IN PARTNERSHIP WITH:
IMT Atlantique Bretagne-Pays de la Loire

Université Rennes 1

Activity Report 2019

Project-Team DIONYSOS

Dependability Interoperability and perfOrmance aNalYsiS Of networkS

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

RESEARCH CENTER
Rennes - Bretagne-Atlantique

THEME
Networks and Telecommunications

Table of contents

1. Team, Visitors, External Collaborators **1**
2. Overall Objectives **2**
3. Research Program **3**
3.1. Introduction 3
3.2. Quality of Service and Quality of Experience 3
3.3. Stochastic modeling 4
4. Application Domains **5**
4.1. Networking 5
4.2. Stochastic modeling 5
5. Highlights of the Year **5**
5.1.1. Awards 5
5.1.2. Conference 5
6. New Software and Platforms **5**
6.1. IPv6 Test Toolkit 5
6.2. Passive Test Tool 6
6.3. T3DevKit 6
6.4. ttproto 6
6.5. CoAP Testing Tool 7
6.6. ioppytest 7
7. New Results **7**
7.1. Performance Evaluation 7
7.2. Distributed Systems 8
7.3. Machine learning 10
7.4. Future networks and architectures 12
7.5. Wireless Networks 13
7.6. Network Economics 14
7.7. Monte Carlo 15
8. Bilateral Contracts and Grants with Industry **17**
8.1. Cifre contract on Device-Assisted Distributed Machine-Learning on Many Cores 17
8.2. Cifre contract on Personalization for Cognitive Autonomic Networks in 5G 17
8.3. Cifre contract on Resiliency as a Service for 5G networks using Machine Learning 17
8.4. Bilateral Contract with Industry: Nokia Bell Labs 17
9. Partnerships and Cooperations **18**
9.1. Regional Initiatives 18
9.2. National Initiatives 18
9.3. European Initiatives 18
9.4. International Initiatives 18
9.4.1. Inria International Partners 18
9.4.2. Participation in Other International Programs 19
9.4.2.1. Ecos Sud program 19
9.4.2.2. Math and Stic AmSud programs 19
9.4.2.3. PHC Ulysses 20
9.5. International Research Visitors 21
10. Dissemination **21**
10.1. Promoting Scientific Activities 21
10.1.1. Scientific Events: Organisation 21
10.1.1.1. General Chair, Scientific Chair 21
10.1.1.2. Member of the Organizing Committees 21
10.1.2. Scientific Events: Selection 21

10.1.2.1. Chair of Conference Program Committees 21
10.1.2.2. Member of the Conference Program Committees 22
10.1.2.3. Reviewer 23
10.1.3. Journal 23
10.1.3.1. Member of the Editorial Boards 23
10.1.3.2. Reviewer - Reviewing Activities 24
10.1.4. Invited Talks 24
10.1.5. Leadership within the Scientific Community 25
10.1.6. Research Administration 25
10.2. Teaching - Supervision - Juries 25
10.2.1. Teaching 25
10.2.2. Supervision 26
10.2.3. Juries 27
10.3. Popularization 28
10.3.1. Internal or external Inria responsibilities 28
10.3.2. Interventions 28
11. Bibliography **28**

Project-Team DIONYSOS

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A1.2.4. - QoS, performance evaluation
A1.2.5. - Internet of things
A1.3.3. - Blockchain
A1.3.4. - Peer to peer
A3.4.1. - Supervised learning
A3.4.2. - Unsupervised learning
A3.4.3. - Reinforcement learning
A3.4.6. - Neural networks
A3.4.8. - Deep learning
A6.1.2. - Stochastic Modeling
A6.2.3. - Probabilistic methods
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B6.2.4. - Optic technology
B6.3.2. - Network protocols
B6.3.3. - Network Management
B6.3.5. - Search engines
B6.4. - Internet of things

1. Team, Visitors, External Collaborators

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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

5.1.1. Awards

Bruno Tuffin was among the five finalists for the Best Contributed Theoretical Paper Award at the Winter Simulation Conference 2019 for his paper “Randomized Quasi-Monte Carlo for Quantile Estimation” co-authored with Z. Kaplan, Y. Li, M. Nakayama (New Jersey Institute of Technology, USA).

5.1.2. Conference

Yassine Hadjadj-Aoul was General co-chair of the 6th International Conference on Information and Communication Technologies for Disaster Management (ICT-DM), Paris, France. The conference took place on December 18-20 2019. Its proceedings will appear in the IEEE xPlore Digital Library.

6. New Software and Platforms

6.1. IPv6 Test Toolkit

FUNCTIONAL DESCRIPTION: These test suites are developed using the TTCN-3 environment.

The packages contains the full Abstract Test Suites written in TTCN-3 and the source files for building the codecs and adapters with the help of T3DevKit.

- Participants: Annie Floch, Anthony Baire, Ariel Sabiguero, Bruno Deniaud, César Viho and Frédéric Roudaut
- Contact: César Viho

6.2. Passive Test Tool

- Participants: Anthony Baire and César Viho
- Contact: Anthony Baire

6.3. T3DevKit

KEYWORDS: IPv6 - Conformance testing - TTCN-3

SCIENTIFIC DESCRIPTION: 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).

FUNCTIONAL DESCRIPTION: 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) that provides an object oriented framework to manipulate TTCN-3 entities (values, ports, timers, external functions. . .) an implementation of the TRI and TCI standard interfaces default implementations for the system adapter (SA), platform adapter (PA), test management (TM), test logging (TL) and component handling (CH) modules default codecs build scripts for the generation of executable test suites, these are tool-independent and facilitate the distribution of test suite sources

- Participants: Annie Floch, Anthony Baire, Ariel Sabiguero, César Viho and Frédéric Roudaut
- Contact: Federico Sismondi

6.4. ttproto

Testing Tool Prototype

KEYWORDS: Interoperability - Conformance testing - TTCN-3

FUNCTIONAL DESCRIPTION: ttproto is an experimental tool for implementing testing tools, for conformance and interoperability testing.

It was first implemented to explore new features and concepts for the TTCN-3 standard, but we also used it to implement a passive interoperability test suite we provided for the CoAP interoperability event held in Paris in March 2012.

This tool is implemented in python3 and its design was influenced mainly by TTCN-3 (abstract model, templates, snapshots, behaviour trees, communication ports, logging) and by Scapy (syntax, flexibility, customisability)

Its purpose is to facilitate rapid prototyping rather than experimentations (rather than production use). We choosed to maximise its modularity and readability rather than performances and real-time considerations.

Now you should have a look at the Features page: https://www.irisa.fr/tipi/wiki/doku.php/testing_tool_prototype:features

- Contact: Federico Sismondi
- URL: https://www.irisa.fr/tipi/wiki/doku.php/testing_tool_prototype

6.5. CoAP Testing Tool

KEYWORDS: Test - Interoperability - Conformance testing - Plugtests

FUNCTIONAL DESCRIPTION: The software helps developers of the CoAP protocol assessing if their implementations (either CoAP clients or CoAP servers) are conformant to protocol specifications, and interoperable with other implementations. It encompasses:

- Coordination of CoAP interoperability tests
- Analysis of CoAP traces & issuing verdicts
- Automation of open source CoAP implementations for based reference interop testing
- Authors: Federico Sismondi and César Viho
- Contact: Federico Sismondi

6.6. ioppytest

Interoperability testing

KEYWORDS: Interoperability - Conformance testing - CoAP - 6LoWPAN - OneM2M

FUNCTIONAL DESCRIPTION: The software is a framework for developing interoperability tests. The interoperability tests help developers of network protocol assessing if their implementations are conformant to protocol specifications, and interoperable with other implementations.

The software already integrates interoperability tests for CoAP, OneM2M and 6LoWPAN The framework provides the following features to the users:

- Coordination of the interoperability tests (enabling remote testing)
- VPN-like connectivity between users' implementations (enabling remote testing)
- Analysis of exchanged network traces & issuing verdicts
- Automation of open source implementations for based reference interop testing

This framework is the evolution of the CoAP Testing Tool (https://bil.inria.fr/fr/software/view/2937/tab)

- Contact: Federico Sismondi
- URL: https://gitlab.f-interop.eu/f-interop-contributors/ioppytest

7. New Results

7.1. Performance Evaluation

Participants: Gerardo Rubino, Bruno Sericola.

Fluid Queues. Stochastic fluid flow models and, in particular, those driven by Markov chains, have been intensively studied in the last two decades. Not only they have been proven to be efficient tools to mimic Internet traffic flows at a macroscopic level but they are useful tools in many areas of applications such as manufacturing systems or in actuarial sciences, to cite but a few. We propose in [61] a chapter which focus on such a model in the context of performance analysis of a potentially congested system. The latter is modeled by means of a finite-capacity system whose content is described by a Markov driven stable fluid flow. We describe step-by-step a methodology to compute exactly the loss probability of the system. Our approach is based on the computation of hitting probabilities jointly with the peak level reached during a busy period, both in the infinite and finite buffer case. Accordingly we end up with differential Riccati equations that can be solved numerically. Moreover, we are able to characterize the complete distribution of both the duration of congestion and of the total information lost during such a busy period.

Connecting irreducible and absorbing Markov chains. Irreducible Markov chains in continuous time are the basic tool for instance in performance evaluation (typically, a queuing model), where in a large majority of cases, we are interested in the behavior of the modeled system in steady-state. Most metrics used are based on the stationary distribution of the model, under unicity natural conditions. Absorbing Markov chains, also in continuous time, play the equivalent role in dependability evaluation, because realistic models must have a finite lifetime, which corresponds here to the absorption time of the chain. In this case, the object of interest is this lifetime, steady-state gives no useful information about the system, and most of the used metrics are defined based on that object. In [30] with describe different connections between the two worlds together with some consequences of those relations in both areas, that is, both in performance and in dependability.

Transient analysis of Markov queueing models. Analyzing the transient behavior of a queueing system is much harder than studying its steady state, the difference being basically that of moving from a linear system to a linear differential system. However, a huge amount of efforts has been put on the former problem, from all kinds of points of view: trials to find closed-forms of the main state distributions, algorithms for numerical evaluations, approximations of different types, exploration of other transient metrics than the basic state distributions, etc. In [62] we focus on the first two elements, the derivation of closed-forms for the main transient state distributions, and the development of numerical techniques. The chapter is organized as a survey, and the main goal is to position and to underline the role of the uniformization technique, for both finding closed-forms and for developing efficient numerical evaluation procedures. In some cases, we extend the discussion to other related transient metrics that are relevant for applications.

7.2. Distributed Systems

Participants: Hamza Ben Ammar, Yann Busnel, Yassine Hadjadj-Aoul, Yves Mocquard, Frédérique Robin, Bruno Sericola.

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.

Membership management is a classic and fundamental problem in many use cases. In networking for instance, it is useful to check if a given IP address belongs to a black list or not, in order to allow access to a given server. This has also become a key issue in very large-scale distributed systems, or in massive databases. Formally, from a subset belonging to a very large universe, the problem consists in answering the question "Given any element of the universe, does it belong to a given subset?". Since the access of a perfect oracle answering the question is commonly admitted to be very costly, it is necessary to provide efficient and inexpensive techniques in the context where the elements arrive continuously in a data stream (for example, in network metrology, log analysis, continuous queries in massive databases, etc.). In [36], we propose a simple but efficient solution to answer membership queries based on a couple of Bloom filters. In a nutshell, the idea is to contact the oracle only if an item is seen for the first time. We use a classical Bloom filter to remember an item occurrence. For the next occurrences, we answer the membership query using a second Bloom filter, which is dynamically populated only when the database is queried. We provide theoretical bounds on the false positive and negative probabilities and we illustrate through extensive simulations the efficiency of our solution, in comparison with standard solutions such as classic Bloom filters.

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 tuples. 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. We consider recently an application to continuous queries, which are processed by a stream processing engine (SPE) to generate timely results given the ephemeral input data. Variations of input data streams, in terms of both volume and distribution of values, have a large impact on computational resource requirements. Dynamic and Automatic Balanced Scaling for Storm (DABS-Storm) [21] is an original solution for handling dynamic adaptation of continuous queries processing according to evolution of input stream properties, while controlling the system stability. Both fluctuations in data volume and distribution of values within data streams are handled by DABS-Storm to adjust the resources usage that best meets processing needs. To achieve this goal, the DABS-Storm holistic approach combines a proactive auto-parallelization algorithm with a latency-aware load balancing strategy.

Sampling techniques constitute a classical method for detection in large-scale data streams. We have proposed a new algorithm that detects on the fly the k most frequent items in the sliding window model [52]. This algorithm is distributed among the nodes of the system. It is inspired by a recent approach, which consists in associating a stochastic value correlated with the item's frequency instead of trying to estimate its number of occurrences. This stochastic value corresponds to the number of consecutive heads in coin flipping until the first tail occurs. The original approach was to retain just the maximum of consecutive heads obtained by an item, since an item that often occurs will have a higher probability of having a high value. While effective for very skewed data distributions, the correlation is not tight enough to robustly distinguish items with comparable frequencies. To address this important issue, we propose to combine the stochastic approach with a deterministic counting of items. Specifically, in place of keeping the maximum number of consecutive heads obtained by an item, we count the number of times the coin flipping process of an item has exceeded a given threshold. This threshold is defined by combining theoretical results in leader election and coupon collector problems. Results on simulated data show how impressive is the detection of the top-k items in a large range of distributions.

Health Big Data Analysis. The aim of the study was to build a proof-of-concept demonstrating that big data technology could improve drug safety monitoring in a hospital and could help pharmacovigilance professionals to make data-driven targeted hypotheses on adverse drug events (ADEs) due to drug-drug interactions (DDI). In [17], we developed a DDI automatic detection system based on treatment data and laboratory tests from the electronic health records stored in the clinical data warehouse of Rennes academic hospital. We also used OrientDb, a graph database to store informations from five drug knowledge databases and Spark to perform analysis of potential interactions between drugs taken by hospitalized patients. Then, we developed a Machine Learning model to identify the patients in whom an ADE might have occurred because of a DDI. The DDI detection system worked efficiently and the computation time was manageable. The system could be routinely employed for monitoring.

Probabilistic analysis of population protocols. The computational model of population protocols 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. In [23] we 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 the 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 random times, nodes successively interact by pairs exchanging their information on the rumor. In a previous paper, we performed a study of the total number of interactions needed for all the nodes of the network to discover the rumor. While most of the existing results involve huge constants that do not allow us to compare different protocols, we provided a thorough analysis of the distribution of this total number of interactions together with its asymptotic behavior. In this paper we extend this discrete time analysis by solving a conjecture proposed previously and we consider the continuous time case, where a Poisson process is associated to each node to

determine the instants at which interactions occur. The rumor spreading time is thus more realistic since it is the real time needed for all the nodes of the network to discover the rumor. Once again, as most of the existing results involve huge constants, we provide tight bound and equivalent of the complementary distribution of the rumor spreading time. We also give the exact asymptotic behavior of the complementary distribution of the rumor spreading time around its expected value when the number of nodes tends to infinity.

Among the different problems addressed in the model of population protocols, average-based problems have been studied for the last few years. In these problems, agents start independently from each other with an initial integer state, and at each interaction with another agent, keep the average of their states as their new state. In [45] and [63], using a well chosen stochastic coupling, we considerably improve upon existing results by providing explicit and tight bounds of the time required to converge to the solution of these problems. We apply these general results to the proportion problem, which consists for each agent to compute the proportion of agents that initially started in one predetermined state, and to the counting population size problem, which aims at estimating the size of the system. Both protocols are uniform, i.e., each agent's local algorithm for computing the outputs, given the inputs, does not require the knowledge of the number of agents. Numerical simulations illustrate our bounds of the convergence time, and show that these bounds are tight in the sense that among extensive simulations, numerous ones fit very well with our bounds.

Organizing both transactions and blocks in a distributed ledger. We propose in [53] a new way to organize both transactions and blocks in a distributed ledger to address the performance issues of permissionless ledgers. In contrast to most of the existing solutions in which the ledger is a chain of blocks extracted from a tree or a graph of chains, we present a distributed ledger whose structure is a balanced directed acyclic graph of blocks. We call this specific graph a SYC-DAG. We show that a SYC-DAG allows us to keep all the remarkable properties of the Bitcoin blockchain in terms of security, immutability, and transparency, while enjoying higher throughput and self-adaptivity to transactions demand. To the best of our knowledge, such a design has never been proposed.

Performance of caching systems. Several studies have focused on improving the performance of caching systems in the context of Content-Centric Networking (CCN). In [16], we propose a fairly generic model of caching systems that can be adapted very easily to represent different caching strategies, even the most advanced ones. Indeed, the proposed model of a single cache, named MACS, which stands for Markov chain-based Approximation of CCN Caching Systems, can be extended to represent an interconnection of caches under different schemes. In order to demonstrate the accuracy of our model, we proposed to derive models of the two most effective techniques in the literature, namely LCD and LRU-K, which may adapt to changing patterns of access.

One of the most important concerns when dealing with the performance of caching systems is the static or dynamic (on-demand) placement of caching resources. This issue is becoming particularly important with the upcoming advent of 5G. In [33] we propose a new technique exploiting the model previously proposed model in [16], in order to achieve the best trade-off between the centralization of resources and their distribution, through an efficient placement of caching resources. To do so, we model the cache resources allocation problem as a multi-objective optimization problem, which is solved using Greedy Randomized Adaptive Search Procedures (GRASP). The obtained results confirm the quality of the outcomes compared to an exhaustive search method and show how a cache allocation solution depends on the network's parameters and on the performance metrics that we want to optimize.

7.3. Machine learning

Participants: Yassine Hadjadj-Aoul, Corentin Hardy, Quang Pham Tran Anh, Gerardo Rubino, Bruno Sericola, Imane Taibi, César Viho.

Distributed deep learning on edge-devices. A recently celebrated type of deep neural network is the Generative Adversarial Network (GAN). GANs are generators of samples from a distribution that has been learned; they are up to now centrally trained from local data on a single location. We question in [37] the performance of training GANs using a spread dataset over a set of distributed machines, following a gossip

approach shown to work on standard neural networks. This performance is compared to the federated learning distributed method, that has the drawback of sending model data to a server. We also propose a gossip variant, where GAN components are gossiped independently. Experiments are conducted with Tensorflow with up to 100 emulated machines, on the canonical MNIST dataset. The position of the paper is to provide a first evidence that gossip performances for GAN training are close to the ones of federated learning, while operating in a fully decentralized setup. Second, to highlight that for GANs, the distribution of data on machines is critical (i.e., i.i.d. or not). Third, to illustrate that the gossip variant, despite proposing data diversity to the learning phase, brings only marginal improvements over the classic gossip approach.

This work is a part of the thesis [14].

Deep reinforcement learning for network slicing. Recent achievements in Deep Reinforcement Learning (DRL) have shown the potential of these approaches to solve combinatorial optimization problems. However, the Deep Deterministic Policy Gradient algorithm (DDPG), which is one of the most effective techniques, is not suitable to deal with large-scale discrete action space, which is the case of the Virtual Network Function-Forwarding Graph (VNF-FG) placement. To deal with this problem, we propose several enhancements to improve DDPG efficiency [25][47]. The conventional DDPG generates only one action per iteration; thus, it slowly explores the action space especially in a large action space. Thus, we propose to enhance the exploration by considering multiple noisy actions. In order to avoid getting stuck at a local minimum, we propose to multiply the number of critic (for Q-value) neural networks [25]. In order to improve further the exploration, we propose in [47] an evolutionary algorithm to evolve these neural networks in order to discover better ones.

The techniques presented above are generic and can be applied to a variety of problems. To make them even more effective for network slicing problems, we have also proposed to combine them with a proposed First-Fit heuristic that allows for even more interesting results.

Machine learning for Indoor Outdoor detection. Detecting whether a mobile user is indoor or outdoor is an important issue which significantly impacts user behavior contextualization and mobile network resource management. In [59] we investigate hybrid/semi-supervised Deep Learning-based methods for detecting the environment of an active mobile phone user. They are based on both labeled and unlabeled large real radio data obtained from inside the network and from 3GPP signal measurements. We have empirically evaluated the effectiveness of the semi-supervised learning methods using new real-time radio data, with partial ground truth information, gathered massively from multiple typical and diversified locations (indoor and outdoor) of mobile users. We also presented an analysis of such schemes as compared to the existing supervised classification methods including SVM and Deep Learning [57].

Cognition of user behavior can be seen as an efficient tool for automation of future mobile networks. The work presented in [51] deals with the user behaviour modeling. The model includes the prediction of two main features related to mobile user context: the environment and the mobility. We investigate Deep Learning based methods for simultaneously detecting the environment and the mobility state. We empirically evaluate the effectiveness of the proposed techniques using real-time radio data, which has been massively gathered from multiple diversified situations of mobile users.

Predicting the future Perceived Quality level with PSQA. PSQA is a technology developed by Dionysos during a period of several years, whose aim is quantifying the Quality of Experience (more precisely, the Perceived Quality) of an application or service built on the Internet around the transport of audio or video-audio signals. The main properties of PSQA are the its accuracy (indistinguishable from a subjective testing session), the fact that it is fully automatic, with no reference, and able to operate in real time. PSQA is based on supervised learning (the tool learns from subjective testing panels); once trained and validated, it works with no human intervention. In the PSQA project we selected the Random Neural Network tool for the supervised learning associated tasks, after a comparison with the available techniques at the beginning of the project. In [31] we recall all these elements, including the numerical aspects on the optimization side of the learning process, and then, we focus in the current developments where the goal is to predict the Perceived Quality in the close future. This includes the description of the Reservoir Computing models for time series forecasting, and of a tool we proposed, called Echo State Queueing Network, which is a mix between Reservoir Computing and Random Neural Networks.

7.4. Future networks and architectures

Participants: Yassine Hadjadj-Aoul, Gerardo Rubino, Quang Pham Tran Anh, Anouar Rkhami.

Machine learning for network slicing. Network Function Virtualization (NFV) provides a simple and effective mean to deploy and manage network and telecommunications' services. A typical service can be expressed in the form of a Virtual Network Function-Forwarding Graph (VNF-FG). Allocating a VNF-FG is equivalent to placing VNFs and virtual links onto a given substrate network considering resources and quality of service (QoS) constraints. The deployment of VNF-FGs in large-scale networks, such that QoS measures and deployment cost are optimized, is an emerging challenge. Single-objective VNF-FGs allocation has been addressed in existing literature; however, there is still a lack of studies considering multi-objective VNF-FGs allocation. In addition, it is not trivial to obtain optimal VNF-FGs allocation due to its high computational complexity even in the single-objective case. Genetic algorithms (GAs) have proved their ability in coping with multi-objective optimization problems, thus we propose, in [26], a GA-based scheme to solve multi-objective VNF-FGs allocation problem. The numerical results confirm that the proposed scheme can provide near Pareto-optimal solutions within a short execution time.

In [25], we explore the potential of deep reinforcement learning techniques for the placement of VNF-FGs. However, it turns out that even the most well-known learning technique is ineffective in the context of a large-scale action space. In this respect, we propose approaches to find out feasible solutions while improving significantly the exploration of the action space. The simulation results clearly show the effectiveness of the proposed learning approach for this category of problems. Moreover, thanks to the deep learning process, the performance of the proposed approach is improved over time.

The placement of services, as described above, is extremely complex. The issue is even more complex when it comes to placing a service on several non-cooperative domains, where the network operators hide their infrastructure to other competing domains. In [56], we address these problems by proposing a deep reinforcement learning based VNF-FG embedding approach. The results provide insights into the behaviors of non-cooperative domains. They also show the efficiency of the proposed VNF-FG deployment approach having automatic inter-domain load balancing.

Consistent QoS routing in SDN networks. The Software Defined Networking (SDN) paradigm proposes to decouple the control plane (decision-making process) and the data plane (packet forwarding) to overcome the limitations of traditional network infrastructures, which are known to be difficult to manage, especially at scale. Although there are previous works focusing on the problem of Quality of Service (QoS) routing in SDN networks, only few solutions have taken into consideration the network consistency, which reflects the adequacy between the decisions made and the decisions that should be taken. Therefore, we propose, in [19], a network architecture that guarantees the consistency of the decisions to be taken in an SDN network. A consistent QoS routing strategy is, then, introduced in a way to avoid any quality degradation of prioritized traffic, while optimizing resources usage. Thus, we proposed a traffic dispersion heuristic in order to achieve this goal. We compared our approach to several existing framework in terms of best-effort flows average throughput, average video bitrate and video Quality of Experience (QoE). The emulations results, which are performed using the Mininet environment, clearly demonstrate the effectiveness of the proposed methodology that outperforms existing frameworks.

Optical networks. In [20] we attack the so called *Capacity Crunch* crisis announced for optical networks infrastructures. This problem refers to the facts that (i) the transmission capacity of an optical fiber is not limitless, (ii) the bandwidth demand continues to increase exponentially and (iii) the limits are getting dangerously close. The cheapest and shortest-term solution is to increase efficiency, because there are several possibilities to do so. This work is a contribution in that direction. We focus on strongly improving the wavelength assignment procedure by moving to an heterogeneous and flexible process, adapting the dimensioning to the individual users' needs in QoS. In the paper we demonstrate that a non-uniform dimensioning strategy and a tighten QoS provision allows to save significant networks capacity, while simultaneously provisioning to each user the QoS established in its Service Level Agreement.

Survivability of internet services is a significant and crucial challenge in designing future optical networks. A robust infrastructure and transmission protocols are needed to handle such a situation so that the users can maintain communication despite the existence of one or more failed components in the network. For this reason, we present in [40] a generalized approach able to tolerate any failure scenario, to the extent the user can still communicate with the remaining components, where a scenario corresponds to an arbitrary set of links in a non-operational state. To assess the survivability problem, we propose a joint solution to the problems listed next. We show how to find a set of primary routes, a set of alternate routes associated with each failure scenario, and the capacity required on the network to allow communication between all users, in spite of the links' failures, while satisfying for each user a specific predefined quality of service threshold, defined in the Service Level Agreement (SLA). Numerical results show that the proposed approach not only enjoys the advantages of low complexity and ease of implementation but is also able to achieve significant resource savings compared to existing methods. The savings are higher than 30% on single link failures and more than a 100% on two simultaneous link failures scenarios as well as in more complex situations.

Network tomography. Internet tomography studies the inference of the internal network performances from end-to-end measurements. For this problem, Unicast probing can be advantageous due to the wide support of unicast and the easy deployment of unicast probing paths. In [48] we propose two statistical generic methods for the inference of additive metrics using unicast probing. Our solutions give more flexibility in the choice of the collection points placement. Moreover, the probed paths are not limited to specific topologies. Firstly, we propose the k-paths method that extends the applicability of a previously proposed solution called Flexicast for tree topologies. It is based on the Expectation-Maximization (EM) algorithm which is characterized by high computational and memory complexities. Secondly, we propose the Evolutionary Sampling Algorithm (ESA) that enhances the accuracy and the computing time but following a different approach. In [49] we present a different approach, targeted at link metrics inference in an SDN/NFV environment (even if it can be exported outside this field) that we called TOM (Tomography for Overlay networks Monitoring). In such an environment, we are particularly interested in supervising network slicing, a recent tool enabling to create multiple virtual networks for different applications and QoS constraints on a Telco infrastructure. The goal is to infer the underlay resources states from the measurements performed in the overlay structure. We model the inference task as a regression problem that we solve following a Neural Network approach. Since getting labeled data for the training phase can be costly, our procedure generates artificial data instead. By creating a large set of random training examples, the Neural Network learns the relations between the measures done at path and link levels. This approach takes advantage of efficient Machine Learning solutions to solve a classic inference problem. Simulations with a public dataset show very promising results compared to statistical-based methods.We explored mainly additive metrics such as delays or logs of loss rates, but the approach can also be used for non-additive ones such as bandwidth.

7.5. Wireless Networks

Participants: Yann Busnel, Yassine Hadjadj-Aoul, Ali Hodroj, Bruno Sericola, César Viho.

Self-organized UAV-based Supervision and Connectivity. The use of drones has become more widespread in recent years. Many use cases have developed involving these autonomous vehicles, ranging from simple delivery of packages to complex emergency situations following catastrophic events. The miniaturization and very low cost of these machines make it possible today to create large meshes to ensure network coverage in disaster areas, for instance. However, the problems of scaling up and self-organization are still open in these use cases. In [35], we propose a position paper that first presents different new requirements for the deployment of unmanned aerial vehicles (UAV) networks, involving the use of many drones. Then, it introduces solutions from distributed algorithms and real-time data processing to ensure quasi-optimal solutions to the raised problems.

More specifically, providing network services access anytime and anywhere is nowadays a critical issue, especially in disaster emergency situations. A natural response to such a need is the use of autonomous flying drones to help finding survivors and provide network connectivity to the rescue teams. In [34], we propose VESPA, a distributed algorithm using only one-hop information of the drones, to discover targets

with unknown location and auto-organize themselves to ensure connectivity between them and the sink in a multi-hop aerial wireless network. We prove that connectivity, termination and coverage are preserved during all stages of our algorithm, and we evaluate the algorithm performances through simulations. Comparison with a prior work shows the efficiency of VESPA both in terms of discovered targets and number of used drones.

Enhancing dynamic adaptive streaming over HTTP for multi-homed users. Mobile video traffic accounted for more than half of all mobile data traffic over the past two years. Due to the limited bandwidth, users demand for high-quality video streaming becomes a challenge, which could be addressed by exploiting the emerging diversity of access network and adaptive video streaming. In [39], a network selection algorithm is proposed for Dynamic Adaptive Streaming over HTTP (DASH),the famous international standard on video streaming, to enhance the received video quality to a "multi-homed user" equipped with multiple interfaces. A Multi-Armed Bandit (MAB) heuristic is proposed for a dynamic selection of the best interface at each step. While the Adaptive Bit rate Rules (ABR) used in DASH allow the video player client to dynamically pick the bit rate level according to the perceived network conditions, at each switching step a quality degradation may occur due to the difference in network conditions of the available interfaces. This paper aims to close this gap by (i) designing a MAB algorithm over DASH for a multi-homed user, (ii) evaluating the proposed mechanism through a test-bed implementation, (iii) extending the classic MAB model and (iv) discussing some open issues.

Vehicular networks. According to recent forecasts, constant population growth and urbanization will bring an additional load of 2.9 billion vehicles to road networks by 2050. This will certainly lead to increased air pollution concerns, highly congested roads putting more strain on an already deteriorated infrastructure, and may increase the risk of accidents on the roads as well. Therefore, to face these issues we need not only to promote the usage of smarter and greener means of transportation but also to design advanced solutions that leverage the capabilities of these means along with modern cities' road infrastructure to maximize its utility. In [38], we explore novel ways of utilizing inter-vehicle and vehicle to infrastructure communication technology to achieve a safe and efficient lane change manoeuvre for Connected and Autonomous Vehicles (CAVs). The need for such new protocols is due to the risk that every lane change manoeuvre brings to drivers and passengers lives in addition to its negative impact on congestion level and resulting air pollution, if not performed at the right time and using the appropriate speed. To avoid this risk, we design two new protocols; one is built upon and extends an existing one, and aims at ensuring a safe and efficient lane change manoeuvre, while the second is an original solution inspired from the mutual exclusion concept used in operating systems. This latter complements the former by exclusively granting lane change permission in a way that avoids any risk of collision.

7.6. Network Economics

Participants: Bruno Tuffin, Patrick Maillé.

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.

In 2019, we have had a particular focus on network neutrality issues, but trying to look at them from original perspectives, and investigating so-called grey zones not yet addressed in the debate.

What implications of a global Internet with neutral and non-neutral portions? Network neutrality is being discussed worldwide, with different countries applying different policies, some imposing it, others acting against regulation or even repealing it as recently in the USA. The goal of [43] is to model and analyze the interactions of users, content providers, and Internet service providers (ISPs) located in countries with different rules. To do so, we build a simple two-regions game-theoretic model and focus on two scenarios of net neutrality relaxation in one region while it remains enforced in the other one. In a first scenario, from an initial situation where both regions offer the same basic quality, one region allows ISPs to offer fast lanes for a premium while still guaranteeing the basic service; in a second scenario the ISPs in both regions play a game on quality, with only one possible quality in the neutral region, and two in the non-neutral one but with a regulated quality ratio between those. Our numerical experiments lead to very different outcomes, with the

first scenario benefiting to all actors (especially the ones in the relaxed-neutrality region) and the second one mainly benefiting mostly to ISPs while Content Providers are worse off, suggesting that regulation should be carefully designed.

Investigating a grey zone: sponsored data. Sponsored data, where content providers have the possibility to pay wireless providers for the data consumed by customers and therefore to exclude it from the data cap, is getting widespread in many countries, but is forbidden in others for concerns of infringing the network neutrality principles. We present in [44] a game-theoretic model analyzing the consequences of sponsored data in presence of competing wireless providers, where sponsoring decided by the content provider can be different at each provider. We also discuss the impact on the proportion of advertising on the displayed content. We show that, surprisingly, the possibility of sponsored data may actually reduce the benefits of content providers and on the other hand increase the revenue of ISPs in competition, with a very limited impact on user welfare.

Search engines, bias, consensus, and search neutrality debate. Different search engines provide different outputs for the same keyword. This may be due to different definitions of relevance, and/or to different knowledge/anticipation of users' preferences, but rankings are also suspected to be biased towards own content, which may prejudicial to other content providers. In [41], we make some initial steps toward a rigorous comparison and analysis of search engines, by proposing a definition for a consensual relevance of a page with respect to a keyword, from a set of search engines. More specifically, we look at the results of several search engines for a sample of keywords, and define for each keyword the visibility of a page based on its ranking over all search engines. This allows to define a score of the search engine for a keyword, and then its average score over all keywords. Based on the pages visibility, we can also define the consensus search engine as the one showing the most visible results for each keyword. We have implemented this model and present an analysis of the results in [41].

7.7. Monte Carlo

Participants: Bruno Tuffin, Gerardo Rubino.

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 of regenerative systems. Rare events occur by definition with a very small probability but are important to analyze because of potential catastrophic consequences. In [32], we focus on rare event for so-called regenerative processes, that are basically processes such that portions of them are statistically independent of each other. For many complex and/or large models, simulation is the only tool at hand but it requires specific implementations to get an accurate answer in a reasonable time. There are two main families of rare-event simulation techniques: Importance Sampling (IS) and Splitting. In a first part, we briefly remind them and compare their respective advantages but later (somewhat arbitrarily) devote most of the work to IS. We then focus on the estimation of the mean hitting time of a rarely visited set. A natural and direct estimator consists in averaging independent and identically distributed copies of simulated hitting times, but an alternative standard estimator uses the regenerative structure allowing to represent the mean as a ratio of quantities. We see that in the setting of crude simulation, the two estimators are actually asymptotically identical in a rare-event context, but inefficient for different, even if related, reasons: the direct estimator requires a large average computational time of a single run whereas the ratio estimator faces a small probability computation. We then explain that the ratio estimator is advised when using IS. In the third part, we discuss the estimation of the distribution, not just the mean, of the hitting time to a rarely visited set of states. We exploit the property that the distribution of the hitting time divided by its expectation converges weakly to an exponential as the target set probability decreases to zero. The problem then reduces to the extensively studied estimation of the mean described previously. It leads to simple estimators of a quantile and conditional tail expectation of the hitting time. Some variants are presented and the accuracy of the estimators is illustrated on numerical examples.

In [46], we introduce and analyze a new regenerative estimator. A classical simulation estimator of this class is based on a ratio representation of the mean hitting time, using crude simulation to estimate the numerator and importance sampling to handle the denominator, which corresponds to a rare event. But the estimator of the numerator can be inefficient when paths to the set are very long. We thus introduce a new estimator that expresses the numerator as a sum of two terms to be estimated separately. We provide theoretical analysis of a simple example showing that the new estimator can have much better behavior than the classical estimator. Numerical results further illustrate this.

Randomized Quasi-Monte Carlo for Quantile Estimation. Quantile estimation is a key issue in many application domains, but has been proved difficult to efficiently estimate. In [42], we compare two approaches for quantile estimation via randomized quasi-Monte Carlo (RQMC) in an asymptotic setting where the number of randomizations for RQMC grows large but the size of the low-discrepancy point set remains fixed. In the first method, for each randomization, we compute an estimator of the cumulative distribution function (CDF), which is inverted to obtain a quantile estimator, and the overall quantile estimator is the sample average of the quantile estimators across randomizations. The second approach instead computes a single quantile estimator by inverting one CDF estimator across all randomizations. Because quantile estimators are generally biased, the first method leads to an estimator that does not converge to the true quantile as the number of randomizations goes to infinity. In contrast, the second estimator does, and we establish a central limit theorem for it. Numerical results further illustrate these points.

Reliability analysis with dependent components. In the reliability area, the Marshall-Olkin copula model has emerged as the standard tool for capturing dependence between components in failure analysis. In this model, shocks arise at exponential random times, affecting one or several components, thus inducing a natural correlation in the failure process. However, because the number of parameter of the model grows exponentially with the number of components, the tool suffers from the "curse of dimensionality." These models are usually intended to be applied to design a network before its construction; therefore, it is natural to assume that only partial information about failure behavior can be gathered, mostly from similar existing networks. To construct them, we propose in [22] an optimization approach to define the shock's parameters in the copula, in order to match marginal failures probabilities and correlations between these failures. To deal with the exponential number of parameters of the problem, we use a column-generation technique. We also discuss additional criteria that can be incorporated to obtain a suitable model. Our computational experiments show that the resulting tool produces a close estimation of the network reliability, especially when the correlation between component failures is significant.

The Creation Process is an algorithm that transforms a static network model into a dynamic one. It is the basis of different variance reduction methods designed to make efficient reliability estimations on highly reliable networks in which links can only assume two possible values, operational or failed. In [18] the Creation Process is extended to let it operate on network models in which links can assume more than two values. The proposed algorithm, that we called Multi-Level Creation Process, is the basis of a method, also introduced here, to make efficient reliability estimations of highly reliable stochastic flow networks. The method proposed, which consists in an application of Splitting over the Multi-Level Creation Process, is empirically shown to be accurate, efficient, and robust. This work was the first step towards a way to implement an efficient estimation procedure for the problem of flow reliability analysis. Our first solution in that direction was presented in [54], where not only we could develop a procedure providing a significant variance reduction but that allows a direct extension to the final target, the solution to the same estimation problem in the more general case of models where the components are dependent. The idea is an original way of implementing a splitting procedure that leads simultaneously to these two properties.

Rare events in risk analysis. One of the main tasks when dealing with critical systems (systems where specific classes of failures can deal to human losses, or to huge financial losses) is the ability to quantify the associated risks, which is the door that, when opened, leads to paths towards understanding what can happen and why, and towards capturing the relationships existing between the different parts of the system, with respect to those risks. This is also the necessary preliminary work allowing to evaluate the relative importance of different factors, always from the viewpoint of the considered risks, an important component of any disaster

management system. Identifying the dominant ones is important to know which parts of the system we must reinforce. The keynote [29] described different tools available for these tasks, and how they can be used depending on the objectives to reach. The focus was on Monte Carlo techniques, the only available ones in general, because the only ones able to evaluate any kind of system, and how they deal with rare events. It also discussed the main related open research problems. The tutorial [64] is closely related to previous talk, but the presentation explores more in general the estimation problem and the main families of techniques available for its solution (Importance Sampling, and the particular case of Zero-Variance methods, Splitting, Recursive Variance Reduction techniques, etc.).

8. Bilateral Contracts and Grants with Industry

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

Participants: Corentin Hardy, Bruno Sericola.

This is a Cifre contract (2016-2019) including a PhD thesis supervision (PhD of Corentin Hardy), done with Technicolor. The starting point of this thesis was 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. The thesis has been defended in April 2019.

8.2. Cifre contract on Personalization for Cognitive Autonomic Networks in 5G

Participant: César Viho.

This is a Cifre contract (2017-2019) including a PhD thesis supervision (PhD of Illyyne Saffar), done with Nokia, on the proposition to use machine learning and data analytics to transform user and network data into actionable knowledge which in turn can be automatically exploited by Autonomic Networking approaches for cognitive self management of the 5G network.

8.3. Cifre contract on Resiliency as a Service for 5G networks using Machine Learning

Participants: Sofiene Jelassi, Gerardo Rubino.

The is a Cifre contract including a PhD thesis supervision (PhD of Soumaya Kaada), done with Nokia (Paris). It concerns providing on demand and evolving resiliency schemes over 5G network using advanced machine learning algorithms. It relies on a highly flexible network infrastructure supporting both wired and wireless programmable data planes through a highly-efficient distributed network operating system.

8.4. Bilateral Contract with Industry: Nokia Bell Labs

Participants: Yassine Hadjadj-Aoul, Quang Pham Tran Anh, Anouar Rkhami, Gerardo Rubino.

Gerardo Rubino is the coordinator of the research action "Analytics and machine learning", with Nokia Bell Labs. The objective is to carry out common research on an integrated framework for 5G, programmable networks, IoT and clouds that aims at statically and dynamically managing and optimizing the 5G infrastructure using, in particular, Machine Learning techniques.

9. Partnerships and Cooperations

9.1. Regional Initiatives

- Yann Busnel is a member of the ONCOSHARe project (ONCOlogy bigdata SHARing for Research) funded by Brittany and Pays de la Loire regions, with 280.000 k€ for 24 months.
- Bruno Sericola continues to work on the analysis of fluid queues with Fabrice Guillemin from Orange Labs in Lannion, France.

9.2. National Initiatives

ANR

- Yassine Hadjadj-Aoul, Sofiene Jelassi and Gerardo Rubino are participating at 20% of their time to the IRT BCOM granted by the ANR.
- Yann Busnel is a member of the two following projects: INSHARE granted by the ANR (ANR-15-CE19-0024) and BigClin granted by the LabEx CominLabs (ANR-10-LABX-07-01).

IPL (Inria Project Lab) BetterNet

Yassine Hadjadj-Aoul, Gerardo Rubino and Bruno Tuffin are members of the IPL (Inria Project Lab) BetterNet: An Observatory to Measure and Improve Internet Service Access from User Experience, 2016-2020.

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: 1) tools, models and algorithms/heuristics will be provided to collect data, 2) acquired data will be analyzed, and shared appropriately with scientists, stakeholders and civil society, and 3) new value-added services will be proposed to end-users.

Inria Exploratory Action SNIDE We are leading of the Inria Exploratory Action SNIDE (Search Non neutratlIty DEtection) 2019-2023, involving Dionysos and MIMR (Grenoble).

Search engines play a key role to access content and are accused to bias their results to favor their own services among others. This has led to the sensitive search neutrality debate, similar to the network neutrality debate currently discussed on the role of ISPs. Our goal in this project is to develop and apply a methodology aiming at highlighting a bias and quantifying its impact.

An initial version of our meta-engine (which will be further develop by incorporating outlier detection tests) can be found at https://snide.irisa.fr/.

9.3. European Initiatives

- Bruno Sericola continues to work on the analysis of fluid queues with Marie-Ange Remiche from the university of Namur in Belgium.
- Gerardo Rubino has a long collaboration with Sebastián Basterrech at the VSB-Technical University of Ostrava, Czech Republic, on Machine Learning.

9.4. International Initiatives

9.4.1. Inria International Partners

9.4.1.1. Informal International Partners

We keep a long collaboration in research with the CalPoly at Pomona, USA, on the transient analysis of Markovian models.

9.4.2. Participation in Other International Programs

9.4.2.1. Ecos Sud program

Project "Masc"

Title: Mathematical Algorithms for Semantic Cognition

International Partner (Institution - Laboratory - Researcher):

Universidad de la República (Uruguay) - Biophysics - Eduardo Mizraji, Jorge Graneri

Universidad de la República (Uruguay) - Computer science - Pablo Rodríguez-Bocca

Duration: 2018 – 2020

Start year: 2018

MASC is a three-year project (code U17E03) with the Faculty of Sciences of the university of the Republic, in Uruguay, on the application of mathematical modeling tools to a better understanding of a cognitive disease called semantic dementia. This involves Prof. Eduardo Mizraji and Jorge Graneri, a PhD student whose co-advisors are Prof. Mizraji and G. Rubino from Dionysos, plus Pablo Rodríguez Bocca, from the Engineering Faculty of the university of the Republic. Our contribution to this project is around the use of mathematical tools applied to the analysis of cognition pathologies.

9.4.2.2. Math and Stic AmSud programs

Project "RareDep"

Title: Rare events analysis in multi-component systems with dependent components

International Partner (Institution - Laboratory - Researcher):

Universidad Adolfo Ibañez (Chile) - Faculty of Engineering and Sciences - Javiera Barrera

Universidad de la República Uruguay (Uruguay) - Computer Science - Héctor Cancela

Universidade Federal de Pernambuco (Brazil) - Mathematics - Pablo Martín Rodríguez

Duration: 2019 – 2020

Start year: 2019

See also: http://mansci-web.uai.cl/raredep/RareDep/Welcome.html

The RareDep project focus on developing new techniques addressing two central elements for the improvement of the available tools for risk analysis of complex systems. One is the case of rare events, occurring both in performance and in dependability evaluation of systems modeled as made of many components. Rare events preclude the use of Monte Carlo techniques when the event of interest has a small probability of occurring, and specific methods are necessary, with many open problems in the area. Independence is the usual assumption when building models (more precisely, in almost all works in the field make this assumption), but we know that the assumption is almost never satisfied. We often are constrained by the necessity of assuming independent components in order to be able to use the available methods. In RareDep, we intend to address both problems simultaneously. This needs to develop new variance reduction techniques, for instance in the Importance Sampling family, or in the Splitting one, to be able to exploit data concerning dependencies between the components of the models. This will be built on top of our accumulated experience in the Monte Carlo area (and related fields, such as Quasi-Monte Carlo, numerical integration, etc.), and a starting effort to begin the exploration of what happens when we relax the omnipresent independence hypothesis. We will also explore what happens if we consider new ideas (several coming from the participants of the proposal) for defining new metrics in some specific areas. In these cases, everything is to be done: procedures to deal with rare events, modeling techniques to deal with dependencies between the system's components, and then, both issues at the same time. Our main application area will concern different types of modern networks (in communications, or in energy distribution, for instance).

Project "ACCON"

Title: Algorithms for the Capacity Crunch problem in Optical Networks

International Partner (Institution - Laboratory - Researcher):

Universidad de la República Uruguay (Uruguay) - Computer Science - Héctor Cancela

UTFSM (Chile) - Télématica - Reinaldo Vallejos

Universidad de Valparaiso (Chile) - Computer Science - Marta Barría

Duration: 2019 – 2020

Start year: 2019

See also: http://accon.elo.usm.cl/

The rapid increase in demand for bandwidth from existing networks has caused a growth in the use of telecommunications technologies, especially WDM optical networks. So far, communication technologies have been able to meet the bandwidth demand. Nevertheless, this decade researchers have anticipated a coming "Capacity Crunch" potential problem associated with these networks. It refers to fact that the transmission capacity limit on optical fibers is close to be reached in the near future. It is then urgent to make the current network architectures evolve, in order to satisfy the relentless exponential growth in bandwidth demand. In other words, the performance bottleneck for optical infrastructures is concentrated around this limiting situation, and the most efficient way of preparing the future of these fundamental technological systems that support the backbone of the Internet is to focus on solving the related management problems. In the previously described scientific context, the ACCON project has a main scientific goal: the development of new strategies capable to provide better resource management techniques to face the threat of the Capacity Crunch. To this end, we will explore the utilization of different analytical techniques to evaluate the performance of several network architecture paradigms, in order to assess their viability in the near future. This will provide us the needed insight leading to finding new strategies for efficiently managing the network resources, and consequently, to contribute addressing this coming Capacity Crunch problem.

9.4.2.3. PHC Ulysses

Project "AFFINE"

Title: Achieving Energy Efficient Communication in Future Networks by Supporting Multi-Access Edge Computing in Internet of Things (IoT)

International Partners (Institution - Laboratory - Researcher):

University College Dublin (Ireland) - Computer Science - Lina Xu

Duration: 1 year

Start year: January 2019

Yassine Hadjadj-Aoul and Lina Xu received a grant from the PHC Ulysses (for French-Irish collaboration). The aim of this project is to improve the energy efficiency for data transmission and communication in IoT networks and therefore to reduce electricity consumption and CO_2 emissions.

Yann Busnel has taken part in several events to develop Indo-French collaborations, notably within the framework of Campus France. In particular, he led the round table on Artificial Intelligence and Mathematics at the Knowledge Summit 2 in Lyon in October 2019, in the presence of the Minister, Frédérique Vidal.

9.5. International Research Visitors

9.5.1. Visits of International Scientists

We have received the following international scientists:

- M. Nakayama (New Jersey Institute of Technology, USA): one week in July 2019.
- DanHua ShangGuan (Institute of Applied Physics and Computational Mathematics, Beijing, China), one month in September 2019.
- Vamsi Bulusu from VJTI Mumbai visited us for 4 months between August and Novembre 2019.
- Jorge Graneri (Sep.–Oct.) and Eduardo Mizraji (Sep.), UDELAR, Uruguay, in the context of the MASC project.
- Nicolás Jara, UTFSM, Chile, Dec., in the context of the ACCON project.
- Franco Robledo, UDELAR, Uruguay, in Feb.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events: Organisation

We are organizing the mini-symposium entitled "Probabilistic approaches for studying blockchain dynamics" of the 8th European Congress of Mathematics, 5 - 11 July 2020, Portorož, Slovenia This mini-symposium aims at bringing together international researchers active on blockchain analysis, and allowing the interaction between different expertises: Markov chain, game theory, fluid limits as well as on different types of stochastic processes. It also aims at gather mathematicians using a theoretical approach to analyze blockchain with those characterizing blockchains through simulations or numerical techniques, and thus it will encourage new collaborations.

10.1.1.1. General Chair, Scientific Chair

- Yassine Hadjadj-Aoul was the General Chair for the *The 6th International Conference on Information and Communication Technologies for Disaster Management (ICT-DM'2019)*, Co-sponsored by IEEE, in Paris (France), December 2019.

10.1.1.2. Member of the Organizing Committees

- Gerardo Rubino and Bruno Tuffin are members of the Steering Committee of the International Workshop on Rare Event Simulation (RESIM) and of Monte Carlo Method Conference (MCM) series.
- Yassine Hadjadj-Aoul is member of the Steering Committee of the International Conference on Information and Communication Technologies for Disaster Management (ICT-DM). He is co-chairing the Steering Committee since 2016.

10.1.2. Scientific Events: Selection

10.1.2.1. Chair of Conference Program Committees

- Bruno Tuffin was TPC co-chair of the 14th Workshop on the Economics of Networks, Systems and Computation (NetEcon 2019), June 2019, Phoenix, AZ, USA.
- Yassine Hadjadj-Aoul was TPC co-chair of *The 11th Wireless Days Conference (WD'2019*, Co-sponsored by IEEE, Manchester, April 2019, Manchester, UK.
- Yassine Hadjadj-Aoul was TPC track chair of the "Satellites IoT and M2M Networks" track, for *The 2nd International Conference on Smart Communications and Networking (SmartNets 2019)*, Co-sponsored by IEEE, December 2019, Sharm El Sheik, Egypt.

- Yassine Hadjadj-Aoul was TPC track chair of the "Cloud & Fog Computing" track, for *International Symposium on Networks, Computers and Communications (ISNCC 2019)*, Co-sponsored by IEEE, June 2019, Istanbul, Turkey.

10.1.2.2. Member of the Conference Program Committees

Bruno Tuffin was TPC member of the following conferences:

- ValueTools 2019, Palma de Mallorca, Spain, March 12-15, 2019
- First IEEE Workshop on the ECOnomics of Fog, Edge, and Cloud Computing (ECOFEC 2019), in conjunction with IEEE INFOCOM 2019, Paris, France
- IEEE International Conference on Communications (IEEE ICC 2019), May 20-24 2019, Shanghai, China.
- 12th International Conference on Monte Carlo Methods and Application (MCM 2019), Sydney, Australia, July 8-12, 2019.
- 31th International Teletraffic Congress (ITC 31), 27-29 August 2019, Budapest, Hungary.
- The International Symposium on Ubiquitous Networking (UNet'19), September 16-19, 2019, Limoges, France.
- GECON 2019 - 16th International Conference on Economics of Grids, Clouds, Software, and Services, Leeds, UK, 17-29 Sept. 2019
- The 2019 IEEE 2nd 5G World Forum (5GWF'19), Dresden, Germany, Sept 30-Oct 2, 2019.
- Financial Risk Track, Winter Simulation Conference (WSC'19), National Harbor, MD, USA, December 8-11, 2019.

Patrick Maillé was TPC member of the following conferences:

- ACM MobiHoc 2019, 20th International Symposium on Mobile Ad Hoc Networking and Computing, Catania, Italy, July 2-5, 2019
- IFIP WIOPT 2019, 17th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks, Avignon, France, June 3–7, 2019
- IEEE International Conference on Communications (IEEE ICC 2019), May 20-24 2019, Shanghai, China.
- Algotel 2019, Narbonne, France, June 3-7, 2019
- NetEcon 2019, 14th workshop on the Economics of Networks, Systems and Computation, Phoenix, AZ, USA, June 28, 2019
- GIIS 2019, Global Information Infrastructure Symposium, Paris, France, December 18-20, 2019
- AdHoc-Now 2019, 18th International Conference on Ad Hoc Networks and Wireless, Luxembourg, October 1-3, 2019
- ValueTools 2019, Palma de Mallorca, Spain, March 12-15, 2019

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

- NCA 2019: 18th IEEE International Symposium on Network Computing and Applications, Boston, USA, September 2019.
- AdHoc Now 2019: 18th International Conference on Ad Hoc Networks and Wireless, Luxembourg, October 2019.

Bruno Sericola was TPC member of the following conference:

- ASMTA 2019 : 25th International Conference on Analytical and Stochastic Modelling Techniques and Applications, Moscow, Russia, October 23 — 25, 2019.

Yassine Hadjadj-Aoul was a member of the program committee of the following events (partial list):

- IEEE Globecom 2019 - IEEE Global Communications Conference, Waikoloa, HI, USA, December 9-13, 2019.
- IEEE ICC 2018 - IEEE International Conference on Communications, Shanghai, China, MO, USA, May 20-24, 2019.
- IEEE WCNC 2019 - IEEE Wireless Communications and Networking Conference, Marrakech, Morocco, April 15-19, 2019.
- IEEE CCNC 2019 - IEEE Consumer Communications & Networking Conference, Las Vegas, USA, January 11-14, 2019.
- IEEE MASCOTS - 2019 - IEEE conference on "Modeling, Analysis, and Simulation On Computer and Telecommunication Systems", Rennes, France, October 22-25, 2019.

Gerardo Rubino was or is a member of the Program Committee of the following events:

- QEST: 16th International Conference on Quantitative Evaluation of SysTems, Glasgow, Scotland, Sep. 2019.
- e-Health: 7th International workshop of e-Health Pervasive Wireless Applications and Services, Lyon, France, Oct. 2019.
- MASCOTS: 28th IEEE International Symposium on the Modeling, Analysis, and Simulation of Computer and Telecommunication Systems, Nice, France, Nov. 2020.
- ICN: 19th International Conference on Networks, Lisbon, Portugal, Feb. 2020.

10.1.2.3. Reviewer

Yann Busnel, Bruno Tuffin, Bruno Sericola, Yassine Hadjadh-Aoul, Gerardo Rubino, and César Viho served as reviewers for several major international conferences.

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

Bruno Tuffin serves as

- Area Editor (simulation): INFORMS Journal on Computing, since Jan. 2015.
- Associate Editor: ACM Transactions on Modeling and Computer Simulation, since July 2009.

Patrick Maillé serves as

- Associate Editor: Electronic Commerce Research and Applications (Elsevier), since April 2019.
- Associate Editor: IEEE Open Journal of Communications Society, since July 2019.

Bruno Sericola serves as 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 "Stochastic Models in Computer Science and Telecommunications Networks", ISTE/WILEY, since March 2015.

Yassine Hadjadj-Aoul was a guest editor of a special issue on: "Emerging topics in wireless communications for future smart cities" for the MDPI International Journal.

Gerardo Rubino is Associate Editor of the Journal of Dynamics & Games, https://www.aimsciences.org/journal/2164-6066.

10.1.3.2. Reviewer - Reviewing Activities

- Yann Busnel served as a reviewer for several major international journals such as TPDS (IEEE Transactions on Parallel and Distributed Systems).
- Bruno Sericola, Bruno Tuffin and Gerardo Rubino served as reviewers for several major international journals.
- Yassine Hadjadj-Aoul served as a reviewer for several major international journals such as: IEEE Journal On Selected Area of Communication *JSAC* "Series on Network Softwarization & Enablers", IEEE Transaction on Vehicular Technologies *TVT*, IEEE Communication Letters, IEEE Transaction on Mobile Computing *TMC*, IEEE Access, Elsevier Future Generation Computer Systems *FGCS*, Journal of Network and Computer Applications *JNCA*.

10.1.4. Invited Talks

Bruno Tuffin gave the following invited talks:

- B. Tuffin. Rare-Event Simulation of Regenerative Systems, Peking University, China, October 10, 2019.
- B. Tuffin. Monte Carlo Simulation and Rare Event Estimation, Mathematical and computational modeling of rare events in complex systems, Recife, Brazil, November 18-20, 2019.

Yann Busnel made several invited and keynote talks in 2019:

- *Blockchain Technology : Synchronization, Consensus and Token Economy*. Cycle of seminars as Invited Professor at VJTI Mumbai, India, September 2019.
- *The need for enlightened sampling in the supervision of large-scale networks*. Keynote at the International Conference on Data Sciences and Engineering, IIT Patna, India, September 2019
- *Large-scale data streaming*. Invited seminar at FEIT, University of Technology Sydney, Australia, August 2019
- *Le besoin d'échantillonnage avisé dans la supervision de réseaux à grande échelle*. Invited seminar at Laboratoire I3S de Sophia-Antipolis, France, April 2019
- *Blockchain opportunities in Europe & Diploma certification using the blockchain @ IMT Atlantique*. Invited talk at International workshop on Blockchain for Global Good, VJTI Mumbai, India, March 2019
- *Le besoin d'échantillonnage avisé dans la supervision de réseaux à grande échelle*. Invited seminar at Laboratoire d'Informatique de Grenoble, France, January 2019.

Yassine Hadjadj-Aoul made several invited and keynote talks in 2019:

- *Reliable Network Function Placement using Evolutionary Algorithms*. Invited tutorial during the 8th IEEE International Conference on Smart Communications in Network & Technologies (SaCoNet), Oran, Algeria, Dec. 2019
- *Virtual Network Function Forwarding Graph Embedding in 5G and post 5G Networks*. Invited Keynote during the 8th IEEE International Conference on Smart Communications in Network & Technologies (SaCoNet), Oran, Algeria, Dec. 2019
- *Efficient support of the upcoming Massive number of IoT devices & in future wireless networks*. Invited talk during the national seminar, SEOC Day, on Embedded Systems and Communicating Objects, Paris France, April 2019

Gerardo Rubino made several invited and keynote talks in 2019:

- *Training recurrent Random Neural Networks: first and second-order techniques, reservoir models, numerical aspects*. Invited talk at ISCIS'19, Conference on Modelling Methods in Computer Systems, Networks and Bioinformatics, Polish Academy of Sciences, Paris, Oct. 15–16, 2019.
- *Relations between irreducible and absorbing Markov chains*. Invited talk at the Fall Western Sectional Meeting of the AMS, Riverside, California, November 9–10, 2019.
- *Rare event analysis in technological catastrophes*. Keynote at the 6th International Conference on Information and Communication Technologies for Disaster Management (ICT-DM), Paris, December 18–20, 2019.

Gerardo Rubino gave a seminar at the Computer Science Department of the UDELAR, in Nov. 2019, about Network Tomography. He also gave a 3 hours-tutorial on dependability analysis at the University Adolfo Ibáñez, Santiago, Chile, in Jan. 2019.

10.1.5. Leadership within the Scientific Community

- Bruno Tuffin is an elected member of I-sim council of Informs society, 2018-2020.
- Yann Busnel is a member of the CSV (the technical committee) of the Images and Networks Cluster of Brittany, France.
- Yann Busnel is a member of the Steering Committee of the RESCOM research group at GDR CNRS RSD.
- Yassine Hadjadj-Aoul is a founding member of Special Interests Group "IEEE Sig on Big Data with Computational Intelligence" under the IEEE COMSOC Big Data TC (Since June 2017).
- Yassine Hadjadj-Aoul is a member of the scientific committee of GT ARC (Automatique et Réseaux de Communication) scientific committee (since Nov. 2017).
- Gerardo Rubino belongs to the CSV (the technical committee) of the Images and Networks Cluster of Brittany, France, since its foundation.
- Gerardo Rubino is the coordinator of the research action "Analytics and machine learning", in collaboration with Nokia Bell Labs.

10.1.6. Research Administration

- Yann Busnel is Head of « Network System, Cybersecurity and Digital law » Research Department at IMT Atlantique (2017–*).
- Yann Busnel is Head of « Network, Telecommunication and Services » Research Department (D2) at IRISA (2019–*).
- 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.
- Bruno Sericola is member of the research commission of the academic council of University of Rennes 1.
- César Viho is member of the HdR commission of the scientific council of Université Rennes 1.
- César Viho is the director of the MathSTIC doctoral school of Université Bretagne Loire.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Master: Bruno Tuffin, MEPS (probablility, queuing systems, simulation) , 35 hours, M1, University of Rennes 1, France

Master: Bruno Tuffin, GTA (Game Theory and Applications), 15 hours, M2, University of Rennes 1, France

MOOC on Queuing Theory, available on EdX: Patrick Maillé (in charge of one week of class)

IMT Atlantique 1st year: Yann Busnel, Wireless Autonomous Robot Swarm, 9 hours.

IMT Atlantique 3rd year: Yann Busnel, Big Data and Stream Processing, 9 hours.

Licence: Bruno Sericola, Mathematics, 14h, L2, IUT/University of Rennes 1, France.

Master: Bruno Sericola, Mathematics, 12h, M2, Istic/University of Rennes 1, France.

Master: Bruno Sericola, Logistic and performance, 12h, M2, Faculté de sciences économiques, Univ of Rennes 1, France

Master: Bruno Sericola, MEPS (performance evaluation), 36h, M1, Univ Rennes, France

Master M1: César Viho, Networks:Rennes 1 from Services to protocols, 36 hours, Istic/University of Rennes 1, France

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

Bachelor L2: César Viho, Network architecture and components, 16 hours, Istic/University of Rennes 1, France

Master, 2nd year: Yassine Hadjadj-Aoul, Scalable Network Infrastructure (SNI), 10 hours, The Research in Computer Science (SIF) master and EIT Digital Master/University of Rennes 1, France

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

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

Master, pro 2nd year: Yassine Hadjadj-Aoul, Software Defined Networks, 6 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: Yassine Hadjadj-Aoul, Introduction to networking (IR), 26 hours, Esir/University of Rennes 1, France

Master: Yassine Hadjadj-Aoul, Mobile and wireless networking (RMOB), 20 hours, Esir/University of Rennes 1, France

Master 2nd year: Yassine Hadjadj-Aoul, Overview of IoT technologies: focus on LPWAN, 2 hours, INSA, France

Sofiene Jelassi is the manager of the master program “Heterogeneous Networks and Systems”, Istic/University of Rennes 1, France

Master pro 2nd year: Sofiene Jelassi, Supervision of heterogeneous networks, 32 hours, Istic/University of Rennes 1, France

Master pro 2nd year: Sofiene Jelassi, Cloud & SDN virtualization, 32 hours, Istic/University of Rennes 1, France

Master pro 2nd year: Sofiene Jelassi, Multimedia networks, 32 hours, Istic/University of Rennes 1, France

Bachelor L1: Sofiene Jelassi, Programming Algorithms, 12 hours, SPM/University of Rennes 1, France

Master, 2nd year: Gerardo Rubino, Scalable Network Infrastructure (SNI), 10 hours, The Research in Computer Science (SIF) master and EIT Digital Master/University of Rennes 1, France

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

Master 2nd year: Gerardo Rubino, Quality of Experience, 2×4 hours (two different groups of students), Esir/University of Rennes 1, France

Esir/University of Rennes 1, 1st year, Graph theory and algorithms, 20 hours.

10.2.2. Supervision

PhD in progress: Ximun Castoreo, Measurements to check network neutrality, University of Rennes 1, Started 10/2018, supervised by Bruno Tuffin.

PhD in progress: Ayman Chouayakh, Auctions for spectrum allocations in 5G, CIFRE Thesis with Orange Labs/University of Rennes 1, Started 03/2017, supervised by Patrick Maillé.

PhD in progress: Hiba Dakdouk, Multi-player multi-armed bandit problems and applications in IoT, CIFRE Thesis with Orange Labs/University of Rennes 1, Started 01/2019, supervised by Patrick Maillé.

PhD in progress: Vasile Cazacu, "Calcul distribué pour la fouille de données cliniques", IMT Atlantique. Advisors: E. Anceaume (CNRS Rennes), Y. Busnel and M. Cuggia (PUPH, CHU Rennes). Defense in 2020.

PhD in progress: Jérôme Henry, "Indoor localization using the most recent standards of 802.11", IMT Atlantique. Advisors: N. Montavont (IMT Atlantique), Romaric Ludinard (IMT Atlantique), Y. Busnel (IMT Atlantique). Defense in 2021.

PhD in progress: Anouar Rkhami, "Data analytics for optimized resources' management in future 5G networks"; started on Oct. 2018; Advisors: Gerardo Rubino and Yassine Hadjadj-Aoul, and Abdelkader Outtagarts, Inria – Nokia Bell labs.

PhD in progress: Imane Taibi, "Big data analysis for network monitoring and troubleshooting"; started on Nov. 2017; Advisors: Gerardo Rubino, Chadi Barakat and Yassine Hadjadj-Aoul, Inria.

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

PhD in progress: Mohamed Rahali, "Machine learning-based monitoring and management for hybride SDN networks"; started on Oct. 2017; Advisors: Gerardo Rubino, Inria, and Jean-Michel Sanner, B-COM.

Post-doc in progress: Noël Gillet, "Analyse de flux de données large-échelle pour les données massives en santé", IMT Atlantique. Advisor: Y. Busnel. October 2018-September 2019.

Post-doc in progress: Frédérique Robin, Modelling the dynamic behaviour of blockchains and analyzing their performance, Inria Rennes. Supervisors: Bruno Sericola and Emmanuelle Anceaume from team Cidre.

PhD: Corentin Hardy, Contribution to the development of deep learning in distributed systems, Defense in April 2019. Supervisors: Bruno Sericola and Erwan Le Merrer from Technicolor.

PhD: Jean-Michel Sanner; Cifre Grant, Orange Labs, "SDN technologies for network services performances adaptation of carriers networks", Defense in July 2019. Supervisors: Yassine Hadjadj-Aoul and Gerardo Rubino.

PhD: Hamza Ben Ammar, "Network and cache resources optimization for efficient media content delivery in CCN", Defense in March 2019; advisors: Yassine Hadjadj-Aoul, Gerardo Rubino and Soraya Ait Chellouche, University Rennes 1 [12].

PhD: Laura Aspirot, "Fluid Approximations for Stochastic Telecommunication Models", University of the Republic, Uruguay. Advisors: E. Mordecki (Uruguay) and G. Rubino (France). Defended on November 21, 2019, [11].

PhD: Jorge Graneri, "Semantic cognition - A mathematical approximation.", University of the Republic, Uruguay. Advisors: E. Mizraji (Uruguay) and G. Rubino (France). Defended on November 22, 2019, [13].

PhD in progress: Illyyne Saffar, "Personalization for Cognitive Autonomic Networks in 5G"; started on Feb. 2017; Advisors: César Viho (Université Rennes 1) and Kamal Deep-Singh (UJM Saint-Etienne) and Marie Line Alberi-Morel (Nokia Bell labs), Université Rennes 1 and Nokia Bell labs. Defense in June 2020.

10.2.3. Juries

Gerardo Rubino was one of the reviewers of the PhD of Fetia Bannour, Software Defined Networking: Extending SDN control to large-scale networks, University of Paris-East, Paris, Nov. 19, 2019.

Bruno Tuffin was rapporteur for the PhD of Wael Labidi, Smart grid-aware radio engineering in 5G mobile networks. Université de Paris-Saclay, Télécom SudParis, March 2019.

Patrick Maillé was a member of the PhD jury of Lilian Besson, Multi-Players Bandit Algorithms for Internet of Things Networks, Supelec Rennes, November 2019

Yann Busnel was rapporteur of the PhD defense committee of Abderrahmen Kammoun, Université Jean Monnet, Saint- Etienne, July 2019.

Yassine Hadjadj-Aoul was a member of the PhD jury of Ghada Moualla, Resilient Virtualized Network Functions for Data Centers and Decentralized Environments, Côte d'Azur University, September 2019

Bruno Sericola was member of the final selecting board for the recruitment of CNRS researchers in 2019.

César Viho was President of the HDR jury of Geraldine Texier, Vers un Internet programmable offrant des garanties de qualité de service, IMT-Atlantique Rennes, December 2019.

10.3. Popularization

10.3.1. Internal or external Inria responsibilities

Yann Busnel is member of Development Council of Computer Sciences Master at Université de Nantes (2017–*).

10.3.2. Interventions

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

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