Activity Report 2016

Project-Team DIANA

Design, Implementation and Analysis of Networking Architectures

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Networks and Telecommunications

Table of contents

Project-Team DIANA

Creation of the Team: 2013 January 01, updated into Project-Team: 2015 July 01

Keywords:

Computer Science and Digital Science:

1.1.7. - Peer to peer
1.1.13. - Virtualization
1.2.1. - Dynamic reconfiguration
1.2.2. - Supervision
1.2.3. - Routing
1.2.4. - QoS, performance evaluation
1.2.8. - Network security
1.2.9. - Social Networks
1.3. - Distributed Systems
1.4. - Ubiquitous Systems

Other Research Topics and Application Domains:

6.2. - Network technologies
6.2.1. - Wired technologies
6.2.2. - Radio technology
6.2.3. - Satellite technology
6.3.2. - Network protocols
6.3.3. - Network Management
6.3.4. - Social Networks
8.5.2. - Crowd sourcing
9.1.1. - E-learning, MOOC
9.4.1. - Computer science
9.4.5. - Data science
9.6. - Reproducibility
9.8. - Privacy

1. Members

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Hala Mazirh [Inria, from Mar 2016 until Aug 2016]
Hakob Melkonyan [Inria, from Mar 2016 until Aug 2016]
Jimmy Rogala [Inria, from May 2016 until Aug 2016]

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 will 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 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 information meaningful 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. 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, fifteen years ago the Internet for the end-users was mostly the Web. Only eight 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. Highlights of the Year

4.1. Highlights of the Year

The R^2lab testbed, part of the national FIT facility, was inaugurated on the SophiaTech campus this year. This new anechoic chamber can be used to remotely perform reproducible wireless network experimentation (5G/software-defined radio). The live public demonstration at the inauguration presented a 4G network being deployed remotely in merely three minutes. For more details see http://r2lab.inria.fr/news.md.

The soTweet project studying the impact Twitter on Media web sites popularity has triggered worldwide media coverage (*Washington Post, Les échos, Le Vif, El Diaro, BFM TV*, etc.) Details and links are in http://www-sop.inria.fr/members/Arnaud.Legout/Projects/sotweet.html. The results are published in [18].

This year witnessed the publication of three RFCs (7834 [36], 7835 [35] and 7927 [31]). These RFCs are the result of a long term contribution by Damien Saucez to the activities on the LISP protocol and in parallel on Information Centric Networking at the IETF and IRTF.

A third session of the Python MOOC by Arnaud Legout and Thierry Parmentelat has been programmed in 2016 and it was also a very big success: 12954 persons registered to the course, out of them 1603 qualified for the final attestation of achievement. This MOOC is adopted by several universities and engineering schools: UPMC L3 program (200 students), first year in CentralSupelec (529 students), SIO Master in CentralParis (16 students), first year of ESISAR school from the Institut Polytechnique de Grenoble group (67 students).

5. New Software and Platforms

5.1. ACQUA

Participants: Chadi Barakat [contact], Thierry Spetebroot, Damien Saucez.

ACQUA is an Application for prediCting Quality of User experience at Internet Access. It was supported by the French ANR CMON project on collaborative monitoring and will be supported in 2016 by both the Inria ADT ACQUA and the ANR Project BottleNet. 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, etc), ACQUA targets the estimated quality of experience 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). An application in ACQUA is a function that links the network-level measurements to the expected quality of experience. In its first version (the version available online), ACQUA was concentrating on delay measurements at the access and on the detection and estimation of the impact of delay anomalies (local problems, remote problems, etc). The current work is concentrating on using the ACQUA principle in the estimation and prediction of the quality of experience of main user's applications. An Android version is under development supported by the Inria ADT ACQUA.

- URL: http://team.inria.fr/diana/acqua/
- Version: 1.1
- ACM: C.2.2, C.2.3
- Keywords: Internet measurement, Internet Access, Quality of Experience
- License: GPL (3)
- Type of human computer interaction: GUI for client, Web interface for experimentation
- OS/Middleware: MS Windows
- Required library or software: visual studio http://www.visualstudio.com/en-us/products/visual-studio-express-vs.aspx
- Programming language: C# for client, java for server, CGI and Dummynet for experimentation

5.2. ElectroSmart

Participants: Arnaud Legout [contact], Mondi Ravi.

The Internet and new devices such as smartphones have fundamentally changed 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 (funding the engineer Mondi Ravi) In August 2016, we released the first stable public release of ElectroSmart. On the 20th December 2016 we had 1502 downloads in Google Play, an average score of 4,66/5, 800 active users, 22 millions measured signals and 500k measured geographic zones.

- URL: http://es.inria.fr
- Version: 1.1
- Keywords: background electromagnetic radiations
- License: Inria proprietary licence
- Type of human computer interaction: Android application
- OS/Middleware: Android
- Required library or software: Android
- Programming language: Java
- Documentation: javadoc

5.3. nepi-ng

Participants: Thierry Parmentelat [correspondant], Thierry Turletti, Mario Antonio Zancanaro.

During the past couple of years, we had developped NEPI, the Network Experimentation Programming Interface, as a wide spectrum tool for orchestrating network experiments on network experimentation platforms.

In the more specific context of R2lab, we have been facing more stringent requirements in terms of response time, especially when synchonizing the parallel parts of a wireless experiment. For that reason, and also because the NEPI codebase was starting to feel much too large for its actual usage, and consequently very brittle, we have decided to start and put together a new set of components, named **nepi-ng** for nepi new generation.

At this point, nepi-ng has a much smaller scope than NEPI 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.

For that reason, the actual size of the nepi-ng codebase is about 12 times smaller than the one of NEPI. However, running the same experiment on R2lab turns out to be about 10 times faster using nepi-ng rather than NEPI, that in this context is impeded by its generic model for resources, that prevents NEPI from being as reactive as what can be achieved with nepi-ng.

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 this becomes necessary.

- URL: http://nepi-ng.inria.fr
- Version: 0.5
- Keywords: networking experimentation, orchestration
- License: CC BY-SA 4.0
- Type of human computer interaction: python library
- OS/Middleware: Linux
- Required library or software: python-3.5 / asyncio
- Programming language: python3

5.4. OpenLISP

Participant: Damien Saucez [contact].

Among many options tackling the scalability issues of the current Internet routing architecture, the Locator/Identifier Separation Protocol (LISP) appears as a viable solution. LISP improves a network's scalability, flexibility, and traffic engineering, enabling mobility with limited overhead. As for any new technology, implementation and deployment are essential to gather and master the real benefits that it provides. We propose a complete open source implementation of the LISP control plane. Our implementation is deployed in the worldwide LISP Beta Network and the French LISP-Lab testbed, and includes the key standardized control plane features. Our control plane software is the companion of the existing OpenLISP dataplane implementation, allowing the deployment of a fully functional open source LISP network compatible with any implementation respecting the standards. As of 2016, OpenLISP is used to provide connectivity between satellite sites of the LISP-Lab project.

- http://www.lisp-lab.org/
- Version: 3.2
- ACM: C.2.1, C.2.2, C.2.6
- Keywords: routing, LISP, control-plane
- License: BSD
- Type of human computer interaction: XML, CLI
- OS/Middleware: POSIX
- Required library or software: Expat 2
- Programming language: C
- Documentation: Unix man
- Deployment: http://ddt-root.org

5.5. Platforms

5.5.1. Reproducible research laboratory ($\mathrm{R}^2\mathrm{lab}$*)*

Scientific evaluation of network protocols requires for experiment results to be reproducible before they can be considered as valid. This is particularly difficult to obtain in the wireless networking domain, where characteristics of wireless channels are known to be variable, unpredictable and hardly controllable.

We have built at Inria Sophia-Antipolis, in the last couple of years, an anechoic chamber, with RF absorbers preventing radio waves reflections and with a Faraday cage blocking external interferences. This lab, named $\mathrm{R}^2\mathrm{lab}$, represents an ideal environment for experiments reproducibility.

$\mathrm{R}^2\mathrm{lab}$ has been operated for 2 years now, in the context of the FIT Equipment of Excellence project, and as such, it is now federated with the other testbeds that are part of the FIT initiative. This testbed is for the long-haul, and is scheduled to remain operational until at least 2020.

During 2016, our focus regarding $\mathrm{R}^2\mathrm{lab}$ has been set on the following aspects. First, we have deployed USRPs (Universal Software Radio Peripherals) together with hardware devices for controlling these USRP extensions. This is extremely interesting, as it considerably widens the fields of application for the tesbed. In particular, and that was our second angle for improvements this year, we have taken advantage of the USRP hardware to provide support for OpenAirInterface-based deployments in the chamber. That feature was demonstrated for example during the formal opening that took place on November 9 this year, where it was demonstrated how to set up a private LTE network in 3 minutes.

For more details see http://r2lab.inria.fr.

6. New Results

6.1. Service Transparency

6.1.1. From Network-level Measurements to Expected QoE

Participants: Chadi Barakat, Thierry Spetebroot, Muhammad Jawad Khokhar, Damien Saucez and Nawfal Abbassi Saber.

Internet applications, especially those of multimedia type and in a mobile context, are very sensitive to the delivery service they get from the network. However, the relation between this network service and the quality of these applications as perceived by the end users is often unknown and hard to be quantified. Some of the applications dispose of their own quality estimation techniques such as Skype and Viber. Others leave the users to their own interpretation of the quality they perceive. Linking the quality of Internet applications as perceived by the Internet users to network-level measurements such as bandwidth or delay is more than ever necessary. Such dependence, known in the literature as linking Quality of Experience (QoE) to Quality of Service (QoS) parameters, serves many purposes. On one side it allows the estimation of the quality an Internet user will obtain before launching the application or even before heading to the place where she/he will connect. On the other side, it helps network operators properly dimension their networks so that to anticipate service degradation and optimize the quality they deliver. The correlation of quality measurements among users, or for the same user among different of his/her locations, can help in troubleshooting the reasons of any degraded quality.

Our project, called ACQUA, aims at the estimation of the quality of Internet applications at the access departing from network-level measurements. It leverages measurements done at the network level as done today (bandwidth, delay, loss rate, etc), and applies over them well calibrated models to estimate/predict the quality of experience for main applications even before launching them. ACQUA is an extensible solution in terms of the applications it can track. It allows a fine-grained profiling of the Internet access at the level of application quality. In a recent work, we have proved the feasibility of the approach with the Skype use case. We have integrated into ACQUA a new model based on decision trees for the estimation of Skype QoE. The model has been validated with both local controlled and PlanetLab experiments. In 2016, we focused on the popular YouTube use case. We set up a new experimental setup to automatically stream videos, change network conditions, and write down the corresponding Quality of Experience (modeled as a function of application level Quality of Service metrics). One of the challenges we had to face is the reduction of the complexity of experimentation that we had to solve using sampling techniques. The first results are very promising as we can considerably reduce the complexity of experimentation while reaching high level of accuracy in the prediction of Youtube Quality of Experience. A paper is currently under submission illustrating the methodology and the

obtained results. More details on this approach and on our project ACQUA can be found in section 5.1 and on the project web page http://project.inria.fr/acqua/.

6.1.2. Testing for Traffic Differentiation with ChkDiff: The Downstream Case

Participants: Ricardo Ravaioli and Chadi Barakat.
In the past decade it has been found that some Internet operators offer degraded service to selected user traffic by applying various differentiation techniques. If from a legal point of view many countries have discussed and approved laws in favor of Internet neutrality, confirmation with measuring tools for even an experienced user remains hard in practice. In this contribution, we extend and complete our tool ChkDiff, previously presented for the upstream case, by checking for shaping also on the user's downstream traffic. After attempting to localize shapers at the access ISP on upstream traffic, we replay downstream traffic from a measurement server and analyze per-flow one-way delays and losses, while taking into account the possibility of multiple paths between the two endpoints. As opposed to other proposals in the literature, our methodology does not depend on any specific Internet application a user might want to test and it is robust to evolving differentiation techniques that alter delays or induce losses. In a recent publication [22], we provide a detailed description of the downstream tool and a validation in the wild for wired, WiFi and 3G connections. This work is the result of collaboration with the SIGNET group at I3S in the context of a PhD thesis funded by the UCN@Sophia Labex and defended in 2016.

6.1.3. Traceroute facility for Content-Centric Network

Participant: Thierry Turletti.
In the context of the UHD-on-5G associated team with our colleagues at NICT, Japan, we have proposed the Contrace tool for Measuring and Tracing Content-Centric Networks (CCNs). CCNs are fundamental evolutionary technologies that promise to form the cornerstone of the future Internet. The information flow in these networks is based on named data requesting, in-network caching, and forwarding – which are unique and can be independent of IP routing. As a result, common IP-based network tools such as ping and traceroute can neither trace a forwarding path in CCNs nor feasibly evaluate CCN performance. We designed Contrace, a network tool for CCNs (particularly, CCNx implementation running on top of IP) that can be used to investigate 1) the Round-Trip Time (RTT) between content forwarder and consumer, 2) the states of in-network cache per name prefix, and 3) the forwarding path information per name prefix. This tool can estimate the content popularity and design more effective cache control mechanisms in experimental networks. We have published an Internet-Draft [30] describing the specification of Contrace.

6.1.4. How news media use Twitter to attract traffic?

Participants: Arnaud Legout, Maksym Gabielkov.
Online news domains increasingly rely on social media to drive traffic to their website. Yet we know surprisingly little about how social media conversation mentioning an online article actually generates a click to it. Posting behaviors, in contrast, have been fully or partially available and scrutinized over the years. While this has led to to multiple assumptions on the diffusion of information, each were designed or validated while ignoring this important step.

We present in [18] a large scale, validated and reproducible study of social clicks – that is also the first data of its kind – gathering a month of web visits to online resources that are located in 5 leading news domains and that are mentioned in the third largest social media by web referral (Twitter). Our dataset amounts to 2.8 million posts, together responsible for 75 billion potential views on this social media, and 9.6 million actual clicks to 59,088 unique resources. We design a reproducible methodology, carefully corrected its biases, enabling data sharing, future collection and validation. As we prove, properties of clicks and social media Click-Through-Rates (CTR) impact multiple aspects of information diffusion, all previously unknown. Secondary resources, that are not promoted through headlines and are responsible for the long tail of content popularity, generate more clicks both in absolute and relative terms. Social media attention is actually long-lived, in contrast with temporal evolution estimated from posts or impressions. The actual influence of an intermediary or a resource is poorly predicted by their posting behavior, but we show how that prediction can be made more precise.

6.1.5. ReCon: Revealing and Controlling PII Leaks in Mobile Network Traffic

Participant: Arnaud Legout.
It is well known that apps running on mobile devices extensively track and leak users' personally identifiable information (PII); however, these users have little visibility into PII leaked through the network traffic generated by their devices, and have poor control over how, when and where that traffic is sent and handled by third parties. In this paper, we present the design, implementation, and evaluation of ReCon: a cross-platform system that reveals PII leaks and gives users control over them without requiring any special privileges or custom OSes. ReCon leverages machine learning to reveal potential PII leaks by inspecting network traffic, and provides a visualization tool to empower users with the ability to control these leaks via blocking or substitution of PII. We evaluate ReCon's effectiveness with measurements from controlled experiments using leaks from the 100 most popular iOS, Android, and Windows Phone apps, and via an Institutional Review Board approved user study with 92 participants. We show that ReCon is accurate, efficient, and identifies a wider range of PII than previous approaches.

6.2. Open Network Architecture

6.2.1. Storage on Wheels: Offloading Popular Contents Through a Vehicular Cloud

Participants: Luigi Vigneri and Chadi Barakat.
The increasing demand for mobile data is overloading the cellular infrastructure. Small cells and edge caching is being explored as an alternative, but installation and maintenance costs for sufficient coverage are significant. In this work, we perform a preliminary study of an alternative architecture based on two main ideas: (i) using vehicles as mobile caches that can be accessed by user devices; compared to small cells, vehicles are more widespread and require lower costs; (ii) combining the mobility of vehicles with delayed content access to increase the number of cache hits (and reduce the load on the infrastructure). Contrary to standard DTN-type approaches, in our system max delays are guaranteed to be kept to a few minutes (beyond this deadline, the content is fetched from the infrastructure). We first propose an analytical framework to compute the optimal number of content replicas that one should cache, in order to minimize the infrastructure load. We then investigate how to optimally refresh these caches to introduce new contents, as well as to react to the temporal variability in content popularity. Simulations suggest that our vehicular cloud considerably reduces the infrastructure load in urban settings, assuming modest penetration rates and tolerable content access delays. This work has been published in [24]. It is the result of collaboration with Thrasyvoulos Spyropoulos from the Mobile Communications Department at Eurecom in the context of a PhD thesis funded by the UCN@Sophia Labex.

In another work, published in [25], and always in the context of the same collaboration with Thrasyvoulos Spyropoulos, we studied the feasibility of the approach using the popular video streaming case. In this work, we assume such a vehicular cloud is in place to provide video streaming to users, and that the operator can decide which content to store in the vehicle caches. Users can then greedily fill their playout buffer with video pieces of the streamed content from encountered vehicles, and turn to the infrastructure immediately when the playout buffer is empty, to ensure uninterrupted streaming. Our main contribution is to model the playout buffer in the user device with a queuing approach, and to provide a mathematical formulation for the idle periods of this buffer, which relate to the bytes downloaded from the cellular infrastructure. We also solve the resulting content allocation problem, and perform trace-based simulations to finally show that up to 50% of the original traffic could be offloaded from the main infrastructure.

6.2.2. SDN for QoE-based network optimization and management

Participants: Vitalii Poliakov, Damien Saucez.

The naive approach of the networking community is to always increase network capacity to absorb the traffic. In this thesis, we take the counterpoint of this approach claiming that it is possible to better use network resources if we take into account the Quality of Experience (QoE) of users while making routing decisions. The idea is that each network service (e.g., video streaming, web, chat) has different requirements in terms of network performances such as bandwidth or delay and that modern networks present high path diversity, particularly 5G. Our work is thus to provide mechanisms to decide how to route traffic in the network, potentially using multiple paths in parallel, based on their real impact on the QoE. For example, if the experience of a user is not negatively impacted if their traffic is diverted on a slow path, we can use it to free resources for traffic that really needs the high speed path. Initial results for this new activities are published in [27] and [21].

6.2.3. Measurements of LISP

Participant: Damien Saucez.

To face the new challenges of the Internet such as the Cloud and mobility the Locator/ID Separation Protocol (LISP) leverages the separation of the identifier and the locator roles of IP addresses. Contrarily to the classical BGP-based routing architecture, LISP relies on a pull model. In particular, routing information is pulled from a new network element, the Mapping System, to provide the association between the identifier (i.e., the address used to identify a host inside a domain) and a list of locators (i.e., the addresses to locate an attachment point) upon an explicit query. We evaluate a LISP Mapping System deployment in the public LISP Beta Network deployment from two aspects: Stability and Consistency. Our measurements show that the mapping information is stable over time and consistent between the different mapping entities and the vantage points. Due to the presence of few cases where the Mapping System is unstable and/or inconsistent, we propose a taxonomy in order to classify such instabilities and/or inconsistencies and investigate them in depth to provide hints on how to improve LISP performance. Results are published in [26].

6.2.4. Rules Placement Problem in OpenFlow Networks

Participants: Xuan Nam Nguyen, Damien Saucez, Chadi Barakat and Thierry Turletti.

Software-Defined Networking (SDN) abstracts low-level network functionalities to simplify network management and reduce costs. The OpenFlow protocol implements the SDN concept by abstracting network communications as flows to be processed by network elements. In OpenFlow, the high-level policies are translated into network primitives called rules that are distributed over the network. While the abstraction offered by OpenFlow allows to potentially implement any policy, it raises the new question of how to define the rules and where to place them in the network while respecting all technical and administrative requirements. We proposed a comprehensive study of the so-called OpenFlow rules placement problem with a survey of the various proposals intending to solve it [17].

6.2.5. Scalable Multicast Service in Software Defined ISP networks

Participants: Hardik Soni, Thierry Turletti, Walid Dabbous.

In the context of the SDN-based multicast mechanisms activity, we have proposed an architectural solution to provide scalable multicast service in ISP networks. In fact, new applications where anyone can broadcast video are becoming very popular on smartphones. With the advent of high definition video, ISP providers may take the opportunity to propose new high quality broadcast services to their clients. Because of its centralized control plane, Software Defined Networking (SDN) seems an ideal way to deploy such a service in a flexible and bandwidth-efficient way. But deploying large scale multicast services on SDN requires smart group membership management and a bandwidth reservation mechanism to support QoS guarantees that should neither waste bandwidth nor impact too severely best effort traffic. We have proposed a Network Function Virtualization based solution for Software Defined ISP networks to implement scalable multicast group management. We also propose in the same paper a routing algorithm called Lazy Load balancing Multicast (L2BM) for sharing the network capacity in a friendly way between guaranteed-bandwidth multicast traffic and best-effort traffic. Our implementation of the framework made on Floodlight controllers and Open vSwitches is used to study the performance of L2BM. A paper on this work is under submission [37].

6.2.6. Towards unifying content level and network level operations

Participants: Amine Loukili, Damien Saucez, Thierry Turletti.
Programmability of the network to provide content level operations is highly desirable. With the advent of virtualization and network function softwarization, the networking world shifts to Software Defined Networking (SDN) and OpenFlow is one of the most suitable candidates to implement the southbound API (the interface allowing the SDN-controller to program network devices). In the meanwhile, the generalization of broadband Internet has led to massive content consumption. However, while content is usually retrieved via layer 7 protocols, OpenFlow operations are performed at lower layers (layer 4 or lower) making the protocol ineffective to deal with contents. To address this issue, we define an abstraction to unify network level and content level operations and present a straw-man logically centralized architecture proposal to support it. Our implementation demonstrates the feasibility of the solution and its advantage over fully centralized approach. This work has been published in the CoNext student workshop [19]. A demonstration was also presented at IEEE SDN/NFV conference [32].

6.2.7. Resiliency in Service Function Chaining

Participants: Ghada Moualla, Damien Saucez, Thierry Turletti.
In the context of the dynamic placement of Virtual Network Functions in the network activity, we have studied the importance of resiliency in service functions chaining. When deploying network service function chains the focus is usually given on metrics such as the cost, the latency, or the energy and it is assumed that the underlying cloud infrastructure provides resiliency mechanisms to handle with the disruptions occurring in the physical infrastructure. In a position paper on this topic published in PROCON 2016 [20], we advocate that while usual performance metrics are essential to decide on the deployment of network service function chains, the notion of resiliency should not be neglected as the choice of virtual-to-physical placement may dramatically improve the ability of the service chains to handle with failures of the infrastructure without requiring complex resiliency mechanisms.

6.2.8. SDN for Public Safety Networks

Participants: Damien Saucez, Xuan Nam Nguyen, Thierry Turletti.
Commercial users of modern communications networks have benefited from a huge progress of the related technologies. However, Public Safety Networks (PSNs) and devices did not follow the same trend. Very often, they still rely on voice or low speed data communications, tempting first responders to use their own private devices when they need to exchange real-time video or geolocation information. Under this consideration, national authorities and specialized organizations have recently initiated the integration of more recent technologies, such as cellular Long Term Evolution (LTE), even though they need further developments to cope with the harsh usages that safety personnel may face. We wrote a report showing the evolution of these networks towards the recent evolution of networking technologies started with Software Defined networking (SDN) and Network Functions Virtualization (NFV). Based on the requirements derived from a standardized earthquake scenario and a study of the main improvements brought by this network softwarization, it analyzes how SDN and NFV can solve part of the issues raised with commercial LTE and enhance PSN communications. The capabilities of these new technologies are applied to a list of characteristics required by mission-critical networks, e.g., rapid deployment, reliability, security or resilience, taking advantage of features such as the separation between control and data planes or the simplified dynamic resources management. The resulting enhancements are then illustrated using example frameworks published in the literature for Cloud Radio Access Networks, resilient backhaul solution, isolated base stations, SDN-based architecture or Service Function Chaining [28].

6.2.9. Standardization Activities

Participant: Damien Saucez.

The Locator/ID Separation Protocol (LISP) aims to improve the Internet routing by leveraging separating the roles of IP addresses. In RFC7834 [36] we studied the impact that the deployment of LISP would have on both the routing infrastructure and the end user if it was largely deployed in today's Internet. In addition, as bringing new protocols to the Internet opens new security questions, in RFC7835 [35] we provide an exhaustive threat analysis of LISP. Both RFCs are used as insights to extend the architecture of LISP to make it more efficient and safer.

Information Centric Networking (ICN) is a radically new way to conceive networks by promoting content information as routing primitives, instead of content location. In RFC7927 [31], we list the research challenges hidden behind this revolutionary approach of networking. This RFC aims to be the baseline for the development of ICN solutions.

6.3. Experimental Evaluation

6.3.1. ORION: Orientation Estimation Using Commodity Wi-Fi

Participants: Mohamed Naoufal Mahfoudi, Thierry Turletti, Thierry Parmentelat, Walid Dabbous.
With MIMO, Wi-Fi led the way to the adoption of antenna array signal processing techniques for fine-grained localization using commodity hardware. These techniques, previously exclusive to specific domains of applications, open the road to reach beyond localization, and now allow to consider estimating the device's orientation in space, that once required other sources of information. Wi-Fi's popularity and the availability of metrics related to channel propagation (CSI), makes it a candidate readily available for experimentation. We have recently proposed the ORION system to estimate the orientation (heading and yaw) of a MIMO Wi-Fi equipped object, relying on a joint estimation of the angle of arrival and the angle of departure. Although the CSI's phase data is plagued by several phase inconsistencies, we demonstrate that an appropriate phase compensation strategy significantly improves estimation accuracy. By feeding the estimation to a Kalman filter, we further improve the overall system accuracy, and lay the ground for an efficient tracking. Our technique allows estimating orientations within high precision. The results of the study were submitted to a specialized workshop on Network Localization on Navigation [33].

7. Bilateral Contracts and Grants with Industry

7.1. Enabling network function composition with Click middleboxes

In the context of the common Inria - Nokia Bell-Labs laboratory on Communication networks of the future, we participate to the Content Centric Networking ADR (Action de Recherche). In the context of this ADR, a post-doctoral researcher, Anandatirtha Nandugudi Sathyaraja, is working on enabling network function composition with Click middleboxes. In fact, the Click modular router has significant advantages for middlebox development, including modularity, extensibility, and reprogrammability. Despite these features, Click still has no native TCP support and only uses nonblocking I/O, preventing its applicability to middleboxes that require access to application data and blocking I/O. In this paper, we attempt to bridge this gap by introducing Click middleboxes (CliMB). CliMB provides a full-fledged modular TCP layer supporting TCP options, congestion control, both blocking and nonblocking I/O, as well as socket and zero-copy APIs to applications. As a result, any TCP network function may now be realized in Click using a modular L2-L7 design. As proof of concept, we develop a zero-copy SOCKS proxy using CliMB that shows up to 4 times gains compared to an equivalent implementation using the Linux in-kernel network stack.

8. Partnerships and Cooperations

8.1. Inria internal funding

- **User Discrimination on the Web:** we have been awarded funding for two post-doc positions each for one year with the the "Inria Actions Marquantes" with Nataliia Bielova from the INDES project-team. Natasa Sarafijanovic-Djukic have just started her post-doc on this project.
- **ADT ElectroSmart:** in the context of the Inria ADT call, we have a funding for a two year engineering position on the ElectroSmart project for the 2017-2019 period.
- **Transverse Master Interships:** we have a funding for a 6-month internship with Nataliia Bielova on Pixel Tracking.
- **ACQUA:** in the context of the Inria ADT call, we have a funding for a two year engineering position on the ACQUA project for the 2015-2017 period. Thierry Spetebroot is hired on this position.

8.2. UCN@Sophia Labex and UCA Idex funding

- **ElectroSmart:** this project has a funding for a two year engineering position from the UCN@Sophia Labex for the 2016-2018 period (Ravi Mondi is hired on this position) and 30KEuros fron the UCA (Université Côte d'Azur) RISE Academy.
- **PhD sholarships:** our team has currently four ongoing PhD thesis (Karyna Gogunska, Mohamed Naoufal Mahfoudi, Vitalii Poliakov and Luigi Vigneri) funded by the UCN@Sophia Labex.

8.3. Regional Initiatives

- **Plate-forme Telecom (Com4innov)** (2011-2017) is a DGCIS funded project, in the context of the competitivity cluster SCS, that aims at providing to PACA region industrials wishing to develop or validate new products related to future mobile networks and services and M2M application, a networking infrastructure and tools helpful for development, test and validation of those products. Other partners : 3Roam, Audilog Groupe Ericsson, Ericsson, Eurecom, Inria, iQsim, MobiSmart, Newsteo, OneAccess, Orange Labs, SCS cluster, ST Ericsson, Telecom Valley. Our contribution is centred around providing a test methodology and tools for wireless networks experimentation. In the context of this project we have realized a study on MPTCP performance in a wireless-wired environment with Orange Labs Sophia. The software tools that were developed in the project have been integrated in the $\mathrm{R}^2\mathrm{lab}$ anechoic chamber.

8.4. National Initiatives

8.4.1. ANR

- **ANR FIT** (2011-2018): FIT (Future Internet of Things) aims at developing an experimental facility, a federated and competitive infrastructure with international visibility and a broad panel of customers. It will provide this facility with a set of complementary components that enable experimentation on innovative services for academic and industrial users. The project will give French Internet stakeholders a means to experiment on mobile wireless communications at the network and application layers thereby accelerating the design of advanced networking technologies for the Future Internet. FIT is one of 52 winning projects from the first wave of the French Ministry of Higher Education and Research's Equipements of Excellence (Equipex) research grant programme. The project will benefit from a 5.8 million euro grant from the French government. Other partners are UPMC, IT, Strasbourg University and CNRS. See also http://fit-equipex.fr/.

- **ANR DISCO** (2014-2016): DISCO (DIstributed SDN COntrollers for rich and elastic network services) aims at exploring the way how Software Defined Networking changes network monitoring, control, urbanisation and abstract description of network resources for the optimisation of services. The project works throughout experimentations and application use cases on the next generation of Software-Defined Networking solutions for large and critical distributed systems. The project studied the distribution of the current SDN control plane and the optimization of network operations that the integrated system view of cloud computing-based architectures allows. See also http://anr-disco.ens-lyon.fr/.
- **ANR REFLEXION** (2015-2017): REFLEXION (REsilient and FLEXible Infrastructure for Open Networking) research project will study the robustness and scalability of the current SDN architectures and the flexibility leveraged by SDN for provisioning resources and virtualized network functions (VNF). The project will address four main scientific objectives: (1) Fault and disruption management for virtualized services, (2) Robust and scalable control plane for next generation SDN, (3) Dynamic performance management of low level resources in SDN/NFV environments and (4) Distribution and optimization of virtual network functions in SDN environments. Our contribution in this project will be focused on fault and disruption management for virtualized services. See also http://anr-reflexion.telecom-paristech.fr/.
- **ANR BottleNet** (2016-2019): BottleNet aims to deliver methods, algorithms, and software systems to measure Internet Quality of Experience (QoE) and diagnose the root cause of poor Internet QoE. This goal calls for tools that run directly at users' devices. The plan is to collect network and application performance metrics directly at users' devices and correlate it with user perception to model Internet QoE, and to correlate measurements across users and devices to diagnose poor Internet QoE. This data-driven approach is essential to address the challenging problem of modeling user perception and of diagnosing sources of bottlenecks in complex Internet services. ANR BottleNet will lead to new solutions to assist users, network and service operators as well as regulators in understanding Internet QoE and the sources of performance bottleneck.

8.5. European Initiatives

8.5.1. FP7 & H2020 Projects

Program: FP7 FIRE programme

Project acronym: Fed4Fire+

Project title: Federation for FIRE Plus

Duration: January 2017 - December 2021

Coordinator: iMinds (Belgium)

Other partners: 20 european partners including IMEC (Belgium), UPMC (Fr), Fraunhofer (Germany), TUB (Germany), etc.

Web site: http://www.fed4fire.eu/

Abstract: 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.

8.6. International Initiatives

8.6.1. Inria Associate Teams Not Involved in an Inria International Labs

8.6.1.1. UHD-on-5G

Title: Ultra High Definition video streaming on future 5G networks

International Partner (Institution - Researcher):

National Institute of Information and Communications Technology (NICT) (Japan) - Hitoshi Asaeda

Start year: 2016

See also: https://team.inria.fr/diana/uhd-on-5g/

The aim of this collaboration is to design and develop efficient mechanisms for streaming UHD video on 5G networks and to evaluate them in a realistic and reproducible way by using novel experimental testbeds.

Our approach leverages and extends when necessary ICN and SDN technologies to allow very high quality video streaming at large scale. We also plan to use Virtual Network Functions (VNF) in order to place easily and dynamically different functions (e.g. transcoding, caching) at strategic locations within the network. Specifically, the placement of these functions will be decided by SDN controllers to optimize the quality of experience (QoE) of users. Moreover, we plan to integrate ICN functionalities (e.g., name-based forwarding and multipath transport using in-network caching) with SDN/NFV to provide better QoE and mobility services support to users than traditional IP architectures. Monitoring mechanisms such as the Contrace tool we developed in a previous associated team (SIMULBED) will be helpful to provide an accurate view of the network at the SDN controllers side. In addition, we will build a large-scale testbed to evaluate our solutions through reproducible experimentations based on two testbeds: the ICN wired CUTEi tesbed developed by NICT and the wireless $\mathrm{R}^2\mathrm{lab}$ testbed developed by Inria.

8.7. International Research Visitors

8.7.1. Visits of International Scientists

Max Ott from Data61/CSIRO (previously NICTA) visited us in November 2016. He gave a seminar on "Confidential Computing - Analysing Data Without Seeing Data" and an invited talk at the $\mathrm{R}^2\mathrm{lab}$ inauguration ceremony.

8.7.1.1. Internships

Ramon Dos Reis Fontes

Date: from Apr 2016 until Sep 2016

Institution: PhD intern, University of Campinas

Supervisor: Thierry Turletti

Subject: Evaluating and Validating Mininet-WiFi

Anastasia Kuznetsova

Date: from Mar 2016 until Aug 2016

Institution: Ubinet Master intern, University of Nice Sophia Antipolis

Supervisor: Arnaud Legout

Subject: User discrimination on Pinterest

Ahmed Loukili

Date: from Mar 2016 until Aug 2016

Institution: Ubinet Master intern, University of Nice Sophia Antipolis

Supervisor: Damien Saucez

Subject: Content Distribution over Software Defined Networks

Hakob Melkonyan

Date: from Mar 2016 until Aug 2016

Institution: Ubinet Master intern, University of Nice Sophia Antipolis

Supervisor: Arnaud Legout

Subject: ElectroSmart Android Project for Exploring Electromagnetic Exposition

Farzaneh Pakzad

Date: from November 2016 to December 2016

Institution: PhD intern, University of Queensland

Supervisor: Thierry Turletti and Walid Dabbous

Subject: Using $\mathrm{R}^2\mathrm{lab}$ to evaluate MANET routing protocols

Jimmy Rogala

Date: from May 2016 until Aug 2016

Institution: ENS Rennes intern

Supervisor: Arnaud Legout

Subject: Collecting statistics on Pinterest users

Nawfal Abbassi Saber

Date: from Mar 2016 until Aug 2016

Institution: Ubinet Master intern, University of Nice Sophia Antipolis

Supervisor: Chadi Barakat

Subject: Experimenting and modeling YouTube Quality of Experience

8.7.2. Visits to International Teams

Walid Dabbous, Thierry Turletti and Hardik Soni visited NICT in Tokyo Japan in the context of the UHD-on-5G associated team in December 2016.

9. Dissemination

9.1. Promoting Scientific Activities

Chadi Barakat is on the editorial board of the *Computer Networks* journal, on the Technical Program Committee for the ACM Internet Measurement Conference (IMC) 2017, the ACM CoNext Conference 2016, the International Teletraffic Congress (ITC) 2017, the Passive and Active Measurement (PAM) Conference 2016, the IEEE Measurement and Networking (M&N) Workshop 2017, the Algotel Conference 2016, and the Asian Internet Engineering Conference (AINTEC) 2016. He is currently the scientific referee for international affairs at Inria Sophia Antipolis and member of the Conseil d'Orientation Scientifique et Technologique at Inria within the working group of international affairs (COST-GTRI).

Walid Dabbous is in member of the technical program committee of the IEEE INFOCOM International Workshop on Computer and Networking Experimental Research Using Testbeds, CNERT 2016. He is founding member of the ns-3 consortium. He co-organizeed the workshop on Future challenges in User-Centric Networks, co-located with Sigmetrics 2016 in June 2016. He is member of the scientific council of the Inria Bell-Labs laboratory on Communication networks of the future. He also servers as a chair of the scientific committee of the User Centric Networking (UCN@Sophia) Laroratory of Excellence. He was member of board of directors of the Telecom Platform Association responsible for the deployment and operation of the Com4Innov mutualized platform until July 2016. He is also member of the Ubinet International Master program steering committee. He is member of the Inria Sophia Antipolis project committee's bureau (Bureau du CP).

Arnaud Legout is on the editorial board of the *Computer Networks* journal, and was PC member of the ACM IMC 2016 conference. Arnaud Legout is the president of the Commission of the users of IT resources of Sophia Antipolis Inria research center.

Damien Saucez was co-organizer of the GdR RSD – Journées Cloud 2016 – with Fabien Hermenier (I3S). The conference over 2 days was composed of 16 presentations and two industrial keynotes (Amazon Web Services and Amadeus) with 50 attendees. The objective of this annual conference is to provide a forum for French researchers from the networking community and the distributed system community to exchange their latest findings. Damien Saucez was TPC member of IEEE ICC 2017, IEEE CCNC 2017, ACM CoNEXT Student Workshop 2016, DRCN 2016, IEEE CCNC 2016, ACM WNS3 2016, and IEEE Globecom 2016 SAC CN.

Thierry Turletti, Senior ACM and IEEE member, served in 2016 in the program committees of the following international workshops and conferences: the ACM SIGCOMM 2016 Posters and Demos, Salvador, Brazil, August 2016, the 7th Workshop on ns-3 at Seattle, Washington, June 15-16, 2016 and the 11th ACM Workshop on Challenged Networks (CHANTS), New York, USA, October 2016. Thierry Turletti is member of the Editorial Boards of the *Journal of Mobile Communication, Computation and Information* (WINET) published by Springer Science and of the *Advances in Multimedia Journal* published by Hindawi Publishing Corporation. He is chairman of the Committee for Technological Development (CDT) and member of the committee NICE that studies postdoc and visiting researcher applications at Inria Sophia Antipolis.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Master Ubinet: Chadi Barakat and Walid Dabbous, Evolving Internet, 31.5 hours, M2, University of Nice-Sophia Antipolis, France.

Master Ubinet: Chadi Barakat and Walid Dabbous, Internet Measurements and New Architectures, 31.5 hours, M2, University of Nice-Sophia Antipolis, France.

Master 1 International: Chadi Barakat, Algorithms for Networking, 22.5 hours, M1, University of Nice-Sophia Antipolis, France.

Master Estel: Chadi Barakat, Voice over IP, 9 hours, University of Nice-Sophia Antipolis, France.

Master RISM: Chadi Barakat, Mobility and wireless networking, 10.5 hours, University of Avignon, France.

Master Ubinet: Arnaud Legout, From BitTorrent to Privacy, 36 hours, M2, University of Nice-Sophia Antipolis, France.

Master 1 International: Arnaud Legout, Oral and written communications, 18 hours, M1, University of Nice-Sophia Antipolis, France.

Master IUP GMI: Damien Saucez, Security and privacy in networks, 38h, M2, University of Avignon, France.

IUT : Damien Saucez, Advanced Network Services and Operator Network Technologies, 27h, L1 and L2, University of Nice-Sophia Antipolis, France.

E-learning

Python: Arnaud Legout and Thierry Parmentelat are co-authors of the MOOC “Python : des fondamentaux à l’utilisation du langage” that lasts 7 weeks on FUN (https://www.france-universite-numerique-mooc.fr/), Inria. For the third session there were 12954 registered persons among them 1603 qualified for the final attestation of achievement.

Bioinformatics: As part of our contribution to E-learning activities, Thierry Parmentelat was co-author in a MOOC published on the FUN platform and named "Bioinformatique : algorithmes et génomes". This MOOC is dedicated to an introduction to the algorithmic techniques used in the interpretation of DNA sequences. It was played for the second time in French in 2016, and Thierry’s contribution, as compared with the first session that was played in 2015. has been the addition of notebooks where the various algorithms are brought to the students’ disposal, so they can run them interactively, or any variation they would want to study, on any DNA fragment they want, including all the ones from the ENA database https://www.ebi.ac.uk/ena/data/sequence/search. The first notebook-enhanced version of this MOOC in French was played in spring 2016 https://www.fun-mooc.fr/courses/inria/41003S02/session02/info, and attracted 3270 students. An English version of the notebook-enhanced MOOC is scheduled to run on the same FUN platform in spring 2017.

9.2.2. Supervision

PhD: Maksym Gabielkov defended his PhD on "Information propagation in social networks" in June 2016. His thesis was supervised by Arnaud Legout.

PhD: Xuan Nam Nguyen defended his PhD on "Software Defined Networking in challenged environments" April 22, 2016. His thesis was co-supervised by Thierry Turletti and Walid Dabbous. Damien Saucez also actively contributed to the thesis direction.

PhD: Riccardo Ravaioli defended his PhD on "Active and Passive Inference of Network Neutrality" on July 13th 2016. His thesis was co-supervised by Chadi Barakat and Guillaume Urvoy-Keller (I3S).

PhD in progress: Karyna Gogunska works on "Empowering Virtualized Networks with Measurement As a Service (MaaS)". Her thesis is co-supervised by Chadi Barakat and Guillaume Urvoy-Keller (I3S).

PhD in progress: Muhammad Jawad Khokhar works on "From Network Level Measurements to Expected Quality of User Experience". His PhD is supervised by Chadi Barakat.

PhD in progress: Mohamed Naoufal Mahfoudi works on cross-layer optimization techniques for next generation MIMO-based networks since November 2015. His thesis is co-supervised by Walid Dabbous and Robert Staraj (LEAT).

PhD in progress: Ghada Moualla works on "the problem of network faults and how to circumvent them by the means of Software Defined Networking, virtualization, and service function chaining" since November 2015. Her thesis is co-supervised by Thierry Turletti and Damien Saucez.

PhD in progress: Vitalii Poliakov works on "the application of Software Defined Networking on 5G networks in order to optimise the Quality of Experience of network services" since November 2015. His thesis is co-supervised by Damien Saucez and Lucile Sassatelli (I3S).

PhD in progress: Hardik Soni works on "Software Defined Networking in challenged environments" since September 2014. His thesis is co-supervised by Thierry Turletti and Walid Dabbous.

PhD in progress: Luigi Vigneri works on "Vehicles as a Mobile Cloud: Leveraging mobility for content storage and dissemination" since April 2014. His thesis is co-supervised by Chadi Barakat and Thrasyvoulos Spyropoulos (Eurecom).

9.2.3. Juries

Chadi Barakat served as reviewer of Panagiotis Matzakos PhD thesis, "Scheduling and Congestion Management Policies for QoS Provision in Disruption Tolerant Networks" defended in October at Eurecom.

Walid Dabbous served as reviewer of Leonardo Linguaglossa PhD thesis, "Two challenges of Software Networking: Name-based Forwarding and Table Verification", defended on September 9th 2016 at the Université Sorbonne Paris Cité.

Walid Dabbous served as jury member of Nikolaos Spountzis PhD thesis, "Network Layer Optimization for Next Generation Heterogeneous Networks", defended on December 14th 2016 at Eurecom.

Walid Dabbous served as reviewer for mid-term PhD defense of Sumit Kumara at Eurecom for his thesis entitled "Simultaneous multi-standard SDR platform".

Arnaud Legout served as reviewer of Riccardo Petrocco PhD thesis, "Scalable Video Coding Support for P2P Networks", defended on April 9, 2016, at TU Delft.

Damien Saucez served as reviewer for mid-term PhD defense of Sergio Livi at Université de Nice Sophia Antipolis for his thesis entitled "Towards NFV-based Green Networks".

Thierry Turletti served as reviewer of Sadaf Yasmin PhD thesis, "Cost-effective routing and cooperative framework or opportunistic networks", defended on February 17 2016 at the Faculty of Computing Mohammad Ali Jinnah University, Islamabad, Pakistan.

Thierry Turletti served as reviewer of Guillaume Gaillard PhD thesis, "Opérer les réseaux de l'Internet des Objets à l'aide de contrats de qualité de service (SLA)", defended on December 19 at University of Lyon, INSA Lyon, France.

9.3. Popularization

Chadi Barakat keeps participating to the organization of the Mediterranean Students Days @ Campus SophiaTech. The fourth edition took place on March 9-11, 2016, and the fifth edition will took place on February 28-March 2, 2017. All details on this event can be found at http://univ-cotedazur.fr/events/meddays.

Walid Dabbous contributed to a large audience book on Big Data ("Les Big Data à Découvert", CNRS Editions, 2017). His participation [29] is on "Networks for Big Data".

Arnaud Legout gave a presentation on Internet Privacy to high school students at Lycée Amiral in Grasse.

Damien Saucez was invited at AuvernIX to give a tutorial on the Locator/ID Separation Protocol (LISP) in December 2016.

Damien Saucez was invited in December 2016 to present Future Internet challenges to high school students at Lycée Aubrac de Bollène in the context of "Science culture au lycée".

Damien Saucez was invited at the Amadeus Global Forum in June 2016 to present the future of Software Defined Networking.

10. Bibliography

Major publications by the team in recent years

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