RESEARCH CENTRE

Inria Center
at Université Côte d'Azur

2022
ACTIVITY REPORT

Project-Team
DIANA

Design, Implementation and Analysis of Networking Architectures

DOMAIN

Networks, Systems and Services, Distributed Computing

THEME

Networks and Telecommunications

Inria

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Project-Team DIANA

Creation of the Project-Team: 2015 July 01

Keywords

Computer sciences and digital sciences

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A1.2.1. – Dynamic reconfiguration

A1.2.2. – Supervision

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2 Overall objectives

2.1 Presentation of the team

The overall objective of the DIANA project-team is to provide network architectural support for improving citizen rights in the Internet. To do so, we work to provide service transparency and user data control in the context of hundreds of billions of both wired and mobile devices. Our methodology includes advanced measurement techniques, design and implementation of architectural solutions, and their validation in adequate experimental facilities.

The high complexity of the Internet architecture, protocols and services, and the economic interests of the big stakeholders result in a lack of transparency concerning information of high interest to the

connected “citizen” such as possible privacy leaks, root cause of service degradation or lock-in behavior. It is therefore important to enhance the network to provide service transparency to citizens.

On the other hand, the ossification of the Internet architecture around the IP protocol makes introduction of new functionalities in the network quite difficult. Users currently have no control on their contents and depend on big companies (e.g., Google drive, iCloud, dropbox, Microsoft OneDrive) to easily access and share data at the expense of their privacy. However, the recent development of software-defined network and network functions virtualization concepts open the perspective of faster deployment of network functionalities, as it abstracts the whole network as a single piece of software, instead of a large number of heterogeneous and dedicated devices to be configured one-by-one.

In the DIANA project-team, we have two main research directions:

- designing and deploying a measurement plane providing network service transparency,
- defining and deploying an open network architecture for user control.

Our research program is presented briefly in the next section.

3 Research program

3.1 Service Transparency

Transparency is to provide network users and application developers with reliable information about the current or predicted quality of their communication services, and about potential leakages of personal information, or of other information related to societal interests of the user as a “connected citizen” (e.g. possible violation of network neutrality, opinion manipulation). Service transparency therefore means to provide meaningful information to users and application developers, such as quality of experience, privacy leakages, or opinion manipulation, etc. rather than network-level metrics such as available bandwidth, loss rate, delay or jitter.

The Internet is built around a best effort routing service that does not provide any guarantee to end users in terms of quality of service (QoS). The simplicity of the Internet routing service is at the root of its huge success. Unfortunately, a simple service means unpredicted quality at the access. Even though a considerable effort is done by operators and content providers to optimise the Internet content delivery chain, mainly by over-provisioning and sophisticated engineering techniques, service degradation is still part of the Internet. The proliferation of wireless and mobile access technologies, and the versatile nature of Internet traffic, make end users quality of experience (QoE) forecast even harder. As a matter of fact, the Internet is missing a dedicated measurement plane that informs the end users on the quality they obtain and in case of substantial service degradation, on the origin of this degradation. Current state of the art activities are devoted to building a distributed measurement infrastructure to perform active, passive and hybrid measurements in the wired Internet. However, the problem is exacerbated with modern terminals such as smartphones or tablets that do not facilitate the task for end users (they even make it harder) as they focus on simplifying the interface and limiting the control on the network, whereas the Internet behind is still the same in terms of the quality it provides. Interestingly, this same observation explains the existing difficulty to detect and prevent privacy leaks. We argue that the lack of transparency for diagnosing QoE and for detecting privacy leaks have the same root causes and can be solved using common primitives. For instance, in both cases, it is important to be able to link data packets to an application. Indeed, as the network can only access data packets, there must be a way to bind these packets to an application (to understand users QoE for this application or to associate a privacy leak to an application). This is however a complex task as the traffic might be obfuscated or encrypted. Our objectives in the research direction are the following:

- Design and develop measurement tools providing transparency, in spite of current complexity
- Deploy those measurement tools at the Internet’s edge and make them useful for end users
- Propose measurements plane as an overlay or by exploiting in-network functionalities
- Adapt measurements techniques to network architectural change
- Provide measurements as native functionality in future network architecture

3.2 Open network architecture

We are surrounded by personal content of all types: photos, videos, documents, etc. The volume of such content is increasing at a fast rate, and at the same time, the spread of such content among all our connected devices (mobiles, storage devices, set-top boxes, etc) is also increasing. All this complicates the control of personal content by the user both in terms of access and sharing with other users. The access of the personal content in a seamless way independently of its location is a key challenge for the future of networks. Proprietary solutions exist, but apart from fully depending on one of them, there is no standard plane in the Internet for a seamless access to personal content. Therefore, providing network architectural support to design and develop content access and sharing mechanisms is crucial to allow users control their own data over heterogeneous underlying network or cloud services.

On the other hand, privacy is a growing concern for states, administrations, and companies. Indeed, for instance the French CNIL (entity in charge of citizens privacy in computer systems) puts privacy at the core of its activities by defining rules on any stored and collected private data. Also, companies start to use privacy preserving solutions as a competitive advantage. Therefore, understanding privacy leaks and preventing them is a problem that can already find support. However, all end-users do not *currently* put privacy as their first concern. Indeed, in face of two services with one of higher quality, they usually prefer the highest quality one whatever the privacy implication. This was, for instance, the case concerning the Web search service of Google that is more accurate but less privacy preserving than Bing or Qwant. This is also the case for cloud services such as iCloud or Dropbox that are much more convenient than open source solutions, but very bad in terms of privacy. Therefore, to reach end-users, any privacy preserving solutions must offer a service equivalent to the best existing services.

We consider that it will be highly desirable for Internet users to be able to *easily* move their content from a provider to another and therefore not to depend on a content provider or a social network monopoly. This requires that the network provides built-in architectural support for content networking.

In this research direction, we will define a new *service abstraction layer* (SAL) that could become the new waist of the network architecture with network functionalities below (IP, SDN, cloud) and applications on top. SAL will define different services that are of use to all Internet users for accessing and sharing data (seamless content localisation and retrieval, privacy leakage protection, transparent vertical and horizontal handover, etc.). The biggest challenge here is to cope in the same time with large number of content applications requirements and high underlying networks heterogeneity while still providing efficient applications performance. This requires careful definition of the services primitives and the parameters to be exchanged through the service abstraction layer.

Two concurring factors make the concept behind SAL feasible and relevant today. First, the notion of scalable network virtualization that is a required feature to deploy SAL in real networks today has been discussed recently only. Second, the need for new services abstraction is recent. Indeed, more than fifteen years ago the Internet for the end-users was mostly the Web. Only ten years ago smartphones came into the picture of the Internet boosting the number of applications with new functionalities and risks. Since a few years, many discussions in the network communities took place around the actual complexity of the Internet and the difficulty to develop applications. Many different approaches have been discussed (such as CCN, SDN) that intend to solve only part of the complexity. SAL takes a broader architectural look at the problem and considers solutions such as CCN as mere use cases. Our objectives in this research direction include the following:

- Identify common key networking services required for content access and sharing
- Detect and prevent privacy leaks for content communication
- Enhance software defined networks for large scale heterogeneous environments
- Design and develop open Content Networking architecture
- Define a service abstraction layer as the thin waist for the future content network architecture
- Test and deploy different applications using SAL primitives on heterogeneous network technologies

3.3 Methodology

We follow an experimental approach that can be described in the following techniques:

- Measurements: the aim is to get a better view of a problem in quantifiable terms. Depending on the field of interest, this may involve large scale distributed systems crawling tools; active probing techniques to infer the status and properties of a complex and non controllable system as the Internet; or even crowdsourcing-based deployments for gathering data on real-users environments or behaviours.

- Experimental evaluation: once a new idea has been designed and implemented, it is of course very desirable to assess and quantify how effective it can be, before being able to deploy it on any realistic scale. This is why a wide range of techniques can be considered for getting early, yet as significant as possible, feedback on a given paradigm or implementation. The spectrum for such techniques span from simulations to real deployments in protected and/or controlled environments.

4 Application domains

The DIANA project-team conducts research activities to provide network architectural support for improving citizen rights in the Internet. The main application domains of the teams are:

- Network and quality of experience measurement
- Detection of private information leaks
- Industrial deterministic networks
- Data center networks
- Deployment of future open radio networks
- Realistic simulations and reproducible experiments

5 Social and environmental responsibility

Public health politics and scientists evaluating the impact of EMF radiations on human beings all face the same challenge: How to assess the real exposure of human beings in order to correlate it with observed symptoms and illness. This problem is even harder considering that the period of observation must be long (years), and the number of observed persons must be large. ElectroSmart is a technological breakthrough that will have scientific, technical, and societal applications, notably on public health politics, by providing the scientific community and potential users with a unique measuring instrument, methods, and models to exploit the invaluable data gathered by the instrument. To fulfill this goal, we decided to open source the code of ElectroSmart under a BSD 3-Clause license. The code has been opened on GitHub in October 2022 and has currently 16 stars and 4 forks.

6 Highlights of the year

6.1 Conference organisation

The Diana team organised the ACM Internet Measurement Conference (IMC) in Nice on Oct 25-27, 2022. ACM IMC is the premier international conference dedicated to the topic of Internet measurement and analysis sponsored by ACM SIGCOMM and ACM SIGMETRICS in cooperation with USENIX. Chadi Barakat was the General Co-Chair of the event, which grouped this year more than 220 participants from all continents and was supported by main industrials in the domain. All details can be found on the conference website.

6.2 Standard Track RFCs publication

After several years of effort in IETF working groups on LISP standardisation, three RFCs were published this year : one informational track RFC on LISP architecture [24] and two standard track RFCs on LISP security protections [26] and on inter-domain message exchanges [25].

7 New software and platforms

7.1 New software

7.1.1 ACQUAmobile

Name: Application for prediCting Quality of User Experience at Internet Access

Keywords: Android, Internet access, Performance measure, Quality of Experience

Scientific Description: ACQUA is an Application for prediCting QUality of Experience (QoE) at Internet Access. It is developed by the Diana team at Inria Sophia Antipolis – Méditerranée and was supported by Inria under the ADT ACQUA grant. The scientific project around ACQUA is supported by Inria Project Lab BetterNet and the French National Project ANR BottleNet. The project also got the approval of Inria COERLE and French CNIL for the part on experimentation with real users. ACQUA presents a new way for the evaluation of the performance of Internet access. Starting from network-level measurements as the ones we often do today (bandwidth, delay, loss rates, jitter, etc), ACQUA targets the estimated Quality of Experience (QoE) related to the different applications of interest to the user without the need to run them (e.g., estimated Skype quality, estimated video streaming quality).

The ACQUA Android application is supposed to be on one hand the reference application for QoE forecasting and troubleshooting for end users at their Internet access, and on the other hand, the feedback channel that allows end users to report to us (if they are willing) on their experience together with the corresponding network measurements so as to help us calibrating better and more realistic models. For this calibration, we are currently performing extensive, efficient and automatic measurements in the laboratory, we will count on end users to help us completing this dataset with further applications and more realistic network and user conditions.

ACQUA is mainly meant for end users, but it is also of interest to (mobile) network operators and to content providers to estimate the QoE of their customers and their networks without each time having to run expensive application-level traffic and to involve real users.

Functional Description: An application in ACQUA is a function, or a model, that links the network-level and device-level measurements to the expected Quality of Experience. Supervised machine learning techniques are used to establish such link between measurements both at the network level and the device level, and estimations of the Quality of Experience for different Internet applications. The required data for such learning can be obtained either by controlled experiments as we did in a prior work on Skype and YouTube Quality of Experience, or by soliciting the crowd (i.e. crowdsourcing) for combinations (i.e. tuples) of network- and application-level measurements and corresponding user-level Quality of Experience. Our current work is concentrating on calibrating further models for ACQUA and on using the dataset of ACQUA to understand the performance of mobile networks and user experience in the wild. We refer to the application web site of the project for further details.

Assessment: Audience = 3, Software Originality = 4, Software Maturity = 3, Evolution and Maintenance = 3, Software Distribution and Licensing = 5.

URL: http://project.inria.fr/acqua/

Authors: Thierry Spetebroot, Chadi Barakat

Contact: Chadi Barakat

7.1.2 ElectroSmart

Keywords: Crowd-sourcing, UMTS, GSM, Bluetooth, Wi-Fi, 4G, 3G, 2G, Electromagnetic waves, Android, LTE

Functional Description: Functional Description: The Internet and new devices such as smartphones have changed fundamentally the way people communicate, but this technological revolution comes at the price of a higher exposition of the general population to microwave electromagnetic fields (EMF). This exposition is a concern for health agencies and epidemiologists who want to understand the impact of such an exposition on health, for the general public who wants a higher transparency on its exposition and the health hazard it might represent, but also for cellular operators and regulation authorities who want to improve the cellular coverage while limiting the exposition, and for computer scientists who want to better understand the network connectivity in order to optimize communication protocols. Despite the fundamental importance to understand the exposition of the general public to EMF, it is poorly understood because of the formidable difficulty to measure, model, and analyze this exposition.

The goal of the ElectroSmart project is to develop the instrument, methods, and models to compute the exposition of the general public to microwave electromagnetic fields used by wireless protocols and infrastructures such as Wi-Fi, Bluetooth, or cellular. Using a pluri-disciplinary approach combining crowd-based measurements, in-lab experiments, and modeling using sparse and noisy data, we address challenges such as designing and implementing a measuring instrument leveraging on crowd-based measurements from mobile devices such as smartphones, modeling the exposition of the general public to EMF to compute the most accurate estimation of the exposition, and analyzing the evolution of the exposition to EMF with time. This technological breakthrough will have scientific, technical, and societal applications, notably on public health politics, by providing the scientific community and potential users with a unique measuring instrument, methods, and models to exploit the invaluable data gathered by the instrument. This project is supported by the UCN@Sophia Labex in 2016/2017/2018 (funding the engineer Mondi Ravi), by an Inria ADT (funding the engineer Abdelhakim Akodadi) 2017/2018, by and Inria ATT (funding the business developer David Migliacci) in 2017/2018, and by the academy 1 of UCAJedi (funding a Ph.D. student Yanis Boussad) 2017/2021.

In August 2016, we released the first stable public release of ElectroSmart. On the 30th December 2022 the app has been downloaded more than 3 million time, we have 200 000 active users and a score of 4,5/5 on Google Play. On Octobre 2022, the code has been opened with a BSD 3-Clause license on github and has currently 16 stars and 4 forks.

URL: https://www-sop.inria.fr/members/Arnaud.Legout/Projects/electrosmart.html

Contact: Arnaud Legout

Participants: Arnaud Legout, Mondi Ravi

7.1.3 nepi-ng

Keywords: Wireless network, Experimentation

Functional Description: In the specific context of R2lab, we have created a tool suite for orchestrating network experiments, that for historical reasons we refer to collectively as nepi-ng, for NEPI new generation. An umbrella website is available.

At this point, nepi-ng has a much smaller scope than its NEPI ancestor used to have, in that it only supports remote control of network experiments over ssh. As a matter of fact, in practice, this is the only access mechanism that we need to have for running experiments on both R2lab, and PlanetLab Europe.

The design of nepi-ng of course is modular, so that it will be perfectly possible to add other control mechanisms to this core if and when it becomes necessary.

- asynciojobs:
  - URL: https://asynciojobs.readthedocs.io/
  - Version: asynciojobs v0.17.0
  - Keywords: asynchronous programming, coroutines, orchestration
  - License: CC BY-SA 4.0
  - Type of human computer interaction: Python library
  - OS/Middleware: Linux
  - Required library or software: Python-3.9 / asyncio
  - Programming language: Python
- apssh:
  - URL: https://apssh.readthedocs.io/
  - Version: apssh v0.24.0
  - Keywords: orchestration, ssh, networking experimentation
  - License: CC BY-SA 4.0
  - Type of human computer interaction: Python library
  - OS/Middleware: Linux
  - Required library or software: Python-3.9 / asyncio
  - Programming language: Python

URL: https://nepi-ng.inria.fr

Contact: Thierry Parmentelat

7.1.4 Distrinet

Name: Distrinet

Keywords: SDN, Emulation, Large-scale Emulators, Network simulator

Scientific Description: Networks have become complex systems that combine various concepts, techniques, and technologies. As a consequence, modelling or simulating them now is extremely complicated and researchers massively resort to prototyping techniques. Mininet is the most popular tool when it comes to evaluate SDN propositions. Mininet allows to emulate SDN networks on a single computer but shows its limitations with resource intensive experiments as the emulating host may become overloaded. To tackle this issue, we propose Distrinet, a distributed implementation of Mininet over multiple hosts, based on LXD/LXC, Ansible, and VXLAN tunnels. Distrinet uses the same API than Mininet, meaning that it is compatible with Mininet programs. It is generic and can deploy experiments on Linux clusters (e.g., Grid'5000), as well as on the Amazon EC2 cloud platform.

Assessment: A5, SO3, SM2, EM2-down, SDL4

Functional Description: Distrinet is an extension of Mininet that relies on LXC to be distributed in the cloud, and particularly in Amazon. The extension has been designed to be fully compatible with Mininet. As using Distrinet potentially involves the collaboration of multiple machines we focused on guaranteeing the correctness (in a sense that results are trustworthy) of simulations when running on multiple machines. To speedup deployments, loading and unloading operations have been parallelised with asynchronous calls. The pool of machines used for simulations is automatically provisioned thanks to Ansible.

Release Contributions: First release

URL: https://distrinet-emu.github.io

Publication: hal-03000617v1

Contact: Walid Dabbous

Participants: Damien Saucez, Giuseppe Di Lena, Andrea Tomassilli, Frédéric Giroire, Thierry Turletti

Partner: Orange Labs

7.1.5 OMNET-TSN

Name: OMNET-TSN

Keywords: Real time, Network simulator

Functional Description: Time Sensitive Networking (TSN) aims at providing real time capabilities to Ethernet networks. To achieve this goal, the 2018 revision of the IEEE802.1Q standard (i.e., IEEE802.1Q-2018) provides the ability to define transmission selection algorithms for queues in IEE802.1Q Ethernet switches.

We are developing an IEEE802.1Q-2018 simulation module for OMNeT++. The usual way to implement a simulation module is to abstract the components to be simulated and leverage the simulator functionalities. As a result, simulations can run very efficiently and scale well. The drawback is that the code base is only understandable by well trained developers and hardly understandable by engineers.

With our implementation we decided to make a direct transpose of the normative documents into the simulator such that anyone that reads the standards can read the code and adapt it if needed. This approach makes simulations runs last much longer than if they code were optimized for simulations but the major advantage is that engineers used to read standards and evaluate appliances provided by third parties can use it with minimal training.

The simulator code is implemented in C++ in Omnest (the commercial version of OMNeT++). As in most industrial environments it is extremely complex to install non corporate software, we implemented a front-end in javascript with the REACT framework. As a consequence, it is possible to install and run the simulation tool on a dedicated machine/VM/container and to drive simulations from any workstation solely by using a web browser.

Release Contributions:

- Multiple bug fixes in CBS
- CBS as a transmission selection algorithm instead of a transmission queue
- Complete tutorials for users
- Full code documentation for developper
- Delete message from QeuingFrame::handleMessage after it has been cloned to reduce memory footprint for large experiments
- Includes std algorithm library to compile on Linux std::set_intersection
- Add processing delay simulation
- Automated testing with docker

URL: https://github.com/dsaucez/

Contact: Damien Saucez

7.2 New platforms

Participants: Thierry Parmentelat, Thierry Turletti, Damien Saucez, Walid Dabbous.

7.2.1 Reproducible research Lab - R2lab

Scientific work around network protocols and related software stacks requires experiments, hence experimental conditions, to be reproducible. This is a particularly challenging requirement in the wireless networking area, where characteristics of wireless channels are known to be variable, unpredictable and hardly controllable.

The R2lab wireless testbed was designed with reproducibility as its central characteristics; it is built around an isolated and anechoic chamber, featuring RF absorbers that prevent radio waves reflections, and a Faraday cage blocking external interferences. R2lab thus provides an ideal environment for running reproducible wireless experiments.

R2lab has been operated since December 2015, in the context of the FIT (Future Internet of Things) Equipment of Excellence project, and as such, it is now federated with the other testbeds that are part of the FIT initiative. As of early 2019, it has been also federated within the Fed4Fire initiative.

Available toolsets, both hardware and software, are mostly stable apart from low noise marginal deployment of new kinds of radio devices, that now encompass among 5G and LoRa, among others. Our focus at this point of the project is to leverage our initial technical and financial investment, and to produce scientific work around reproducibility, particularly from a methodological standpoint, as illustrated by various publications listed in the R2lab web site.

Worth being mentioned as well, as part of a partnership with the OpenAirInterface initiative, R2lab is used on a daily basis for system-wide regression tests of the OAI stack, which in return allows us to offer up-to-date images for running OAI-based experiments. Emphasis has been put lately on offering tools that leverage kubernetes as the swiss-knife for orchestrating the deployment of a complete 5G infrastructure as an elastic set of microservices.

In 2021, the management tools on R2lab were extended to support running docker images, in addition to the historic, metal-based image format (.ndz). This allows experimenters to build their images using mainstream tools and base images. Thanks to that, we can now expose the latest OAI code as R2lab-ready docker images, both for EPC and RAN.

Access to R2lab is open 24/7. R2lab is used by more than 150 users half of them from France and the other half from all over the world (Australia, Belgium, Brazil, Canada, Chile, Spain Finland, Germany, India, Indonesia, Italy, Japan, Luxembourg, Netherlands Norway, Tunisia, Turkey, UK, US, Vietnam, etc.) to evaluate a wide range of wireless networking scenarios in realistic and reproducible environment. Examples are deployment of a 4G network in less than 4 minutes (demonstrated at Sigcomm 2017 [6]), Mininet-WiFi calibration (demon paper at Sigcomm 2016 [28]), Orientation Estimation, Joint range extension and localization, Mobile Edge Cloud scenarios, Ad-hoc routing protocols comparison, side channel analysis (CCS), QoE for Internet Video, Mobile video streaming leveraging in-network functions, Reproducible 5G network automation with Kube5G, Fidelity Monitoring of Distributed Network Emulation, Cross-layer Loss Discrimination Algorithms for MEC in 4G networks, Reproducing the OpenRF experiment (Reproducibility workshop, Sigcomm [27]). For more details see R2lab home page. As the future of R2lab, there are wider plans to rebuild the Inria Sophia facility more or less from scratch. As R2lab is still used by the community, the plan is to include R2lab as an addition the Sophia Node that is currently being developed in collaboration with the OpenAirInterface consortium at Eurecom.

7.2.2 SophiaNode: an open programmable 5G platform

Our project-team collaborates with Eurecom to deploy and operate an open programmable platform to test post-5G services. Last year, R2lab was connected to sister site at Eurecom with 600 Gbps fibers forming together the so-called SophiaNode of the ESFRI SLICES-RI project. This year we enriched R2lab with 5G professional radio units and compute resources managed by Kubernetes clusters to provide an experimental cloud-native environment to test with open source (OAI, SrsLTE) software and some commercially licensed software (e.g. Amarisoft) for 5G/6G networks supporting for example scenarios with disaggregated 5G networks elements. Fully automated deployments of the infrastructure are on their way and in 2023 it is expected to provide a first public version of a full DevOps stack to experimenters to deploy complex experiments on the SophiaNode.

8 New results

8.1 Service Transparency

8.1.1 Leveraging Web browsing performance data for Network monitoring: A data-driven approach

Participants: Chadi Barakat.

Monitoring network performance becomes crucial today since it allows content providers to ensure a good quality of their services by identifying the root causes of service degradation. Also, it gives the end-user a better understanding of the performance they have (state of the networks). A widely used monitoring technique involves performing measurements from within the browser in an effort to capture the network status as close as possible; we talk about Web-based network monitoring. Many Web measurement tools have recently been proposed, however, most of these tools either have a high computational cost or exaggeratedly consume data. In this work done in collaboration with the Ermine Inria team in Rennes, we propose a lightweight solution able to estimate the underlying network status accurately and perform Web troubleshooting in order to detect anomalies. We develop and implement a distributed system that collects measurements at both levels: browser and network. Then, we build an original network monitoring framework based on Bayesian Gaussian Mixture Models coupled with an algorithm to detect in real time the occurrence of anomalies. We follow a browser-based passive measurement and data-driven approach to derive our inference models, which leads to an efficient Web browsing troubleshooting solution. The results of this work were part of Imane Taibi PhD thesis [29] defended in September 2022, and got published in [20].

8.1.2 Ray tracing for accurate estimation of signal power and QoS map generation in mobile networks

Participants: Bernard Tamba Sandouno, Chadi Barakat, Walid Dabbous, Thierry Turletti.

Ray Tracing is a propagation modelling approach that accurately estimates the signal power received by end users while taking into account the details of the environment in their vicinity. This accuracy is at the cost of high computational load and high memory consumption due to the heavy computation performed by processes such as Ray Generation. In this work done in collaboration with the Sogudo SME in the context of the PhD thesis of Bernard Tamba Sandouno, we introduced a site-specific ray generation technique able to generate up to 1 million rays within 5 seconds and a root mean square error for bandwidth estimation within 2 Mbps. Depending on the location of the antenna and the coverage area, our technique gives the minimum possible number of rays required in order to estimate end-users' signal power received and their download bitrate. The results of this work were published in [22].

We next built upon this work and used Ray Tracing as a propagation modeling approach for accurate generation of Quality of Service (QoS) maps in mobile networks (signal power, bitrate, etc). The challenge here is that due to the complexity of Ray Tracing, current implementations fail to generate such maps in wide areas. In this second contribution that will appear in [21], we propose an optimization to Ray Tracing able to accurately generate QoS maps in a reasonable time. Using the above site-specific ray launching technique and an alternative to the reception test process we develop in this work, we are able to divide by almost 1200 the execution time of Ray Tracing with less than 2% of memory usage.

8.1.3 Longitudinal Study of Exposure to Radio Frequencies at Population Scale

Participants: Yanis Boussad, Arnaud Legout, Walid Dabbous.

Evaluating exposure to radio frequencies (RF) at population-scale is important for conducting sound epidemiological studies about possible health impact of RF radiations. Numerous studies reported population exposure to RF radiations used in wireless telecommunication technologies, but used very small population samples. In this context, the real exposure of the population at scale remains poorly understood. Here, to the best of our knowledge, we report the largest crowd-based measurement of population exposure to RF produced by cellular antennas, Wi-Fi access points, and Bluetooth devices for 254,410 unique users in 13 countries from January 2017 to December 2020. First, we present methods to assess the population exposure to RF radiations using smartphone measurements obtained using the ElectroSmart Android app. Then, we use these methods to evaluate and characterize the evolution of RF exposure. We show that total exposure has been multiplied by 2.3 in the four-year period considered, with Wi-Fi as the largest contributor. The cellular exposure levels are orders of magnitude lower than regulation limits and are not correlated to national regulation policies. The population tends to be more exposed at home; for half of the study subjects, personal Wi-Fi routers and Bluetooth devices contributed to more than 50% of their total exposure. In this work, we showcase how crowdsource-based data allow large-scale and long-term assessment of population exposure to RF radiations. This work has been published in Environment International [11].

8.1.4 My Cookie is a phoenix: detection, measurement, and lawfulness of cookie respawning with browser fingerprinting

Participants: Imane Fouad, Arnaud Legout.

Stateful and stateless web tracking gathered much attention in the last decade, however they were always measured separately. To the best of our knowledge, our study is the first to detect and measure cookie respawning with browser and machine fingerprinting. We develop a detection methodology that allows us to detect cookies dependency on browser and machine features. Our results show that 1, 150 out of the top 30, 000 Alexa websites deploy this tracking mechanism. We find out that this technique can be used to track users across websites even when third-party cookies are deprecated. Together with a legal scholar, we conclude that cookie respawning with browser fingerprinting lacks legal interpretation under the GDPR and the ePrivacy directive, but its use in practice may breach them, thus subjecting it to fines up to 20 million €. This work has been published in PETS'2022 [18].

8.2 Open Network Architecture

8.2.1 RAPID: a RAN-aware Performance Enhancing Proxy for High Throughput Low Delay Flows in MEC Networks

Participants: Mamoutou Diarra, Thierry Turletti, Walid Dabbous.

5G enhanced Mobile broadband (eMBB) aims to provide users with a peak data rate of 20 Gbps in the Radio Access Network (RAN). However, since most Congestion Control Algorithms (CCAs) rely on startup and probe phases to discover the bottleneck bandwidth, they cannot quickly utilize the available RAN bandwidth and adapt to fast capacity changes without introducing large delay increase, especially when multiple flows are sharing the same Radio Link Control (RLC) buffer. To tackle this issue, we propose RAPID, a RAN-aware proxy-based flow control mechanism that prevents CCAs from overshooting more than the available RAN capacity while allowing near optimal link utilization. Based on analysis of up-to-date radio information using Multi-access Edge Computing (MEC) services and packet arrival rates, RAPID is able to differentiate slow interactive flows from fast download flows and allocate the available bandwidth accordingly. Our simulation and experimentation results with concurrent Cubic and BBR flows show that RAPID can reduce delay increase by a factor of 10 to 50 in both Line-of-Sight (LOS) and Non-LOS (NLOS) conditions while preserving high throughput in both 4G and 5G environments. The results of this study were published in Computer Networks journal [12].

8.2.2 Machine Learning for Next-Generation Intelligent Transportation Systems

Participants: Tingting Yuan, Katia Obraczka, Chadi Barakat, Thierry Turletti.

Intelligent Transportation Systems, or ITS for short, include a variety of services and applications such as road traffic management, traveler information systems, public transit system management, and autonomous vehicles, to name a few. ITS systems expected to be an integral part of urban planning and future smart cities, contributing to improved road and traffic safety, transportation and transit efficiency, as well as to increased energy efficiency and reduced environmental pollution. On the other hand, ITS poses a variety of challenges due to its scalability and diverse quality-of-service needs, as well as the massive amounts of data it will generate. In this work, we explore the use of Machine Learning (ML), which has recently gained significant traction, to enable ITS. We provide a thorough survey of the current state-of-the-art of how ML technology has been applied to a broad range of ITS applications and services, such as cooperative driving and road hazard warning, and identify future directions for how ITS can further use and benefit from ML technology. The results of this study were published in [15].

8.2.3 Provable real time network updates

Participants: Damien Saucez.

Next generations of smart factories and industrial systems will rely on commodity Ethernet hardware and 5G. In this context, it is essential to provided means to guarantee that any configuration action in the network preserves network performances within known and acceptable boundaries. By means of binary decision diagrams we are building models of incremental network updates that guarantee not only latency and bandwidth contraints but also jitter and that are immune to vulnerabilities. This ongoing work is done in collaboration with Inria Nancy and Aalborg University.

8.2.4 LISP standardisation

Participants: Damien Saucez.

Our project-team has been involved in IETF for long time. However, more recently the development of open source software and tools became a prominent part of our approach to standardisation. The rationale for being in favour of open source development with limited efforts in standardisation is that in most situations the solutions to be deployed largely dependent on software stack and evolve at rapid pace (timeframes of 3-6 months) thanks to the DevOps approach now being generalised. Nevertheless, in some cases, such as security protections or inter-domain message exchanges, true standards are still needed, even though they represent only a small fraction of innovations today. After several years of effort in IETF working groups on LISP standardisation, three RFCs were published this year : one informational track RFC on LISP architecture [24] and two standard track RFCs on LISP security protections [26] and on inter-domain message exchanges [25].

8.3 Experimental Evaluation

8.3.1 SLICES, a scientific instrument for the networking community

Participants: Walid Dabbous, Thierry Parmentelat, Thierry Turletti, Damien Saucez.

A science is defined by a set of encyclopedic knowledge related to facts or phenomena following rules or evidenced by experimentally-driven observations. Computer Science and in particular computer networks is a relatively new scientific domain maturing over years and adopting the best practices inherited from more fundamental disciplines. The design of past, present and future networking components and architectures have been assisted, among other methods, by experimentally-driven research and in particular by the deployment of test platforms, usually named as testbeds. However, often experimentally-driven networking research used scattered methodologies, based on ad-hoc, small-sized testbeds, producing hardly repeatable results. We believe that computer networks needs to adopt a more structured methodology, supported by appropriate instruments, to produce credible experimental results supporting radical and incremental innovations. In this contribution, we report lessons learned from the design and operation of test platforms for the scientific community dealing with digital infrastructures. We introduce the SLICES initiative as the outcome of several years of evolution of the concept of a networking test platform transformed into a scientific instrument. We address the challenges, requirements and opportunities that our community is facing to manage the full research-life cycle necessary to support a scientific methodology. The results were published in Computer Communications [14].

8.3.2 Sophia-node: A Cloud-Native Mobile Network Testbed

Participants: Mohamed Lahsini, Thierry Parmentelat, Thierry Turletti, Walid Dabbous, Damien Saucez.

New cellular technologies combine complex software stacks and heterogeneous hardware. As a result, even if models and simulators are still essential to understand them, validation must go to the next level and rely on real software and hardware testbeds. Unfortunately, building comprehensive testbeds is expensive and this is why we propose the Sophia-node, a cloud-native cellular network testbed accessible to the community. In this demonstration [19], published in NFV-SDN'22 we show how to run arbitrary *G experiments in this testbed by following DevOps techniques.

8.3.3 Delay-based Fidelity Monitoring of Distributed Network Emulation

Participants: Houssam Elbouanani, Chadi Barakat, Walid Dabbous, Thierry Turletti.

Distributed Network emulators (e.g., Mininet Cluster Edition) have proven to be an attractive solution to perform extreme-scale network and systems evaluation on smaller-size testbeds and experiment platforms. They can provide contained, customisable, and scalable testing environments for researchers to evaluate their contributions and reproduce their results. The major drawback of this approach in network experimentation is the use of virtual components (hosts, network switches, etc.) that do not behave with perfect similarity to the physical components they emulate, mainly due to the concurrency in using the underlay network and computing resources. We thus present in this work, which is part of the PhD thesis of Houssam ElBouanani, a methodology to monitor emulation fidelity by measuring the network delays of emulated packets. Our methodology relies on statistical metrics to evaluate the inaccuracy of emulated packet delays. While this is not difficult to implement in a single-machine setting (e.g. with Mininet), monitoring is limited by the lack of time synchronization in scenarios where the emulation is distributed over multiple physical machines (e.g., Distrinet). In a first contribution, we tackle the case of packet delay monitoring, to which we propose a methodology for passively measuring one-way delays with underlying assumptions about time synchronization, and round-trip delays otherwise. For an efficient implementation of our methodology, we propose an eBPF-based packet measurement tool that performs better than current packet sniffers under emulation-specific assumptions. We implement and evaluate our system in an open testbed and show that it can reach results within few microseconds of perfect accuracy and precision. This first contribution has been published in the Computer Communications journal in 2022, Vol. 195, in [13]. In a second contribution, we dig into the possible sources of emulation inaccuracy and show how our system can detect them to avoid biased experiment results. We particularly

show through a common experiment scenario how undetected network emulation errors can lead to biased results. This work is accepted at the TASIR workshop in [16]. In a third contribution we described a prototype lightweight and highly scalable distributed emulator we developed to support large scale experiments, and a framework for fidelity monitoring through passive measurement of emulated packet delays. A series of reproducible experiments has been conducted on Grid5000. The results were published in a demo paper in IEEE Conference on Standards for Communications and Networking [17].

8.3.4 Running 5G OpenAirInterface with emulated RAN on the SophiaNode/R2lab platform

Participants: Thierry Parmentelat, Thierry Turletti.

We have written a nepi-ng script that allows to run 5G OpenAirInterface (OAI) Core Network (CN) and RAN (currently emulated with the OAI RF simulator) on our new SophiaNode platform. This script aims to demonstrate how to automate a OAI5G deployment on our SophiaNode Kubernetes-based cluster using worker nodes running both on the servers on our k8s cluster and FIT R2lab nodes. More precisely, the script deploys a preconfigured Kubernetes (k8s) image on 4 R2lab FIT nodes to run the following 5G functions (oai-amf, oai-spgwu, oai-gnb and oai-nr-ue) and all the other OAI 5G pods (e.g., oai-smf or oai-spgwu) are launched on the regular k8s worker nodes of the SophiaNode platform. In a nutshell, once the k8s R2lab image is installed on the R2lab FIT nodes, the script connects them to the SophiaNode k8s cluster and uses one of them to orchestrate the whole OAI 5G demo. It will clone the Eurecom's OAI oai-cn5g-fed git repository, apply all the required configuration to match the SophiaNode/R2lab environment and deploy the OAI5G pods on the k8s cluster. All the steps to reproduce the demo, documentation and code are available in GitHub. Work is in progress to extend the demo with real gNB (e.g. based on USRP N3XX) and UE nodes (e.g. 5G Quectel devices).

9 Bilateral contracts and grants with industry

Participants: Chadi Barakat, Walid Dabbous, Mamoutou Diarra, Arnaud Legout, Giuseppe Di Lena, Bernard Tamba Sandouno, Damien Saucez, Thierry Turletti.

9.1 Bilateral contracts with industry

Collaboration with Ekinops
Participants: Walid Dabbous, Mamoutou Diarra, Thierry Turletti.

We have started a collaboration with Ekinops on the topic of Multi-access Edge Computing. The activity started with a CIFRE thesis. The PhD student Mamoutou Diarra started his PhD on this topic on November 2019. Currently, he is working on efficient congestion control mechanisms for 5G scenarios in mutli-access edge environments.

Collaboration with YDATA
Participant: Chadi Barakat, Walid Dabbous Bernard Tamba Sandouno, Thierry Turletti.

We have started a collaboration with YDATA on the topic of geolocation assessment of mobile network performance. The activity started with a CIFRE thesis. The PhD student Bernard Tamba Sandouno started his PhD on this topic on May 2021. Currently, he is working on developing a tool to predict the geolocation performance of mobile broadband networks using a ray tracing approach coupled with wireless channel propagation models.

10 Partnerships and cooperations

10.1 International research visitors

10.1.1 Visits of international scientists

Inria International Chair

Participants: Katia Obraczka, Harikrishna Kuttivelil, Chadi Barakat, Thierry Turletti.

Professor Katia Obraczka has been awarded an Inria International Chair for the 2021-2025 period. The research program entitled: "Smart Networks: When Computational Intelligence and Networking Meet" will explore synergies between machine learning (ML) and networking domains by addressing two complementary goals: (1) As users of ML, explore ML techniques as they apply to networks, their protocols, and their services towards intelligent network systems that are simple, automatically adapt to current conditions, do not require human in the loop, and deliver adequate end-to-end performance; and (2) Investigate how networking can benefit and empower ML. More specifically, as computing and storage shift to the edge of the network, we are interested in exploring how ML can leverage the network as a distributed, decentralized computing resource to handle the enormous amounts of data generated at the edge by providing full decentralization without compromising accuracy and preserving end user privacy. The first visit of Prof Obraczka happened in November 2022 and focused on establishing initial contacts with the MASSAI and NEO project-teams, and discussing with DIANA researchers to refine the collaboration topics. Another important result of this one month visit, is the ongoing negotiation of a collaboration and student exchange agreement between UC Santa Cruz and Université Côte d'Azur. During her visit, Prof. Obraczka gave a presentation at Forum Numerica entitled "From Sensor Networks to the Internet of Everything in the Age of Edge Intelligence". Her next visit is scheduled in spring 2023.

In the context of Prof Obraczka's International Chair, Harikrishna Kuttivelil, PhD student supervised by her at UC Santa Cruz joined our project-team in October 2022 for a six-month visit. He has been conducting research across two inter-related projects: community-structured decentralized learning, and a network simulation bridge to connect applications to network simulators. In the former, Hari has been developing a network-cognizant and community-structured approach to fully decentralized learning at the Internet's edge, exploiting the network and application affinities within the learning agents. To this end, he has been designing and implementing model-agnostic strategies for community formation. The next step is to integrate knowledge about the underlying network into the community formation strategies. He has been also developing a network simulation bridge to integrate developer applications to network simulators. This will allow him to test, evaulate and validate his network-cognizant, community-structured decentralized learning mechanisms.

10.2 European initiatives

10.2.1 H2020 projects

SLICES - SC
SLICES - SC project on cordis.europa.eu

Title: Scientific Large-scale Infrastructure for Computing/Communication Experimental Studies – Starting Community

Duration: From March 1, 2021 to February 29, 2024

Partners: UTH, Mandat International, PSNC, IMDEA, CNR,EURECOM, COSM, IoTLab,University of Oulu, INRIA, Imec, SZTAKI, TUM.

INRIA contact: Walid Dabbous

Summary: Today we are experiencing the digital transformation happening with an unprecedented pace, with the community constantly researching on new solutions to support this transformation with ample computational power and connectivity. Towards addressing such research efforts, Research Infrastructure (RI) specific to addressing Digital Sciences research efforts have been deployed worldwide, towards trying to address key issues contrary to off-the-shelf commercial infrastructure: 1) Full control over the parameters of an experiment, 2) Repeatable experiments regardless of the physical infrastructure, 3) Valid experimental results, which are easy to cross-reference and replicate. As such, several RIs have emerged, offering experimentation services with bleeding edge resources, that otherwise are only offered only in industrial R&D laboratories, with limited functionality. Towards combating these issues, SLICES Research Infrastructure is about to be deployed, aiming to provide high quality experimentation services with emerging technologies around the area of digital sciences (5G/6G, NFV, IoT and Cloud Computing), in an Internet-scale setup. With SLICES-SC, we aspire to foster the community of researchers around this ecosystem, create and strengthen necessary links with relevant industrial stakeholders for the exploitation of the infrastructure, advance existing methods for research reproducibility and experiment repeatability, and design and deploy the necessary solutions for providing SLICES-RI with an easy to access scheme for users from different disciplines. A set of detailed research activities has been designed to materialize these efforts in tools for providing transnational (remote and physical) access to the facility, as well as virtual access to the data produced over the facilities. The respective networking activities of the project aspire in fostering the community around these infrastructures, as well as open up to new disciplines and industrial stakeholders.

Fed4FIREplus
Fed4FIREplus project on cordis.europa.eu

Title: Federation for FIRE Plus

Duration: From January 1, 2017 to June 30, 2022

Partners: Twenty european partners including IMEC (Belgium), INRIA (Fr), Sorbonne University (Fr),Fraunhofer (Germany), TUB (Germany), etc.

INRIA contact: Thierry Parmentelat

Summary: The Fed4FIRE+ project has the objective to run and further improve Fed4FIRE's "best-in-town" federation of experimentation facilities for the Future Internet Research and Experimentation initiative. Federating a heterogeneous set of facilities covering technologies ranging from wireless, wired, cloud services and open flow, and making them accessible through common frameworks and tools suddenly opens new possibilities, supporting a broad range of experimenter communities covering a wide variety of Internet infrastructures, services and applications Fed4FIRE+ will continuously upgrade and improve the facilities and include technical innovations, focused towards increased user satisfaction (user-friendly tools, privacy-oriented data management, testbed SLA and reputation, experiment reproducibility, service-level experiment orchestration, federation ontologies, etc.). It will open this federation to the whole FIRE community and beyond, for experimentation by industry and research organisations, through the organization of Open Calls and Open Access mechanisms. The project will also establish a flexible, demand-driven framework which allows test facilities to join during the course of its lifetime by defining a set of entry requirements for new facilities to join and to comply with the federation. FIRE Experimental Facilities generate an ever increasing amount of research data that provides the foundation for new knowledge and insight into the behaviour of FI systems. Fed4FIRE+ will participate in the Pilot on Open Research Data in Horizon 2020 to offer open access to its scientific results, to the relevant scientific data and to data generated throughout the project's lifetime. Fed4FIRE+ will finally build on the existing community of experimenters, testbeds and tool developers and bring them together regularly (two times a year) in engineering conferences to have maximal interaction between the different stakeholders involved.

10.2.2 ESFRI Roadmap: SLICES-RI

ESFRI, the European Strategy Forum on Research Infrastructures, is a strategic instrument to develop the scientific integration of Europe and to strengthen its international outreach. Our project team has been involved in the last years in the preparation of a large-scale infrastructure project called SLICES-RI (Scientific Large Scale Infrastructure for Computing and Communication Experimental Studies-Research Infrastructure) that was accepted on the ESFRI roadmap for funding. Consortium members of this long term project are eligible to specific calls to design, bootstrap, deploy and operate a European wide flexible platform designed to support large-scale, experimental research focused on networking protocols, radio technologies, services, data collection, parallel and distributed computing and in particular cloud and edge-based computing architectures and services. The DIANA project-team is involved in the main SLICES-RI and companion projects: SLICES-DS (Design Study) focused on the Design Study of the Research Infrastructure) and SLICES-SC (Starting Community) focused on bootstrapping the users community for the RI presented here above and SLICES-PP (Preparatory Phase) focused on setting the policies and decision processes for the governance of SLICES-RI.

11 Dissemination

Participants: Chadi Barakat, Walid Dabbous, Arnaud Legout, Thierry Parmentelat, Damien Saucez, Thierry Turletti.

11.1 Promoting scientific activities

Chadi Barakat is on the editorial board of the Computer Networks journal, and was General Co-Chair of the ACM Internet Measurement Conference (IMC) that was held in Nice on October 25-27, 2022. He also is/was on the Technical Program Committee for the Passive and Active Measurement conference (PAM 2022), the International Teletraffic Congress (ITC 2022), the Network Traffic Measurement and Analysis conference (TMA 2022), and the Mediterranean Communication and Computer Networking Conference (MedComNet 2022 and 2023). He is currently in charge of international affairs at Inria centre at Université Côte d'Azur and member of the organising committee for the Forum Numerica seminars of EUR DS4H.

Walid Dabbous is Director of the Academy of Excellence RISE (Networks, Information and Digital Society). He is also member of the scientific committee of the DS4H Graduate school and member of the Ubinet International Master program steering committee. He is also member of the INRIA Evaluation Committee. In 2022, he participated to the recruting committee of full-time Assistant Professors at École Polytechnique.

Arnaud Legout is member of the scienfic board of the Regalia project whose aim is to build a software environment for testing and regulation support to deal with the risks of bias and disloyalty generated by the algorithms of digital platforms. He is also in the technical program committee and editorial board of the Proceedings on Privacy Enhancing Technologies (PoPETs) in 2021 and 2022.

Thierry Turletti participated in the program committees of the following workshops and conferences: 13th Workshop on ns-3, June 22-23, 2022, at the U.S. NIST, in Gaithersburg, Maryland, USA, IEEE International Conference on Communications (ICC'22), 16–20 May 2022, Seoul, South Korea, and the 18th IEEE/IFIP Network Operations and Management Symposium (NOMS), 25-29 April 2022, Budapest, Hungary. He is still on the editorial boards of the "Wireless Networks" journal published by Springer Science and of the "Advances in Multimedia" Journal published by Hindawi Publishing Corporation. Since June 202 is a member of the Comité de Suivi Doctoral (CSD) at INRIA Sophia Antipolis Méditerranée.

Damien Saucez organised a hands-on season at the 1st SLICES-SC summer school. The hands-on was a 2h practical session where attendees (about 30 persons from junior to senior researchers) deployed by themselves a SD-Fabric infrastructure by means of the automation tools developed within our team.

11.2 Teaching - Supervision - Juries

11.2.1 Teaching

- Master 2 Ubinet: Chadi Barakat and Walid Dabbous, Evolving Internet, 31.5 hours, M2, Université Côte d'Azur, France.
- Master 2 Ubinet: Chadi Barakat and Walid Dabbous, Internet Measurements and New Architectures, 31.5 hours, M2, Université Côte d'Azur, France.
- Master 1 in Computer Science: Chadi Barakat, Computer Networks, 30 hours, M1, Université Côte d'Azur, France.
- Master 2 Estel: Chadi Barakat, Voice over IP, 9 hours, Université Côte d'Azur, France.
- Master Ubinet: Arnaud Legout, From BitTorrent to Privacy, 22.5 hours, M2, Université Côte d'Azur, France.
- Master module AWARE (Awarness-Raising to research) : Arnaud Legout, lecture 2 hours, Eurecom, France.
- Thierry Parmentelat helps coordinating the CS courses for the first year students of École des Mines de Paris, covering general topics like Numerical Programming with Python, Advanced Python Programming, and Introduction to Web technologies.
- **E-learning**
  - Python: Arnaud Legout and Thierry Parmentelat are co-authors of the MOOC: "Python 3 : des fondamentaux aux concepts avancés du langage". Since its creation in 2014, this MOOC has reached a consolidated number of 122 290 registered students and 11845 attestations. This MOOC is in French, as we felt like there was a gap in the previous offering, with the vast majority of teaching resources available in English only.

11.2.2 Supervision

PhD students

- PhD defended: Imane Taibi finished her PhD on "Web-based data driven network monitoring: from performance estimation to anomaly detection" in September 2022, within the Ermine project-team in Inria Rennes. Her PhD was co-supervised by Chadi Barakat from the Diana team and Gerardo Rubino and Yassine Hadjadj-Aoul from the Ermine team. The thesis was funded by Inria within Project Lab BetterNet.
- PhD defended: Mamoutou Diarra finished his PhD on "Multi-access Edge Computing". He was co-supervised by Thierry Turletti and Walid Dabbous from the Diana team, and by Amine Ismail from Ekinops. His thesis is funded by a CIFRE grant in collaboration with Ekinops.
- PhD in progress: Bernard Tamba Sandouno works on a "Geolocation assessment model of mobile network performance". His PhD is co-supervised by Chadi Barakat, Thierry Turletti and Walid Dabbous from the Diana team, and by Yamen Alsaba from YDATA. His thesis is funded by a CIFRE grant in collaboration with YDATA.
- PhD in progress: Houssam Elbouanani works on "Introducing Fidelity into Network Emulation". His PhD is co-supervised by Chadi Barakat, Thierry Turletti and Walid Dabbous from the Diana team and funded by the Fed4Fire+ H2020 project.

Visiting PhD students

- Raza UI Mustafa:
  - Institution: University of Campinas, Brazil

- Date: June 2022 - November 2022
- Subject: Real-time DASH video QoE inference for 5G
- Supervisor: Chadi Barakat

- Harikrishna Kuttivelil:
  - Institution: University of California, Santa Cruz, USA.
  - Date: September 2022 - March 2023
  - Subject: Community-structured decentralized learning
  - Supervisor: Thierry Turletti

Master Interns

- Mariella Jreidy :
  - Master: Ubinet
  - Institution: Université Côte D'Azur
  - Date: Mar 2022 - Aug 2022
  - Subject: Leveraging the wealth of data available in the browser for network monitoring and troubleshooting
  - Supervisors: Chadi Barakat and Yassine Hadjadj-Aoul from the Ermine team in Rennes.
- Ayyoub Hajjaji :
  - Master: Ubinet
  - Institution: Université Côte D'Azur
  - Date: Mar 2022 - Aug 2022
  - Subject: Emulation Fidelity in Cloud Environments
  - Supervisors: Walid Dabbous and Thierry Turletti and Chadi Barakat
- Mohamad Lahsini:
  - Master: Ubinet
  - Institution: Université Côte D'Azur
  - Date: Mar 2022 - Aug 2022
  - Subject: Automated deployement of open 5G networks
  - Supervisor: Damien Saucez
- Pasquale Damato:
  - Master: Ubinet
  - Institution: Université Côte D'Azur
  - Date: Nov 2022 - Feb 2023
  - Subject: Deployment of open cellular networks platform
  - Supervisor: Damien Saucez, Thierry Turletti and Walid Dabbous
- Kaoutar Chiboub:
  - Master: Ubinet
  - Institution: Université Côte D'Azur
  - Date: Nov 2022 - Feb 2023
  - Subject: Deployment of open cellular networks platform

  - Supervisor: Damien Saucez, Thierry Turletti and Walid Dabbous

- Pietro Ventrella:
  - Master: Ubinet
  - Institution: Université Côte D'Azur
  - Date: Nov 2022 - Feb 2023
  - Subject: Inferring mobile network performance from web browsing performance
  - Supervisor: Chadi Barakat

- Yaacoub Yaacoub:
  - Master: Ubinet
  - Institution: Université Côte D'Azur
  - Date: Nov 2022 - Feb 2023
  - Subject: Inferring mobile network performance from web browsing performance
  - Supervisor: Chadi Barakat

- Anass Dahcour:
  - Master: Ubinet
  - Institution: Université Côte D'Azur
  - Date: Nov 2022 - Feb 2023
  - Subject: A digital twin for intelligent cellular networks
  - Supervisor: Damien Saucez and Walid Dabbous

- Abderrahmane Soufi:
  - Master: Ubinet
  - Institution: Université Côte D'Azur
  - Date: Nov 2022 - Feb 2023
  - Subject: Study of unknown Bitcoin transactions
  - Supervisor: Arnaud Legout

- Giovanni Pantaleo:
  - Master: Ubinet
  - Institution: Université Côte D'Azur
  - Date: Nov 2022 - Feb 2023
  - Subject: Measurements in mobile edge networks
  - Supervisor: Chadi Barakat and Thierry Turletti

Apprentices

- Téo Haÿs:
  - Master1 Informatique
  - Institution: Université Côte D'Azur
  - Date: Sep 2021 - Aug 2022
  - Subject: Tools for reproducible experimentation on R2Lab
  - Supervisor: Thierry Parmentelat

11.2.3 Juries

- Chadi Barakat served as reviewer of Kamal Singh HDR thesis, "Towards Data Driven Inteligent Networks", defended in July 2022 at University Jean Monnet & University of Lyon.
- Chadi Barakat served as jury member for the mid-term review of Jin Yan's PhD thesis, "Realization of URLLC Services in 5G-NR Sidelink V2X", Eurecom, held in June 2022.
- Chadi Barakat served as jury member for the mid-term review of Olha Chuchuk's PhD thesis, "Data access optimisation at CERN and in the Worldwide LHC Computing Grid", Inria, Université Côte d'Azur and CERN, held in April 2022.
- Walid Dabbous served as president of the thesis defense jury of Tareq Si-Salem PhD thesis on "Sequential learning for resource allocation in networks", Inria and Université Côte d'Azur, held in October 2022.
- Arnaud Legout served as reviewer of Jean-Philippe Eisenbarth Ph.D. thesis "Analyse, valorisation et protection des réseaux pair-à-pair de blockchains publiques" defended December 13, 2022 at Loria.
- Thierry Turletti served as reviewer of Tsu-Han Wang PhD thesis "Real-time Software Architectures and Performance Evaluation Methods for 5G Radio Systems" defended on December 13, 2022 at Sorbonne Université.
- Thierry Turletti served as reviewer of Flavien Ronteix-Jacquet "Réduction de la Latence et de la Gigue dans le Réseau d'Accès Radio 5G", defended on December 13, 2022 at École Nationale Supérieure Mines-Télécom Atlantique Bretagne Pays-de-la-Loire, IMT Atlantique.
- Thierry Turletti participated to the examination of the mid-term thesis progress report of Mr. Abderaouf Khichane on November 21 2022 at Université Paris Saclay.
- Thierry Turletti participated to the examination of the mid-term thesis progress report of Sagar Arora "Dynamic resource and allocation solution for cloud-native network microservices " on January 19, 2022 at Eurecom.

11.3 Popularization

11.3.1 Internal or external Inria responsibilities

Damien Saucez is chargé de mission médiation scientifique interne. The role is to promote and favour scientific exchanges between Sophia's center researchers but also to popularise sciences within the center, not only for the researchers but for all personnel of the center.

The two main activities that are put in place are the so-called In'tro and Café In.

The concept of In'Tro has been proposed by Fabien Gandon and we implemented it successfully in March 2021. In'Tro aims to promote recently hired researcher in order to foster new collaborations. Every month, a researcher is allocated a slot of 30 minutes during lunch time to presents her/his work during 15 minutes and to answer questions during 15 minutes. The 7 events of 2022 were virtual meetings. Presentations are made publicly available on VoD. On average we counted about 25 live attendees. We also observe that the videos are watched on demand after the presentation, not only by Inria people but also by anonymous viewers that received YouTube suggestions.

The Cafe'-In events are different in their objective and organised since 2012. Once a month a one hour slot is dedicated to popularise sciences to Inria personnel, regardless of whether they are scientific or not. After lunch, a researcher, or a panel of researchers, is invited to talk about a subject of his/her choice around a coffee. The main objective is not to foster new collaborations but to allow everyone at Inria to understand important research subjects that are work on by Inria researchers and to open their curiosity. In 2022, with the end of the restrictions we progressively move from purely virtual meetings to hybrid and final on-site meetings but noticed limited participation (around 20 attendees) and we decided to give more slack between events, hence only 6 meetings have been proposed.

For more information, check the MASTIC website.

Last year, we promoted the use of the center's zimbra calendar to advertise internal team seminars. As of now, we lack of indicators to determine if this calendar has boosted inter-team or cross disciplines collaborations however we notice that most teams advertise their seminars in the center's calendar.

11.3.2 Interventions

Damien Saucez made 5 Chiche! sessions this year. See the Chiche Web site.

Damien Saucez regularly animates educative workshops within Terra Numerica premises to present algorithmic principles, mathematical proofs, and logic reasoning to pupils between their 4th and their 10th grade.

12 Scientific production

12.1 Major publications

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