UMR IRISA

Activity Report 2022

Team ADOPNET

Advanced Technologies for Operated Networks

D2 – Networks, Telecommunications and Services

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1 Team composition

Faculty Members

Xavier Lagrange, Professor (HDR), IMT Atlantique (leader of the team)
Alberto Blanc, Associate Professor, IMT Atlantique
Bernard Cousin, Professor (HDR), UR1
Cédric Gueguen, Associate Professor, UR1
Nicolas Huin, Associate Professor, IMT Atlantique
Romaric Ludinard, Associate Professor, IMT Atlantique
Loutfi Nuaymi, Professor (HDR), IMT Atlantique
Bruno Stévant, Research Engineer, IMT Atlantique
Géraldine Texier, Professor (HDR), IMT Atlantique
César Viho, Professor (HDR), UR1 (until july 2022)

Post-Doctoral Fellows

Cesar Vargas Anamuro, IMT Atlantique

Research Engineers

Julien Saint-Martin, IMT Atlantique

PhD students

Tania Alhajj, IMT Atlantique, since October 2019
Zahraa El Attar, Univ. Rennes 1, since November 2021
Chourouk Ghodhbane, IRT b<>com/UR1, since December 2021
Pierre-Marie Lechevalier, IMT Atlantique, since October 2021
Christopher Merlhe, Univ. Rennes 1, since October 2020
Amath Ndao, IMT Atlantique, since October 2021
Menuka Perera, CIFRE Exfo/IMT ATlantique, since May 2021
Flavien Ronteix–Jacquet, Orange Labs CIFRE/IMT ATlantique, until Dec 2022
Masoud Taghavian, IRT b<>com/IMT ATlantique, since October 2020
El Hadj Mohamed Traore, Orange Labs CIFRE/IMT ATlantique, since Nov 2021
Juan-Carlos Vargas, Enensys CIFRE/IMT Atlantique, since Dec 2019

Administrative assistant

Hélène de la Ruée (part-time), Inria
Sandrine Frouin (part-time), IMT Atlantique

2 Overall objectives

2.1 Overview

To access the Internet, end-users can use various types of network access technologies (e.g., optical, cellular, and WiFi). This variety of technologies is one of today's approaches to cope with two sustained trends:

- The growing heterogeneity of terminals that are connected to the Internet, is driven, in part, by the increasing adoption of Machine to Machine (M2M) communication. For example, a home media center with a fiber connection differs from a connected drone on multiple aspects, including mobility, energy constraints, and availability.

- The growing heterogeneity of applications that rely on the Internet to communicate. For example, a Ultra High Definition (UHD) video service requires a bandwidth greater than 20 megabits per second (Mbps), while uploading measurements from a sensor can require only a few bytes per minute.

Though there are very different requirements regarding the Quality of Service, 5G can be considered as the main *convergence* technology as well as an enabler to accommodate the various types of heterogeneity.

Convergence does not mean a monolithic network but a multifaceted and agile network. Virtualization of the network functions and the concept of slicing, which are possible in 5G, make it the dominant technology for the next decade. Furthermore, wireless transmission is the most used access technology.

The spectrum used for mobile services keeps increasing: in addition to the traditional bands between 700 and 2600 MHz, higher frequencies are being deployed (3.4 GHz) or planned (26 GHz) to eventually reach THz in 6G. This evolution does not only concern radio transmissions but has an influence on the network because the very low coverage resulting from very high frequencies leads to multi-layer networks (mixing small and large cells). This paradigm shift identified more than 20 years ago has not yet been translated into reality because the layers interact weakly. The virtualization of radio functions makes it possible to have agile networks whose radio resources are adapted to demand and where the traditional notion of a cell disappears, as a terminal is connected to several access points that vary over time.

5G is characterized by two aspects at the network level: it is a configurable distributed system that can be deployed in multiple slices, each providing a certain quality of service, and it is based on an increasingly sophisticated integration of software technologies in the network (virtualization of network functions, Software-Defined Networking (SDN) approach). The combination of these two aspects leads to the possibility of an agile network, whose configuration evolves according to needs.

Among the quality criteria, latency is an element that was little taken into account by previous technologies and is vital for many applications (haptics, interactive 360-degree videos). The electrical consumption of the terminals and the network is also an essential issue. The two constraints are often contradictory: minimizing latency leads to placing

the processing as close as possible to the terminals (Edge Computing) but reduces the possibilities of mutualization and consequently increases energy consumption.

Ensuring compliance with quality of service criteria requires optimizing each protocol, but with a holistic approach that takes into account all the layers and elements of the network. The challenge is also to set up and optimize an agile network whose capacities adapt to demands, relying among other things on artificial intelligence techniques but also on operational research. Generally speaking, the relevance of learning mechanisms depends closely on the available data and requires good data engineering, i.e., the set of techniques that allow the capture and the collection of data disseminated in a network and their formatting in order to allow their processing (the data can be observations of the network).

The ADOPNET team will contribute to the specification of architectures, protocols, control mechanisms for next-generation networks. Our goal is to design flexible networks that adapt in real-time to the exact demand and typology of services in order to provide to each user or application an adapted level of service while minimizing the operation cost (including the energy footprint) of both the network and the terminals.

We identify two research axes: control of radio networks and control of edge networks.

2.2 Scientific foundations

Since the objective of a network is to interconnect various types of devices and to share different types of resources (information, storage capacity, computing power), studying a network is, by nature, a multi-disciplinary activity. Furthermore, it requires a holistic approach because the global optimization of the network must take into account several criteria (including transmission bit rate, latency, energy) and various types of constraints (*e.g.*, robustness and simplicity of the protocols and scalability). In many cases, simulations and implementations on test beds are required to analyze the global performance. However, when the analysis is focused on a particular mechanism, several scientific tools can be used, like stochastic analysis or discrete optimization.

2.2.1 Stochastic systems

Keywords: Queuing systems analysis, Markov chains, stochastic geometry.

Traffic is an object of study in itself and as such, it can be analyzed in order to discover interesting properties such as long-range dependence, non-stationarities, non-gaussianity, or heavy-tailed distributions. It is necessary to produce accurate traffic models in order to predict, for example, the utilization of resources or the quality of service. Very often, traffic models are of stochastic nature. They can be very simple such as a Poisson process or more sophisticated such as Markov modulated models or, for example, fractional Brownian motions. These models are often parametric and their parameters must be estimated by the analysis of traffic captures.

The theory of queuing systems is used in order to predict the performance offered to the applications. It can be used to analyse the cost of mobility management in mobile

networks as signalling related to mobility management represents a more and more important part of the total traffic. It is also useful for the analysis of the performance of complex link layer protocols in radio networks.

2.2.2 Discrete Optimization

Keywords: optimization, integer linear programs, approximate algorithms, exact algorithms, heuristics.

Operations research is a scientific area that has developed a special relation with network. The network resource (memory, processing, data rate, radio spectrum) is inherently limited. However, network operators should provide a quality of service (QoS) as good as possible. It is thus common that network scientists formulate optimization problems with an objective function to minimize (or maximize) subject to various constraints.

For example, network design relies on minimizing the cost of the resources requested to support a given traffic matrix. The traffic matrix is based on "busy hour" traffic flow predictions by the operator. Supporting the traffic on the network can often be expressed as a set of linear equations, involving traffic flows and sets of resources. Linear programming is then used to minimize the cost of resources. For small networks, an exact solution can be identified, thanks to mathematical solvers whereas large network design often relies on various heuristics.

2.3 Application domains

2.3.1 Control of radio networks

Participants: Bernard Cousin, Cédric Gueguen, Xavier Lagrange, Loutfi Nuaymi, Tania Alhajj, Chourouk Ghodhbane, Christopher Merlhe, Amath Ndao, Flavien Ronteix–Jacquet, Julien Saint-Martin, El Hadj Mohamed Traore, Cesar Vargas, Juan-Carlos Vargas.

The radio access network is no longer a set of base stations, each one working independently from each other, but a group of radio units controlled by a central unit with the advent of Cloud/Centralised Radio Access Networks (C-RAN). Furthermore, the multi-layer aspect should be used to provide a network with both high-capacity and energy efficiency. Massive Multi-Input Multiple-Output (MIMO) transmissions and more generally all multi-antenna techniques give the possibility to limit the co-channel interference and to increase the capacity but they require intensive processing and high-data bit rates between the radio units and the central unit (fronthaul links). In exceptional circumstances including natural disaster and low-density environment, the fronthaul links are based on radio transmission. Furthermore, a high degree of reliability is required, possibly at the expense of lower capacity.

Our aim is to contribute to the definition of new radio-access architectures and associated control procedures that are able to adapt to the varying load conditions regarding both the time dimension, the space and the type of services. This axis includes

studies on

- Radio Resource management (scheduling with service differentiation, power-control, MIMO modes, energy saving),
- Functional split between the radio units and the central unit for different fronthaul types.
- Terminal-access point association in a multi-layer context,
- Hybrid networks that combine device-to-device and device-to-network transmissions or radio-based fronthaul,

All these questions can be seen as multi-objective optimization problems. The objective can include the total capacity, the latency, the fairness, the energy consumption and the resiliency.

2.3.2 Control of edge networks

Participants: Alberto Blanc, Bernard Cousin, Nicolas Huin, Romaric Ludinard, Loutfi Nuaymi, Bruno Stévant, Géraldine Texier, Zahraa El Ataar, Pierre-Marie Lechevalier, Menuka Perera, Masoud Taghavian.

Network Function Virtualization (NFV) is a strong trend in networks. It is adopted for example for all Network Functions (NF) of a 5G network. A service is defined by a composition of elementary functions, called VNF (Virtual Network Functions), which can be deployed at different locations on the network, potentially operated by different actors. It thus allows the emergence of virtualized or non-virtualized service providers and their composition.

In addition, network slicing allows operators to define several virtual networks dedicated to specific use cases. The slices are implemented with different levels of isolation on the same physical infrastructure, which is potentially complex and operated by different actors. Depending on the type of use case they address, slices must respect a set of properties that can range from properties of availability, quality of service (latency, jitter, ...) to properties related to energy consumption or security. Fulfilling constraints on these properties is challenging, especially for use-cases implying dynamic “edge-to-edge" communications. Therefore, enabling slicing requires mechanisms to ensure their dynamic adaptation to the network conditions involving self-configuration, monitoring, analysis and planning. However, the objective is not to design fully self-organized networks but to put these mechanisms at the service of the implementation of a global strategy. An important issue is to determine when auto-adaptation actions should be performed in a distributed way or require a centralized approach and to which extent hybrid approaches can be used.

There are several research issues to address.

- The first question is how to define the slices, where to locate the involved virtual network functions in order to provide the expected quality of the global network

service especially in term of latency and throughput while minimizing the energy consumption of the system and ensuring a minimum resiliency against failures. We will consider automatic scaling and placement of these functions as part of the solution to dynamically adapt the slicing to changes in the initial conditions.

- The second question is related to reliability when the service involves several actors. The different actors can be all kinds of IT systems, not necessarily sharing the very same objectives nor being designed to achieve security or more generally reliability at system scale. In a context that is highly distributed by nature, and without any real trust, composing the services while respecting the constraints imposed by it is a real challenge. Distributed trusts solutions like blockchains can be a solution to this problem.

3 Scientific achievements

3.1 Resource Allocation and Radio Access Network architecture

Participants: Cédric Guéguen, Xavier Lagrange, Loutfi Nuaymi, Tania AlHajj, Flavien Ronteix–Jacquet.

Reducing Latency and Jitter of 5G.

Cellular networks present high latencies, especially in the Radio Acccess Network (RAN). The new generation of cellular technology 5G, in addition to increasing transmission throughput, must offer low latency in mobile connectivity.

The objective of F. Ronteix-Jacquet in his thesis [1] is to propose mechanisms for reducing latency in the RAN. In this perspective, he set up a software-defined RAN experimentation platform based on the OpenAirInterface project and designed a tool for fine-grained measurement of RAN internal latencies called LatSeq. LatSeq highlights the role of the radio resource allocation mechanism in the jitter and latency of the uplink channel. He showed how the partial knowledge of the transmission buffer length by the scheduling algorithm from Buffer Status Reports (BSRs) and Scheduling Requests (SRs) induces bursts of transmissions, significant jitter and under-utilization of the radio channel capacity. He then proposed a new mechanism for estimating the terminal transmission buffer length [13]. He demonstrated that this method is compatible with 3GPP LTE and 5G standards and makes it possible to reduce the latency of the uplink channel and even more the jitter experienced by packet flows.

Energy management and base station switching in green mobile networks.

This large increase of small cells in 5G networks demands a significant increase in the energy consumption and carbon footprint followed by complex interference management. In order to address these challenges, [6] considers multi-level Sleep Mode (SM) where BS components with similar activation/deactivation times can be put to sleep.

The deeper and higher energy efficient the SM is, the longer it will take the BS to activate, which might impose degradation in the Quality of Service (QoS). While this adds operational flexibility to the BS, it brings complex management to the operator. In this paper, we consider a heterogeneous network architecture where small cells can switch to different SM levels to save energy and reduce dropping rate. We propose a reinforcement learning algorithm for small cells that adapts their activities subject to service delay constraint. In this regard, the algorithm intelligently learns from the environment based on the co-channel interference, the cell buffer size and the expected cell throughput in order to decide the best SM policy. Numerical values show that important energy savings can be obtained with an acceptable dropping rate. Moreover, we show that while offloading users to the macro cell can significantly reduce their delay, dropping rate and the cluster energy consumption, it comes at a cost of decreasing the network energy efficiency up to 5 times compared with the case of no offload.

Auctions for Effective 5G Licensed Shared Access, LSA.

Licensed Shared Access (LSA) is a concept recently proposed by the radio spectrum policy group in order to optimize spectrum usage: a Mobile Network Operator (MNO) can access temporarily to other incumbent's spectrum after obtaining a license. The licensing process is made via an auction mechanism. The mechanisms proposed in the literature for the LSA context are one-shot auction mechanisms which allocate all the available spectrum as a one block. In [5], first we show how to increase the performances of those auctions (in terms of revenue, efficiency and fairness of the allocation)-while preserving truthful bidding- by splitting spectrum and converting single block auctions to multi-block auctions. Simulations results illustrate how the appropriate number of blocks allow to increase the aforementioned metrics. Second, we show how to convert one-shot mechanisms to equivalent ascending mechanisms (in terms of allocations and payments) so that we add transparency and privacy to the auction.

3.2 Content delivery in wireless networks

Participants: Juan-Carlos Vargas, Xavier Lagrange.

The ever increasing demand for high quality multimedia content in mobile networks requires the implementation of techniques for both efficient spectrum management and low energy consumption. Broadcast transmission is the preferred solution for scenarios in which the same content is transmitted to many users at the same time.

The objective of [16] is to propose an analytical method to calculate the user threshold to switch from unicast to broadcast in order to reduce radio resource utilization. We compute the probability of coverage of a given location in a Multicast Broadcast Single Frequency Network (MBSFN) area using tools from stochastic geometry. This expression is general and valid for a point not necessarily in the center of the MBSFN area. We use it to develop a method to calculate the user threshold analytically.

In [17], we consider the energy consumption issue. We study the Base Station (BS) and User Equipment (UE) energy consumption. We present analytical models

to calculate the energy consumption in uni-cast, Multicast Broadcast Single Frequency Network (MBSFN), and Single-Cell Point-to-Multipoint (SC-PTM). Furthermore, we calculate the number of users per cell from which SC-PTM or MBSFN help to reduce BS and UE energy consumption compared to unicast.

3.3 Function and Service Placement in Networks

Participants: Alberto Blanc, Bruno Stévant, Géraldine Texier, Masoud Taghavian, Loutfi Nuaymi, Menuka Perera Jayasuriya Kuranage.

Towards a participatory infrastructure for hosting services: QoS-aware dynamic orchestration of microservices.
A participatory infrastructure attempts to provide a solution for hosting services intended for a virtual community of users. Such a community has requirements that are not fully met by hosting solutions in data centers. We therefore propose a new approach where the members of the community host these services on home equipments. Such participatory infrastructure raises issues related to the heterogeneity of the participating devices and networks, as well as to the variations of their computing and communication capabilities.

Through the study of existing solutions, microservices-based application architecture raise our interest. It allows for a more flexible placement of applications on the participating devices. The first part of our work was therefore to find a placement of microservices on these devices that optimizes the application response time. After defining a model of this response time, we used the PSO heuristic to find a solution close to the optimal one.

We tested this placement in real use conditions to evaluate the influence of network QoS variations on the application response time. This study showed that, under certain conditions, an adaptation of the placement might improve the measured performance. We therefore added to our participatory infrastructure a mechanism able to decide, based on the measured response times, if an adaptation is necessary and to compute a placement adapted to the new conditions.

This work is done as part of Bruno Stévant thesis [2] under supervision of Jean-Louis Pazat, from MYRIADS team, advised by Alberto Blanc. Bruno Stévant successfully defended his PhD on May, 23th 2022.

Placement of network services using network virtual functions.

The advent of 5G offers opportunities to define network services with higher speeds and very low latencies. Software Defined Networking (SDN) and Network Function Virtualization (NFV) paradigms pave the way for automating the instantiation of network services with respect to a set of given constraints.

To satisfy the expectations of NFV, sophisticated algorithms are required to allocate the physical resources in an optimal way, within a fair time constraint. Resources are allocated by determining the suitable placements of the service requests over the

Substrate Network (SN). The placement problem is classified as an NP-Hard problem in terms of complexity, as it is a generalization of the Virtual Network Embedding (VNE) problem.

As summarized in [15], we previously addressed the placement problem, proposing a fast reliable solution for systematically placing network services based on a Branch and Bound (BB) method, which allows us to evaluate different artificial intelligence search strategies. We demonstrated how to obtain near-optimal and optimal results with a high degree of the scalability. The effectiveness of our approach is confirmed by the exhaustive evaluations made by our NSPlacer tool. In [14], we present NSPlacer, which we designed and implemented to evaluate and compare several placement algorithms. Our tool is accessible online to facilitate the study of placement algorithms for the research community. It offers a wide set of parameters to adjust, either related to the substrate network, the service specifications, or the placement algorithm, our online tool provides near-optimal and optimal results to serve as a comparison with many placement solutions.

This work is done as part of Masoud Taghavian's thesis under supervision of Géraldine Texier, co-advised with Philippe Bertin from IRT b<>com and Yassine Hadjadj-Aoul from University of Rennes.

Deep learning-based resource forecasting for 5G core network scaling in Kubernetes environment.

5G networks are moving towards cloudification which gives the telecom operators the flexibility to manage their networks efficiently and cost-effectively. Scaling network functions on demand is one of the advantages of using containerbased deployment in cloud environments. With the continuously changing network traffic patterns due to the emerging new 5G use cases, there is a need for novel automated network resources management approach in cloud-native environments. Considering the scale and the complexity of the 5G network, managing resources is a challenge. To address this, we propose ([12]) a deep learning-based resource usage forecasting approach that provides useful insights for decision-making in containerized Network Function (CNF) scaling for the Kubernetes environment. Kubernetes is a container orchestration tool that becoming popular among Telecom operators due to its simplicity. We implemented a testbed in the Kubernetes environment to generate a dataset closer to real-world data for deep learning model training and evaluated the best-performing model for resource usage forecasting. We benchmarked our approach against another deep learning-based resource usage forecasting approach which proved our method can provide a highly accurate forecast for further horizons.

Lagrangian relaxation for the design of virtual IGP topologies.

Large-scale telecommunication networks rely on Interior Gateway Protocols (IGP), such as the Open Shortest Path First (OSPF) protocol, to build and maintain a single shortest path tree for each router. Using Link State Advertisements (LSA), OSPF distributes the network's state to each router, which then computes a shortest-path

tree towards other equipment. Routers use this tree to determine the next hop on which packets are forwarded. The weights given to the links heavily influence the shape of the shortest-path tree.

To increase routing options, to support different application needs, or to better load balance traffic in the network, an extension of IGP called Multi-Topology Routing (MTR) has been proposed. It runs multiple IGP instances in parallel, each of them working with a different set of link weights and maintaining a Shortest-Path Tree (SPT). Each SPT, also called a topology, relates to different routing criteria (e.g., cost, hop, delay). As routers execute multiple IGP instances, each instance advertises its link states. In practice, if the number of topologies is large, it may lead to a huge protocol overhead. It can be the case when a heterogeneous set of QoS requirements must be satisfied.

We propose [11] a new system architecture that extends MTR to build several virtual topologies on top of existing (real) ones. The main goal is to reduce the protocol overhead that may occur with a large number of topologies and to accommodate a large set of demands with heterogeneous QoS requirements. Instead of designing link weights for different topologies, our system derives virtual topologies from real ones (e.g., cost, latency) using Lagrangian relaxation. In this case, only Lagrangian multipliers are communicated by the network management system to routers, one per real topology which drastically reduces overhead. In addition the virtual topologies that are created are "silent", i.e., they do not exchange additional LSA messages. We also provide an polynomial algorithm that minimizes the number of such virtual topologies, based on the lagrangian relaxation.

3.4 Advanced management of optical networks

Participants: Bernard Cousin, Loutfi Nuaymi, Minqi Wang.

Multicast reconfiguration in optical networks.

Network reconfiguration is an important task in WDM optical networks, which enables the optimization of network resources. With the growing demand for multicast applications (e.g., distance learning, IPTV), Reconfiguring the routing of a multicast connection is an important issue. In [4], the path of the multicast connection is represented by a light-tree. A light-tree reconfiguration consists of migrating an optical flow from a light-tree to a new one. However, it is very difficult to automate light-tree reconfiguration without flow interruption. Flow interruption is undesirable for network operators. Therefore, the problem studied here is to find a sequence of operations in order to migrate an optical flow from a light-tree to a new one without flow interruption in a sparse wavelength converter network. For solving the light-tree reconfiguration problem, we propose a method based on a sub-tree approach. The comprehensive simulation results demonstrated the effectiveness of our method.

Smart placement of optical splitters could decrease link cost and number of wavelengths used in an optical network. In [10], we address the efficient placement of splitters

to minimize the global cost of optical links for a multicast session. We use a hierarchical structure (a form of optical tree in which a node can be visited more than once). Then, two algorithms are proposed to select a set of multicast capable nodes in order to minimize the global cost of links of a multicast session. Simulations results show that the proposed algorithms are significantly better than the ND (node degree) algorithm with regard to number of wavelengths used and total cost of links.

Virtualization in optical networks.

The new 5G service requirements will force operators to rethink the deployment of infrastructure and management tools. A proof-of-concept of an optical central office with Multi-Edge Computing (MEC), User Plane Function (UPF) and disaggregated Optical Line Terminal (OLT) sharing an X86- server is experimentally demonstrated in [18]. We obtained 200 micro-seconds latency and 10 micro-seconds jitter performance for 5G time-critical services. This work demonstrates a generic purpose server hosting disaggregated OLT functions for fixed access, but also mobile functions such as edge cloud and UPF. The convergence of those functionalities enables the mobile network to meet the strong latency and jitter constraints, benefiting from the central office location of the FTTH. By co-hosting the UPF from mobile network and edge cloud with the OLT, this work shows an end-to-end latency decrease of 93% and 80% in our real- time test bed with PtP and PtMP topologies, respectively, and of 90% and 11% for packet jitter.

Some Class of Service (CoS) algorithms need to be developed to ensure that different and heterogeneous services are properly transported through optical fibers in a fixed-mobile converged scenario. Many organizations are considering the use of Transmission Containers (T-CONTs) (the indicator of the bandwidth distribution in the PON uplink) for PON slicing, but the CoS for mobile traffic in PON, Passive Optical, Network (PON) technology has not yet been defined. In parallel, the new Access Networksmanagement solutions are mostly focused on Software-Defined Network (SDN) Northbound/Southbound Interfaces (NBI/SBI) between orchestrators and abstraction entities. However, if an End-to-End (E2E) 5G slice instance needs to be dynamically applied in a fixed-mobile converged architecture, the coordination between mobile and residential management systems is necessary. In [9], we propose a disaggregated OLT with SDN controller that leverages the advantages of virtualization technologies and the currently deployed OLT. This work proposes the "East-West" interface between fixed and mobile SDN controllers and we successfully implemented a 5G slicing Proof of Concept (PoC) in access transport networks using this interface. Uplink latency and jitter are reduced by 25% to 50% thanks to a smart optimization of T-CONT, which could be interesting for Ultra Reliable and Low Latency Communication (URLLC) applications.

Minqi Wang successfully defended her PhD on 3 November 2022. Her thesis [3] studied virtualization technologies as key enablers for convergent fixed PON Network and mobile access networks, in addition to 5G slicing application in these converged access networks. The thesis contributions show that the SDN-based optical access nodes and converged PON provide novel and very promising architectures for time-critical and high-availability services. Finally, some interesting perspectives can be evaluated, such as advanced dynamic load balancing within OLT, or Virtual Machine (VM) resource

optimization with a generic server in access networks.

4 Contracts and collaborations

4.1 International Initiatives

4.1.1 AI4Green Celtic European project

Participants: Loutfi Nuaymi.

- Title: Artificial Intelligence for green networks
- Framework: Celtic European project
- Duration: October 2019- September 2022 (36 months)
- Partners: KTH (Coordinator), Allbesmart, BI Nordic, Canaima Communications, Celfinet, Instituto Politecnico de Castelo Branco, Instituto Superior de Engenharia de Lisboa, Orange SA, P.I. Works, Tele2 , Turkcell, Turkgen, University of Oulu, Verkotan Oy, VTT Technical Research Centre of Finland, Institute Mines Telecom,
- Abstract: Artificial Intelligence and Machine learning have been successfully applied to various domains. This success suggests that these techniques could be successfully applied in the context of wireless networks to improve the overall performance and efficiency. AI4Green is built around the need to build comprehensive, sophisticated and energy-efficient algorithms and solutions at both radio access and core networks, but also on data centres and storage while keeping in mind the emergence of new architectures and the development of smart grids. AI4Green Project ended in November 2022

4.2 National Initiatives

4.2.1 Beyond 5G

Participants: Amath Ndao, Nicolas Huin, Xavier Lagrange, Pierre-Marie Lechevalier, Romaric Ludinard, Loutfi Nuaymi, Géraldine Texier.

- Title: Beyond 5G
- Framework: Strategic Sector Committee (CSF) for Digital Infrastructure: Sovereignty in Telecommunications Networks
- Duration: November 2020 - Jan 2024 (38 months)
- Partners: Thales SIX GTS France, Ericsson France, Eurecom, Institut Mines-Telecom

- Abstract: The participants in the "Beyond 5G" program will work together for three years to design technical solutions for the development of sovereign and secure next-generation 5G networks, while developing innovative uses for the industry of the future. The project goes far beyond a simple technical improvement by paving the way for a wide range of industrial uses based on new cognitive, predictive and contextual capabilities in order to provide an unprecedented experience. The project teams will also focus on post-5G developments, which will be driven by the introduction of disruptive technologies with severe constraints in terms of digital security.

4.2.2 SPIDER project at IRT b<>com

Participants: Romaric Ludinard.

- Title: SPIDER: Self-managing Programmable Intelligent Network DEtection and Response
- Framework: IRT
- Duration: June 2021- Mai 2024 (36 months)
- Partners: Orange, Nokia, Secure-IC, b<>com, IMT Atlantique, University UBO, University Rennes 1 and CentraleSupélec
- Abstract: The main objective of SPIDER is to develop an Autonomous cyber defense against Internet threats for 5G private networks. In order to reach this aim, 4 main drivers will be considered:
  - Proactive threat hunting based on threat intelligence and contextual correlations
  - Autonomous decision making and action orchestration for Incident Response
  - Security as PaaS offering
  - Federated solution across domains

The project hosts the thesis of Antoine Rebstock under supervision of Yann Busnel, co-advised by Romaric Ludinard and Yann Busnel, from IMT Atlantique and Stéphane Paquelet from IRT b<>com. The goal is to study and propose mechanisms for the correlation of alerts and prediction attacks scenarios in the context of SOC.

4.2.3 Maya project at IRT b<>com

Participants: Cédric Gueguen, Xavier Lagrange.

- Title: Réseau MAIllés et Intelligence Artificielle
- Framework: IRT

- Duration: October 2020- September 2023 (36 months)
- Partners: Airbus Defence & Space, Nokia, CentraleSupélec, INSA Rennes, Secure-IC, Orange Labs, University of Rennes 1, IMT Atlantique
- Abstract: The Maya project deals with the optimisation of meshed wireless networks when there is no infrastructure (natural disaster, desert zone). The approach is to use learning methods when possible.

4.2.4 ANR SAFE project

Participants: Bernard Cousin, Cédric Gueguen, Guillaume Terrier,.

- Title: SAFE : Contrôle de réseaux par apprentissage automatique interprétable et respectant des bornes de stabilité
- Framework: Agence Nationale pour la Recherche (ANR), appel générique
- Duration: March 2022- February 2026 (48 months)
- Partners: LabHC/University of Saint Etienne; XLIM/University of Poitiers; IRISA/University of Rennes 1; Huawei Technologies France; QoS Design.
- Abstract: SAFE stands for Controlling Networks with SAFety bounded and InterErpretable Machine Learning. It aims to focus on the design of ML solutions that are safe and explainable for network control plane. The project is built around two main objectives: (1) Hierarchical architecture with global and centralized ML as well as local AI models, (2) Explainable and Safe Algorithms for global and local levels. This architecture and algorithms are for use cases like intelligent path selection, automatic queue in scheduling algorithms for software-defined routing and traffic engineering.

4.2.5 WEC-UP project at IRT b<>com

Participants: Géraldine Texier, Masoud Taghavian.

- Title: Wireless Edge Computing and User Plane
- Framework: IRT
- Duration: Novembre 2019- October 2022 (36 months)
- Partners: Orange, TDF, Nokia, Mitsubishi Electric, Enensys, Aviwest, Exfo, University of Rennes 1, University UBO and IMT Atlantique
- Abstract: The WEC-UP project proposes to build optimized, cooperative and coordinated Networks and Edge Clouds for verticals. The architecture enables the network to evolve into an E2E Cloud Native infrastructure that integrates 5G NR RAN, 5G Core network and EDGE computing.

The project hosts the thesis of Masoud Taghavian that started in September 2020, under supervision of Géraldine Texier, co-advised by Géraldine Texier and Philippe Bertin from IRT b<>com and Yassine Hadjadj-Aoul from University of Rennes 1. The goal is to study and propose mechanisms for the instantiation of VNF/CNF in the edge, for services with high QoS needs and potentially a short lifespan.

4.3 Bilateral industry grants

4.3.1 CIFRE Thesis with Orange

Members of ADOPNET have numerous research projects in cooperation with Orange.

- CIFRE thesis (2019-2022) on the optimization of Ultra-Reliable Low Latency communications (URLLC) (Xavier Lagrange)
  - The objective of the thesis is, through a cross-layer approach, to identify the combination of transport protocols, scheduling algorithms, congestion control and buffer management that allows to ensure a very low latency in 5G networks and to achieve an open implementation.
- CIFRE thesis (2019-2022) on the Introduction of virtualization technologies (SDN/NFV) in the optical access network (Loutfi Nuaymi, Isabel Amigo)
  - The thesis aims to study the evolution of the optical network access due to the introduction of virtualization in the access: characteristics required for the SDN controller, need for an abstraction layer between the controller and the network equipment (such as offers in the literature), choice of protocols and their limits, choice of data models and their limits, limits of the management architecture (failures, latency, etc.), choice of functions to be virtualized (e.g. bandwidth allocation) and associated constraints, integration of the SDN/NFV architecture chosen in the global network context, other equipment, other controllers. Minqi Wang successfully defended her PhD on 3 November 2022 ([3])
- CIFRE thesis (2021-2024) on the use of D2D communication for industrial IoT (Xavier Lagrange)
  - The objective of the thesis is to propose innovative solutions for the integration of D2D communications in the 5G new-radio (NR) interface for Industrial IoT (IIoT) applications, with a strong focus on the emergence of new use cases.
- CIFRE thesis (2021-2024) on efficient and Zero Touch deployment of Cloud-Native network slicing for flexible and scalable 5G networks (Loutfi Nuaymi)
  - The mobile data traffic continues to grow rapidly. This explosion in data volume is a key factor for the development of 5G technologies that should significantly improve the speed of data transmission as well as the reliability of connected objects.

This 5G network with many and diverse services requires a tailor-made, on-demand and autonomous behavior orchestrating efficiently the 5G slices and adjusting the network closer to the customer. The Zero touch orchestration paradigm raises new and important challenges in terms of infrastructure and resource management at the network-core level.

The objective of this thesis is to propose a model for the efficient deployment and orchestration of 5G slices in the cloud native core network.

PhD Student : Menuka Perera Jayasuriya Kuranage

4.3.2 Hybrid Broadcast-Unicast Cellular Networks

Participants: Xavier Lagrange, Juan-Carlos Vargas.

- Title: Integration of Multicast and Unicast for Highly Efficient Video Delivery in Cellular Networks
- Framework: CIFRE framework
- Duration: December 2019- December 2022 (3 years)
- Partners: Enensys
- Abstract: The objective of the thesis is to analyze the performance of unicast and multicast/broadcast modes and to study how to combine them in a really hybrid mode in order to maximize the quality of service while limiting the radio resource that is used.

4.3.3 Optimisation of mobile relays for LTE

Participants: Xavier Lagrange, Julien Saint-Martin.

- Title: Optimization of mobile relays for LTE
- Framework: Industrial Contract
- Duration: June 2022- May 2023 (12 months)
- Partners: SGP (Société du Grand Paris)
- Cooperation with IMT-Atlantique/Lab-STICC (Karine Amis)
- Abstract: Even with dense base station deployments, public transport users often have a low quality for mobile services. Due to the insulation of the vehicle, passengers experience little to no connectivity on their end devices and low data bit rate. The objective of the project is to propose a mobile relay architecture for LTE and to study how it can be adapted and optimized for 5G.

4.4 Collaborations

4.4.1 International forum

Bernard Cousin is IRISA's representative to the Traffic Management forum (TM Forum). TM Forum is an international association for digital business, connecting talented individuals, leading companies, and diverse ecosystems to accelerate digital business transformation.

5 Dissemination

5.1 Promoting scientific activities

5.1.1 Scientific Events Selection

Member of Conference Program Committees Bernard Cousin is member of IEEE Technical Committee on Information Infrastructure and Networking (TCIIN). He served, in 2022, in the Program Committee of the following conferences:

- FNC 2022, International Conference on Future Networks and Communications
- Globecom 2022 NGNI, IEEE Global Communications Conference: Next-Generation Networking and Internet Symposium
- ICC 2022, IEEE International Conference on Communications: Next-Generation Networking and Internet Symposium
- ICN 2022, International Conference on Networks
- IPCCC 22, International Performance, Computing, and Communications Conference
- OPAL 2022, International Conference on Optics, Photonics and Lasers

Xavier Lagrange serves in the Program Committee of the following conferences:

- IEEE ICC 2022, IEEE International Conference on Communications, Mobile and Wireless Networks Symposium
- IEEE PIMRC 2022, 33th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications
- IEEE WCNC 2022, Wireless Communications and Networking Conference
- HiPNet 2022, Worskhop on High-Precision, Predictable, et Low-Latency (HiPNet)

Romaric Ludinard serves in the Program Committee of the following conferences:

- NCA 2022: 21st IEEE International Symposium on Network Computing and Applications

- ICBC 2022: IEEE International Conference on Blockchain and Cryptocurrency
- AFT 2022: 4th ACM Advances in Financial Technologies

Géraldine Texier has served in the Program Committee of AlgoTel 2022.

Nicolas Huin has served in the Program Committee of CoRes 2022.

Loutfi Nuaymi has served in the Program Committees of ISCC 2022, PIMRC 2022 and WiOpt 2022. He was also Workshops co-chair for WiOpt 2022 and SWirNet'22 (Sustainable Wireless Networking) workshop co-chair, held in Torino, Italy, in sept 2022.

5.1.2 Journals

In 2022, Bernard Cousin was member of the Editorial Boards for Wireless Communication & Mobile Computing journal (Wiley).

Loutfi Nuaymi was reviewer for Transactions on Network and Service Management.

Romaric Ludinard was reviewer for Journal of Computer Security.

Géraldine Texier is regular reviewer for Internet Technology Letters and Computer Networks.

5.1.3 Research Administration

Romaric Ludinard is member of the Network and Distributed Systems CNRS Research group (GDR RSD) steering committee.

5.2 MOOCs

Several MOOCs on mobiles networks have been made available on Coursera:

- The 4G technology, which is a basis for 5G, is presented both in french https://www.coursera.org/learn/4g-principes-des-reseaux-mobiles and in english https://www.coursera.org/learn/4g-network-fundamentals.
- A new course on several aspects of 5G (services and architecture, new radio interface, data flow management, security and service-based architecture) was developed in 2022. It is also available both in french https://www.coursera.org/learn/5g-principes-de-fonctionnement/ and english https://www.coursera.org/learn/5g-network-fundamentals.
- A new course on blockchain fundamentals and cryptographic tools was developed in 2022. It is available in french https://www.coursera.org/learn/blockchain-enjeux-et-mecanismes-cryptographiques-bitcoin.

- In the framework of a cooperation between OCIF, STACK2 (LS2N/INRIA) and Adopnet, a new course on IoT Communications and Networks was developed in 2022. It is available in english https://www.coursera.org/learn/iot-communications-networks. It presents the building blocks of the IoT network architecture in order to help learners to adapt to the fast changing communications and networking environment of IoT.

5.3 Popularization

Launched in 2020, 5G commercial networks were still debated in 2022. In this context, Xavier Lagrange was interviewed by Philippe Baqué for an article on 5G (La 5G entre promesse et inquiétude) in Rotary Mag, Issue 825, May 2022.

Xavier Lagrange published a chapter on the 5G architecture in french encyclopedia "Techniques de l'ingénieur" [7].

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