UMR IRISA

Activity Report 2024

Team ERMINE

Measuring and Managing Network Operation and Economics

Joint team with Centre Inria de l'Université de Rennes

D2 – Networks, Telecommunications and Services

Université de Rennes | rennes | INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES RENNES | cnrs | Inria | Inserm | CentraleSupélec | IMT Atlantique Bretagne-Pays de la Loire École Mines-Télécom | Université Bretagne Sud ubs

Contents

Project-Team ERMINE 1

1 Team members, visitors, external collaborators 2

2 Overall objectives 3

3 Research program 3
3.1 Context . . . 3
3.2 Managing network operations . . . 4
3.3 Measuring . . . 5
3.4 Research axes . . . 5

4 Application domains 6

5 Social and environmental responsibility 7
5.1 Impact of research results . . . 7

6 Highlights of the year 8
6.1 Awards . . . 8

7 New software, platforms, open data 8
7.1 New software . . . 8
7.1.1 SNIDE . . . 8
7.1.2 DemoWehe . . . 8

8 New results 9
8.1 Network Economics . . . 9
8.2 Managing next generation networks & massive IoT communication . . . 10
8.3 Measuring, monitoring & regulation . . . 11
8.4 Measuring performance metrics based on models . . . 12
8.5 Artificial Intelligence (AI) in networking . . . 14

9 Bilateral contracts and grants with industry 15
9.1 Bilateral contracts with industry . . . 15
9.1.1 DEFI SmartNet . . . 15
9.1.2 ANR Genie . . . 16
9.1.3 ANR Intelligentsia . . . 16
9.1.4 ANR EDEN4SG . . . 17
9.1.5 AAP PME NaviDEC . . . 17
9.2 Bilateral Grants with Industry . . . 17
9.2.1 CRE on SCHC with Orange . . . 17
9.2.2 Cifre on network slicing, with Nokia . . . 18
9.2.3 Cifre on green video streaming: modeling, evaluation and regulation . . . 18
9.2.4 Cifre on safe resource management in 6G with distributed decision making . . . 18
9.2.5 Cifre on societal, environmental, and economic impacts of digital infrastructures . . . 18

10 Partnerships and cooperations 19
10.1 International initiatives . . . 19
10.1.1 Associate Teams in the framework of an Inria International Lab or in the framework of an Inria International Program . . . 19
10.2 National initiatives . . . 19
10.2.1 PEPR 5G and future networks . . . 19
10.2.2 Inria pilot-project REGALIA . . . 20
10.3 Regional initiatives . . . 20
10.3.1 Informal local partners . . . 20

10.3.2 CMA RIS3 20

11 Dissemination **20**
11.1 Promoting scientific activities 20
11.1.1 Scientific events: organisation 20
11.1.2 Scientific events: selection 21
11.1.3 Journal 21
11.1.4 Invited talks 22
11.1.5 Leadership within the scientific community 23
11.1.6 Research administration 23
11.2 Teaching - Supervision - Juries 23
11.2.1 Teaching 23
11.2.2 Supervision 25
11.2.3 Juries 25
11.3 Popularization 26
11.3.1 Others science outreach relevant activities 26

12 Scientific production **27**
12.1 Publications of the year 27

Project-Team ERMINE

Creation of the Project-Team: 2022 June 01

Keywords

Computer sciences and digital sciences

A1.1.9. – Fault tolerant systems
A1.2.2. – Supervision
A1.2.4. – QoS, performance evaluation
A1.2.5. – Internet of things
A1.3.3. – Blockchain
A1.3.4. – Peer to peer
A1.3.5. – Cloud
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
A6.2.4. – Statistical methods
A6.2.6. – Optimization
A8.2.1. – Operations research
A8.6. – Information theory
A8.7. – Graph theory
A8.11. – Game Theory
A9.2. – Machine learning
A9.7. – AI algorithmics

Other research topics and application domains

B6.2.1. – Wired technologies
B6.2.2. – Radio technology
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
B9.6.3. – Economy, Finance

1 Team members, visitors, external collaborators

Research Scientists

- Bruno Tuffin [Team leader, INRIA, Senior Researcher]
- Mael Le Treust [CNRS, Researcher]
- Gerardo Rubino [INRIA, Emeritus]
- Bruno Sericola [INRIA, Senior Researcher]

Faculty Members

- Soraya Ait Chellouche [UNIV RENNES , Associate Professor]
- Mouloud Atmani [UNIV RENNES , from Nov 2024]
- Yassine Hadjadj-Aoul [UNIV RENNES , Professor]
- Sofiene Jelassi [UNIV RENNES , Associate Professor]
- Patrick Maillé [IMT ATLANTIQUE, Professor]
- Raymond Marie [UNIV RENNES , Emeritus]
- Cesar Viho [UNIV RENNES]

PhD Students

- Ahcene Boumhand [ORANGE LABS, until Feb 2024]
- Abdelmounaim Bouroudi [NOKIA BELL LABS, until Sep 2024]
- Sid Hamideche [UNIV RENNES , until Feb 2024]
- Burak Kara [SYNAMEDIA, CIFRE]
- Wilem Lamdani [UNIV RENNES]
- Rajabzadeh Parsa [UNIV RENNES]
- Orland-Medy Saizonou [INRIA]

Technical Staff

- Muhammad Al Qabbani [UNIV RENNES]
- Kaouther Boulaouinat [INRIA, Engineer, until Oct 2024]
- Nada Dandachi [INRIA, Engineer, from Jun 2024]
- Ghina Dandachi [UNIV RENNES , from Sep 2024]
- Ghina Dandachi [INRIA, Engineer, until Aug 2024]
- Ivan Martinez Bolivar [UNIV RENNES , from Nov 2024]
- Chetna Singhal [INRIA, Engineer, from Jul 2024]

Interns and Apprentices

- Haraesh Jayasethu Ramachandran [UNIV RENNES , from May 2024 until Aug 2024]
- Kilian Le Saux [UNIV RENNES , from Jun 2024 until Aug 2024]

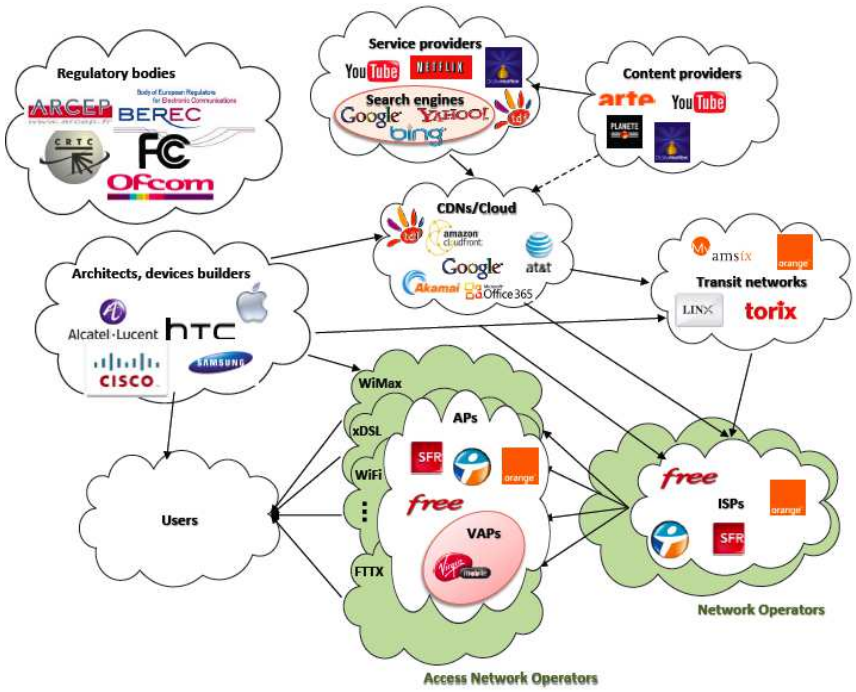


Figure 1: The ICT ecosystem: a complex set of interdependent actors

Administrative Assistant

- Gwenaelle Lannec [UNIV RENNES]

Visiting Scientist

- Hamza Drid [Université de Batna, from Jun 2024 until Jul 2024]

2 Overall objectives

Networks are omnipresent and increasingly complex, and require an efficient management of their operations. The ERMINE team designs and analyzes procedures and policies for efficiently managing network operations, but also works on the required measurement and monitoring of performance metrics. Our specific and original management activity focuses on network economics, regulation, and automated decision making. In terms of needed measurement, we make use of standard modeling and performance analysis techniques, but also carry out direct measurements to be analyzed statistically. A cross-cutting research axis for both management and measuring is artificial intelligence. Our activity is a trade-off between methodological/mathematical developments and practical implementations.

3 Research program

3.1 Context

Telecommunication networks are ubiquitous in our daily life. The network ecosystem and its infrastructure are increasingly complex with more and more involved actors and technologies which have to interoperate. This complexity is illustrated in Figure 3.1, where the basic network paradigm with network operators simply sending content from/to end users has moved to a topology with many players having different roles. A complete telecommunications system has to integrate traditional networks

capabilities but also all other innovative Internet services into a single service platform. Selfishness of actors, heterogeneity of requests and technologies, interoperability of services and automation of decisions are major challenges to be tackled.

ERMINE deals with network operations management and the required associated monitoring and measurements and performance analysis. Operation network management means for us performance-based management, fault analysis, or the design of procedures and strategies for resource provisioning and quality-of-service fulfillment. On this management side, we aim at looking at the whole topic of networks economics, studying the best economic strategies of actors of the digital economy, their interactions and the potential need for regulation. We also want to address resource management through artificial intelligence for automated decision as another main research direction. On the measurement side, monitoring services of all sorts is a major challenge for regulatory bodies to ensure a fair and legal behavior of providers, and is also of primary importance for providers themselves to optimize decisions; this often requires new modeling, analysis and artificial intelligence tools. This is detailed below.

3.2 Managing network operations

The heterogeneity and complexity of the ICT (for Information & Communications Technology) world bring a number of challenges to network operations management. ERMINE addresses key issues for network management: i) the challenges of ICT economics; ii) network control and interoperability iii) automated decisions through AI.

ICT is omnipresent in our modern society, and the economy has gone beyond the industrial economy to the Internet and ICT economy. Thanks to hyper-connectivity, there are now lots of opportunities for innovation. As of May 2020, among the top-10 most valuable companies worldwide, seven are ICT companies, trusting the places from 2 to 8 (Microsoft, Apple Inc., Amazon Inc., Alphabet Inc., Facebook, Alibaba Group, Tencent). Internet Service Providers (ISPs), Content Delivery Networks (CDNs) and cloud providers, social network actors, all services and content providers are among actors needing a business model as profitable as possible. Designing and analyzing such business models and their acceptance by end users are issues to be addressed, leading to challenges in terms of outcome for all players (who act in most cases selfishly) and in terms of benefits for society. On that last point, regulators have to determine rules that actors need to follow in order to avoid harmful behaviors and maximize social welfare. The issues we address include: the design of economic rules for new services, the analysis of the impact of players decisions and interactions, and the potential design of rules or incentives from regulatory bodies leading to the most adequate (social) outcome. One of the frameworks to be used is that of game theory, and in particular of mechanism design.

There has been a metamorphosis in the last few years on the management of network operations, driven by the virtualization of networks and services. This evolution allows to meet the needs in terms of the dynamic scaling of infrastructures and the agility of the decision-making, namely, a necessary prerequisite for reducing operating costs as well as improving return on investment. These developments are radically changing the way services are managed, as they become more complex (i.e., services in the form of graphs, micro-services, etc.), their expectations can be very diverse and strategies for their placement could consider a single domain or spanning across several domains, whether cooperative or not. Thus, the operation of the network becomes extremely difficult and requires not only optimization of resources but also economic considerations, especially when management involves several domains. We believe that *automated* management and control is the key direction for an efficient solution. We deal with the automation of the network by contributing to ongoing standardization efforts, notably by the "Zero touch network & Service Management" (ZSM) group of the ETSI (the European Telecommunications Standards Institute), and through the elaboration of solutions based on the most recent advances in machine learning techniques, and in particular in deep reinforcement learning. Some of the challenges we tackle include dynamic placement of complex and constrained – QoS/QoE – services (i.e., network slicing), automatic service scaling, congestion control in the context of new generation networks, including IoT networks (e.g., massive Machine-Type Communications (mMTC)). Different aspects are taken into account when developing the various solutions, including reliability, resilience, guaranteed performance (i.e., deterministic networks), but also the energy efficiency on which the viability of the latter depends. Ensuring the performance of the solutions when using machine learning techniques is, however, a major problem that is poorly addressed in the literature. We address it by proposing techniques that offer at

least similar performances to heuristics. Indeed, even if heuristics can be very efficient, they often have, however, some limitations. One of these is the blocking at the level of local minima. AI techniques can address this issue encountered in combinatorial problems (of the NP-hard type, such as the travelling salesman one). They sometimes yield near-optimal results. AI techniques have the additional advantage of being able to learn by interacting with the environment, and can therefore find solutions that heuristics could not.

3.3 Measuring

A proper management of network services and operations cannot be effective without measurement/monitoring and without the analysis of relevant metrics. Indeed, decision making cannot be realized without knowledge and data on the past, present and even future status of the activity. This is typically the case for agile capacity planning and resource sharing for which usage needs to be computed and even predicted. This is a challenge for which tools coming from AI are very promising. Another relevant example of challenge is measurements for regulation purposes, in relation with our activity on network economics: defining regulation rules means designing measurement procedures to verify that the rules are followed. It is for example required to monitor a neutral behavior of ISPs as expected from the Net neutrality principles. While there exist a few tools towards that goal, they are actually all devoted to very specific hindrances to neutrality (blocking, degradation) for specific types of flows or traffic; a major challenge is to detect any type of non-authorized behavior. Many other actors of the ICT economy, if not all, are barely monitored while an unfair behavior could be seen as harming end users and society. To name some noticeable examples, we can cite CDNs which cache some content at the edge of the network and could unfairly propose a better quality to selected customers, or search engines who can prioritize the web. In all those cases, different and specific techniques have to be designed to analyze and detect unexpected behaviors.

Similarly, managing resources and operations calls for evaluating (measuring) the impact of decisions to determine the most appropriate ones. Modeling and performance evaluation techniques are appropriate and useful solutions at a low cost, without the need to build and run the real system. While we have in the group a long experience on performance evaluation, new challenges keep popping up due to new types of services translated into new problems to be modeled and analyzed through performance evaluation tools, and adaptations or extensions of existing techniques for better decision making. They usually require to develop new appropriate network metrics to assess network service operations effectiveness. Illustrative examples are blockchains. The popularity of blockchain lies in the introduction of the concept of a public distributed ledger shared by all participants of the system without relying on a centralized authority. This distributed ledger records all the transactions between parties efficiently and in a verifiable and permanent way. In order to enjoy higher throughput and self-adaptivity to transactions demand in ICT, it requires the development of a new architecture and thus specific modeling and analysis techniques.

3.4 Research axes

Our activity is organized in five subtopics (or axes). The first two axes are on network management, and the next two are orthogonal on the associated and required measurements. Axis 5 on AI is transverse. The axes and their intersections are described in Figure 2.

As a brief description:

- **Network Economics.** The digital economy has gained and keeps gaining in scale, scope, and significance. The ecosystem is quickly evolving and one of our main goals is to answer all questions related to the Internet & digital economy that pop up in line with what we started to do, and to be reactive to the news in that domain. We want to address issues concerning Internet resource allocation and pricing models, the economics of services, issues with vertical integration, the economics of structuring platforms, as well as economics and regulation (including network neutrality).

- **Managing next generation networks & massive IoT communication.** One of the fundamental challenges in the traffic management of new and emerging networking activities is to describe,

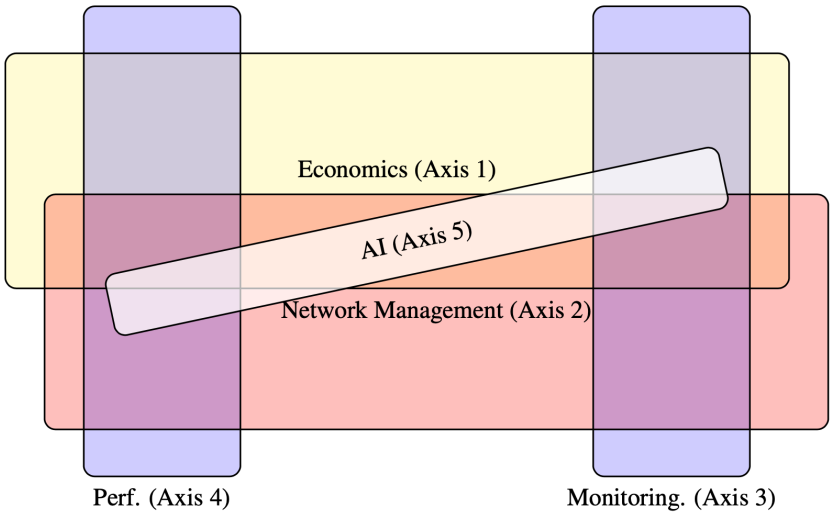


Figure 2: The five research axes: two on network management, two orthogonal on measurements and transverse on AI, with intersections.

analyze and control heterogeneous resources and complex services, under energy constraints. While AI is a main research direction to address this problem, there exist many other possibilities. The main questions of interest include the automation of infrastructure management (a typical example being network slicing) or the massive access in IoT networks.

- **Measuring, monitoring & regulation.** With the rapid evolution of networks, many needs are appearing for the design of measurement techniques associated with new services, but also for regulators to monitor network's activity. Measurements are of two possible categories: passive, monitoring existing traffic, or active, i.e., based on injecting traffic to investigate the network behavior. The goal of this research direction is to develop practical network operations measurement techniques, from the two different points of view: operators (for a better management) and regulators (for monitoring).

- **Measuring performance metrics based on models.** Measuring performances has to be done not only to observe and monitor directly a service like in previous subsection, but also at different phases such as at conception or to propose enhancements. Indeed, network services management and decision making cannot be applied efficiently without a valid and accurate evaluation of performance metrics through the construction and analysis of models. We are carrying out such evaluations.

- **Artificial Intelligence (AI) in networking.** AI is a transverse research axis, since it is used for both management and measuring. We are not only users of the technology but also interested in the methodology itself, that is, we also develop new techniques, based on our networking problems but usable outside. This concerns mainly supervised learning, in particular time series forecasting using this type of learning, and reinforcement learning. From the point of view of the tools, our skills and work are essentially related to Random Neural Networks, Reservoir Computing and deep neural architectures in Reinforcement Learning.

4 Application domains

Our global research effort concerns networking problems.

The need to support services requiring increasingly high throughput and extremely short latencies in 5G and Beyond 5G (B5G) networks is causing a major transformation of operators' infrastructure. The

latter are increasingly being virtualized and expanded to be as close as possible to service consumers, in particular through the development of edge computing. Operators should increasingly collaborate to respond optimally to demands (i.e., cross-domain networks), and eventually converge their networks (i.e., networks' federation). The ultimate solution to this growing complexity is to move towards a fully automated network (i.e., zero-touch network). Our efforts will be dedicated, not on architectural improvements, but on the development of algorithms to manage these infrastructures in an automated way. The efficient and automatic placement of dynamic network services (i.e., network slicing), accommodating simultaneously a wide range of services, is certainly one of the most important concept to move towards zero-touch networks. Similarly, the limited radio resources, the random access to the medium and the spectrum sharing between different applications are critical issues in the IoT context. The focus is not only on 5G and beyond-5G networks, but also on unlicensed networks spectrum such as LoRaWan (for Long Range Wide Area Network; to enable IoT devices to communicate over long distances with minimal battery usage). In LoRaWan networks, the management challenges are even more important given their inherent characteristics, where access is not regulated at all, as it is the case in cellular networks like NB-IoT (for Narrowband Internet of Things).

Still on the management side, with the telecommunications ecosystem quickly evolving, one of our main goals is to answer all questions related to the Internet & digital economy that pop up in line with what we started to do, and to be reactive to the news in that domain to help economic actors and society. Typical and illustrative current questions requiring reactivity are: Is USA repealing neutrality good for some actors in the world, what reactions would be beneficial? Is free roaming in Europe bad for network providers? Is the 2019 Orange-TF1 argument part of the neutrality debate? Should search engines be regulated? Etc. Our goal is mainly to help regulators define proper rules, but we also aim at helping economic actors in decision making (economic choices of CDNs, search engines, etc.) and study their interactions.

On the measurement side, when developing practical network operations measurement techniques, we are interested in two different points of view: operators (for a better management) and regulators (for monitoring). Many of the techniques developed at Ermine 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.

5 Social and environmental responsibility

5.1 Impact of research results

Our research on network economics and particularly neutrality issues aims to view how, and if, regulation can help to improve social welfare, among other goals. Typical examples are how tools SNIDE and DemoWehe described later explaining how potential deviations from rules by respectively search engines and Internet service providers can be detected. Our modeling works on neutrality also allow to investigate the appropriate rules toward a benefice to society. This has led to collaborations with specialists of human sciences in information networks (R. Badouard from Pantheon-Assas and I. Lyubareva from IMT Atlantique) to tackle the socially sensitive issue of bias in information networks, in particular from search engines.

We also work on so-called *green streaming* to analyze the interactions and strategies of various vendors in the market and provide valuable insights that can contribute to the sustainable growth of the Content Delivery Network (CDN) industry. By understanding the implications of energy pricing and its impact on the market dynamics, this research endeavors to offer potential solutions and recommendations to address the challenges and foster a more sustainable and efficient CDN ecosystem. Similarly, we have started to work on the societal, environmental, and economic impacts of digital infrastructures through a Cifre PhD with Orange Labs.

6 Highlights of the year

6.1 Awards

- Paper [25] won the best paper award at the 11th International Conference on Network Games, Control and Optimization (NETGCOOP'2024).
- Paper [16] won the best paper award at the 50th Latinoamerican Conference in Computer Science (CLEI 2024).
- Paper [6] won the Editor's Choice Awards 2024 in Elsevier, Internet of Things Journal.

7 New software, platforms, open data

7.1 New software

7.1.1 SNIDE

Name: Search Non neutratlIty DEtection

Keywords: Search Engine, Statistic analysis

Scientific Description: The goal of this tool is, for a search, to collect the ordered lists from the main search engines, to compare them, to perform statistical tests to point out potential outliers, and to propose two meta search engines reducing biases.

Functional Description: Different search engines provide different outputs for the same keyword. This may be due to different definitions of relevance, to different ranking aggregation methods, and/or to different knowledge/anticipation of users' preferences, but rankings are also suspected to be biased towards own content, which may be prejudicial to other content providers.

Contact: Bruno Tuffin

Participants: Patrick Maillé, Bruno Tuffin, Guillermo Andrade Barroso

Partner: IMT Atlantique

7.1.2 DemoWehe

Name: Demontrator of Wehe Net Non-Neutrality Detection Tool on Video Streaming

Keywords: Network monitoring, Network neutrality

Functional Description: DemoWehe creates a topology made of three virtual machines. One is acting as the Wehe server and one is acting as the client device (or end user). Communications between client and server are done thanks to the third virtual machine representing the network on which service can be differentiated. The same video is played and displayed simultaneously non-differentiated and with the chosen performance degradation. Wehe test is applied and the user can visually evaluate the difference between degradation and possible detection.

URL: https://files.inria.fr/wehe_demonstrator/package_wehe.zip

Contact: Bruno Tuffin

Participants: Patrick Maillé, Bruno Tuffin, Antoine Lesieur

8 New results

8.1 Network Economics

Participants: Patrick Maillé, Bruno Tuffin, Maël Le Treust, Yassine Hadjadj-Aoul.

Economics and regulation: network neutrality and network slicing. A non-negligible part of our activity on network economics was focusing in 2024 on network neutrality and its consequences.

Network slicing is a key component of 5G-and-beyond networks but induces many questions related to an associated business model and its need to be regulated due to its difficult co-existence with the network neutrality debate. We propose in [5] a slicing model in the case of heterogeneous users/applications where a service provider may purchase a slice in a wireless network and offer a “premium” service where the improved quality stems from higher prices leading to less demand and less congestion than the basic service offered by the network owner, a scheme known as Paris Metro Pricing. We obtain thanks to game theory the economically-optimal slice size and prices charged by all actors. We also compare with the case of a unique “pipe” (no premium service) corresponding to a fully-neutral scenario and with the case of vertical integration to evaluate the impact of slicing on all actors and identify the “best” economic scenario and the eventual need for regulation.

Slicing is therefore seen as a key characteristic of 5G-and-beyond networks, however it seems in contradiction with neutrality principles promoted worldwide. We detail in [20] the two contradictory but considered compulsory notions, and discuss how they can be accommodated.

Search neutrality. The digital transformation has revolutionized information consumption, with search engines playing a pivotal role in shaping user access to diverse media. Employing algorithms, these engines influence content visibility and aggregate news sources, significantly molding public opinion. As gatekeepers of information, search engines impact media outlet visibility, affecting online traffic, revenue, and journalistic diversity. In breaking news and societal issues, search engines expedite information dissemination, influencing initial narratives. Understanding their role is crucial for transparency and user access to diverse information. Focusing on movements against police violence, our paper [36] conducts a comparative analysis across 12 search engines for terms "Black Lives Matter" and "Justice pour Adama". Our innovative methodology identifies biases in information diversity, providing insights into the dynamics shaping visibility of societal issues.

Platforms regulation. The regulation of platforms has been a hot topic, particularly in Europe with the Digital Markets Act (DMA) passed in 2022. The purpose of [25] is to design a mathematical model representing a game between long-term revenue-oriented platforms in competition playing with their ranking strategy of items. The objective of platforms is to apply a trade-off between short-term revenue from each visit by displaying most profitable items and long-term number of visits due to the satisfaction of users from the relevance of the displayed items. We analyze the output of the game and the impact of proposed regulation rules on platforms and users.

Information and decision making. In [30], we investigate the mismatched distortion-rate problem formulated by Lapidoth in 1997, where the characterization of the distortion-rate tradeoff is a difficult open problem. This problem also relates to distributed decision-making problems which is under study in [33] for the counter-example of the Witsenhausen (1968). In [2], we investigate the zero-error coding for computing problems with encoder side information formulated by Shannon (1956). An encoder communicates with a decoder that possesses side information Y and aims to retrieve some function with zero probability of error. In this article, we study the side information design problem, which consists of finding the best trade-offs between the quality of the encoder’s side information optal rate. We construct two greedy algorithms that give an achievable set of points in the side information design problem, based on partition refining and coarsening.

8.2 Managing next generation networks & massive IoT communication

Participants: Soraya Ait Chellouche, Yassine Hadjadj-Aoul, Patrick Maillé, Fatima Zahra Mardi.

Optimization of Massive-IoT emission strategies. The expanding Internet of Things landscape, combined with a significant reduction in the cost of connected devices, has enabled the widespread deployment of sensors. These sensors, often situated in close proximity to each other, frequently produce overlapping data. The paper [39] aims to identify such overlaps in sensor data to effectively cluster similar sensors in order to reduce data transmissions. For that, we develop a similarity metric that employs interpolation techniques to manage noisy, irregular, and unsynchronized data. Simulations highlight the superiority of our method compared to the state-of-the-art Dynamic Time Warping distance and a hierarchical clustering with complete linkage inspired by related works.

Efficient resource allocation in Wireless Sensor Networks (WSNs), particularly in LoRaWAN environments, has become increasingly challenging due to limited bandwidth and diverse service requirements. The paper [6] presents three novel resource allocation solutions for LoRaWAN network slicing to address this challenge. These solutions are based on the Multi-Armed Bandit (MAB) algorithm, which is known for balancing the exploration of available actions with the exploitation of optimal decisions. Our objective is to dynamically and efficiently allocate resources to network slices by treating the resource allocation as a MAB problem. This approach aims to maximize Packet Delivery Rate (PDR) performance while ensuring each service's Service Level Agreement (SLA). The first solution, UCB-MAB, uses the Upper Confidence Bound (UCB) strategy to balance exploration and exploitation to improve network performance. The second solution, Q-UCB-MAB, continuously updates Q-values using the Q-learning update equation and incorporates the UCB strategy for further optimization. Finally, the third solution, ARIMA-UCB-MAB, leverages the predicted reward value from the Autoregressive Integrated Moving Average (ARIMA) model within the UCB framework to enhance network performance. Our results demonstrate that all three solutions offer efficient resource allocation in terms of PDR and SLA satisfaction. Specifically, the ARIMA-UCB-MAB solution outperforms the two other solutions.

Service management in the cloud-edge continuum. With the increasing sophistication and heterogeneity of network infrastructures, the need for Virtual Network Embedding (VNE) is becoming more critical than ever. VNE consists of mapping virtual networks on top of the physical infrastructure to optimize network resource use and improve overall network performance. Considered as one of the most important bricks of network slicing, it has been proven to be an NP-hard problem. Several heuristics and meta-heuristics were proposed to solve it. As heuristics do not provide satisfactory solutions, meta-heuristics allow a good exploration of the solutions' space, though they require testing several solutions, which is generally unfeasible in a real world environment. Other methods relying on deep reinforcement learning (DRL) and combined with heuristics yield better performance without revealing issues such as sticking at local minima or poor space exploration limits. Nevertheless, these algorithms present varied performances according to the employed approach and the problem to be treated, resulting in robustness problems. To overcome these limits, we propose a robust placement approach based on the Algorithm Selection paradigm. In [1], we propose to dynamically select the best algorithm from a set of learning strategies regarding reward and sample efficiency at each time step. The proposed strategy acts as a meta-algorithm that brings more robustness to the network since it dynamically selects the best solution for a specific scenario. We propose two selection algorithms. First, we consider an offline selection in which the placement strategies are updated outside the selection period. In the second algorithm, the different agents are updated simultaneously with the selection process, which we call an online selection. Both solutions proved their efficiency and managed to dynamically select the best algorithm regarding acceptance ratio of the deployed services. Besides, the proposed solutions succeed in commuting to the best placement strategy depending on the strategies' strengths while outperforming all standalone algorithms.

Despite the opportunities offered by the recent advances in network virtualization and distributed cloud infrastructure, these developments introduce complexities in the context of multi-domain networks. We propose, in [15] a collaborative orchestration approach based on the message-passing paradigm. Orchestration actions are performed using a Horizontal Pod Autoscaling (HPA) algorithm on each domain

independently according to the required and allocated resources. We have developed a simulation testbed based on OMNeT++, allowing the creation and manipulation of multi-domain topologies and customized network slices. We show that exploiting inter-domain communication through message exchanges enables more accurate scheduling decisions than non-communicative orchestration, reducing data rate losses and enabling more efficient resource utilization. The paper [14] presents a distributed version that leverages deep reinforcement learning (DRL) to enhance network function orchestration (NFO) with intelligent scaling decisions, facilitating seamless cross-domain information exchange. First, we develop a DRL agent designed to handle fluctuating traffic loads and generate scaling actions tailored for the considered network function (NF). This trained DRL agent is then integrated into a multi-domain message exchange scaling framework with traffic prediction capabilities. Moreover, we develop a simulation testbed to manipulate multi-domain topologies, customize network slices, and enable precise per-slice and per-domain scaling decisions. Our DRL-based solution outperforms the Horizontal Pod Autoscaling heuristic used by Kubernetes, improving resource utilization and reducing data rate losses.

8.3 Measuring, monitoring & regulation

Participants: Burak Kara, Patrick Maillé, Gerardo Rubino, Bruno Tuffin
.

Our activity on monitoring has focused in 2024 on specific contexts but notice that we still work on network neutrality monitoring, starting to develop a demonstrator of the efficiency of existing tools which will help to suggest improvements.

Network neutrality monitoring. With network neutrality regulation imposed worldwide at different extents, there is a need for monitoring tools to verify if Internet service providers (among other actors) comply with the existing rules. Among the very few maintained tools, Wehe has been developed by Northeastern University and has been publicized by the French regulator, ARCEP. The tool runs traces and produces a positive or negative response about service differentiation, but users have to trust that result without any visual perception of the degradation. Our goal in [24] is to describe a demonstrator of Wehe for video streaming, from which we can simultaneously see a baseline video and its manuallydifferentiated counterpart, as well as run Wehe to evaluate its response with respect to the perceived quality degradation. The demonstrator allows to study the efficiency of Wehe in order to propose potential improvements, if needed.

CDNs. The Content Delivery Networks (CDNs) in a multi-CDN delivery have variable requirements and capabilities. Multi-CDN communication over content steering server aims to address this problem in real-time by allowing a CDN to manage its traffic load based on internal metrics via communication with other CDNs over the content steering server while aligning with the standard. The communication process involves operation requests, acceptances, rejections, or negotiations for client offloading/onloading. [21, 22] implement this approach and utilize power efficiency as the internal CDN metric. We present the implementation details and the possible lifecycles of a communication process. Future work includes the comprehensive evaluation and introduction of learning-based approaches by predicting future traffic load and initiating communication process before the internal metrics catastrophe.

Network slices monitoring. Network virtualization enables 5G slicing, a technique for sharing physical resources among isolated slices managed by different actors. However, monitoring slices' performance is becoming challenging due to the significant network overhead associated with direct measurements. To overcome this problem, we propose, in [17], using network tomography to estimate slices' delays in the network. In particular, we investigate the problem of finding the minimal combination of end-to-end simple monitoring paths needed to minimize the estimation error of the slices' delays in a network. To improve the search for the optimal solution, we investigate both a fixed mutation approach and our proposed adaptive mutation approach. Our evaluations show the effectiveness of both approaches; however, the adaptive mutation method outperforms the fixed method by exploring new solutions and avoiding local minima, leading to faster convergence and better results. In [18], we

introduce the use of the Relational Graph Convolutional Network (RGCN) model to meet the challenge of generalizing monitors' placement across a network. We conduct a comparative analysis between the RGCN and a traditional Neural Network (NN) across two network topologies, considering every possible node configuration within these topologies. Our findings indicate that the RGCN model, once trained on a specific node pair, exhibits superior generalization ability and accuracy. It consistently transfers its learning to changes in monitors' placement and accurately estimates links delays beyond its initial training monitors. This paper not only demonstrates the effectiveness of the RGCN model in generalizing the monitors' placement problem but also paves the way for its broader application in dynamic network monitoring contexts.

Passive network monitoring and troubleshooting from within the browser. Despite recent advances in terms of network performance, end users still face slow web browsing situations, which can have a range of causes, such as a congested Wi-Fi, a bad wireless signal, or a loaded network or end host. It is thus crucial to monitor the network and troubleshoot the specific causes of slow web browsing, as this benefits end users, operators, and internet service providers alike. Various tools attempting to actively troubleshoot the network through the injection of probes exist. However, these tools are, on the one hand, expensive to run and, on the other hand, not general enough to be able to identify the specific cause of web browsing slowness. The paper [23] addresses the problem by proposing a new lightweight passive measurement solution capable of transforming the web performance measurements collected from within the browser into indicators of network performance anomalies. We validate our solution by emulating a controlled network environment with manually injected anomalies; then, we leverage the measurement data available within the browser to build a predictive model that uses a random forest classifier to correctly categorize the causes of web browsing performance degradation, with an accuracy of over 95%. This implies that one can build on our solution to propose a tool, in the form of a browser extension, that can be used in the wild to monitor the network and shed light on its anomalies by solely relying on a regular user's web activity.

Resilience in 5G Radio Access networks. Resilience is defined as the ability of a network to resist, adapt to and quickly bounce back from disruptions, to continue keeping an acceptable level of service from users' perspective. To characterize and analyze the resilience of a 5G Radio Access Network, we must be able to measure current and prospective performance levels using relevant metrics. This year Soumeya Kaada defended her PhD [35] on this topic. In the project, made in collaboration with Nokia, we proposed Markovian models and tools to evaluate the resilience, and we studied methods to improve it on real communication networks.

8.4 Measuring performance metrics based on models

Participants: Bruno Tuffin, Gerardo Rubino, Bruno Sericola.

Our work on performance analysis in 2024 can be decomposed in simulation, with application to resilience, transient analysis, with application to protocols, and distributed systems.

Monte Carlo simulation. We have continued our work on rare event simulation. The paper [26] examines the relative errors (REs) of quantile estimators of various stochastic models under different asymptotic regimes. Depending on the particular limit considered and the Monte Carlo method applied, the RE may be vanishing, bounded, or unbounded. We provide examples of these possibilities.

Network reliability. Network reliability computation is an NP-hard problem which has attracted much attention in literature. In [16], we discuss the Permutation Monte Carlo method, an estimation algorithm which has shown much promise but that is prone to numerical problems in the case of networks with a large number of links. We discuss this situation and we present a simple way to rewrite the algorithm's computations which is more numerically stable. We present computational results showing the efficiency

of our technique for highly reliable networks, in particular when it is applied to topologies with hundreds of links.

Finite sample Ranking and Selection. The paper [28] introduces a new perspective on the problem of finite sample Ranking and Selection. An asymptotically equivalent approximation to the probability of correct selection in terms of power series is derived beyond the classic large deviations principle that has been widely adopted for the design and measurement of allocation policies. The novel approximation method provides more information on the finite sample performance of allocation policies, based on which a new finite computing budget allocation policy is proposed. The asymptotically equivalent approximation may also serve as an estimate of policy performance after allocating the samples. We develop a simple finite computing budget allocation policy based on our approximation and carry out experiments in various settings to show its superiority.

Randomized Quasi-Monte Carlo. Another domain in simulation concerns Randomized Quasi-Monte Carlo (RQMC) methods. Randomized quasi-Monte Carlo methods have been introduced with the main purpose of yielding a computable measure of error for quasi-Monte Carlo approximations through the implicit application of a central limit theorem over independent randomizations. But to increase precision for a given computational budget, the number of independent randomizations is usually set to a small value so that a large number of points are used from each randomized low-discrepancy sequence to benefit from the fast convergence rate of quasi-Monte Carlo. While a central limit theorem has been previously established for a specific but impractical type of randomization, it is also known in general that fixing the number of randomizations and increasing the length of the sequence used for quasi-Monte Carlo can lead to a non-Gaussian limiting distribution. [7] presents sufficient conditions on the relative growth rates of the number of randomizations and the quasi-Monte Carlo sequence length to ensure a central limit theorem and also an asymptotically valid confidence interval. We obtain several results based on the Lindeberg condition and expressed in terms of the regularity of the integrand and the convergence speed of the quasi-Monte Carlo method. We also analyze the resulting estimator's convergence rate. [12] recalls the results and further illustrates that t-bootstrap, thought in the community to be a relevant way to obtain a confidence interval with a good coverage is not as efficient as the regular Student-t one.

Markov chains. In [9] and [11] we continue the development of two transformations of an arbitrary square matrix M, one designed to facilitate the calculation of any power of M, the other one for the evaluation of the exponential of M. In many situations, calculating on the transformed matrices is easier than working with the original ones. The main application of this tool is the evaluation of the transient distribution of an arbitrary Markov chain, in discrete or in continuous time. The idea generalizes the concept of duality introduced by Siegmund, and appears to be very efficient in the analysis of several fundamental models.

Measuring the performance of distributed systems. Distributed systems protocols and network protocols sometimes make use of random walks (i.e., token circulation) on such systems, to explore them in order to collect information from them and to make systems reliable. Important performancemeasures of these protocols such as the search time and the time to visit all the sites obviously depend on some quality measures on random walks such as the hitting and the cover times. The cover time of a discrete-time homogeneous Markov chain or of a random walk is the time needed to visit all the states of the process. We analyze in [8] both the distribution and the moments of the cover time of a general Markov chain and we are interested in exact results instead of asymptotic values of the mean cover time which are generally considered in the literature. These results are applied to particular graphs namely the generalized cycle graph, the complete graph and the generalized path graph. We analyze in detail in [38] the moments and the distribution of the hitting and cover times of a random walk in the specific case of the complete graph. We obtain recurrence relations for the moments of all orders and we use these relations to analyze the asymptotic behavior of the hitting and cover times distributions when the number of states tends to infinity. We perform a similar analysis in [37] on the lollipop graph which is the graph exhibiting the maximum expected hitting time among all the graphs having the same number of nodes.

8.5 Artificial Intelligence (AI) in networking

Participants: Yassine Hadjadj-Aoul, Gerardo Rubino, César Viho.

On Time Series Forecasting in climate change.
In [10], we describe two projects whose last works were done in 2024, and will finish in 2025. One of them concernes Echo State Networks, and the other one, being the object of this paragraph, concernes forecasting macro-characteristics of a future period of time, typically next summer. The project involved people from Uruguay, Argentina, Chile and France. The goal was to forecast the maximal temperature reached in, say, next summer. In the paper, we report partial result concerning the project. The main tool used was Auto Machine Learning.

Drift detection in time series. Modeling non-stationary data in time series analysis is a challenging problem in the field of continual learning, and data distribution shifts may result in negative consequences on the performance of a machine learning model. Classic learning tools are often vulnerable to perturbations of the input covariates, and are sensitive to outliers and noise, and some tools are based on rigid algebraic assumptions. Distribution shifts are frequently occurring due to changes in raw materials for production, seasonality, a different user base, or even adversarial attacks. Therefore, there is a need for more effective distribution shift detection techniques. In [27], we propose a continual learning framework for monitoring and detecting distribution changes. We explore the problem in a latent space generated by a bio-inspired self-organizing clustering and statistical aspects of the latent space. In particular, we investigate the projections made by two topology-preserving maps: the Self-Organizing Map and the Scale Invariant Map. Our method can be applied in both a supervised and an unsupervised context. We construct the assessment of changes in the data distribution as a comparison of Gaussian signals, making the proposed method fast and robust. We compare it to other unsupervised techniques, specifically Principal Component Analysis (PCA) and Kernel-PCA. Our comparison involves conducting experiments using sequences of images (based on MNIST and injected shifts with adversarial samples), chemical sensor measurements, and the environmental variable related to ozone levels. The empirical study reveals the potential of the proposed approach.

Network Traffic Classification for Multi-Activity Situations Detection. Classifying network traffic is one of the most crucial aspects of monitoring. In order to facilitate network management, network traffic classification has historically concentrated on identifying individual activities, such as streaming or talking. However, new methods are required to precisely identify and react to these patterns when users exhibit more multi-activity behaviors. We have proposed a strategy to identify single and multiple activities within a network. Experimental results from both studies show that these multi-activity recognition methods achieve performance levels that match or even exceed those of traditional, single-activity-focused approaches, highlighting the potential for these techniques to improve quality of service and network management strategies in modern, dynamic network environments. Similarly, this year we propose to go a step further by identifying the specific activities and applications being used. This more granular approach provides deeper insights into user behavior patterns, enabling more fine-tuned network optimizations [34].

Adaptative AI for an Efficienct Schedulers in Wireless Networks. With the increased demands for 5G networks and the limited radio resources, providing high spectral efficiency, low delay, low energy consumption, and other Key Performance Indicators (KPIs) is a challenging task. Extensive research has been conducted to propose efficient solutions for specific objectives and contexts. Although these solutions (often heuristicbased) are highly effective in specific contexts, their performance diminishes when applied in different conditions. This implies difficulties in adapting to environmental variations and/or changes in objectives. In order to overcome this problem, we propose, in [29], an approach employing reinforcement learning to dynamically derive the formula for a scheduler that can be adapted to any context and objective. The proposed solution is validated with a Proof of Concept (PoC), which

highlights the AI ability to identify the adequate scheduler to optimize spectral efficiency in different traffic loads contexts.

ML-based Network Slicing. Network slicing, a key component of post-5G networks, has brought virtual network embedding (VNE) to the forefront of networking research. However, existing VNE approaches are limited by their consideration of static network topologies, failing to account for the dynamic nature of real-world networks. This limitation becomes particularly problematic in the face of link failures or topology modifications, rendering these approaches ineffective. To address this, the paper [4] proposes a new service placement strategy that remains effective even when the network topology changes. Furthermore, we introduce several service migration strategies and thoroughly investigate their effectiveness. Our results demonstrate the adaptability of our proposed strategy, which leverages graph neural networks, in handling link failures without necessitating relearning. This adaptability underlines the potential of our approach to significantly enhance the robustness and flexibility of service migration in VNE, thereby contributing to the evolution of network slicing in post-5G networks.

Using Self Organizing Maps to model cognitive deseases. Since the 1990s, Self-Organizing Maps (SOMs) have been instrumental in reducing dimensionality and visualizing high-dimensional data. In [13] and [19], we modified SOMs to explore the neural representation of human concepts, their neural 'word net' mapping, and the deterioration of these mappings in certain neurological disorders. Our model draws inspiration from semantic dementia, a severe condition that degrades semantic knowledge in the brain. Although our exploration utilizes a low-dimensional model —- a rough simplification with respect of our brains —-, it successfully replicates observed clinical patterns. These promising results inspire further research to enhance our understanding of language pathophysiology in neurological disorders. The article [19] continues the work presented in [13], exploring complemetary aspects of the model.

Enhancing Autonomous Driving Navigation Using AI. Autonomous vehicles have gained extensive attention in recent years, both in academia and industry. For these self-driving vehicles, decision-making in urban environments poses significant challenges due to the unpredictable behavior of traffic participants and intricate road layouts. While existing decision-making approaches based on Deep Reinforcement Learning (DRL) show potential for tackling urban driving situations, they suffer from slow convergence, especially in complex scenarios with high mobility. In [3], we present a new approach based on the Soft Actor-Critic (SAC) algorithm to control the autonomous vehicle to enter roundabouts smoothly and safely and ensure it reaches its destination without delay. For this, we introduce a destination vector concatenated with extracted features using Convolutional Neural Networks (CNN). To evaluate the performance of our model, we conduct extensive experiments in the CARLA simulator and compared it with the Deep Q-Network (DQN) and Proximal Policy Optimization (PPO) models. Qualitative results reveal that our model converges rapidly and achieves a high success rate in scenarios with high traffic compared to the DQN and PPO models.

9 Bilateral contracts and grants with industry

9.1 Bilateral contracts with industry

9.1.1 DEFI SmartNet

Participants: Yassine Hadjadh-Aoul, Soraya Aït-Chellouche.

Title: SmartNet "AI methods for smart network management"

Partner Institution(s):

- Nokia Bell Labs
- Inria

Date/Duration: Nov. 2023-Dec. 2027 (4 years)

Summary: The objective of the SMARTNET project is dedicated to exploring the transformative potential of AI methods in enabling smart network management. The project strategically focuses on two key areas: slice provisioning and causal analysis of network malfunctions. The project involves several teams in Inria (Aptikal, Coati, Ermine, Neo, Spades, and Stack) and the work of several PhD students and postdocs. Yassine Hadjadj-Aoul is the coordinator of the DEFI SmartNet.

9.1.2 ANR Genie

Participants: Soraya Ait Chellouche, Yassine Hadjadj-Aoul, Gerardo Rubino.

Title: Generative Network Intelligence and Optimization Ecosystem.

Partner Institution(s):

- Université de Rennes
- Côte d'Azur University
- Jean Monnet University
- La Rochelle University
- IMT Atlantique

Date/Duration: Oct. 2024-Oct. 2028 (4 years)

Summary: GENIE aims to revolutionize network infrastructure management by leveraging Large Language Models (LLMs) and domain-specific expertise. It focuses on creating automated, adaptable, and interpretable network management solutions by translating high-level intentions into optimized configurations. The project will design an LLM pipeline for efficient decision-making using collaborative and evolutionary strategies. GENIE aims to advance network infrastructure management and contribute to AI-driven network automation.

9.1.3 ANR Intelligentsia

Participants: Soraya Ait Chellouche, Ghina Dandachi, Yassine Hadjadj-Aoul, Patrick Maillé, Gerardo Rubino.

Title: INTelligent Edge using Learning Loops & Information GEneration for NeTwork State Inference-based Automation.

Partner Institution(s):

- Orange Labs
- Inria
- CNAM
- Acklio
- Aguila

Date/Duration: Nov. 2020-Nov. 2024 (4 years)

Summary: The Intelligentsia project aims at (1) specifying novel media access protocols and resources sharing policies to be able to support network slicing for IoT access networks in general, and LoRa networks in particular; (2) designing of a network automation framework that incorporates novel learning algorithms to configure the IoT access network.

9.1.4 ANR EDEN4SG

Participants: Patrick Maillé.

Title: Efficient and Dynamic ENergy Management for Large-Scale Smart Grids

Partner Institution(s):

- Orange Labs
- Université Toulouse 3 - Paul Sabatier
- CNRS
- IMT Atlantique/IRISA
- EDF
- SRD

Date/Duration: January 2023-January 2027 (4 years)

Summary: The wide-scale deployment of electrical vehicles (EVs) represents a challenge as well as an opportunity to render more efficient and affordable the transformation of the current power system into a smarter grid. The goal of the project is to develop more efficient, decentralised, and dynamic energy management methods able to ensure coordination of large-scale fleets of EVs with conflicting objectives/constraints. In addition, the energy management of power systems closer-and-closer to real-time will require the intensive use of pervasive information and communication technologies (ICT). These technologies may suffer from an imperfect quality of service (QoS) (e.g. delays) which may greatly decrease the performance of smart grids.

9.1.5 AAP PME NaviDEC

Participants: Muhammad El Qabbani, Soraya Ait Chellouche, Yassine Hadjadj-Aoul.

Title:

Partner Institution(s):

- Sodira-Connect
- Université de Rennes
- Inpixal

Date/Duration: Sep. 2021 - Apr. 2024

Summary: The NaviDEC project aims to research, develop, test, and validate an “IoT and Image Processing” platform that brings processing capabilities to the micro-edge of the network. This platform will enable easy deployment of intelligent services, even in the context of intermittent connectivity.

9.2 Bilateral Grants with Industry

9.2.1 CRE on SCHC with Orange

Participants: Patrick Maillé.

This 12-month project aims to expand and optimize the use of SCHC (Static Context Header Compression) technology beyond its initial application in LPWAN networks. The collaboration revolves around three major objectives: developing solutions for efficient SCHC session management in multi-hop IP networks, designing mechanisms for automatic SCHC rule generation through machine learning, and evaluating SCHC's potential impact on various network technologies (4G/5G, NTN, optical fiber). The goal is to improve energy efficiency and resource utilization in telecommunications networks by optimizing packet header compression while ensuring viable implementation on constrained embedded systems.

9.2.2 Cifre on network slicing, with Nokia

Participants: Yassine Hadjadh-Aoul, Gerardo Rubino.

This is a Cifre contract 2021-2024 including a PhD thesis supervision (PhD of Abdelmounaim Bouroudi), done with Nokia Bell Labs (Nozay) and Inria, on multi-agent reinforcement learning for resource allocation and scheduling in post-5G networks. The objective of the thesis is to propose a distributed resource placement and control system allowing automating network operations in their whole life-cycle from the creation of an end-to-end network slice to its deletion, while continuously optimally self-tuning the resource allocation to match the targeted performances.

9.2.3 Cifre on green video streaming: modeling, evaluation and regulation

Participants: Bruno Tuffin.

This is a Cifre contract 2023-2025 including a PhD thesis supervision (PhD of Burak Kara), done with Synamedia, on the modeling of end-to-end streaming for a greener distribution. The goal is to determine which strategies could allow to reduce the energy impact of streaming. Thoses strategy can be implemented via a regulator. We can think of economic regulation, through taxes and/or incentives, or a technicval regulation by imposing constraints.

9.2.4 Cifre on safe resource management in 6G with distributed decision making

Participants: Yassine Hadjadh-Aoul, Soraya Aït Chellouche.

This is a Cifre contract 2023-2026 including a PhD thesis supervision (PhD of Parsa Rajabzadeh), done with Nokia Bell Labs (Nozay) and Inria, on IA/ML driven safe resource management in 6G with distributed decision making. The objective of the thesis is to propose a trusted and scalable scheduling strategies for managing network resources in a multi-level distributed context with a distributed decision-making using artificial intelligence (e.g.,multi-agent deep reinforcement learning).

9.2.5 Cifre on societal, environmental, and economic impacts of digital infrastructures

.

Participants: Patrick Maillé.

Cifre contract 2024-2027 with Orange (PhD thesis of Nogbou Henriette Grâce Bénédicte Kongo) mixing economy, sociology and applied mathematics on the impact of digital infrastructures.

10 Partnerships and cooperations

10.1 International initiatives

10.1.1 Associate Teams in the framework of an Inria International Lab or in the framework of an Inria International Program

IoT4Pest

Title: Smart Sensors Networks for monitoring Agricultural Environment: Applied to Pest monitoring in Farm of Sub-Saharan Africa

Duration: 2024 ->

Coordinator: Arnaud Ahouandjinou (arnaud.ahouandjinou@imsp-uac.org)

Partners:

- Université d'Abomey-Calavi, Bénin (Bénin)

Inria contact: Cesar Viho

Summary: The main scientific goal of this research work in collaboration is to propose a smart system for digitized agriculture. This project focuses on a new agronomic challenge in the context of agroecology through the development of a new digital method of pest control based on an intelligent crop monitoring network system. The proposed approach is based on smart sensors by combining a set of usual agricultural parameter measurement sensors (temperature, humidity) and electronic nose type sensors for the measurement of volatile substances in the environment of the caterpillar using a brand new electronic system to design in order to detect early caterpillars. This project aims at developing a sensor-based system for the early detection of pests in agricultural fields. Specifically, it is initially a question of designing a global architecture of smart monitoring systems dedicated to best managing human activities and crop growth.

10.2 National initiatives

10.2.1 PEPR 5G and future networks

Participants: Yassine Hadjadj-Aoul, Maël Le Treust, Patrick Maillé, Bruno Tuffin.

We participate to the project NF-MUST of the PEPR 5G and Future Networks. It focuses mainly on transforming client requests into end-to-end service orderings and on mapping them to resources and network level services (to be) provisioned by the multiple underlying networks. There is a clear evolution of 5 and 6G networks towards the provisioning of services involving multiple players and multiple technologies. Project NF-MUST addresses the related roles and interactions between customers and multiple domains in connection to the other "PEPR 5G and Future Networks" projects, to ensure automated production and operation of multi-domain services across multiple providers. Besides ordering services, NF-MUST will drive the management of the life cycle of the infrastructures" provisioned services and partake in their dynamic and automated adaptation and operation.

We also participate to the project NF-FOUNDS of the PEPR 5G and Future Networks. Distributed algorithms allowing one to reach or approximate the fundamental limitations of wireless networking are central to 5 and 6G networking. In this project, we investigate the fundamental limits of decentralized decision problems, that rely on coding algorithms for the coordination of autonomous devices.

10.2.2 Inria pilot-project REGALIA

Participants: Patrick Maillé, Bruno Tuffin.

The Regalia pilot project, led by Inria, aims to build a software environment for testing and regulation support to address the risks of bias and disloyalty generated by the algorithms of digital platforms. We participate to this project through the development of the demonstrator DemoWehe on the supervision and detection of differentiated behaviors for Internet service providers.

10.3 Regional initiatives

10.3.1 Informal local partners

Participants: Bruno Sericola.

We collaborate with Emmanuelle Anceaume (Inria team Pirat) and François Castella (Inria team Mingus) on the analysis of population protocols and of random walks on graphs.

10.3.2 CMA RIS3

Participants: Yassine Hadjadj-Aoul.

Digital networks and infrastructures are vital for the digital transformation of industries and society, supporting applications from smart cities to energy management. However, challenges include insufficient training capacities, the need for high-level expertise, and integrating sustainability in design. The RIS3 project aims to advance expertise in next-generation networks and disruptive communication technologies. Anchored in Brittany, it leverages the region's strong telecom ecosystem, including major players like Orange and Bouygues. Yassine Hadjadj-Aoul is a member of the CMA steering committee and is responsible for an action related to apprenticeship training at ESIR.

11 Dissemination

Participants: Soraya Ait Chellouche, Yassine Hadjadj-Aoul, Sofiene Jelassi, Mael Le Treust, Patrick Maillé, Gerardo Rubino, Bruno Sericola, Bruno Tuffin, Cesar Viho.

11.1 Promoting scientific activities

11.1.1 Scientific events: organisation

General chair, scientific chair

- Bruno Tuffin has been the Chair of the Steering Committee of the International Conference on Monte Carlo Methods and Applications (MCM) series since August 2021.
- Bruno Tuffin is member of steering committee os the International Conference on Network Games, Control and Optimization (NETGCOOP).
- Yassine Hadjadj-Aoul is chairing the steering committee of the International Conference on Information and Communication Technologies for Disaster Management (ICT-DM).

- Gerardo Rubino and Bruno Tuffin are members of the Steering Committee of the International Workshop on Rare Event Simulation (RESIM).

11.1.2 Scientific events: selection

Chair of conference program committees

- Bruno Tuffin was TCP chair of GECON 2024 - 20th International Conference on Economics of Grids, Clouds, Software, and Services, Rome, Italy, 26-27 Sept. 2024.
- Bruno Tuffin was TPC co-chair of the 11th International Conference on Network Games, Control and Optimization (NETGCOOP 2024), Lille, France, October 9-11, 2024.
- Yassine Hadjadj-Aoul has been a TPC co-Chair of the IEEE Symposium on Computers and Communications (ISCC), Paris, France, June 2024.

Member of the conference program committees

- Bruno Tuffin served as TPC member of the 16th International Conference on Monte Carlo and Quasi-Monte Carlo Methods in Scientific Computing (MCQMC'24), the 20th International Conference on Economics of Grids, Clouds, Software, and Services (GECON'24), and IEEE Globecom 2024.
- Bruno Sericola served as TPC member of the 28th International Conference on Analytical & Stochastic Modelling Techniques & Applications (ASMTA 2024) and the 22nd International Symposium on Network Computing and Applications (NCA 2024).
- Patrick Maillé served as TPC member for the 20th International Conference on the Economics of Grids, Clouds, Systems and Services (GECON'24), the 14th Global Information Infrastructure and Networking Symposium (GIIS'24), the IEEE International Conference on Communicationsand (ICC'24), and the IEEE Global Communications Conference (Globecom 2024).
- Maël Le Treust served as TPC member for the "IEEE International Symposium on Information Theory (ISIT)" and the "2024 International Zurich Seminar on Information and Communication (IZS)".
- Yassine Hadjadj-Aoul served as TPC member of several conferences among which ISCC'24, ICC'24, Globecom'24.
- Gerardo Rubino served as TPC member of the conference MASCOTS'24 (the 32nd International Symposium on the Modeling, Analysis, and Simulation of Computer and Telecommunication Systems).

11.1.3 Journal

Member of the editorial boards

- Bruno Tuffin is Area Editor for *INFORMS Journal on Computing* (since Jan. 2016) and Associate Editor for *ACM Transactions on Modeling and Computer Simulation* (since 2009) and *Queueing Systems* (since 2022).
- Gerardo Rubino is Associate Editor for *Journal of Dynamics & Games* and for *Performance Evaluation.*
- Patrick Maillé is an Associate Editor for *Electronic Commerce Research and Applications* and for the *IEEE Open Journal of the Communications Society.*
- Bruno Sericola serves as Associate Editor for *Performance Evaluation.* He also is Editor in Chief of the books series "Stochastic Models in Computer Science and Telecommunications Networks", ISTE/WILEY. He was coordinator of the book "Phase Type Distributions. Theory and Application" by András Horváth and Miklós Telek.

- Maël Le Treust serves as associate editor for IEEE Transactions on Information Theory, Area Privacy and Security (1st term: Oct. 2021 - Sept. 2024, 2nd term: Oct. 2024 - 2027).

11.1.4 Invited talks

- Yassine Hadjadj-Aoul delivered a tutorial, entitled: “Hands-On Network Slicing Optimization: A Graph Neural Network Perspective”’ during the 9th International conference on Information and & Communication Technologies for Disaster Management (ICT-DM’2024), Setif, Algeria, Nov. 2024.
- Yassine Hadjadj-Aoul delivered a keynote, entitled: “Graph Neural Networks for Network Slicing: Promises, & Challenges, and Future Directions”, during the 1st International Conference on Innovative and & Intelligent Information Technologies (IC3IT’24), Batna, Algeria, Dec. 2024.
- Yassine Hadjadj-Aoul delivered a keynote, entitled: “Graph Neural Networks for Network Slicing: Promises, & Challenges, and Future Directions”, during a seminar at the Coventry University, Coventry, UK, Jul. 2024.
- Yassine Hadjadj-Aoul delivered a keynote, entitled: “Advanced Network Management through Graph Neural Networks: & Applications and Insights”, to the COMSOC TC, Information Infrastructure and Networking (TCIIN), Denver, USA, Jun. 2024.
- Yassine Hadjadj-Aoul delivered a talk, entitled: “Exploring the promises and limitations of GNNs for network optimization” for the CNAM ROC team yearly workshop, Loctudy, France, May 2024.
- Yassine Hadjadj-Aoul delivered a talk, entitled: “Graph Neural Networks: A New Frontier in Network Optimization” for L3I e-Adapt Seminar, La Rochelle, France, May 2024.
- Yassine Hadjadj-Aoul delivered a talk, entitled: “Advanced Network Management through Graph Neural Networks: & Applications and Insights” for the COMSOC TC, Information Infrastructure and Networking (TCIIN), Denver, USA, June 2024.
- Yassine Hadjadj-Aoul delivered a talk, entitled: “Graph Neural Networks for Network Slicing: Promises, Challenges, & and Future Directions” during a seminar at the Coventry University, Coventry, UK, July 2024.
- Bruno Tuffin gave a talk entitled “Recent activties on simulation", Guanghua School of Management, Peking University in Jan. 2024.
- Bruno Tuffin gave a plenary talk entitled “On Confidence Intervals for Randomized Quasi-Monte Carlo Estimators" at the 7th Workshop on Simulation Analytics. Beijing, China, June 2024. China, January 21, 2024.
- Bruno Tuffin was a plenary speaker on “Rare event simulation : theory and practice" at the 2024 International Conference on Information and Communication Technologies for Disaster Management (ICT-DM 2024), Setif, Algeria, November 2024.
- Bruno Tuffin gave a talk at Seoul National University on “Network Slicing and Network Neutrality" in November 2024.
- Patrick Maillé gave a talk entitled “An Economic Analysis of 5G Network Slicing and the Impact of Regulation”, LINCS laboratory, Saclay, in Sept 2024.
- Maël Le Treust gave a talk at the 2024 Mediterranean Game Theory Symposium, Aix-Marseille School of Economics (AMSE UMR 7316), Marseille, 28-31th May 2024.
- Maël Le Treust gave a talk at the workshop on Entropies et divergences : modélisation . statistique . algorithmique, Laboratoire de Mathématiques Nicolas Oresme (LMNO UMR 6139) of Univ. Caen, 14-17th May 2024.
- Maël Le Treust gave a talk at the Information Processing and Communication Lab Seminar at Imperial College London video streamed at Cambridge, Bristol and Warwick Universities, 2nd Oct. 2024.

11.1.5 Leadership within the scientific community

- Yassine Hadjadj-Aoul is a member of the scientific committee of GT ARC(Automatique et Réseaux de Communication), since Nov. 2017.
- Yassine Hadjadj-Aoul is a member of the“IEEE Sig on Big Data with Computational Intelligence” Special Interests Group under the IEEE COMSOC Big Data TC, Since June 2017.
- Mael Le Treust is organizer of the weekly Paris Game Theory seminar at Institut Henri Poincare ‘ (Nov. 2023 -).

11.1.6 Research administration

- Mael Le Treust is member of the scientific council of CNRS INS2I.
- Patrick Maillé serves as an elected member for the Research Committee of IMT Atlantique.

11.2 Teaching - Supervision - Juries

11.2.1 Teaching

- Master: Bruno Tuffin, MEPS (simulation and performance evaluation), 22 hours, M1 Université de Rennes, France.
- Master: Patrick Maillé (Game Theory and Agent-Based Modeling), 20 hours, IMT Atlantique.
- Bachelor L3: Patrick Maillé (Network performance modeling basics), 20 hours, IMT Atlantique.
- Bachelor L3: Patrick Maillé (Models for semiconductor-based components), 15 hours, IMT Atlantique.
- Master: Patrick Maillé (Economics of Digital Platforms), 15 hours, IMT Atlantique.
- Master, 1st year: Patrick Maillé (Probability and Statistics), 50 hours, IMT Atlantique.
- Master: Patrick Maillé (Convex optimization), 12 hours, Université de Rennes.
- Master: Bruno Sericola, MEPS (performance evaluation), 35 hours, M1, Université de Rennes, France.
- BUT 3: Bruno Sericola, Probability and Statistics, 20 hours, IUT de Rennes - Université de Rennes, France.
- Master M2-Cyber: César Viho, Dynamic Routing Algorithms, 6 hours, ISTIC/Université de Rennes, France.
- Master M1-Cloud and Networks: César Viho, Networks : from Services to protocols, 36 hours, ISTIC/Université de Rennes, France.
- Bachelor L3: César Viho, Algorithms on graphs, 40 hours, ISTIC/Université de Rennes, France.
- Bachelor L3: César Viho, Linux commands/scripts and C Programming, 64 hours, IsticISTIC/Université de Rennes, France.
- Bachelor L2: César Viho, Network basics and main protocols, 32 hours, ISTIC/Université de Rennes, France.
- Bachelor L3: Sofiene Jelassi, Oriented Object Programming (JAVA), 44 hours, Istic/Université de Rennes, France.
- Bachelor L3: Sofiene Jelassi, Computer Networks, 20 hours, Istic/Université de Rennes, France.

- Bachelor L3: Sofiene Jelassi, Computer Networks, 4 hours, Istic/Université de Rennes, France.
- BUT 2 : Soraya Ait Chellouche, Network security, 12 hours, IUT de Lannion - Université de Rennes, France.
- BUT 1 : Soraya Ait Chellouche, Internet architecture, 50 hours, IUT de Lannion - Université de Rennes, France.
- BUT 1 : Soraya Ait Chellouche, Network services, 26 hours, IUT de Lannion - Université de Rennes, France.
- LP ASUR : Soraya Ait Chellouche, TIC, 50 hours, IUT de Saint Malo - Université de Rennes, France.
- Engineering school 3rd year & Master 2, Soraya Ait Chellouche, Voice Over IP, 15 hours, ESIR & ISTIC - Université de Rennes, France.
- L3 - ISTIC : Soraya Ait Chellouche, Network services, 9h.
- ISTIC/ETRS - FC : Soraya Ait Chellouche, Computer networks fundamentals, 39h.
- ISTIC/ETRS - FC : Soraya Ait Chellouche, Linux fundamentals and Network services, 40h.
- ISTIC/ETRS - FC : Soraya Ait Chellouche, Network security, 98h.
- Master, 2nd year: Yassine Hadjadj-Aoul, Scalable Network Infrastructure (SNI), 18 hours, The Research in Computer Science (SIF) master and EIT DigitalMaster/Université de Rennes, France.
- Master, pro 2nd year: Yassine Hadjadj-Aoul, Multimedia streaming over IP (MMR), 48 hours, Esir/Université de Rennes, France.
- Master, pro 2nd year: Yassine Hadjadj-Aoul,Multimedia services in IP networks (RSM), 29 hours, Esir/Université de Rennes, France.
- Master, pro 2nd year: Yassine Hadjadj-Aoul, Software Defined Networks, 10 hours, Istic/Université de Rennes, France.
- Master, 2nd year: Yassine Hadjadj-Aoul, Video streaming over IP, 8 hours, Istic/Université de Rennes, France.
- Master: YassineHadjadj-Aoul, Introduction to networking (RES), 26 hours, Esir/Université de Rennes, France.
- Master: Yassine Hadjadj-Aoul,Mobile and wireless networking (RESA), 20 hours, Esir/Université de Rennes, France.
- Master 2nd year: Yassine Hadjadj-Aoul, Overview of IoT technologies: focus on LPWAN, 2 hours, INSA, France.
- C. Viho was a member of the juries for the recruitment of young Associate Professors and senior Professors at ISTIC-Université Rennes.
- Soraya Ait Chellouche was member of validation and certification of studies juries for military personal on network security.
- Soraya Ait Chellouche supervised 15 students on dual study program, IUT de Lannion/IUT de Saint Malo - univ-Rennes & engineering school ESAIP.
- Master M1-SIC ENS Rennes, Maël Le Treust, Information Theory.
- Master IMT Brest, Maël Le Treust, Physical Layer Security.

11.2.2 Supervision

Thesis defended in 2024:

- Soumeya Kaada, “Resilience as a Service on Demand for 5G Networks Led by Machine Learning”, CIFRE thesis with Nokia Bell Labs, started in 2020, co-supervised by Sofiene Jelassi and Gerardo Rubino. Defended in September 2024.
- Sid Ali Hamideche, “Automation beyond 5G: Machine learning applied to profiling user behaviour in mobile services” CIFRE thesis with Nokia Bell Labs, started in 2020, supervised by César Viho. Defended in December 2024.
- Masoud Taghavian, “VNF Placement in 5G Networks using AI/ML” thesis with B-COM, started in 2020, supervised by Yassine Hadjadj-Aoul (thesis within ADOPNET IRISA team). Defended in September 2024.

Thesis in progress:

- PhD in progress: Burak Kara “Towards a green video streaming: modeling, evaluation and regulation". CIFRE Thesis with Synamedia, started in 2023, supervised by Bruno Tuffin.
- PhD in progress: Orland Medy Saizonou, “Towards an efficient economic orchestration of 5G and beyond networks". PhD funded by the PEPR 5G and furutre network, started in November 2023 and supervised by Patrick Maillé and Bruno Tuffin.
- PhD in progress: Parsa Rajabzadeh “IA/ML driven safe resource management in 6G with distributed decision making". CIFRE Thesis with Nokia Bell Labs, started in 2021, co-supervised by Yassine Hadjadj-Aoul and Soraya Aït-Chellouche.
- PhD in progress: Zahraa El Attar “Network Function Virtualization and Slice Monitoring". PhD funded by a Ministery Scholarship and started in 2021, co-directed by Yassine Hadjadj-Aoul.
- PhD in progress: Abdelmounaim Bouroudi, “Multi-Agent Reinforcement learning for resources allocation in 5G". CIFRE Thesis with Nokia Bell Labs, started in 2021, co-supervised by Yassine Hadjadj-Aoul and Gerardo Rubino.
- PhD in progress: Amine Rguez,“AnavailabilityawareNFVsplacementusingDeepReinforcement Learning". CIFRE Thesis with EXFO, started in 2020, co-supervised by Yassine Hadjadj-Aoul and Gerardo Rubino.
- PhD in progress: Ahcene Boumhand,“Multi-Task Learning for Home Context Discovery”, CIFRE thesis with Orange, started in 2020, co-supervised by Yassine Hadjadj-Aoul and César Viho.
- PhD in progress: Wilem Lamdani “User/network context-aware resource management for constrained-services in 5G and Beyond 5G networks". Doctoral Contract of Université de Rennes, started in 2023, co-supervised by Soraya Aït-Chellouche and César Viho.
- PhD in progress: Fatima Zahra Mardi, Université Moulay Ismail Mekne‘s, Morocco, PhD in mobility.
- PhD in progress: Nogbou Henriette Grêce Béne‘dicte Kongow, “ocietal, environmental, and economic impacts of digital infrastructures", Cifre with Orange, supervised by Patrick Maillé.

11.2.3 Juries

- Bruno Tuffin was president of the jury of the PhD of Karim Tit. Reliability of Deep Learning with Rare Event Simulation: Theory and Practice. Université de Rennes, April 2024.
- Bruno Tuffin was reviewer for the Habilitation of Isabel Amigo. Controlling and Managing Data Networks for Improved Quality and Flexibility. IMT Atlantique, Brest, June 2024.
- Maël Le Treust was jury member for Moyen Incitatifs at Inria Rennes, 4th June 2024.

- Maël Le Treust was was a jury member of the following PhD thesis:
  - Ismaila Salihou Adamou, on “Error Exponent Bounds and Practical Short-Length Coding Schemes for Distributed Hypothesis Testing (DHT)”, IMT-Atlantique, Brest, France, 9th Dec. 2024, as a reviewer.
  - Gaston De Boni Rovella, on “Machine learning applications to decoding and demodulation for M2M satellite communication”, ISAE-SUPAERO/ONERA in team SCANR, Toulouse, France, 13th Dec. 2024, as a reviewer.
  - Omar Boufous, on “Correlated Equilibria and Learning”, Université d’Avignon and Orange Labs Chatillon, 20th Dec. 2024 as an examiner.
- Yassine Hadjadj-Aoul was an examiner of the Habilitation of Gilles Guette. Contributing to network security and understanding attacks and attackers. Université de Rennes, March 2024.
- Yassine Hadjadj-Aoul was a jury member of the following PhD thesis:
  - Pierre Larrenie,“Adaptive Intelligent Networks: Optimisation and Prediction in MANETs”, Gustave Eiffel University (December 2024), as a reviewer.
  - Sid Ali Hamideche, “Machine learning applied to the identification of user behavior in 5G mobile networks and beyond: environment and application classification”, Université de Rennes (December 2024), as a jury president.
  - Soumeya Kaada, “Resilience as an on-demand service for 5G networks driven by Machine Learning”, Université de Rennes (September 2024), as an examiner.
  - Fatma Laidoui, “Game theory for solving the dynamic frequency allocation problem in a GSM network”, ESI Algiers Ingineering School (June 2024), as a reviewer.
  - Shaik Shakeera, “Energy based swarm mobility for micro auvs and embedded architecture for their prototype”, Indian Institute of Information Technology, Sri City, India (March 2024), as a reviewer.
  - Issam Abdeldjalil Ikhlef, “Optimised placement and chaining of network functions using the SDN/NFV paradigm”, University Sorbonne Paris Nord (January 2024), as a reviewer.
- Gerardo Rubino was a jury member of the following PhD thesis:
  - Soumeya Kaada, “Resilience as an on-demand service for 5G networks driven by Machine Learning”, Université de Rennes (September 2024), as an examiner.
  - Sid Ali Hamideche, “Machine learning applied to the identification of user behavior in 5G mobile networks and beyond: environment and application classification”, Université de Rennes (December 2024), as an examiner.

11.3 Popularization

11.3.1 Others science outreach relevant activities

G.Rubino makes regular presentations to high school students about the research work ingeneral, and specific technical topics in particular.

Current talks:

- Randomness as a tool.
- Internet as a research problem
- Greatest challenge in maths: the Riemann Hypothesis.
- Greatest challenge in computer science:the “P versus NP” problem.

12 Scientific production

12.1 Publications of the year

International journals

[1] A. Bouroudi, A. Outtagarts and Y. Hadjadj-Aoul. 'A dynamic AI-based algorithm selection for Virtual Network Embedding'. In: *Annals of Telecommunications - annales des télécommunications* (4th June 2024). DOI: 10.1007/s12243-024-01040-6. URL: https://inria.hal.science/hal-04749254 (cit. on p. 10).

[2] N. Charpenay, M. Le Treust and A. Roumy. 'Side Information Design in Zero-Error Coding for Computing'. In: *Entropy* 26.4 (16th Apr. 2024), pp. 1–18. DOI: 10.3390/e26040338. URL: https://hal.science/hal-04679240 (cit. on p. 9).

[3] B. Elallid, N. Benamar, M. Bagaa and Y. Hadjadj-Aoul. 'Enhancing Autonomous Driving Navigation Using Soft Actor-Critic'. In: *Future internet* 16.7 (4th July 2024), p. 238. DOI: 10.3390/fi16070238. URL: https://inria.hal.science/hal-04749227 (cit. on p. 15).

[4] F. Giarrè and Y. Hadjadj-Aoul. 'Exploring the effectiveness of service migration strategies for virtual network embedding'. In: *Computer Networks* 250 (Aug. 2024), p. 110553. DOI: 10.1016/j.comnet.2024.110553. URL: https://inria.hal.science/hal-04749250 (cit. on p. 15).

[5] Y. Hadjadj-Aoul, M. Le Treust, P. Maillé and B. Tuffin. 'Network Slicing: Is It Worth Regulating in a Network Neutrality Context?' In: *Performance Evaluation* 165 (Aug. 2024). DOI: 10.1016/j.peva.2024.102422. URL: https://inria.hal.science/hal-04551193 (cit. on p. 9).

[6] F. Z. Mardi, Y. Hadjadj-Aoul, M. Bagaa and N. Benamar. 'Resource Allocation for LoRaWAN Network Slicing: Multi-Armed Bandit-based Approaches'. In: *Internet of Things* 26 (July 2024), p. 101195. DOI: 10.1016/j.iot.2024.101195. URL: https://inria.hal.science/hal-04749270 (cit. on pp. 8, 10).

[7] M. K. Nakayama and B. Tuffin. 'Sufficient Conditions for Central Limit Theorems and Confidence Intervals for Randomized Quasi-Monte Carlo Methods'. In: *ACM Transactions on Modeling and Computer Simulation* 34.3 (2024), pp. 1–38. URL: https://inria.hal.science/hal-03196085 (cit. on p. 13).

[8] B. Sericola. 'On cover times of Markov chains'. In: *Stochastic Models* 40.4 (2024), pp. 685–727. URL: https://inria.hal.science/hal-04364216. In press (cit. on p. 13).

Invited conferences

[9] G. Rubino. 'On the power-dual and the exponential-dual of a matrix.Applications to Markov chain analysis'. In: 2024 - Fall Western Sectional Meeting. Riverside (CA), United States, 2024. URL: https://inria.hal.science/hal-04756134 (cit. on p. 13).

[10] G. Rubino. 'Time series forecasting using Machine Learning: some results of two research projects: Prédiction de séries temporelles avec l'apprentissage statistique : quelques résultats de deux projets'. In: CORE 2024 - 23th International Conference on Computer Science Congress. Mexico DF, Mexico, 2024. URL: https://inria.hal.science/hal-04756220 (cit. on p. 14).

[11] G. Rubino. 'Two algebraic matrix transformations with applications to Markov chain analysis'. In: JMM 2024 - Joint Mathematics Meetings. San Francisco (CA), United States, 6th Jan. 2024. URL: https://inria.hal.science/hal-04756101 (cit. on p. 13).

[12] B. Tuffin. 'On Confidence Intervals for Randomized Quasi-Monte Carlo Estimators'. In: 2024 - 13ème Atelier en Évaluation des Performances. Toulouse, France, 2024, pp. 1–1. URL: https://hal.science/hal-04765316 (cit. on p. 13).

International peer-reviewed conferences

[13] S. Basterrech, J. Graneri, E. Mizraji and G. Rubino. 'A modified Self Organizing Map for semantic impairment'. In: *MITA'23: 19th International Conference on Multimedia Information Technology and Applications*. MITA 2023 - 19th International Conference on Multimedia Information Technology and Applications. Ostrava, Czech Republic, 2024, pp. 1–9. URL: https://inria.hal.science/hal-04358017 (cit. on p. 15).

[14] A. Bouroudi, A. Outtagarts and Y. Hadjadj-Aoul. 'A Novel DRL Framework for Cross-Domain Network Scaling in 6G Networks'. In: HPSR 2024 - IEEE 25th International Conference on High Performance Switching and Routing. Pisa, Italy: IEEE, 2024, pp. 118–123. DOI: 10.1109/HPSR62440.2024.10635964. URL: https://inria.hal.science/hal-04749290 (cit. on p. 11).

[15] A. Bouroudi, A. Outtagarts and Y. Hadjadj-Aoul. 'Multi-Domain Scaling Algorithm with Inter-Orchestrator Communication for Beyond 5G/6G Networks'. In: IWCMC 2024 - International Wireless Communications and Mobile Computing. Ayia Napa, Cyprus: IEEE, 2024, pp. 1054–1061. DOI: 10.1109/IWCMC61514.2024.10592587. URL: https://inria.hal.science/hal-04749299 (cit. on p. 10).

[16] H. Cancela, L. Murray and G. Rubino. 'Robust implementation of Permutation Monte Carlo for network reliability estimation'. In: *Proceedings of the 50th Conferencia Latinoamericana de Informática (CLEI'2024)*. CLEI 2024 - 50th Conferencia Latinoamericana de Informática. Bahía Blanca, Argentina, 2024, pp. 1–13. URL: https://inria.hal.science/hal-04756576 (cit. on pp. 8, 12).

[17] Z. El Attar, Y. Hadjadj-Aoul and G. Texier. 'Monitoring Network Slices with a Genetic Algorithm Approach'. In: CCNC 2024 - IEEE Consumer Communications & Networking Conference. Las Vegas, United States: IEEE, 2024, pp. 1–6. URL: https://inria.hal.science/hal-04368540 (cit. on p. 11).

[18] Z. El Attar, K. Hoarau, Y. Hadjadj-Aoul and G. Texier. 'RGCN for Beyond Pairwise Training: Generalizing Monitors Selection in Network Tomography'. In: ISNCC 2024 - 11th International Symposium on Networks, Computers and Communications. Washinghton, United States, 2024. URL: https://inria.hal.science/hal-04749283 (cit. on p. 11).

[19] J. Graneri, S. Basterrech, E. Mizraji and G. Rubino. 'Exploring Self-Organizing Maps for Addressing Semantic Impairments'. In: *Proceedings of ESANN'24*. ESANN 2024 - 32nd European Symposium on Artificial Neural Networks, Computational Intelligence and Machine Learning. Bruge, Belgium, 2024, pp. 1–8. URL: https://inria.hal.science/hal-04756530 (cit. on p. 15).

[20] Y. Hadjadj-Aoul, P. Maillé and B. Tuffin. 'How to Accommodate Network Slicing and Network Neutrality?' In: GECON 2024 - 20th International Conference on the Economics of Grids, Clouds, Systems, and Services. Rome, Italy: LNCS, Springer Verlag, 2024, pp. 1–7. URL: https://inria.hal.science/hal-03709661 (cit. on p. 9).

[21] B. Kara and G. Simon. 'Dynamic Content Steering Services: How to Make Everyone Happy in a Multi-CDN World'. In: MHV 2024 - Mile-High Video Conference. Denver (Colorado), United States: ACM, 14th Feb. 2024, pp. 95–95. DOI: 10.1145/3638036.3640252. URL: https://inria.hal.science/hal-04571116 (cit. on p. 11).

[22] B. Kara and G. Simon. 'Power Efficient Multi-CDN Communication over Content Steering Server'. In: MMSys 2024 - 15th ACM Multimedia Systems Conference. Bari, Italy: ACM, 17th Apr. 2024, pp. 478–484. DOI: 10.1145/3625468.3652196. URL: https://inria.hal.science/hal-04571125 (cit. on p. 11).

[23] N. Kirimi, C. Barakat and Y. Hadjadj-Aoul. 'Passive network monitoring and troubleshooting from within the browser: a data-driven approach'. In: IWCMC 2024 - 20th International Wireless Communications & Mobile Computing Conference. Ayia Napa, Cyprus, 2024, pp. 1–6. URL: https://inria.hal.science/hal-04564562 (cit. on p. 12).

[24] A. Lesieur, P. Maillé and B. Tuffin. 'Non-Neutrality Detection of Video Streaming: Wehe Tool Demonstrator and Efficiency'. In: *Proceedings of VALUETOOLS 2024*. VALUETOOLS 2024 - 17th EAI International Conference on Performance Evaluation Methodologies and Tools. Milan (Italie), Italy, 2024, pp. 1–4. URL: https://inria.hal.science/hal-04222971 (cit. on p. 11).

[25] P. Maillé and B. Tuffin. 'Impact of Regulation and the Digital Markets Act on Competing Platforms'. In: 11th International Conference on Network Games, Control and Optimization (NETGCOOP). Lille, France: LNCS, Springer Verlag, 9th Oct. 2024. URL: https://inria.hal.science/hal-04613560 (cit. on pp. 8, 9).

[26] M. K. Nakayama and B. Tuffin. 'Some Asymptotic Regimes for Quantile Estimation'. In: 2024 Winter Simulation Conference. Orlando (FL), United States, 18th Apr. 2024. URL: https://inria.hal.science/hal-04551483 (cit. on p. 12).

[27] G. Rubino, S. Basterrech and L. H. Clemmensen. 'A Self-Organizing Clustering System for Unsupervised Distribution Shift Detection'. In: *2024 International Joint Conference on Neural Networks (IJCNN)*. IJCNN 2024 - International Joint Conference on Neural Networks. Yokohama, Japan: IEEE Xplore, 2024, pp. 1–14. DOI: 10.1109/IJCNN60899.2024. URL: https://inria.hal.science/hal-04756489 (cit. on p. 14).

[28] X. Shi, Y. Peng and B. Tuffin. 'Finite Budget Allocation Improvement in Ranking and Selection'. In: 2024 Winter Simulation Conference. Orlando (FL), United States, 2024. URL: https://inria.hal.science/hal-04711071 (cit. on p. 13).

[29] G. Terrier, C. Gueguen and Y. Hadjadj-Aoul. 'Adaptative Artificial Intelligence for Efficiency Schedulers Provider in Wireless Networks'. In: ISNCC 2024 - 11th International Symposium on Networks, Computers and Communications. Washington, United States, 2024, pp. 1–6. URL: https://inria.hal.science/hal-04749287 (cit. on p. 14).

[30] M. L. Treust and T. Tomala. 'A Converse Bound on the Mismatched Distortion-Rate Function'. In: ISIT 2024 - IEEE International Symposium on Information Theory. Athènes, Greece: IEEE, 19th Aug. 2024, pp. 1–6. URL: https://hal.science/hal-04679207 (cit. on p. 9).

[31] M. Zhao, T. Oechtering and M. L. Treust. 'Optimal Gaussian Strategies for Vector-valued Witsenhausen Counterexample with Non-causal State Estimator'. In: CDC 2024 - 63rd IEEE Conference on Decision and Control. Milano, Italy: IEEE, 23rd Aug. 2024, pp. 1–6. URL: https://hal.science/hal-04863317.

[32] M. Zhao, M. L. Treust and T. Oechtering. 'Causal Vector-Valued Witsenhausen Counterexamples with Feedback'. In: ITW 2024 - IEEE Information Theory Workshop. Shenzhen, China: IEEE, 6th Aug. 2024, pp. 687–692. DOI: 10.1109/ITW61385.2024.10806960. URL: https://hal.science/hal-04863320.

[33] M. Zhao, M. L. Treust and T. Oechtering. 'Coordination Coding with Causal Encoder for Vector-Valued Witsenhausen Counterexample'. In: *ISIT 2024 Proceedings*. ISIT 2024 - IEEE International Symposium on Information Theory. Athens, Greece: IEEE, 19th Aug. 2024, pp. 3255–3260. DOI: 10.1109/ISIT57864.2024.10619377. URL: https://hal.science/hal-04679217 (cit. on p. 9).

Conferences without proceedings

[34] A. Boumhand, K. Singh, Y. Hadjadj-Aoul, M. Liewig and C. Viho. 'Multi-task learning for identifying multi-activity situations and application type from network traffic'. In: WiMob 2024 - 20th International Conference on Wireless and Mobile Computing, Networking and Communications. Paris, France, 2024, pp. 1–7. URL: https://hal.science/hal-04722028 (cit. on p. 14).

Doctoral dissertations and habilitation theses

[35] S. Kaada. 'Resilience-as-a-Service for 5G RAN driven by Machine Learning methods'. Université de Rennes, 23rd Sept. 2024. URL: https://hal.science/tel-04801064 (cit. on p. 12).

Reports & preprints

[36] R. Badouard, I. Lyubareva, P. Maillé and B. Tuffin. *An inquiry into Search Engine Neutrality: the case of movements against police violence in France and the U.S.* 2024. URL: https://inria.hal.science/hal-04690241 (cit. on p. 9).

[37] F. Castella and B. Sericola. *Hitting times on the lollipop graph*. Centre Inria de l'université de Rennes, 13th Dec. 2024, pp. 1–30. URL: https://inria.hal.science/hal-04143403 (cit. on p. 13).

[38] F. Castella and B. Sericola. *Random walk in the complete graph : hitting and cover times*. Centre Inria, 17th Dec. 2024, p. 27. URL: https://inria.hal.science/hal-04365696 (cit. on p. 13).

[39] G. Maudet, P. Maillé, L. Toutain and M. Batton-Hubert. *Grouping Similar Sensors Based on their Sent Data in a Massive IoT Scenario*. 2024. URL: https://hal.science/hal-04424455 (cit. on p. 10).