size of the problem, or the number of points of the low discrepancy sequence for randomized quasi-Monte Carlo methods.

The first main topic is rare event simulation. In this context, speeding up the simulation is a primordial issue because so-called standard estimators, which simulate the system following the real process, are totally inefficient. Many works have been devoted to this topic but there exist many new frameworks for which no robust estimator exist (like up to very soon for the heavy-tail queues that have attracted interest in telecommunications).

⁹This looks more futuristic, but some preliminary evaluations seem to indicate that it is possible to make the idea work, at least in some cases.

We would to develop our work around the approximation of the zero-variance estimator, not only via importance sampling, but also via control variates and other variance reduction techniques such as splitting. Heuristic rules need to be imagined, and dynamic learning algorithms can be applied to go closer to the zero variance. Another main challenge is to take into account the dependencies between events: the known efficient methods are almost always for models assuming independence, but dependence is a characteristic of recently observed catastrophic events (economic crisis, nuclear catastrophe in Fukushima, etc.). The goal will be here to model dependence in specific situations, and to develop adequate simulation analysis methods. Last, related to the evolution of communication infra-structures, there is a need for capturing new aspects of the dependability properties of the systems through appropriate metrics and, then, to develop the corresponding evaluation techniques. We are starting research activities in this direction through the PhD of **Pablo Sartor**, specifically on the so-called “diameter constrained” reliability measure.

Randomized quasi-Monte Carlo (RQMC) methods have known for the past ten years a significant development because of their efficiency and remarkable simplicity of use. We have already applied those methods to the simulation of networks of queues, but we want to develop and popularize their use in telecommunications mainly (via the computation of mathematical expectations), because their potential is not known enough according to us, and therefore far from being fully exploited (the main applications up to now being in finance, for the computation of options). In the case of static models, the RQMC methods we have designed should be efficient even when the mathematical dimension is quite large (a challenge will be to reduce the *effective dimension*). In the dynamic case, we will more specifically consider the RQMC method we have developed for Markov chains. It is very efficient if the states can be (smartly) totally ordered and represented in a unidimensional way. The efficiency of the method depends a lot on the selected ordering and it would be helpful to design an automatic procedure for building it. This difficulty is particularly notable for applications where the state space is expressed in a large dimension, and therefore the method difficult to adapt.

5.3 Network economics

Because the Internet and telecommunications in general have been open to (economic) competition, it is needed to study the relations between the different actors. Those actors are i) the users who choose their provider, their applications and the technologies to reach content, all this in terms of the price and the available QoS ii) the network service providers (or Internet Service providers (ISPs)) who try to maximize their revenue by determining the best contracts to propose to customers and to other providers when necessary iii) the content providers who often obtain their revenue from advertisement iv) the search engines to reach the relevant content. The goal is to study the best strategies of these actors and to understand and propose how their relations can evolve.

First, modeling users requires to represent their reactions to price and QoS. In all pricing propositions of the literature, as usually in economy, the human behavior is represented by functions called utility functions. It has to be noticed that those functions are often chosen (somewhat arbitrarily) for their mathematical properties and/or for their a priori validity in some areas, but a limited effort has been devoted to the determination and validation of the utility functions. Some projects have been funded throughout the world to better understand users’ behavior in term of pricing; we can mention the INDEX project at Berkeley, the project M3I... One of our goals will be to determine the demand distribution for given QoS parameters and prices. The skills of the team on quantitative quality assessment will be particularly helpful here.

At the ISP level, competition has been barely considered in the literature and we have started a leading line of research on the topic. Indeed, the choice of a pricing method has to be decided taking into account the choice of other providers, which introduces a new game level in addition to the providers association game for users. The pricing strategies of each provider have to be determined, in terms of the cost and service capacity constraints but also in terms of competitors' choices which influence the customers reactions. These problems have to deal with the heterogeneity of users, of applications, and of technologies (UMTS, WiFi, WiMAX or LTE, wired...) which can be chosen with their various QoS, but also combined (multihoming). Several problems have to be studied, considering the numerous competitive contexts in telecommunications: how demand distributes itself among providers in terms of the price and the QoS? Is there one or several equilibria and what is the *price of anarchy* (the loss of efficiency due to non-cooperation)? How to plan resources? Is it interesting or necessary to introduce regulation mechanisms? The context of the relationships between operators are in permanent evolution and require a deep analysis. A typical example is about the relations between the "real" mobile network operators (MNOs) and the virtual ones (MVNOs), this last category owning no license and leasing their access to the MNOs: what economic model to impose to make the system viable? This is something we have just started to investigate. The economics of communities such as FoN is also of interest for us.

While what we have just described deals with direct competition between operators, but it is necessary to study the inter domain relationships. The network entities are indeed often independent if not concurrent (the Internet for example is made of thousands of such nodes) which can refuse to collaborate for different reasons, the main one being that forwarding the traffic of other entities induces a cost in terms of resources which does not bring directly any personal advantage. Introducing a pricing model between nodes could incentivize the nodes to cooperate to the network by rewarding the nodes accepting to transmit the packets of their neighbors; or a somewhat equivalent reputation-based mechanism which would restrict the transmission of non-cooperative nodes. Numerous pricing schemes have been published, but we have proved that none can satisfy altogether a combination of expected properties: efficiency, incentive compatibility, individual rationality and financial balance. For examples the second price auctions, usually considered as a key mechanism in the literature, do not satisfy the financial balance property and require an entity a government for instance) to permanently inject money into the system; this can hardly be envisioned. We propose to analyze the various relaxations and approximations of properties to determine the most appropriate mechanism.

The third family of actors is made of content providers. Those providers use the network to reach their customers (or users), and generate their revenue thanks to advertisement in most cases. This advertising is displayed through banners and links to the relevant companies or brands, depending on the content and on the user. For classic web pages, such as news web sites, the advertisers pay each time the banner is displayed. Search engines such as Google, Bing or Yahoo!, which constitute a fourth set of actors needed to reach content, make money by having similarly specific slots allocated to advertisers when a search is performed; those advertisers bid for the keywords they are interested in and pay each time their link is clicked through. The bidding strategies of advertisers and the allocation and pricing rules need to be better studied and improved, the competitive context being relevant here. The pricing of peer-to-peer networks and clouds is also an application area that will deserve our attention.

This global vision of network economics and important players leads us to a topical subject: the relations between ISPs and content providers and the network neutrality debate. We wish to study the relevance of the arguments developed by both sides (impact

on investments in the network for ISPs, and impact on innovation and freedom of speech for content providers and users associations) and to propose a trade-off which could satisfy them. Search neutrality is a similar issue to study. Some ISPs push also, in order to bypass the neutrality problem, to change the current and established flat-rate pricing by a usage-based one, supported by governments such as Canada. Our previous works on network pricing will become even more relevant here.

The relations between the different kinds of players therefore need to be combined to take into account their impact on the users demand. Many questions pop up concerning network economics and we aim to investigating those issues.

Finally, we would like to stress that we plan to start to write a book titled *Network Economics: from economic theory to practical telecommunications issues* which should be published by *Cambridge University Press*.

5.4 Stochastic theory of large-scale distributed systems

This work will be done in collaboration with the ADEPT project-team (a part of it being now an Irisa team called Cider).

Large-scale distributed systems such as peer to peer networks or wireless sensor networks have generally a huge number of nodes and a complex structure. In [130] and [170], we presented a very detailed analysis of the behavior of clusters in a structured overlay network using Markov chains. This analysis took into account not only the induced churn in the clusters but also adversarial strategies performed by malicious nodes. The analysis of the whole network has been done under the hypothesis that all the clusters behave independently. In [27], we have considered dependent clusters, i.e. Markov chains, competing at each instant for a transition and we obtained new asymptotic results when the number of clusters, i.e. of nodes, grows to infinity.

These works suggest that there should be a general stochastic framework based on local behaviors and which may model accurately a wide class of structured cluster-based distributed and dynamic systems. The collaboration between specialists in both areas of distributed systems and stochastic modeling is essential. This is exactly an example of the desired objectives by the group MAPI (Applied Mathematics for Computer Science, http://www.irisa.fr/dionysos/pages_perso/sericola/MAPI.html) headed by Bruno Sericola.

5.5 Shaping the evolution of the future Internet

The Internet is recognized today to be present in everyday life and in all domains like education, health, defense, commerce, travel and entertainment. Meanwhile, it is generally agreed that Internet was not designed for such a high level of usage, and there is a need for new and simpler but more powerful constructs to allow the network to behave better in terms of quality of service, mobility, energy consumption, utilization and interoperation of new technologies. Internet is considered nowadays as subject of ossification and has reached a critical point. Now, major structural and functional changes are necessary; new architectural approaches are studied today, evolutionary and/or revolutionary for both networking aspects and high level services. Solutions are needed for Future Internet (FI), versus the existing best-effort Internet IP architecture (related to QoS, network control, security, reliability, etc.) in order to enable for ubiquitous, integrated and flexible access to variety of existing and new services.

Internet of Things (IoT) The Internet of Things (IoT) is shaping the evolution of the future Internet. After connecting people anytime and everywhere, the next step is to

interconnect heterogeneous things / machines / smart objects both between themselves and with the Internet. By this way, the IoT concept has grown into a multiple dimensions encompassing wireless/sensors networks able to provide a service oriented collaboration of distributed smart objects via local networks or worldwide interconnections such as the Internet. Even though significant technological advances have been observed, several challenges need to be tackled.

- **Resource management.** As the number of connected objects will increase in order of magnitude, solutions provided in the previous evaluation period for resource management will need to be adapted. In this regard we just begin working on issues related to the deployment of Machine to Machine (M2M) communication over cellular based networks (LTE). Indeed, one of the issue related to this topic is the problem of congestion introduced by the high number of sensor devices connected to the network. Preliminary work was done in [96], where we proposed new solution for handling congestion when high number of M2M devices detect an event and tried to attach to the cellular network to send their reports to a remote server. Clearly, this work shows that new analytical models and efficient resource management procedures are needed to help Mobile Network Operator to dimension and control their network resources in order to support the high number of interconnected sensors and actuators.
- **Interoperability.** As it is observed for the IoT, future networks will continue to be heterogeneous, multi-vendors, multi-services and largely distributed. Consequently, the risk of non-interoperability will increase. It is important to guarantee that network components will interoperate. One main way among others is to provide new efficient and accurate interoperability testing methodology that helps in testing thoroughly the underlying protocols used by connected objects.
- **Testbeds and experimentations.** The expected heterogeneity of objects/devices in the future IoT and the underlying solutions require that experimental testbeds reflect this heterogeneity in terms of hardware and embedded applications as well as the nature of experiments that can be supported. In this context, we intend to extend our Senslab (sensor) platform through interconnection/federation with other testbeds/platforms. This will provide a solid basis for experimentations with solutions to overcome research issues and challenges brought by this multidisciplinary/multi-technology domain.

Information centric video delivery The forecast dramatic growth of both the number of connected devices and the volume of video traffic calls for shifting some of the mechanisms used to distribute video in the Internet. The recent development of Information Centric Networking (ICN), which clearly advocates for a cooperative action of the network elements, is clearly a promising approach. In this context, we argues that clean slate approaches applying Information Centric Networking (ICN) to distribute video contents overlook the complex video distribution value chain and its associated business models. These business models align with the traditional notion of inter and intra domain networking, where each domain manages its own resources and peering conditions obey business related rationales. Building on the business models evolution, we are working on proposing an evolutionary and pragmatic method to efficiently deploy an ICN architecture based on the collaboration between service providers or traditional CDNs and peer-assisted CDNs operated by ISPs.

Additionally to the architectural aspects, we are planning to work on ISP-assisted and distributed caching techniques, which is an essential element of ICNs. Modeling such distributed system is also essential to derive algorithms, which can adapt to variable network conditions.

We also want to explore extensions considering the support of the Dynamic Adaptive HTTP Streaming (DASH) in next generation delivery systems. QoE will certainly be considered as a metric to select the optimal peers to consider, the optimal quality to download, etc.

Content Centric Networks Content Centric Networks (CCN) (also content-based networking, data-oriented networking or named data networking) is an alternative approach to the current internet architecture, or a new paradigm for the future Internet. CCN is based on the principle that communication network should allow users to focus on the data, rather than having to reference a specific, physical location where that data is to be retrieved from. CCN is motivated by the fact that the vast majority of current Internet usage (a ‘high’90% level of traffic”) consists of data being disseminated from a source to several users. We are interested in such an architecture, where we plan to investigate different open issues structured as follows:

- Traffic control must be completely rethought: TCP is no longer applicable and queue management will require new, name-based criteria to ensure fairness and to realize service differentiation.
- Naming, routing and forwarding are partially addressed in the PARC¹⁰ proposal. However, choices are often expedients to facilitate overlay implementation. It is necessary to prove the name-based routing and forwarding is scalable and to design algorithms suitable for full-scale implementation.
- CCN trades off expensive bandwidth for cheap memory as content chunks can be cached within the network, avoiding the need to repeatedly fetch copies of popular items. It largely remains to define replication and caching strategies and to evaluate their performance.
- Since most of the proof of concept (PoC) are dedicated to best effort traffic, there is a need to study how CCN can support real-time traffic such as HTTP video streaming. Indeed, this point is a recent collaboration with Technicolor R&D where a master student was hired to work in this topic, and a CIFRE grant is planified for September 2012.

LOCARN Another direction we want to explore for the Post-IP evolution is in the context of our new collaboration with Orange Labs (Cifre grant). In fact, this collaboration concerns the evaluation and development of a new plug-and-play routing protocol (called Low Opex and Capex Architecture for Resilient Networks - LOCARN), which do not require any network management and configuration. It follows the same principle of Ethernet, where user simply plugs it computer to the network and it gets connection. LOCARN is a source routing protocol, where the entire route is encoded in the packet header. Thus, no need for a routing table at the intermediate routers. LOCARN works on the top of layer 2 and it is independent from the IP layer. LOCARN could be deployed in emerging country, where the cost of management and configuration are high. LOCARN

¹⁰See <http://www.parc.com/work/focus-area/networking/>

is in beginning of its definition, so there is a needs for analytical and simulation models to validate this protocol and to derive enhancement for the future versions.

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