UMR IRISA

Activity Report 2023

Team ADOPNET

Advanced Technologies for Operated Networks

D2 – Networks, Telecommunications and Services

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1 Team composition

Faculty Members

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Bernard Cousin, Emeritus Professor (HDR), Univ. de Rennes
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Post-Doctoral Fellows

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Tania Alhajj, IMT Atlantique, until May 2023
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El Hadj Mohamed Traore, Orange Labs CIFRE/IMT ATlantique, until Sep 2023
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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, 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, 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: Bernard Cousin, Cédric Guéguen, Xavier Lagrange, Loutfi Nuaymi, Nicolas Huin, Géraldine Texier, Tania AlHajj.

Impact of centralized-radio access network architecture on 5G performance.

Fifth Generation (5G) mobile networks are paving the way for a new Radio Access Network (RAN) architecture. This is the Centralized-RAN (C-RAN) which groups some of the Base Station (BS) functions in a Central Unit (CU) connected to Radio Units (RU) distributed in different sites where the other BS functions are implemented. The thesis of Tania Alhajj [1] studies how to take advantage of C-RAN to combine high reliability and low latency on the one hand and to minimize the power consumption of the BS on the other hand. Both single and multi-RU transmissions, as well as a mixture of both, are evaluated. We compare a single-RU approach where the Hybrid Automatic Repeat reQuest (HARQ) mechanism, which combines all the ARQ retransmissions, is located in the RU to a multi-RU transmission with an HARQ centralized in the CU. We show that multi-RU transmissions provide high reliability and low latency due to spatial diversity, even though centralization increases the round trip time. In [6], we consider radio resource allocation. We evaluate the energy consumed by the BSs using a consumption model that integrates both the transmission power and the energy consumed for processing. At low load, multi-RU transmissions in a C-RAN, where all RUs serve one user, save BS energy consumption, without coverage degradation, compared to serving a user with a single RU. We pose and solve an optimization problem to minimize the energy consumption and increase the capacity to moderate load by reusing radio resources between RUs.

Optimal placement of virtualized DUs in O-RAN architecture.

Open Radio Access Network (O-RAN) is very promising for flexible and efficient 5G and 6G wireless networks. The O-RAN architecture consists of three main units: Radio Unit (RU), Distributed Unit (DU), and Centralized Unit (CU). In [11], we study the

placement of virtualized DUs. This placement has strong consequences on cost and delay, among others, and is thus an important challenge. First, we analyze the throughput between the O-RAN interfaces. Based on our analysis, we propose an efficient Integer Linear Programming (ILP) model. The objective is to minimize the O-RAN cost depending on the DU placement while respecting the delay and capacity constraints. We evaluate our model on a real topology. Our results provide interesting insights into the cost savings with regard to a legacy architecture. Moreover, the proposed model provides solutions in a configuration where a fully centralized Cloud RAN architecture would not. We also estimate the limits of capacity of a given configuration. In [10], we consider a RAN load that varies over the day and we study the ORAN-DUs (ORAN-Distributed Units) placement for different frequency bands. We use data obtained from real topology. First, we analyze the percentage of utilization, throughput and Modulation and Coding Scheme (MCS) selections of each frequency band for each hour of the day. We modify the previous ILP model to take into account the use of different bands. Our results analyse the cost savings of the proposed model w.r.t the DRAN (Distributed RAN), the solution prevailing before ORAN, during off-peak and peak hours.

Load-Efficiency-Balance Cell Selection Policy for IAB Networks.

The 3rd Generation Partnership Project (3GPP) has proposed recently the Integrated Access and Backhaul (IAB) to simplify the deployment of new base stations. The connection between the User Equipment (UE) and the Core Network (CN) is provided by a multi-hop 5G wireless connection between the IAB nodes. In [8], the main contribution is to propose a cell selection policy specific to IAB that aims to guarantee the lowest possible total transmission bandwidth cost (including the backhaul cost which is a significant factor in an IAB context) while respecting the base stations capacities in order to boost IAB network capacity. In this context, a comparative performance study was performed between the proposed policy and state-of-the-art policies. System level simulation results show that the solution provides the best system capacity via a trade-off between spectral efficiency and load balancing.

Traffic Load Prediction and Power Consumption Reduction for Multi-band Networks.

Energy is a major expense issue for mobile operators. In the case of wireless networks, base stations have been identified as the main source of energy consumption. In [7], we study the energy consumption reduction problem based on real measurements for a commercial multi-band LTE network. Specifically, we are interested in sleep modes to turn off certain frequency bands during low traffic periods and consequently reduce power consumption. We determine the number of frequency bands really needed at each time period. The frequency bands that are not needed can be disabled to reduce energy consumption. In order to allow the operator to predict how many bands can be switched off without major impact on the quality of service, we propose to use a deep learning algorithm, such as Long-Short Term Memory (LSTM). Based on the captured data traces, we have shown that the proposed LSTM model can save an average of 8% to 21% of the energy consumption during working days.

3.2 Content delivery in wireless networks

Participants: Juan-Carlos Vargas, Cesar Vargas Anamuro, Xavier Lagrange, Bruno Stévant.

Broadcast vs unicast in mobile networks.

Data traffic on mobile networks increases every year, especially video content. However, spectrum is scarce and expensive and operators need to optimize its use. In scenarios where the same content is transmitted at the same time to many devices in the same geographical area, the preferred solution to reduce bandwidth consumption is broadcast transmission. Unicast transmission benefits from link adaptation techniques. However, the same content is transmitted as many times as the number of users demanding the same service. Conversely, a single broadcast transmission can cover a large number of users. Nevertheless, the bitrate in broadcast is fixed considering the users with the worst channel quality. Multicast-Broadcast Single-Frequency-Network (MBSFN) is a broadcast technique in which a group of synchronized cells transmit the same waveform. On the other hand, with Single-Cell Point-To-Multipoint (SC-PTM) each cell performs broadcast transmission independently. The problem is to determine when is it better to use unicast, MBSFN or SC-PTM. In the PhD thesis of J.C. Vargas [2], we compare the performance of unicast, MBSFN and SC-PTM through system level simulations and analytical models. We consider base stations located according to Poisson distributions, the use of beamforming in unicast and different broadcast configurations. Furthermore, we propose an analytical method to calculate the number of users demanding the same content from which MBSFN or SC-PTM become more efficient than unicast. We prove that a switching mechanism based on this user threshold reduces bandwidth utilization and energy consumption. This method is based on stochastic geometry results for wireless networks.

Video transmission from Unmanned Aerial Vehicle (UAV).

The use of UAVs (security, defense, parcel delivery, infrastructure surveillance, etc.) is rapidly expanding. The security and reliability of data link modules are particularly crucial. Drone Geofencing, a company specializing in drone fleet management, is developing a high-speed communication module designed for UAVs. The objective is to transmit, to a base station (relay antenna), the video stream captured by cameras, along with telemetry data such as battery level, motor status, position, route, speed, etc. The module, connected to a ground station independent of the drone's remote control, simultaneously communicates through four 5G infrastructure networks, associated with the four major 5G operators in France. Being multi-interface and multi-operator, the module takes advantage of various possible connections to ensure continuous connectivity of the drone to the ground station and to maximize bandwidth for video transmission. Drone Geofencing engaged the ADOPNET team's expertise on the design of the communication module, focusing on the scheduling mechanism prioritizing the different radio interfaces. A first identified problem is to obtain an anticipated

assessment of the network Quality of Service (QoS) provided by each interface before actual traffic transmission. As part of a student internship, we initiated a study to explore potential correlations between the offered network QoS and 5G radio indicators (RSSI, RSRP, RSRQ, CQI, etc.). Evaluations were conducted in controlled lab conditions with a 5G network emulation and in real-world scenarios using a production network. Results, detailed in an internal report, revealed that clear correlations could not be distinctly identified, but emphasized the relevance of a subset of these indicators. Further measurements are planned to create a dataset suitable for training machine-learning algorithms.

3.3 Traffic analysis

Participants: Alberto Blanc, Cesar Vargas Anamuro, Xavier Lagrange.

Mobile traffic classification through burst traffic statistical features.

Mobile traffic classification is a topic of interest for researchers focused on improving the network capacity or for those seeking to identify potential risks to users' privacy. In recent years, traffic classification accuracy has significantly improved thanks to machine learning techniques. These techniques allow traffic identification even if it is encrypted, as in mobile networks. In [13], we show that it is feasible to classify mobile traffic applications with high accuracy using downlink control information (DCI) messages and machine learning. The DCI messages are collected using a sniffer located near the base station. Then we extract the statistical features of the bursts and inter-burst periods of the traffic generated by mobile applications at the physical layer. This strategy uses few features and does not require a big dataset. We have tested our approach on a 4G cellular network testbed and a commercial 4G cellular network. The results show an accuracy greater than 92% and 95% for application and category classification, respectively.

Characterizing and Comparing Cellular Network Traffic in French Cities Characterizing mobile networks' data traffic in the time and space domains is critical in improving how these networks are dynamically configured. In [15], we study the NetMob 2023 Data Challenge dataset. We first establish the existence of a weekly pattern for the total traffic in each major city in France. We show that the daily pattern is essentially the same from Monday till Thursday but with more traffic on Wednesday. Some deviations are clearly visible on Friday. Using the IRIS zones, we try to group zones exhibiting similar patterns. We find that four or five different clusters can best characterize the traffic in most cities. Identifying these clusters is a valuable step in optimizing the placement of network functions. Finally, we analyze the percentage of traffic generated by different applications, showing that, while the overall percentage of traffic generated by an application is similar in each city, the spatial diversity for a given application varies from city to city.

3.4 Function and Service Placement in Networks

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

Placement of network services using network virtual functions.

Network operators adopt network virtualization and network programmability, enabled by the introduction of Network Function Virtualization (NFV) and Software Defined Networking (SDN), in 5G networks to create more flexible networks that can rapidly integrate new services. In NFV and SDN, service placement is a crucial step that involves allocating heterogeneous network resources for service requests meeting QoS constraints. The placement of network services demanding strict end-to-end latency requirements presents a challenging problem: they can not be placed in cloud networks, where the resources are abundant but far from the end users, introducing additional delays, they must stay on the edge where resources are scarcer. In terms of complexity, the problem of the placement falls into the class of NP-Complete. Two general categories considered for the placement problem in the literature are *offline* and *online* placements. In an offline placement scenario, all the service requests are known in advance, while in an online placement scenario, requests are placed on the fly, without any information about future service requests. Thus, online placement can lead to sub-optimal solutions as they result from a trade-off between the time to solve the problem and the quality of the solution.

In [5], after modeling the placement problem and proposing the exact resolutions using Integer Linear Programming (ILP) and Column Generation (CG), we propose a deterministic placement solution, capable of obtaining optimal results with the scalability of a heuristic-grade approach. Our method is organized as a Branch and Bound (BnB) structure, applying Artificial Intelligence (AI) search strategies (especially A*) to address the problem of network service placement. We believe that it is suitable for a range of applications in online placement scenarios, whether we concentrate on the quality of the results or on the strict time constraints. We are interested in the popular objective of Service Acceptance (SA) maximization and have carried out several extensive evaluations. The obtained results confirm the effectiveness of our solution.

In [12], we propose a Branch-and-Bound search approach for finding optimal placements of the network services by applying several cost functions to maximize the service acceptance. Our exploration of several cost functions and search strategies leads us to demonstrate the inconsistency of bandwidth and/or latency optimization, and the benefits of fair placement, to maximize service acceptance. Here, *fairness* is achieved by a fair distribution of the resources in the placements, but also by a fair compromise between the edge (with low latencies but less resources) and the network/cloud provider (resources are abundant and cheaper but farther, introducing delays). For comparison, we model the problem in ILP and resolve the model to obtain the global optimum (which can only be achieved in an offline scenario). Extensive evaluations have been carried out, and the results confirm significant improvements when we consider a fair distribution of the resources on the edge.

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

5G networks have to meet huge, diverse customer demands and novel use cases with stringent QoS requirements and minimized costs. To meet these challenges, the 5G network adopts a cloud-native approach, which brings the potential for great flexibility such as dynamic scalability for its network functions. Over the years, Kubernetes became a desirable option for telecom operators as a container orchestration software for cloud-native network solutions thanks to its versatility.

As it stands, Kubernetes' default resource scaling solution HPA (Horizontal Pod Autoscaling) represents a significant step forward in addressing the need to dynamically adapt compute resources to current demands.

However, in ([9]) we observe that in some cases, HPA genericity can be costly in terms of resources mobilized and QoS degradation. Experimental analysis performed on a volatile traffic profile demonstrates the limitations of HPA. We propose a deep learning-based proactive scaling solution to overcome them and balance the cost-QoS trade-off. Essentially, it predicts the future CPU load of the Containerized Network Function (CNF) and makes decisions based on a new scaling algorithm. We also embed our approach in ETSI ZSM (Zero touch network and Service Management) framework. We compare our solution with the standard Kubernetes HPA and another alternative approach found in the state of the art. Our results show that the proposed solution outperforms these scaling mechanisms in terms of maintaining QoS levels during scaling and reducing operational costs.

Routing and slot allocation in 5G hard slicing.

Current network slicing solutions suffer from poor inter-slice isolation, as the performance of one slice can be influenced by the traffic in other slices. New technologies such as Flex Ethernet can offer hard isolation via dedicated resources at the physical and MAC layers. However, to create cost-efficient hard slices in large 5G access networks, a "routing and slot allocation" must be solved quickly. While the underlying network design problem is not new, two extra constraints need to be considered: a specific order in slot activations and a bandwidth allocation policy with statistical multiplexing.

We propose a compact and extended formulation to derive FlexE-CG [4], an algorithm based on column-generation to solve large instances. We reinforce the extended formulation to improve the lower bound by deriving valid inequalities, and we provide necessary and sufficient conditions under which the inequalities are facet-defining. We show that these inequalities improve the lower bound by more than 20% on various IP-Radio Access Networks (RAN). We also show that FlexE-CG can provide solutions within an optimality gap of 10% in a few minutes.

Placement of Logical Functionalities in 5G/B5G Networks.

5G technology has brought tremendous growth in connectivity, mobile traffic capacity, and enhanced performance with greater throughput, lower latency, ultra-high reliability, higher connectivity, and an expanded range of mobility. We present here a unified E2E logical functionality placement with the joint placement of distributed units (DU), centralized Units (CU) and user plane functions (UPF).

We model the problem as a large-scale integer linear program that we solve using decomposition techniques [14]. It includes all key network and IT resources and optimizes DU, CU and UPF placements and their numbers. We perform a sensitivity analysis on an open Montreal traffic dataset where we investigate the impact of the number of locations hosting DU, CU and UPF functionalities on the delays of the request flows. We show that the placement reduce link capacity utilization and that we provision requests with up to 50% spared delay

3.5 Advanced management of optical networks

Participants: Bernard Cousin.

Placement of Splitters in WDM Network for Optical Trees.
Optical splitters could decrease link cost and number of wavelengths used in an optical network. In [3], 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 also 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.

4 Contracts and collaborations

4.1 Collaborations

Ndolane Diouf who is PhD student at University of Cheikh Anta Diop in Senegal spent a 3-month period with the team. This gave the opportunity to start a cooperation on the application of learning algorithms to 4G-5G mobile networks with the objective of reducing the energy consumption of such networks.

Dr. Kevin Hoarau, from the University of La Réunion, came to work 5 weeks with Géraldine Texier and Nicolas Huin. During his stay, they worked on the use of Graph Neural Networks for topology abstraction in the context of network virtualization and 5G slicing.

4.2 National Initiatives

4.2.1 JEN

Participants: Loutfi Nuaymi.

- Title: 'Just Enough Networks' to respond to user requirements (JEN)
- Framework: France 2030, Programmes et équipements prioritaires de recherche (PEPR) Future Networks
- Duration: May 2023 - Dec 2027 (56 months)
- Partners: IMT, Inria, CNRS, CEA
- Abstract: Communication networks are often presented as a necessary means of reducing the impact on the environment of various sectors of industry. In practice, the roll-out of new generations of mobile broadband networks has required increased communication resources for wireless access networks. This has proved an effective approach in terms of performance but concerns remain about its energy cost and more generally its environmental impacts. Exposure to electromagnetic fields also remains a cause of concern despite existing protection limits. In the JEN project, we propose to develop just enough networks: network whose dimension, performance, resource usage and energy consumption are just enough to satisfy users needs. Along with designing energy-efficient and sober networks, we will provide multi-indicators models that could help policy-makers and inform the public debate.

4.2.2 Fitness

Participants: Amina Mokdad, Xavier Lagrange with A. Pelov and L. Toutain from OCIF.

- Title: From IoT breakthroughs to Network Enhanced ServiceS (Fitness)
- Framework: France 2030, Programmes et équipements prioritaires de recherche (PEPR) Future Networks
- Duration: May 2023 - Dec 2027 (56 months)
- Partners: IMT, Inria, CNRS, CEA
- Abstract: The Internet of Things (IoT) revolution promises significant benefits in terms of efficiency, sustainability and safety for both industry and society future. Nevertheless, massive deployment of connected IoT devices will necessitate to consider challenges such as Cost and power consumption, Easiness of roll-out, compactness and performance fullfilment, Inter-operability and self-adaptive network. The objectives of NF-FITNESS are to provide with some consistent blocks

and their vertical integration towards these IoT implementation and co-existence issues. Challenges require considering a vertical manner for end-to-end communication implementation.

4.2.3 NAI

Participants: Géraldine Texier, Nicolas Huin.

- Title: Networks & Infrastructures Architectures and Networks-Cloud-Sensing Convergence (NAI)
- Framework: France 2030, Programmes et équipements prioritaires de recherche (PEPR) Future Networks
- Duration: May 2023 - Dec 2027 (56 months)
- Partners: IMT, Inria, CNRS, CEA
- Abstract: Beyond traditional objectives, including advances in throughput, execution speed, latency, or object connection density, the outcomes of the NAI project will enable the effective integration of multiple new technologies, including technologies for the physical layer (e.g. reconfigurable intelligent surfaces), transition to 3D systems (e.g. NTN – non-terrestrial networks) and architectural principles (e.g. slicing and dynamic end-to-end orchestration). The project will facilitate the emergence of new applications and services by reaching the objective of transparency – towards uses – in terms of performance, robustness and security. The project will also design interfaces offering a rich level of capabilities and personalization to the service plane and to application developers, over the whole chain, from connected mini-objects to large data centres through multi-access edge computing (MEC).

4.2.4 Beyond 5G

Participants: Amath Ndao, Nicolas Huin, Xavier Lagrange, Pierre-Marie Lechevalier, 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.

4.2.5 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, IMT Atlantique
- Abstract: The Maya project deals with the optimization of meshed wireless networks when there is no infrastructure (natural disaster, desert zone). The approach is to use learning methods when possible.

4.2.6 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 IntErpretable 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. These architectures and algorithms are for use cases like intelligent path selection, automatic queue in scheduling algorithms for software-defined routing and traffic engineering.

4.3 Bilateral industry grants

4.3.1 Zero Touch deployement of Cloud-Native Networks

Participants: Loutfi Nuaymi, Menuka Perera.

- Title: Efficient and Zero Touch deployment of Cloud-Native network slicing for flexible and scalable 5G networks
- Framework: CIFRE framework
- Duration: May 2021- April 2024 (3 years)
- Partners: ExFo and b<>com
- Abstract: 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.

4.3.2 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.

5 Dissemination

5.1 Promoting scientific activities

5.1.1 Scientific Events Selection

Member of Conference Program Committees Bernard Cousin served, in 2023, in the Program Committee of the following conferences:

- FNC 2023, International Conference on Future Networks and Communications
- Globecom 2023 NGNI, IEEE Global Communications Conference: Next-Generation Networking and Internet Symposium
- ICC 2023, IEEE International Conference on Communications: Next-Generation Networking and Internet Symposium
- IPCCC 23, International Performance, Computing, and Communications Conference
- OPAL 2023, International Conference on Optics, Photonics and Lasers

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

- IEEE ICC 2023, IEEE International Conference on Communications, Mobile and Wireless Networks Symposium
- IEEE WCNC 2023, Wireless Communications and Networking Conference

Géraldine Texier has served in the Program Committee of AlgoTel 2023.

Nicolas Huin has served in the Program Committee of CoRes 2023.

Loutfi Nuaymi has served in the Program Committees of ICC 2023 GreenNet Workshop and ISCC 2023.

Cédric Gueguen has served in the Program Committees of SAFE workshop of CONEXT 2023 conference.

5.1.2 Journals

Loutfi Nuaymi was reviewer for IEEE Communications Magazine, IEEE Transactions on Network and Service Management and Computer Networks Magazine.

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

5.2 Popularization

Xavier Lagrange published a chapter on the new radio interface defined for 5G in french scientific database "Techniques de l'ingénieur" [16].

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[2] J. C. Vargas Rubio, *Unicast versus broadcast in cellular networks*, Theses, Ecole nationale supérieure Mines-Télécom Atlantique, March 2023, https://theses.hal.science/tel-04186106.

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[3] A. Dafeur, B. Cousin, F. Bouhatem, S. A. Belkacem, F. Abba, "Hierarchical Structure and Placement of MC Nodes in Optical WDM Network", *Lecture Notes in Networks and Systems 624*, February 2023, p. 373–379, https://hal.science/hal-03974481.

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