IN PARTNERSHIP WITH:
Université Rennes 1

Activity Report 2016

Project-Team DIONYSOS

Dependability Interoperability and perfOrmance aNalYsiS Of networkS

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

RESEARCH CENTER
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THEME
Networks and Telecommunications

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2. Overall Objectives

2.1. Overall objectives

The main objectives of the project are the identification, the conception and the selection of the most appropriate network architectures for a communication service, as well as the development of computing and mathematical tools for the fulfillment of these tasks. These objectives lead to two types of complementary research fields: the systems' qualitative aspects (e.g. protocol testing and design) and the quantitative aspects which are essential to the correct dimensioning of these architectures and the associated services (performance, dependability, Quality of Service (QoS), Quality of Experience (QoE) and performability); our activities lie essentially in the latter.

The Dionysos group works on different problems related to the design and the analysis of communication services. Such services require functionality specifications, decisions about where and how they must be deployed in a system, and the dimensioning of their different components. The interests of the project concern not only particular classes of systems but also methodological aspects.

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

For most of previous mentioned problems, our work concern their quantitative aspects. The quantitative aspects we are interested in are QoE, performance, dependability, performability, QoS, vulnerability, etc. We develop techniques for the evaluation of these different aspects of the considered systems through *models* and through *measurement techniques*. In particular, we develop techniques to measure in an automatic way the quality of a video or audio communication *as perceived by the final user*. The methods we work with range from discrete event simulation and Monte Carlo procedures to analytical techniques, and include numerical algorithms as well. Our main mathematical tools are stochastic processes in general and queuing models and Markov chains in particular, optimization techniques, graph theory, combinatorics, etc.

3. Research Program

3.1. Introduction

The scientific foundations of our work are those of network design and network analysis. Specifically, this concerns the principles of packet switching and in particular of IP networks (protocol design, protocol testing, routing, scheduling techniques), and the mathematical and algorithmic aspects of the associated problems, on which our methods and tools are based.

These foundations are described in the following paragraphs. We begin by a subsection dedicated to Quality of Service (QoS) and Quality of Experience (QoE), since they can be seen as unifying concepts in our activities. Then we briefly describe the specific sub-area of model evaluation and about the particular multidisciplinary domain of network economics.

3.2. Quality of Service and Quality of Experience

Since it is difficult to develop as many communication solutions as possible applications, the scientific and technological communities aim towards providing general *services* allowing to give to each application or user a set of properties nowadays called “Quality of Service” (QoS), a terminology lacking a precise definition. This QoS concept takes different forms according to the type of communication service and the aspects which matter for a given application: for performance it comes through specific metrics (delays, jitter, throughput, etc.), for dependability it also comes through appropriate metrics: reliability, availability, or vulnerability, in the case for instance of WAN (Wide Area Network) topologies, etc.

QoS is at the heart of our research activities: We look for methods to obtain specific “levels” of QoS and for techniques to evaluate the associated metrics. Our ultimate goal is to provide tools (mathematical tools and/or algorithms, under appropriate software “containers” or not) allowing users and/or applications to attain specific levels of QoS, or to improve the provided QoS, if we think of a particular system, with an optimal use of the resources available. Obtaining a good QoS level is a very general objective. It leads to many different areas, depending on the systems, applications and specific goals being considered. Our team works on several of these areas. We also investigate the impact of network QoS on multimedia payloads to reduce the impact of congestion.

Some important aspects of the behavior of modern communication systems have subjective components: the quality of a video stream or an audio signal, *as perceived by the user*, is related to some of the previous mentioned parameters (packet loss, delays, ...) but in an extremely complex way. We are interested in analyzing these types of flows from this user-oriented point of view. We focus on the *user perceived quality*, in short, PQ, the main component of what is nowadays called Quality of Experience (in short, QoE), to underline the fact that, in this case, we want to center the analysis on the user. In this context, we have a global project called PSQA, which stands for Pseudo-Subjective Quality Assessment, and which refers to a technology we have developed allowing to automatically measure this PQ.

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

3.3. Stochastic modeling

The scientific foundations of our modeling activities are composed of stochastic processes theory and, in particular, Markov processes, queuing theory, stochastic graphs theory, etc. The objectives are either to develop numerical solutions, or analytical ones, or possibly discrete event simulation or Monte Carlo (and Quasi-Monte Carlo) techniques. We are always interested in model evaluation techniques for dependability and performability analysis, both in static (network reliability) and dynamic contexts (depending on the fact that time plays an explicit role in the analysis or not). We look at systems from the classical so-called *call level*, leading to standard models (for instance, queues or networks of queues) and also at the *burst level*, leading to *fluid models*.

In recent years, our work on the design of the topologies of WANs led us to explore optimization techniques, in particular in the case of very large optimization problems, usually formulated in terms of graphs. The associated methods we are interested in are composed of simulated annealing, genetic algorithms, TABU search, etc. For the time being, we have obtained our best results with GRASP techniques.

Network pricing is a good example of a multi-disciplinary research activity half-way between applied mathematics, economy and networking, centered on stochastic modeling issues. Indeed, the Internet is facing a tremendous increase of its traffic volume. As a consequence, real users complain that large data transfers take too long, without any possibility to improve this by themselves (by paying more, for instance). A possible solution to cope with congestion is to increase the link capacities; however, many authors consider that this is not a viable solution as the network must respond to an increasing demand (and experience has shown that demand of bandwidth has always been ahead of supply), especially now that the Internet is becoming a commercial network. Furthermore, incentives for a fair utilization between customers are not included in the current Internet. For these reasons, it has been suggested that the current flat-rate fees, where customers pay a subscription and obtain an unlimited usage, should be replaced by usage-based fees. Besides, the future Internet will carry heterogeneous flows such as video, voice, email, web, file transfers and remote login among others. Each of these applications requires a different level of QoS: for example, video needs very small delays and packet losses, voice requires small delays but can afford some packet losses, email can afford delay (within a given bound) while file transfer needs a good average throughput and remote login requires small round-trip times. Some pricing incentives should exist so that each user does not always choose the best QoS for her application and so that the final result is a fair utilization of the bandwidth. On the other hand, we need to be aware of the trade-off between engineering efficiency and economic efficiency; for example, traffic measurements can help in improving the management of the network but is a costly option. These are some of the various aspects often present in the pricing problems we address in our work. More recently, we have

switched to the more general field of network economics, dealing with the economic behavior of users, service providers and content providers, as well as their relations.

4. Application Domains

4.1. Networking

Our global research effort concerns networking problems, both from the analysis point of view, and around network design issues. Specifically, this means the IP technology in general, with focus on specific types of networks seen at different levels: wireless systems, optical infrastructures, peer-to-peer architectures, Software Defined Networks, Content Delivery Networks, Content-Centric Networks, clouds.

A specific aspect of network applications and/or services based on video or voice content, is our PSQA technology, able to measure the Perceptual Quality automatically and in real time. PSQA provides a MOS value as close as it makes sense to the value obtained from subjective testing sessions. The technology has been tested in many environments, including one way communications as, for instance, in video streaming, and bi-directional communications as in IP telephony, UDP- or TCP-based systems, etc. It has already served in many collaborative projects as the measuring tool used.

4.2. Stochastic modeling

Many of the techniques developed at Dionysos are related to the analysis of complex systems in general, not only in telecommunications. For instance, our Monte Carlo methods for analyzing rare events have been used by different industrial partners, some of them in networking but recently also by companies building transportation systems. We develop methods in different areas: numerical analysis of stochastic models, bound computations in the same area, Discrete Event Simulation, or, as just mentioned, rare event analysis.

5. Highlights of the Year

5.1. Highlights of the Year

Pierre L'Ecuyer received the 2016 ACM SIGSIM Distinguished Contributions Award.

BEST PAPERS AWARDS:

[75]
Y. MOCQUARD, B. SERICOLA, S. ROBERT, E. ANCEAUME. *Analysis of the Propagation Time of a Rumour in Large-scale Distributed Systems*, in "Symposium on Network Computing and Applications", Boston, United States, October 2016, This article has received the Best Student Paper Award, https://hal.archives-ouvertes.fr/hal-01354815

[49]
M. BOUZOUITA, Y. HADJADJ-AOUL, N. ZANGAR, G. RUBINO, S. TABBANE. *Dynamic adaptive access barring scheme for heavily congested M2M networks*, in "International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWIM 2016)", Malta, Malta, ACM (editor), ACM, November 2016, https://hal.inria.fr/hal-01421614

6. New Software and Platforms

6.1. The Passive Test Tool (ttproto) and CoAP Testing Tool

`ttproto` is an experimental tool for implementing testing tools, for conformance and interoperability testing. It was first implemented to explore interesting features and concepts for the TTCN-3 standard. It was also used to implement a passive interoperability test suite we provided for the CoAP (Constrained Application Protocol) interoperability event held in Paris in March 2012. It is currently used for the purpose of developing testing tools (for interoperability and conformance testing) for the F-interop european project (see http://www.f-interop.eu/). This tool is implemented in `python3` and its design was influenced mainly by TTCN-3 (abstract model, templates, snapshots, behavior trees, communication ports, logging) and by Scapy (syntax, flexibility, customizability) Its purpose is to facilitate rapid prototyping and experimentation (rather than production use). We chose to maximize its modularity and readability rather than performances and real-time considerations.

- Participants: César Viho, Federico Sismondi
- Contact: César Viho, Federico Sismondi
- http://www.irisa.fr/tipi

6.2. T3DevKit and IPv6 testing tools

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).

T3DevKit is a free open source toolkit to ease the development of test suites in the TTCN-3 environment. It provides a CoDec generator (t3cdgen) that automates the development process of the CoDec needed for coding TTCN-3 values into physically transmittable messages and decoding incoming messages. A library (t3devlib) provides an object oriented framework to manipulate TTCN-3 entities (values, ports, timers, external functions). T3DevKit offers an implementation of the TRI and TCI standard interfaces a default implementations for the system adapter (SA), platform adapter (PA), test management (TM), test logging (TL) and component handling (CH) modules and a default codec. Built-in scripts for the generation of executable test suite, which are tool-independent facilitate the distribution of test suite sources.

IPv6 test suites have been developed using the TTCN-3 environment. The full Abstract Test Suites are written in TTCN-3 and the source files for building the codecs and adapters with the help of T3DevKit.

- Participants: César Viho, Federico Sismondi
- Contact: Federico Sismondi

6.3. Performance and dependability evaluation

Participants: Gerardo Rubino, Bruno Sericola, Bruno Tuffin.

We develop software tools for the evaluation of two classes of models: Markov models and reliability networks. The main objective is to quantify dependability aspects of the behaviors of the modeled systems, but other aspects of the systems can be handled (performance, performability, vulnerability). The tools are specialized libraries implementing numerical, Monte Carlo and Quasi-Monte Carlo algorithms.

One of these libraries has been developed for the Celar (DGA), and its goal is the evaluation of dependability and vulnerability metrics of wide area communication networks (WANs). The algorithms in this library can also evaluate the sensitivities of the implemented dependability measures with respect to the parameters characterizing the behavior of the components of the networks (nodes, lines).

We are also developing tools with the objective of building Markovian models and to compute bounds of asymptotic metrics such as the asymptotic availability of standard metrics of models in equilibrium, loss probabilities, blocking probabilities, mean backlogs, etc. A set of functions designed for dependability analysis is being built under the internal name `DependLib`.

We contribute to the development of SPNP (*Stochastic Petri Net Package*). SPNP is used by more than 200 companies and universities. The main designer is Duke University. Our contributions are on Monte Carlo methods. We plan to increase our participation in the development of this tool.

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

7. New Results

7.1. Performance Evaluation of Call Centers

Participant: Pierre L'Ecuyer.

We develop research activities around the analysis and design of call centers, from a performance perspective. The effective management of call centers is a challenging task mainly because managers are consistently facing considerable uncertainty.

One aspect studied in [23] is the development of stochastic models for the daily arrival rate in a call center. Models in which the busyness factors are independent across periods, or in which a common busyness factor applies to all periods, have been studied previously. But they are not sufficiently realistic. We examine alternative models for which the busyness factors have some form of dependence across periods.

We also carry out in [14] large-scale data-based investigation of service times in a call center with many heterogeneous agents and multiple call types to investigate the validity of traditionally used standard Erlang queueing models, based on independent and identically distributed exponential random variables. Our study provides empirical support to the theoretical research that goes beyond standard modelling assumptions in service systems.

In [56], we consider a stochastic staffing problem with uncertain arrival rates. The objective is to minimize the total cost of agents under some chance constraints, defined over the randomness of the service level in a given time period. We present a method that combines simulation, mixed integer programming, and cut generation to solve this problem. In [84], we consider a particular staffing problem with probabilistic constraints in an emergency call center. We propose an algorithm to solve the problem, and validate it with a simulation model based on real data from the 911 emergency call center of Montreal, Canada.

We are also interested in predicting the waiting time of customers upon their arrival in some service system such as a call center or emergency service. In [86], we propose two new predictors that are very simple to implement and can be used in multiskill settings. They are based on the waiting times of previous customers of the same class. In our simulation experiments, these new predictors are very competitive with the optimal ones for a simple queue, and for multiskill centers they perform better than other predictors of comparable simplicity.

7.2. Analytic models

Participants: Gerardo Rubino, Bruno Sericola.

Sojourn times in Markovian models. In [98], we discuss different issues related to the time a Markov chain spends in a part of its state space. This is relevant in many application areas including those interesting Dionysos, namely, in the performance and dependability analysis of complex systems. For instance, in dependability, the reliability of a system subject to failures and repairs of its components, is, in terms of a discrete-space model of it, the probability that it remains in the subset of operational or up states during the whole time interval $[0, t]$. In performance, the occupancy factor of some server is the probability that, in steady state, the model belongs to the subset of states where the server is busy. This book chapter reviews some past work done by the authors on this topic (see our book [111] for a synthesis of these works), and add some new insights on the properties of these sojourn times.

Queuing systems in equilibrium. In the late 70s, Leonard Kleinrock proposed a metric able to capture the tradeoff between the work done by a system and its cost, or, in terms of queueing systems, between throughput and mean response time. The new metric was called *power* and among its properties, it satisfies a nice one informally called "keep the pipe full", specifying that the operation point of many queues that maximizes their power also leads to a mean backlog equal to exactly one customer. Last year [110] we explored what happens with this metric when we consider Jackson queuing networks. After showing that the same property holds for them, we showed that the power metric has some drawbacks, mainly when considering multiserver queues and networks of queues. We then proposed a new metric that we called *effectiveness*, identical to power when there is a single queue with a single server, but different otherwise, that avoids these drawbacks. We analyze it and, in particular, we showed that the same "keep the pipe full" holds for it. In the keynote [34] we presented these ideas together with some new results (for example, the analysis of G-queues from this point of view).

For other analytical-oriented work, see [72] for new applications of queueing theory used at the Markovian level, and [72] for applications of stochastic analysis to general problems where performance and dependability are simultaneously taken into account in the same model.

7.3. Performance Evaluation of Distributed Systems

Participants: Bruno Sericola, Yann Busnel, Yves Mocquard.

Detection of distributed deny of service attacks. A Deny of Service (DoS) attack tries to progressively take down an Internet resource by flooding this resource with more requests than it is capable to handle. A Distributed Deny of Service (DDoS) attack is a DoS attack triggered by thousands of machines that have been infected by a malicious software, with as immediate consequence the total shut down of targeted web resources (*e.g.*, e-commerce websites). A solution to detect and to mitigate DDoS attacks it to monitor network traffic at routers and to look for highly frequent signatures that might suggest ongoing attacks. A recent strategy followed by the attackers is to hide their massive flow of requests over a multitude of routes, so that locally, these flows do not appear as frequent, while globally they represent a significant portion of the network traffic. The term "iceberg" has been recently introduced to describe such an attack as only a very small part of the iceberg can be observed from each single router. The approach adopted to defend against such new attacks is to rely on multiple routers that locally monitor their network traffic, and upon detection of potential icebergs, inform a monitoring server that aggregates all the monitored information to accurately detect icebergs [41]. Now to prevent the server from being overloaded by all the monitored information, routers continuously keep track of the c (among n) most recent high flows (modeled as items) prior to sending them to the server, and throw away all the items that appear with a small probability. Parameter c is dimensioned so that the frequency at which all the routers send their c last frequent items is low enough to enable the server to aggregate all of them and to trigger a DDoS alarm when needed. This amounts to compute the time needed to collect c distinct items among n frequent ones. A thorough analysis of the time needed to collect c distinct items appears in [10].

Stream Processing Systems. Stream processing systems are today gaining momentum as tools to perform analytics on continuous data streams. Their ability to produce analysis results with sub-second latencies, coupled with their scalability, makes them the preferred choice for many big data companies.

A stream processing application is commonly modeled as a direct acyclic graph where data operators, represented by nodes, are interconnected by streams of tuples containing data to be analyzed, the directed edges (the arcs). Scalability is usually attained at the deployment phase where each data operator can be parallelized using multiple instances, each of which will handle a subset of the tuples conveyed by the operators' ingoing stream. Balancing the load among the instances of a parallel operator is important as it yields to better resource utilization and thus larger throughputs and reduced tuple processing latencies. We have proposed a new key grouping technique targeted toward applications working on input streams characterized by a skewed value distribution [80]. Our solution is based on the observation that when the values used to perform the grouping have skewed frequencies, the few most frequent values (the *heavy hitters*) drive the load distribution, while the remaining largest fraction of the values (the *sparse items*) appear so rarely in the stream that the relative impact of each of them on the global load balance is negligible. We have shown, through a theoretical analysis, that our solution provides on average near-optimal mappings using sub-linear spaces in the number of tuples read from the input stream in the learning phase and the support (value domain) of the tuples. In particular this analysis presents new results regarding the expected error made on the estimation of the frequency of heavy hitters.

Load shedding is a technique employed by stream processing systems to handle unpredictable spikes in the input load whenever available computing resources are not adequately provisioned. A load shedder drops tuples to keep the input load below a critical threshold and thus avoid unbounded queuing and system trashing. In [102] and [79] we propose Load-Aware Shedding (LAS), a novel load shedding solution that, unlike previous works, does not rely neither on a pre-defined cost model nor on any assumption on the tuple execution duration. Leveraging sketches, LAS efficiently builds and maintains at runtime a cost model to estimate the execution duration of each tuple with small error bounds. This estimation enables a proactive load shedding of the input stream at any operator that aims at limiting queuing latencies while dropping as few tuples as possible. We provide a theoretical analysis proving that LAS is an (ε, δ)-approximation of the optimal online load shedder. Furthermore, through an extensive practical evaluation based on simulations and a prototype, we evaluate its impact on stream processing applications, which validate the robustness and accuracy of LAS.

Shuffle grouping is a technique used by stream processing frameworks to share input load among parallel instances of stateless operators. With shuffle grouping each tuple of a stream can be assigned to any available operator instance, independently from any previous assignment. A common approach to implement shuffle grouping is to adopt a Round-Robin policy, a simple solution that fares well as long as the tuple execution time is almost the same for all the tu-ples. However, such an assumption rarely holds in real cases where execution time strongly depends on tuple content. As a consequence, parallel stateless operators within stream processing applications may experience unpredictable unbalance that, in the end, causes undesirable increase in tuple completion times. In [77] we propose Online Shuffle Grouping (OSG), a novel approach to shuffle grouping aimed at reducing the overall tuple completion time. OSG estimates the execution time of each tuple, enabling a proactive and online scheduling of input load to the target operator instances. Sketches are used to efficiently store the otherwise large amount of information required to schedule incoming load. We provide a probabilistic analysis and illustrate, through both simulations and a running prototype, its impact on stream processing applications.

Estimating the frequency of any piece of information in large-scale distributed data streams became of utmost importance in the last decade (*e.g.*, in the context of network monitoring, big data, *etc.*). If some elegant solutions have been proposed recently, their approximation is computed from the inception of the stream. In a runtime distributed context, one would prefer to gather information only about the recent past. This may be led by the need to save resources or by the fact that recent information is more relevant. In [78], we consider the *sliding window* model and propose two different (on-line) algorithms that approximate the items frequency in the active window. More precisely, we determine a (ε, δ)-additive-approximation meaning that the error is greater than ε only with probability δ. These solutions use a very small amount of memory with respect to the size N of the window and the number n of distinct items of the stream, namely, $O(\frac{1}{\varepsilon} \log \frac{1}{\delta}(\log N + \log n))$ and $O(\frac{1}{\tau\varepsilon} \log \frac{1}{\delta}(\log N + \log n))$ bits of space, where τ is a parameter limiting memory usage. We also provide their distributed variant, *i.e.*, considering the *sliding window functional monitoring* model, with a communication cost of $O(\frac{k}{\varepsilon^2} \log \frac{1}{\delta} \log N)$ bits per window (where k is the number of nodes). We compared

the proposed algorithms to each other and also to the state of the art through extensive experiments on synthetic traces and real data sets that validate the robustness and accuracy of our algorithms.

Randomized Message-Passing Test-and-Set. In [101], we have presented a solution to the well-known Test&Set operation in an asynchronous system prone to process crashes. Test&Set is a synchronization operation that, when invoked by a set of processes, returns yes to a unique process and returns no to all the others. Recently, many advances in implementing Test&Set objects have been achieved. However, all of them target the shared memory model. In this paper we propose an implementation of a Test&Set object in the message passing model. This implementation can be invoked by any number $p \leq n$ of processes where n is the total number of processes in the system. It has an expected individual step complexity in $O(\log p)$ against an oblivious adversary, and an expected individual message complexity in $O(n)$. The proposed Test&Set object is built atop a new basic building block, called selector, that allows to select a winning group among two groups of processes. We propose a message- passing implementation of the selector whose step complexity is constant. We are not aware of any other implementation of the Test&Set operation in the message passing model.

Throughput Prediction in Cellular Networks Downlink data rates can vary significantly in cellular networks, with a potentially non-negligible effect on the user experience. Content providers address this problem by using different representations (*e.g.*, picture resolution, video resolution and rate) of the same content and switch among these based on measurements collected during the connection. If it were possible to know the achievable data rate before the connection establishment, content providers could choose the most appropriate representation from the very beginning. We have conducted a measurement campaign involving 60 users connected to a production network in France, to determine whether it is possible to predict the achievable data rate using measurements collected, before establishing the connection to the content provider, on the operator's network and on the mobile node. We show that it is indeed possible to exploit these measurements to predict, with a reasonable accuracy, the achievable data rate [81].

Population Protocol Model. The computational model of population protocols, introduced by Angluin and his colleagues in 2006, is a formalism that allows the analysis of properties emerging from simple and pairwise interactions among a very large number of anonymous finite-state agents. Significant work has been done so far to determine which problems are solvable in this model and at which cost in terms of states used by the protocols and time needed to converge. The problem tackled in [74] is the population proportion problem: each agent starts independently from each other in one of two states, say A or B, and the objective is for each agent to determine the proportion of agents that initially started in state A, assuming that each agent only uses a finite set of state, and does not know the number n of agents. We propose a solution which guarantees with any high probability that after $O(\log n)$ interactions any agent outputs with a precision given in advance, the proportion of agents that start in state A. The population proportion problem is a generalization of both the majority and counting problems, and thus our solution solves both problems. We show that our solution is optimal in time and space. Simulation results illustrate our theoretical analysis.

The context of [75] is the well studied dissemination of information in large scale distributed networks through pairwise interactions. This problem, originally called "rumor mongering", and then "rumor spreading", has mainly been investigated in the synchronous model. This model relies on the assumption that all the nodes of the network act in synchrony, that is, at each round of the protocol, each node is allowed to contact a random neighbor. In this paper, we drop this assumption under the argument that it is not realistic in large scale systems. We thus consider the asynchronous variant, where at time unit, a single node interacts with a randomly chosen neighbor. We perform a thorough study of T_n, the total number of interactions needed for all the n nodes of the network to discover the rumor. While most of the existing results involve huge constants that do not allow for comparing different protocols, we prove that in a complete graph of size $n \geq 2$, the probability that $T_n > k$ for all $k \geq 1$ is less than $(1 + 2k(n-2)^2/n)(1-2/n)^{k-1}$. We also study the behavior of the complementary distribution of T_n at point $cE(T_n)$ when n tends to infinity, in function of c. This paper received the Best Student Paper Award from the 15th IEEE Symposium on Network Computing and Applications (IEEE NCA 2016).

Bitcoin. Decentralized cryptocurrency systems offer a medium of exchange secured by cryptography, without the need of a centralized banking authority. Among others, Bitcoin is considered as the most mature one. Its popularity lies on the introduction of the concept of the blockchain, a public distributed ledger shared by all participants of the system. Double spending attacks and blockchain forks are two main issues in blockchain-based protocols. The first one refers to the ability of an adversary to use the very same bitcoin more than once, while blockchain forks cause transient inconsistencies in the blockchain. We show in [43], [89], [42] through probabilistic analysis that the reliability of recent solutions that exclusively rely on a particular type of Bitcoin actors, called miners, to guarantee the consistency of Bitcoin operations, drastically decreases with the size of the blockchain.

7.4. Future networks and architectures

Participants: Adlen Ksentini, Bruno Sericola, Yassine Hadjadj-Aoul, Jean-Michel Sanner, Hamza Ben Ammar.

SDN and NFV. Network Function Visualization (NFV) and Software Defined Network (SDN) currently play a key role to transform the network architecture from hardware-based to software-based.

SDN is in the process of revolutionizing the way of managing networks by providing a new way to support current and future services. However, by relocating the control functionality in a remote entity, the measurements' accuracy of the resources' utilization becomes more difficult, which complicates the decision making. Although there are previous works focusing on the problem of network management and measurement in SDN networks, only a few proposed solutions have taken into consideration the trade-off existing between statistics' polling frequency (i.e. generated overhead), and the accuracy of monitoring results (i.e. optimized resourcesâ allocation). In [62], we proposed a new approach calculating accurately the bandwidth utilization while adapting the polling frequency according to ports/switches activity. The emulations' results under Mininet clearly demonstrate the effectiveness of the proposed solution, which proved to be scalable compared to classical approaches. The controllers' placement is another important concern that emerged recently to solve the scalability and the reliability issues of SDN networks. The placement efficiency is influenced by both network operators (NO) strategy and the supported service requirements, which makes more complex the decision-making process. In particular, the need to support QoS-constrained services may lead NO to guide the controllers' placement in a way to ensure services efficiency while optimizing the underlying infrastructure. In [82] and [66], we proposed a model for the placement of network controllers, and we formulated a general optimization problem. To provide more flexibility and to avoid time-prohibitive calculations, we proposed a hierarchical clustering strategy for the controllers' placement allowing to minimize the number of network controllers while reducing the potential disparity of burden between the different controllers. Besides, the algorithms' structure makes it easy to act on other network parameters to improve the reliability of the SDN network. In [107], we proposed an improvement of such algorithms, by considering an evolutionary solution based on a genetic technique with an ad hoc cross-over operator designed to solve a mono-objective controller placement problem.

To connect the VNFs hosted in the same Data Center (DC) or across multiple DCs, virtual switches are required. Besides forwarding functions, virtual switches can be configured to mirror traffics for network management needs. Among the existing virtual switch solutions, Open vSwitch (OVS) is the most known and used. OVS is open source, and included in most of the existing Linux distributions. However, OVS performance in terms of throughput for smaller packets is very smaller than of line rate of the interface. To overcome this limitation, OVS was ported to Data Plane Development Kit (DPDK), namely OVDK. The latter achieves an impressive line rate throughput across physical interfaces. In [83], we presented the result of OVDK performance test when flow and port mirroring are activated, which was not tested so far. The performance test focuses on two parameters, throughput and latency in OVDK, allowing to validate the use of OVDK for flow forwarding and network management in the envisioned virtualized network architecture.

Mobile cloud. To cope with the tremendous growth in mobile data traffic on one hand, and the modest average revenue per user on the other hand, mobile operators have been exploring network virtualization and cloud computing technologies to build cost-efficient and elastic mobile networks and to have them offered as a

cloud service. In such cloud-based mobile networks, ensuring service resilience is an important challenge to tackle. Indeed, high availability and service reliability are important requirements of carrier grade, but not necessarily intrinsic features of cloud computing. Building a system that requires the five nines reliability on a platform that may not always grant it is therefore a hurdle. Effectively, in carrier cloud, service resilience can be heavily impacted by a failure of any network function (NF) running on a virtual machine (VM). In [31], we introduce a framework, along with efficient and proactive restoration mechanisms, to ensure service resilience in carrier cloud. As restoration of a NF failure impacts a potential number of users, adequate network overload control mechanisms are also proposed. A mathematical model is developed to evaluate the performance of the proposed mechanisms. The obtained results are encouraging and demonstrate that the proposed mechanisms efficiently achieve their design goals.

Typically, maintaining a static pool of cloud resources to meet peak requirements with good service quality makes the cloud infrastructure costly. To cope with this, [58] proposes an approach that enables a cloud infrastructure to automatically and dynamically scale-up or scale-down resources of a virtualized environment aiming for efficient resource utilization and improved quality of experience (QoE) of the offered services. The QoE-aware approach ensures a truly elastic infrastructure, capable of handling sudden load surges while reducing resource and management costs. The paper also discusses the applicability of the proposed approach within the ETSI NFV MANO framework for cloud-based 5G mobile systems.

Video distribution. Due to the Internet usage evolution over these last years, the current IP-based architecture becomes heavier and less efficient for providing Internet services. In order to face this shortcoming, "Content Centric Networking" has been proposed. One of its important features is the use of in-network caching as a way of improving network performance and service scalability. However, in most of the existing CCN-based approaches several copies of the same content are present in the network, which reduce its efficiency. In [45], we proposed the "CLIque-based cooperative Caching" (CLIC) strategy, which basically consists in detecting cliques within the network topology to allocate more efficiently the content in the network. The main motivation of the proposed solution is to eliminate contents' redundancy between neighboring nodes while promoting the most popular contents. This approach guarantees a sufficient number of copies of popular files within the network while maximizing the number of distinct content items. We evaluate the proposed scheme through simulation. The results show significant improvements in terms of cache management and network performance.

In [59], we make the case for opening the telco CDN infrastructure to content providers by means of network function virtualization (NFV) and cloud technologies. We design and implement a CDN-as-a-Service architecture, where content providers can lease CDN resources on demand at regions where the ISP has presence. Using open northbound RESTful APIs, content providers can express performance requirements and demand specifications, which can be translated to an appropriate service placement on the underlying cloud substrate. To gain insight which can be applied to the design of such service placement mechanisms, we evaluate the capabilities of key enabling virtualization technologies by extensive testbed experiments.

Network design using new dependability metrics. When designing a network taking into account its capabilities face to possible failures to its components, the basic theoretical framework is classical network reliability, where the system under study is represented by a graph with perfect nodes and imperfect links randomly and independently failing. The corresponding connectivity-based metrics must then be evaluated in order to quantify the robustness of the networking architecture. Recently, a new family of metrics, called diameter-constrained, have been proposed and analyzed by Dionysos' collaborators and members. In [53], we developed some elements for a factoring theory associated with these metrics. The paper is focused on the detection of irrelevant components, a key task when evaluating these types of quantities using factorization. The paper also includes a factoring algorithm, which is an up-to-date procedure exploiting all available results for implementing the pivoting idea (proved to be one of the most powerful methods in classical reliability analysis).

In [54], we consider an homogeneous network (identical and independent components). In this context, if p is the probability that each of the components works, then any reliability metric is necessarily a polynomial in p, and computing these metrics can be reduced to counting problems (counting specific classes of paths or

of cuts, for instance). In the paper, we quantify, in some sense, the "degree of difficulty" of these counting processes, and we identify the situations where they are "easy". The second contribution of the paper is to propose a fundamental problem from survivable network design, called the Network Utility Problem. The goal is to maximize network utility (defined as the opposite of the level of difficulty minus one), under a minimum edge-connectivity requirement.

Optical network design. Paper [65] presents a fast and accurate mathematical method to evaluate the blocking probability (the probability of a burst loss) in dynamic WDM networks without wavelength conversion (the present used technology). We assume that all links have the same number of wavelengths (the same capacity). The proposed model considers different traffic loads at each network connection (heterogeneous traffic). To take into account the wavelength continuity constraint, the method divides the network into a sequence of networks where all the links have capacity 1. Every network in the sequence is evaluated separately using an analytical technique. Then, a procedure combines the results of these evaluations in a way that captures the dependencies that occur in the real system due to the competition for bandwidth between the different connections. The method efficiently achieves results very close to those obtained by simulation, but orders of magnitude faster, allowing the evaluation of the blocking probability of all users (connections) for mesh network topologies.

7.5. Network Economics

Participants: Bruno Tuffin, Pierre L'Ecuyer.

The general field of network economics, analyzing the relationships between all acts of the digital economy, has been an important subject for years in the team. The whole problem of network economics, from theory to practice, describing all issues and challenges, is described in our book published in 2014 [109].

Network neutrality. Most of our activity has been devoted to the vivid network neutrality debate, going beyond the traditional for or against neutrality. We especially responded to the public consultation on draft BEREC Guidelines on implementation of net neutrality rules held during Summer 2016.

Network neutrality is often advocated by content providers, stressing that side payments to Internet Service Providers would hinder innovation. However, we also observe some content provider actually paying those fees. In [20] we intend to explain such behaviors through economic modeling, illustrating how side payments can be a way for an incumbent content provider to prevent new competitors from entering the market. We investigate the conditions under which the incumbent can benefit from such a barrier-to-entry, and the consequences of that strategic behavior on the other actors: content providers, users, and the Internet Service Provider. We also describe how the Nash bargaining solution concept can be used to determine the side payment.

In [105], we explain how non neutrality may be pushed by big CPs to their benefits. Major content/service providers are publishing grades they give to ISPs about the quality of delivery of their content. The goal is to inform customers about the "best" ISPs. But this could be an incentive for, or even a pressure on, ISPs to differentiate service and provide a better quality to those big content providers in order to be more attractive. This fits the network neutrality debate, but instead of the traditional vision of ISPs pressing content providers, we face here the opposite situation, still possibly at the expense of small content providers though. We design in [105] a model describing the various actors and their strategies, analyzes it thanks to non-cooperative game theory, and quantifies the impact of those advertised grades with respect to the situation where no grade is published. We illustrate that a non-neutral behavior, differentiating traffic, is not leading to a desirable situation.

While neutrality is focusing on the behavior of ISPs, we claim that the debate should be generalized. Indeed, the reality of the Internet in the 2010s is that various actors contribute to the delivery of data, with sometimes contradictory objectives. We highlight in [19] the fact that neutrality principles can be bypassed in many ways without violating the rules currently evoked in the debate. For example via Content Delivery Networks (CDNs), which deliver content on behalf of content providers for a fee, or via search engines, which can hinder competition and innovation by affecting the visibility and accessibility of content. We therefore call for

an extension of the net neutrality debate to all the actors involved in the Internet delivery chain. We particularly challenge the definition of net neutrality as it is generally discussed. Our goal is to initiate a relevant debate for net neutrality in an increasingly complex Internet ecosystem, and to provide examples of possible neutrality rules for different levels of the delivery chain, this level separation being inspired by the OSI layer model.

The impact of a revenue-oriented CDN is particularly investigated in [104] and [70]. Content Delivery Networks (CDN) have become key telecommunication actors. They contribute to improve significantly the quality of services delivering content to end users. However, their impact on the ecosystem (end-users, the network operators and the content providers) raises concerns about their "neutrality", and therefore the question of their inclusion in the network neutrality debate becomes relevant. We compare the outcome with that of a neutral behavior, and at investigating whether some regulation should be introduced. We present a mathematical model and show that there exists a unique optimal revenue-maximizing policy for a CDN actor, in terms of dimensioning and allocation of its storage capacity, and depending on parameters such as prices for service/transport/storage. In addition, using the real traces, we compare the revenue-based policy with policies based on several fairness criteria. The CDN activity being potentially lucrative and not included in the neutrality debate, we analyze in [71] the revenue-optimal strategies and impact of a vertically integrated ISP-CDNs, which can sell those services to content providers. Our approach is based on an economic model of revenues and costs, and a multilevel game-theoretic formulation of the interactions among actors. Our model incorporates the possibility for the vertically-integrated ISP to partially offer CDN services to competitors in order to optimize the trade-off between CDN revenue (if fully offered) and competitive advantage on subscriptions at the ISP level (if not offered to competitors). Our results highlight two counterintuitive phenomena: an ISP may prefer an independent CDN over controlling (integrating) a CDN; and from the user point of view, vertical integration is preferable to an independent CDN or a no- CDN configuration. Hence, a regulator may want to elicit such CDN-ISP vertical integrations rather than prevent them.

Online platforms and search engines. Another set of key actors in the Internet economy is the online platforms and search engines. When a keyword-based search query is received by a search engine, a classified ads website, or an online retailer site, the platform has exponentially many choices in how to sort the search results. Two extreme rules are (a) to use a ranking based on estimated relevance only, which improves customer experience in the long run because of perceived quality, and (b) to use a ranking based only on the expected revenue to be generated immediately, which maximizes short-term revenue. Typically, these two objectives (and the corresponding rankings) differ. A key question then is what middle ground between them should be chosen.We introduce in [16] stochastic models that yield elegant solutions for this situation, and we propose effective solution methods to compute a ranking strategy that optimizes long-term revenues. This strategy has a very simple form and is easy to implement if the necessary data is available. It consists in ordering the output items by decreasing order of a score attributed to each. This score results from evaluating a simple function of the estimated relevance, the expected revenue of the link, and a real-valued parameter. We find the latter via simulation-based optimization, and its optimal value is related to the endogeneity of user activity in the platform as a function of the relevance offered to them.

The impact on other actors of search engines has led to the so-called search neutrality debate, as a parallel to the network neutrality debate. Search engines accused of biasing the ranking of their organic links to provide a competitive advantage to their own content. Based on the optimal ranking policy for a search engine obtained in [16], we investigate in [67] on an example whether non-neutrality impacts innovation. We illustrate that a revenue-oriented search engine may indeed deter innovation at the content level, hence the validity of the argument (without necessarily meaning that search engines should be regulated).

Sponsored auctions. Advertisement in dedicated webpage spaces or in search engines sponsored slots is usually sold using auctions, with a payment rule that is either per impression or per click. But advertisers can be both sensitive to being viewed (brand awareness effect) and being clicked (conversion into sales). In [33], [92], we generalize the auction mechanism by including both pricing components: the advertisers are charged when their ad is displayed, and pay an additional price if the ad is clicked. Applying the results for Vickrey-Clarke-Groves (VCG) auctions, we show how to compute payments to ensure incentive compatibility from advertisers as well as maximize the total value extracted from the advertisement slot(s). We provide tight upper

bounds for the loss of efficiency due to applying only pay-per-click (or pay-per-view) pricing instead of our scheme. Those bounds depend on the joint distribution of advertisement visibility and population likelihood to click on ads, and can help identify situations where our mechanism yields significant improvements. We also describe how the commonly used generalized second price (GSP) auction can be extended to this context.

7.6. Monte Carlo

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

We maintain a research activity in different areas related to dependability, performability and vulnerability analysis of communication systems, using both the Monte Carlo and the Quasi-Monte Carlo approaches to evaluate the relevant metrics. Monte Carlo (and Quasi-Monte Carlo) methods often represent the only tool able to solve complex problems of these types.

Rare event simulation. However, when the events of interest are rare, simulation requires a special attention, to accelerate the occurrence of the event and get unbiased estimators of the event of interest with a sufficiently small relative variance (see our book [108] for a global introduction to the field). This is the main problem in the area. Dionysos' work focuses then on dealing with the rare event situation, with a particular focus on dependability [40].

A non-negligible part of our activity on the application of rare event simulation was about the evaluation of static network reliability models. In a static network reliability model one typically assumes that the failures of the components of the network are independent. This simplifying assumption makes it possible to estimate the network reliability efficiently via specialized Monte Carlo algorithms. Hence, a natural question to consider is whether this independence assumption can be relaxed, while still attaining an elegant and tractable model that permits an efficient Monte Carlo algorithm for unreliability estimation. In [12], we provide one possible answer by considering a static network reliability model with dependent link failures, based on a Marshall-Olkin copula, which models the dependence via shocks that take down subsets of components at exponential times, and propose a collection of adapted versions of permutation Monte Carlo (PMC, a conditional Monte Carlo method), its refinement called the turnip method, and generalized splitting (GS) methods, to estimate very small unreliabilities accurately under this model. The PMC and turnip estimators have bounded relative error when the network topology is fixed while the link failure probabilities converge to zero, whereas GS does not have this property. But when the size of the network (or the number of shocks) increases, PMC and turnip eventually fail, whereas GS works nicely (empirically) for very large networks, with over 5000 shocks in our examples. In [73], we propose a methodology for calibrating a dependent failure model to compute the reliability in a telecommunication network, following a similar starting point (that is, using Marshall-Olkin copulas). In practice, this model is difficult to calibrate because it requires the estimation of a number of parameters that is exponential in the number of links. We formulate an optimization problem for calibrating a Marshall-Olkin copula model to attain given marginal failure probabilities for all links and the correlations between them. Using a geographic failure model, we calibrate various Marshall-Olkin copula models using our methodology, we simulate them, and we benchmark the reliabilities thus obtained. Our experiments show that considering the simultaneous failures of small and connected subsets of links is the key for obtaining a good approximation of reliability, confirming what it is suggested by the telecommunication literature.

A related problem is when links have random capacities and a certain target amount of flow must be carried from some source nodes to some destination nodes is considered in [47]. Each destination node has a fixed demand that must be satisfied and each source node has a given supply. The goal is to estimate the unreliability of the network, defined as the probability that given the realized link capacities, the network cannot carry the required amount of flow to meet the demand at all destination nodes. We adapt GS and PMC to this context. In [55], we explore other methods designed to reduce the variance of the estimators in this context. All of them are adaptations of methods originally developed to make reliability estimations on different network models. These methods are introduced together with a brief review of the algorithms on which they are based.

A new application of our previously designed zero-variance approximation importance sampling method has been developed in [76]: To accurately estimate the reliability of highly reliable rail systems and comply with contractual obligations, rail system suppliers such as ALSTOM require efficient reliability estimation techniques. While in our previous works, the studied graph models were dealing with failing links, we propose an adaptation of the algorithm to evaluate the reliability of real transport systems where nodes are the failing components. This is more representative of railway telecommunication system behavior. Robustness measures of the accuracy of the estimates, bounded or vanishing relative error properties, are discussed and results from a real network (Data Communication System used in automated train control system) showing bounded relative error property, are presented.

Random variable generation. Simulation requires the use of pseudo-random generators. In [18], we examine the requirements and the available methods and software to provide (or imitate) uniform random numbers in parallel computing environments. In this context, for the great majority of applications, independent streams of random numbers are required, each being computed on a single processing element at a time. Sometimes, thousands or even millions of such streams are needed. We explain how they can be produced and managed. We devote particular attention to multiple streams for GPU devices.

Sampling from the Normal distribution truncated to some finite or semi-infinite interval is of particular interest for certain applications in Bayesian statistics, such as to perform exact posterior simulations for parameter inference. We study and compare in [46] various methods to generate such random variables, with special attention to the situation where the interval is far in the tail. The algorithms are implemented and available in Java, R, and MATLAB, and the software is freely available.

Quasi-Monte Carlo (QMC). Finally, we have continued our work on QMC methods. In [15], we review the Array-RQMC method, its variants, sorting strategies, and convergence results. We are interested in the convergence rate of measures of discrepancy of the states at a given step of the chain, as a function of the sample size, and also the convergence rate of the variance of the sample average of a (cost) function of the state at a given step, viewed as an estimator of the expected cost. We summarize known convergence rate results and show empirical results that suggest much better convergence rates than those that are proved. We also compare different types of multivariate sorts to match the chains with the RQMC points, including a sorting procedure based on a Hilbert curve.

The description of a new software tool and library named Lattice Builder, written in C++, that implements a variety of construction algorithms for good rank-1 lattice rules (a familiy of sequences used in QMC methods) is provided in [17]. The library is extensible, thanks to the decomposition of the algorithms into decoupled components, which makes it easy to implement new types of weights, new search domains, new figures of merit, etc.

7.7. Wireless Networks

Participants: Osama Arouk, Btissam Er-Rahmadi, Adlen Ksentini, Meriem Bouzouita, Pantelis Frangoudis, Yassine Hadjadj-Aoul, César Viho, Quang Pham, Gerardo Rubino.

We are continuing our activities around wireless and mobile networks, by focusing more on leveraging the current mobile and wireless architecture toward building the 5G systems.

Congestion control for M2M applications. Machine-to-Machine (M2M) communications are expected to be one of the major drivers for the future 5G network. It is expected that M2M will come up with substantial revenue growth for Mobile Network Operators (MNO), but they represent at the same time the most important challenge they are facing. For instance, a massive number of Machine-to-Machine (M2M) devices performs simultaneously Random Accesses (RA), which causes severe congestions and reduces the RA success probability. To control the Radio Access Network (RAN) overload and alleviate the congestion between M2M devices, 3GPP developed the Access Class Barring (ACB) procedure that depends on an access probability called the ACB factor. In [48][24], we first presented a simple fluid model of M2M devices' random access. This model is then used to derive an optimal regulator of the ACB factor based on nonlinear non affine control theory. The main advantages of the proposed approach are twofold. First, the proposal is

fully compliant with the standard while it reduces significantly the computation and the signaling overheads. Second, it provides an efficient mean to regulate adaptively the ACB factor as it guarantees having an optimal number of M2M devices accessing concurrently to the RAN. The obtained results based on simulations show clearly the robustness of the proposed approach, and its superiority compared to existing proposals. However, such a model assumes a perfect knowledge about the number of M2M attempting the ACB and the RA, which is not possible in realistic use cases. For this reason, we proposed in [50] a system-agnostic controller, which computes the barring factor dynamically based only on the mismatch between the average number of M2M devices succedding in the RA and the optimal number of M2M which should succeed. We base our controlling algorithm in a Propostional Integral Derivative (PID)-based controller. Simulation results show that the algorithm outperforms the existing solutions by improving significantly the access success probability while minimizing radio resources' underutilization.

Different schemes were proposed in the literature to solve the congestion problem by regulating the M2M devices' opportunities of transmission. Nonetheless, as revealed in [51], these schemes turn out to be ineffective in case of heavily congested M2M networks. In fact, in such a condition, the unpredictable and increasingly accumulated number of devices cannot be blocked. This augments the risk of M2M devices' synchronized access, which may result in a congestion collapse. Consequently, we proposed, in [49], a methodology for a better estimation of the number of M2M devices attempting the access. We also proposed a novel implementation of the ACB process, which dynamically computes the ACB factor according to the network's overload conditions and includes a corrective action adapting the controller work, based on the mismatch existing between the computed and the targeted mean load. The simulation results show that the proposed algorithms allow improving considerably the estimation of the number of M2M devices' arrivals, while outperforming existing techniques.

In [32], we proposed a novel approach to deal with massive synchronous access attempts, tailored for both M2M delay-sensitive applications and energy constrained ones. The main idea behind the paper is to leverage crowd sourcing data, transmitted from the devices succeeding in the RACH procedure, to tune the access parameters, without requiring too complex techniques for the estimation of the number of attempts. Simulation results show that the proposed scheme achieves sub-optimal performance in the wireless resources' utilization while reducing significantly both the number of access attempts and the access latency for delay sensitive applications. This allows guaranteeing energy conservation.

In [44], we proposed two optimal solutions that use Device-to-Device (D2D) communications to lightweight the overhead of M2M devices on 5G networks. Each scheme has a specific objective, and aims to manage the communications between devices and eNodeBs to achieve its objective. The proposed solutions nominate the devices that should communicate using D2D communications and those that should directly communicate with eNodeBs. The first solution aims to reduce the energy consumption, whereas the second one aims to reduce the data transfer delay at the eNodeBs. The performance of the proposed schemes is evaluated via simulations and the obtained results demonstrate their feasibility and ability in achieving their design goals.

Network selection and optimization. With the explosion of mobile data traffic, the Fixed and Mobile Converged (FMC) network are being heavily required. Mobile devices have the capability of connecting simultaneously to different access networks in the FMC architecture. Access network selection becomes an issue when mobile devices are under coverage of different access networks, since a bad selection may lead to network congestion and degrade the QoE of users. In order to address this problem, in [91] we modeled and analyzed the interface selection procedure using control theory. Based on our model, we designed a controller which can send to mobile devices a network selection command calculated instantaneously for the access network selection.

Dynamic Adaptive Streaming over HTTP (DASH), with its different proprietary versions, is presently the most widely adopted technology for video delivery over the Internet. DASH offers significant advantages, enabling users to switch dynamically between different available video qualities responding to variations in the current network conditions during video playback. This is particularly interesting in wireless and mobile access networks, which present such variations in a hard to predict manner, but sometimes quite frequently. Moreover, mobile users of these networks share a common radio access link and, thus, a common

bottleneck in case of congestion, which may cause user experience to degrade. In this context, the Mobile Edge Computing (MEC) emerging standard gives new opportunities to improve DASH performance, by moving IT and cloud computing capabilities down to the edge of the mobile network. In [69] and [103] we proposed a novel architecture for adaptive HTTP video streaming tailored to a MEC environment. The proposed architecture includes an adaptation algorithm running as a MEC service, aiming to relax network congestion while improving the Quality of Experience (QoE) for mobile users. Our mechanism is standards-compliant and compatible with receiver-driven adaptive video delivery algorithms, with which it cooperates in a transparent manner.

Low-rate wireless personal area networks (WPANs) (and also wireless sensor networks) suffer from many constraints. The IEEE 802.15.4 standard proposes the slotted CSMA/CA as a communication channel access mechanism with collision avoidance that takes into account the constraints of WPANs. In [22], we proposed to introduce a data fragmentation mechanism into slotted CSMA/CA to improve a bandwidth utilisation. The novelty here is the use of the fragmentation mechanism to replace an acknowledgement frame after the transmission of the fragment and the remaining frame. The beacon frame is used to confirm the success transmission of a data fragment. To evaluate the performance of our proposition, we have developped a three dimension Markov chain which modelises the behaviour of the node using IEEE 802.15.4 with data fragmentation mechanism without using an ACK frame. The analytical results concerning the network throughput and the transmission success delay demonstrate the improvement of the bandwidth occupation.

Mobile networks' improvements. In [85], we introduced the concept of elastic bearer in Evolved Packet System (EPS), which allows the users to enhance on-demand the performance of certain applications and permits the network to efficiently manage the resource allocation taking into account the application type. In particular, the paper introduces a set of mechanisms to trigger and support bearer elasticity in EPS based on the Quality of Experience (QoE) perceived by users or based on feedback from Radio Access Network (RAN). Bearer elasticity can be attained through potential Packet Data Network/Serving Gateway (PDN/S-GW) relocation to eventually improve QoE within and beyond the mobile network operator premises. The paper also introduces a set of methods to identify and cope with a storm of requests for particular applications at densely populated areas.

One important objective of 5G mobile networks is to accommodate a diverse and ever-increasing number of user equipment (UEs). Coping with the massive signaling overhead expected from UEs is an important hurdle to tackle so as to achieve this objective. In [11], we devised an efficient tracking area list management (ETAM) framework that aims for finding optimal distributions of tracking areas (TAs) in the form of TA lists (TALs) and assigning them to UEs, with the objective of minimizing two conflicting metrics, namely paging overhead and tracking area update (TAU) overhead. ETAM incorporates an online part and an and offline one, in order to achieve its design goal. In the online part, two strategies were proposed to assign in real time, TALs to different UEs, while in the offline part, three solutions were proposed to optimally organize TAs into TALs. The performance of ETAM is evaluated via analysis and simulations, and the obtained results demonstrate its feasibility and ability in achieving its design goals, improving the network performance by minimizing the cost associated with paging and TAU.

QoE aware routing in wireless networks. This year we continued our research on QoE-based optimization routing for wireless mesh networks. First, we approximate PSQA models by explicit mathematical forms, which can be used to find the optimal or near to optimal routes. Next, the hardness of the problem is studied and decentralized algorithms are proposed. The quality of the solution, computational complexity of the proposed algorithm, and the fairness are the main concerns of this work. Several centralized approximation algorithms have been proposed in order to address the complexity and the quality of the published solutions. The results can be found in the following papers: [25],[94], [95] and [26]. However, these centralized algorithms are not appropriate in large-scale networks. Thus, a distributed algorithm is necessary as a complement of the existing centralized methods. This is currently studied at the team.

8. Bilateral Contracts and Grants with Industry

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

Participants: Bruno Tuffin, Gerardo Rubino.

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

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

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

Participant: Bruno Tuffin.

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

8.3. Cifre contract on Device-Assisted Distributed Machine-Learning on Many Cores

Participants: Corentin Hardy, Bruno Sericola.

This is a Cifre contract including a PhD thesis supervision (PhD of Corentin Hardy), done with Technicolor. The starting point of this thesis is to consider the possibility to deploy machine-learning algorithms over many cores, but out of the datacenter: on the devices (home-gateways) deployed by Technicolor in users' homes. In this device-assisted view, an initial processing step in the device may significantly reduce the burden on the datacenter back-end. Problems are numerous (power consumption, CPU power, network bandwidth and latency), but costs for the operator can be lowered and scale may bring some new level in data processing.

8.4. Cifre contract on SDN for 5G mobile networks

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

This is a Cifre contract (2015-2018) including a PhD thesis supervision (PhD of Imad Alawe), done with TDF, on cooperation in SDN use for the 5th generation of mobile networks. The objective of the thesis is to study and devise appropriate solutions to introduce SDN in the current LTE architecture.

8.5. Camion

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

We are working in the 2-year (October 2014 to October 2016) Eurostars European Project Camion, which aims at offering cost-efficient, QoE-optimized content delivery, allowing for faster content access, as well as offline operation, while improving wireless network capacity and coverage. Camion is leaded by JCP-Connect, and the partners are a SME (FON) and our team. The project is extended until June 2017.

8.6. DVD2C

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

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

9. Partnerships and Cooperations

9.1. National Initiatives

9.1.1. ANR

- Adlen Ksentini is participating at 20% of his time to the IRT BCOM granted by the ANR.
- Yassine Hadjadj-Aoul is participating at 20% of his time to the IRT BCOM granted by the ANR.
- Yann Busnel is a member of the two following projects: Inhare granted by the ANR (ANR-15-CE19-0024) and DeSCeNt granted by the LabEx CominLabs (ANR-10-LABX-07-01).

9.2. Inria Project Labs

Participants: Yassine Hadjadj-Aoul, Gerardo Rubino, Bruno Tuffin.

Inria Project Labs' (IPL) initiatives enable the launch of ambitious research projects directly linked with the institute.

9.2.1. BetterNet

BetterNet aims at building and delivering a scientific and technical collaborative observatory to measure and improve the Internet service access as perceived by users. In this Inria Project Lab, we will propose new original user-centered measurement methods, which will associate social sciences to better understand Internet usage and the quality of services and networks. Our observatory can be defined as a vantage point, where:

- tools, models and algorithms/heuristics will be provided to collect data,
- acquired data will be analyzed, and shared appropriately with scientists, stakeholders and civil society,
- and new value-added services will be proposed to end-users.

Inria Project Teams involved: Diana, Dionysos, Inria Chile, Madynes, Muse, Spirals

9.3. European Initiatives

9.3.1. FINTEROP

Program: H2020-ICT-12-2015

Project acronym: F-Interop

Project title: FIRE+ online interoperability and performance test tools to support emerging technologies from research to standardization and market launch

Duration: November 2015 – October 2018

Coordinator: UPMC-LIP6

Other partners: 9 partners including our team Dionysos (F. Sismondi and C. Viho), and Eva (T. Watteyne)

Abstract: The goal of F-Interop is to extend FIRE+ with online interoperability and performance test tools supporting emerging IoT-related technologies from research to standardization and to market launch for the benefit of researchers, product development by SME, and standardization processes.

9.3.2. Collaborations with Major European Organizations

Partner 1: Sapienza University of Rome, Italy.

We work with Nicoló Rivetti and Leonardo Querzoni on the analysis of stream processing systems.

9.4. International Initiatives

9.4.1. Inria International Partners

9.4.1.1. MOCQUASIN

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

International Partner (Institution - Laboratory - Researcher):

University of Montreal (Canada)

Duration: started in 2013

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

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

9.4.1.2. Collaborations with the UTFSM at Valparaíso, Chile

We maintain a strong line of collaborations with the Technical University Federico Santa María (UTFSM), Valparaíso, Chile. Over the years, this has taken different forms (associated team Manap, Stic AmSud project "AMMA", Stic AmSud project "DAT", see next module). Currently, we have a joint PhD work running (PhD of Nicolás Jara, to be defended in 2017), and a new joint PhD to be started in 2017 (PhD of Jonathan Olavarría). The first one is on optical network analysis and design, the second one on modeling evaluation techniques.

9.4.1.3. International Initiatives

DAT

Title: Dependability Analysis Tool

International Partners:

Prof. H. Cancela, Univ. of the Republic, Computer Science, Uruguay;

Prof. R. Vallejos, UTFSM, Valparaíso, Electrical Eng., Chile;

G. Rubino, Dionysos, Inria, general responsible for the project.

Duration: 2015 - 2016

Start year: 2015

The main scientific objective of this project is to develop new techniques to assess the most important dependability properties of a complex system subject to the failures and possible repairs of its components. The central argument behind our proposal is our previous work in the area and some unpublished preliminary and promising results that we believe deserve deep exploration and that should lead to faster evaluation procedures than those available today. We also intend to implement these techniques in an integrated software package usable both in industry and for teaching purposes. Concerning applications, again based on the skills of the participating teams and our past common work, we will illustrate our findings on problems coming from the wireless and optical networking domains.

SM-HCD-HDD

Title: Statistical methods for highly complex and/or high dimensional data

International Partners:

Prof. Ricardo Fraiman, Mathematics, Univ. of the Republic, Uruguay, head of the project;

many partners in Uruguay, Argentina and Chile,

G. Rubino for Dionysos, Inria

Duration: 2016 - 2017

Start year: 2016

The aim of this project is to develop theoretical and computational tools to solve statistical problems that occur when data leaves in high dimensional spaces and/or lives in complex spaces that induce complex geometries.

9.5. International Research Visitors

9.5.1. Visits of International Scientists

Jebali Ameni, from INSAT (Tunisia)

Jorge Graneri, from UDELAR, Uruguay

Héctor Cancela, from UDELAR, Uruguay

Franco Robledo, from UDELAR, Uruguay

Claudio Risso, from UDELAR, Uruguay

Reinaldo Vallejos, from UTFSM, Chile

Marta Barría, from university of Valparaíso, Chile

9.5.1.1. Research Stays Abroad

Yann Busnel has been granted as an invited professor at La Sapienza Universitá di Roma, Italy, for 3 months from March to June 2016.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. Member of the Organizing Committees

Pierre L'Ecuyer is member of the Steering Committee of MCQMC.

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

Y. Hadjadj-Aoul is a member of the steering committee of the International Conference on Information and Communication Technologies for Disaster Management (ICT-DM) from December 2015.

Yann Busnel has been "Habilité à diriger les recherches" at the École Normale Supérieure de Rennes, under the seal of University Bretagne Loire, in December 2016, presenting a defense entitled "Analyse et traitement de flux de données large échelle".

10.1.2. Scientific Events Selection

10.1.2.1. Chair of Conference Program Committees

- Bruno Tuffin served as TPC co-chair for the 10th International Conference Performance Evaluation Methodologies and Tools (Valuetools'16), September 2016, Taormina, Italy.
- Yassine Hadjadj-Aoul served as TPC co-chair for the 3rd International Symposium on Networks, Computers and Communications (ISNCC 2016), May 2016, Hammamet, Tunisia.
- Yassine Hadjadj-Aoul served as TPC co-chair for the 13th conférence francophone sur les nouvelles technologies de la répartition (NOTERE 2016), Paris, France.

10.1.2.2. Member of the Conference Program Committees

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

- MCQMC'2016: Twelve International Conference on Monte Carlo and Quasi-Monte Carlo Methods in Scientific Computing, Stanford, California, Aug. 2016.
- SIMULTECH 2016: International Conference on Simulation and Modeling Methodologies, Technologies and Applications, Lisbon, Portugal, July 2016.
- ICORES 2016: International Conference on Operations Research and Enterprise Systems, Rome, Italy, Feb. 2016.

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

- 5th Workshop on Smart Data Pricing (SDP 2016), Workshop of IEEE INFOCOM 2016, San Francisco, USA, April 2016.
- IEEE ICC 2016 - Communications Software, Services and Multimedia Applications Symposium, 23-27 May 2016, Kuala Lumpur, Malaysia.
- 22nd Asia-Pacific Conference on Communications (APCC 2016), Yogyakarta, Indonesia on 25-27 August 2016.
- GECON2016 (13th International Conference on Economics of Grids, Clouds, Systems, and Services), 20-22 September 2016, Athens, Greece.
- The International Conference on Wireless Networks and Mobile Communications (WINCOM?16). Fez, Morocco, October 26-29, 2016.
- Globecom'16 - CSSMA (2016 IEEE Global Communications Conference: Communications Software, Services and Multimedia Apps), 4-8 December 2016, Washington VD, USA.

Bruno Sericola was member of the program committee of the following events:

- ASMTA 2016: 23rd International Conference on Analytical and Stochastic Modelling Techniques and Applications, Cardiff, Wales, UK, August 2016.
- MACOM 2016: 9th International Workshop on Multiple Access Communications, Aalborg, Denmark, November 2016.
- INTERNET 2016: 8th International Conference on Evolving Internet, Barcelona, Spain, November 2016.
- DEPEND 2016: 9th International Conference on Dependability, Nice, France, July 2016.

Yann Busnel was a member of the program committee of the following events:

- NCA 2016: 15th IEEE International Symposium on Network Computing and Applications, Boston, USA, October 2016.
- CoRes 2016: 1ères Rencontres Francophones sur la Conception de Protocoles, l'Évaluation de Performance et l'Expérimentation des Réseaux de Communication, Bayonne, France, May 2016.

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

- IEEE ICC 2016 Mobile Wireless Networks Symposium, Kuala Lumpur, Malaysia 2016.
- IEEE Globecom 2016 Mobile Wireless Networks Symposium, Washington, DC USA 2016.
- IEEE WCNC 2016, Doha, Qatar, 2016.

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

- IEEE ICC 2016 Mobile Wireless Networks Symposium, Kuala Lumpur, Malaysia 2016.
- IEEE Globecom 2016 Mobile Wireless Networks Symposium, Washington, DC USA 2016.
- IEEE WCNC 2016, Doha, Qatar, 2016.
- IEEE CSCN 2016 IEEE Conference on Standards for Communications & Networking, Berlin, Germany, 2016.

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

- Networking 2016, The IFIP Networking Conference, Vienne, Autriche, May 2016.
- MAM9 (9th) International Conference on Matrix Analytic Methods in Stochastic Models, Budapest, Hongrie, June 2016.
- COMTEL 2016, VIII International Congress in Computer Science and Telecommunications, Lima, Perú, September 2016.
- Mascots 2016, the IEEE International Symposium on Modelling, Analysis and Simulation of Computer and Telecommunications Systems, Londres, UK, September 2016.

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

Bruno Tuffin is the Simulation Area Editor for *Informs Journal on Computing*.

Bruno Tuffin is an associate editor for the following journal:

- Mathematical Methods of Operations Research, since November 2008.

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

- ACM Transactions on Mathematical Software, since August 2004.
- Statistics and Computing (Springer-Verlag), since June 2003.
- International Transactions in Operational Research, since May 2007.

Bruno Sericola is an associate editor for the following journals:

- International Journal of Stochastic Analysis, since April 2010.
- Performance Evaluation, since April 2015.

Bruno Sericola is Editor in Chief of the books series "Stochatic Models in Computer Science and Telecommunications Networks", ISTE/WILEY, since March 2015.

Yassine Hadjadj-Aoul is a member of the editorial broad of the CSC "International Journal of Computer Networks (IJCN)" since 2012.

Yassine Hadjadj-Aoul was a member of the guest editorial board of the following journals:

- Special issue in IGI, International Journal of Distributed Systems and Technologies (IJDST), "Information and Communication Technologies for Disaster Management" [99], Vol. 7, Issue 4, ISSN: 1947-3532 (October 2016)
- Hindawi Mobile Information Systems (Editorial), "Wireless and Mobile Technologies for the Internet of Things" [100], vol. 2016, ID 8206548 (2016)

10.1.3.2. Reviewer - Reviewing Activities

In addition to the reports done during his associate editor and conference TPC member duties, Bruno Tuffin has reviewed papers in 2016 for COMNET, Operations Research, Stochastic Models, Computers & OR, Journal of Communications & Networks.

Bruno Sericola served as a reviewer for several major international journals and conferences.

Adlen Ksentini has reviewed papers in 2016 for Transaction Paralel Distributed Systems-TPDS, Transaction on Wireless Communication - TWC, Transaction on Vehicular Technology - TVT, Wireless Communication Magazine, Elsevier Computer Communication.

Yassine Hadjadj-Aoul has reviewed papers in 2016 for Transaction on Vehicular Technology-TVT, Wireless Communication Magazine, Elsevier Computer Communication and for the following international conferences: Globecom'16, ICC'16, WCNC'16 and others.

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

Gerardo Rubino has reviewed papers for several international journals and conferences (Networking 2016, MAM9, Mascots 2016, ...), ANR projects, etc.

10.1.4. Invited Talks

B. Tuffin. gave a plenary talk "Some applications of importance sampling to dependability analysis" at the International Conference on Monte Carlo techniques, Paris, France, July 2016.

B. Tuffin gave the following seminar presentations:

- B. Tuffin. Net neutrality. IRISA Evaluation by HCRES, Jan. 2016.
- P. L'Ecuyer, P. Maillé, N. Stier-Moses, B. Tuffin. Stochastic Optimization for Search Engines: Revenue-Maximizing Rankings with Quality-Sensitive Consumers. CREM-IRISA Workshop on Network Economics, January 2016.
- P. Maillé, G. Simon, B. Tuffin. On revenue-oriented Content Delivery Networks and their impact on Net Neutrality. CREM-IRISA Workshop on Network Economics, January 2016.
- B. Tuffin. La neutralité du Net. Journées scientifiques Inria, Rennes, Juin 2016.
- P. Maille and B. Tuffin. Auctions For Online Ad Space Among Advertisers Mixing Pay-per-view And Pay-per-click. DIRO, Université de Montréal, Canada, Nov 30, 2016.

Y. Hadjadj-Aoul gave a plenary talk "Efficient support of Massive M2M communications during emergency situations" at the International Conference on Information and Communication Technologies for Disaster Management (ICT-DM 2016), Vienna, Austria, December 2016.

Y. Busnel gave a plenary talk "Comment générer des échantillons uniformes sur des grandes masses de données ?" at the 9ème Colloque Francophone sur les sondages, Gatineau, Canada, October 2016.

G. Rubino made several invited and keynote talks in 2016:

- an invited talk at Advances in Uncertainty Quantification Methods, Algorithms and Applications, Kaust, Saudi Arabia, about rare event analysis [37];
- an invited talk at SIAM Conference on Uncertainty Quantification, Lausanne, Suisse, about rare event analysis in static models [39];
- a keynote at Mascots'16, London, UK, about a new performance metric [34];
- an invited talk at Technoconférence "Nouvelles expériences son et vidéo", Rennes, France, about QoE measuring [35];
- a keynote in Math AmSud Seminar, Montevideo, Uruguay, about QoE analysis and Big Data problems [38];
- a keynote at SoCPaR'16, Vellore, India, about new results concerning Perceptual Quality measuring [36].

10.1.5. Leadership within the Scientific Community

Bruno Tuffin is the co-director of the common lab ALSTOM-Inria since 2014.

Gerardo Rubino is one of the three French representatives at the Scientific Committee of the IFCAM (Indo-French Centre for Applied Mathematics), managing the cooperation in mathematics of the two countries, and federating at the French side, among several other participants, Inria and CNRS.

Gerardo Rubino is a member of the CSV (the technical committee) of the Images and Networks Cluster of Brittany, France.

10.1.6. Research Administration

- Bruno Sericola is responsible for the Inria Rennes-Bretagne Atlantique budget.
- Bruno Sericola is the leader of the research group MAPI (Math Appli Pour l'Info) the goal of which is to improve the collaboration between computer scientists and mathematicians.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Master 2nd year: Bruno Sericola, Mathematics, 12 hours, M2, Istic/University of Rennes 1, France.

Master 2nd year: Bruno Sericola, Logistic and performance, 12 hours, M2, Faculté de sciences économiques/University of Rennes 1, France.

Master 2nd year: Gerardo Rubino, Performance Evaluation, Istic/University of Rennes 1, France, 16 hours.

Master 2nd year: Performance Evaluation, Bruno Tuffin, Istic/University of Rennes 1, France, 4 hours.

Master 2nd year: César Viho, Algorithms on graphs, 40 hours, Istic/University of Rennes 1, France

Master 2nd year: César Viho, Multimedia Networking, 8 hours, Istic/University of Rennes 1, France

Master 2nd year: Yassine Hadjadj-Aoul, Multimedia streaming over IP (MMR), 48 hours, Esir/University of Rennes 1, France

Master 2nd year: Yassine Hadjadj-Aoul, Multimedia services in IP networks (RSM), 29 hours, Esir/University of Rennes 1, France

Master 2nd year: Yassine Hadjadj-Aoul, Software Defined Networks, 4 hours, Istic/University of Rennes 1, France

Master 2nd year: Yassine Hadjadj-Aoul, Video streaming over IP, 8 hours, Istic/University of Rennes 1, France

Master pro. 2nd year: Yassine Hadjadj-Aoul, C Programming, 12 hours, Istic/University of Rennes 1, France

ENSAI Rennes 3rd year: Gerardo Rubino, Neural Networks, 9 hours.

Supelec Rennes 3rd year: Gerardo Rubino, Dependability Analysis, 15 hours.

Seminars: Yann Busnel, Big Data for Security and Safety, 12 hours, Sapienza Universitá di Roma, Italy, April 2016.

Seminars: Yann Busnel, Big Data for Security and Safety, 18 hours, Indian Institute of Technology, Indore, India, October 2016.

10.2.2. Supervision

PhD in progress: Ajit Rai, "Availability prediction with logistics", started in May 2015; advisors: B. Tuffin & G. Rubino, University Rennes 1.

PhD in progress: Corentin Hardy,"Device-Assisted Distributed Machine-Learning on Many Cores", started in April 2016; advisors: Bruno Sericola & Erwan Le Merrer from team Cidre, University Rennes 1.

PhD in progress: Yves Mocquard, "Analyse de flux de données massifs dans les systèmes distribués large échelle", started on September 2015; advisors: Bruno Sericola and Emmanuelle Anceaume from team Cidre, University Rennes 1.

PhD in progress: Ali Hodroj, "Enhancing content delivery to multi-homed users in broadband mobile networks", started in November 2015; advisors: Bruno Sericola, Marc Ibrahim and Yassine Hadjadj-Aoul, University Rennes 1 and St Joseph University of Beyrouth.

PhD in progress: Hamza Ben Ammar, "Socially-aware network and cache resources optimization for efficient media content delivery in Content Centric Networks", started in October 2015; advisors: Yassine Hadjadj-Aoul, Adlen Ksentini and Soraya Ait Chellouche, University Rennes 1.

PhD in progress: Imad Alawe, "Mobile SDN architecture", started in October 2015; advisors: César Viho, Yassine Hadjadj-Aoul, University Rennes 1, Philippe Bertin, B-COM and Davy Darche, TDF.

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

PhD in progress: Yue Li; Cifre Grant, Orange Labs; title: "Elaboration d'une architecture réseau unifiée, ouverte et flexible", started on October 2013; Advisors: Y. Hadjadj-Aoul and G. Rubino; University Rennes 1.

PhD in progress: Nicolás Jara, "Fault tolerant design of dynamic WDM optical networks", Technical University Federico Santa María (UTFSM) and university of Rennes 1, France. Advisors: R. Vallejos (Chile) and G. Rubino (France). Defense in 2017.

PhD in progress: Laura Aspirot, "Fluid Approximations for Stochastic Telecommunication Models", University of the Republic, Uruguay. Advisors: E. Mordecki (Uruguay) and G. Rubino (France). Defense in 2017.

PhD in progress: Jorge Graneri, "Mathematical Models for Semantic Memory", University of the Republic, Uruguay. Advisors: E. Mizraji (Uruguay) and G. Rubino (France). Started end 2016.

Master Project R& I 2016–2017, of Joshua Peignier and Estelle Varloot: "Game-theoretic tools to analyze classical vs collaborative economies". Advisors: B. Tuffin and P. Maillé from Telecom Bretagne.

10.2.3. Juries

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

- Juan Eduardo Piccini: "Static Reliability and Resilience in Dynamic Systems", University of the Republic, Montevideo, Uruguay, Mars 2016; reviewer.
- Maïder Estécahandy: "Méthodes accélérées de Monte-Carlo pour la simulation d'événements rares. Applications aux Réseaux de Petri", Université de Pau et de l'Amour, Mars 2016; reviewer.
- Wenjing Shuai: "Management of electric vehicle systems with self-interested actors", Telecom Bretagne, Sept. 2016; president.
- Simon Theissing: "Supervision en Transport Multimodal", université de Paris-Saclay, Dec. 2016.

Bruno Sericola was a reviewer of the following PhD defense committee:

- A. Anjuka: "Stationary analysis of fluid queueing models", Faculty of Science and Humanities, Anna University, Chennai, India.

Bruno Sericola was the president of the jury for the recruitement of Inria researchers in 2016.

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

- Juan Eduardo Piccini: "Static Reliability and Resilience in Dynamic Systems", University of the Republic, Montevideo, Uruguay, Mars 2016; reviewer.
- Wassim Abbessi: "Mesures et Modélisation Fluide de Trafic Multimédia en Vue d'une Meilleure Gestion du Flux", ENSI, Tunisia, November 12, 2016; reviewer.
- Yu-Ting Lin: "Performance analysis of video streaming services in mobile networks', ParisTech, Paris, December 9, 2016; reviewer.

César Viho was:

- a member of juries for the recruitment of young graduate scientists and senior researchers at Inria;
- a member of the juries for the recruitment of young Associate Professors and Full Professors at ISTIC-Université Rennes 1;
- the Director of the MATISSE (Mathematics, Electronics and Computer Sciences) doctoral school in charge of managing the recruitment of PhD students and their activities during their doctorate, in all the concerned areas of the doctoral school.

10.3. Popularization

- P. Maillé and B. Tuffin responded to the public consultation on draft BEREC Guidelines on implementation of net neutrality rules. 2016.
- G. Rubino makes regular presentations to high school students about the research work in general, and specific technical topics in particular. Current talks:
  - Randomness as a tool
  - Internet as a research problem
  - Great challenges in maths: the Riemann Hypothesis
  - Great challenges in math/computer science: the “P versus NP” problem

11. Bibliography

Major publications by the team in recent years

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

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