Activity Report 2019

Project-Team DIANA

Design, Implementation and Analysis of Networking Architectures

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Networks and Telecommunications

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

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1. Team, Visitors, External Collaborators

Research Scientists

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Chadi Barakat [Inria, Senior Researcher, HDR]
Arnaud Legout [Inria, Researcher, HDR]
Damien Saucez [Inria, Researcher, until Sep 2019, on leave at Safran Electrical & Power since Oct 2019]
Thierry Turletti [Inria, Senior Researcher, HDR]

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Yanis Boussad [Univ de Nice - Sophia Antipolis, PhD Student]
Giuseppe Di Lena [Orange Labs, PhD Student]
Mamoutou Diarra [Ekinops, PhD Student, from Sep 2019, granted by CIFRE]
Thibaut Ehlinger [Inria, PhD Student, until Apr 2019]
Houssam Elbouanani [Inria, PhD Student, from Dec 2019]
Imane Fouad [Inria]
Karyna Gogunska [Inria, PhD Student, until Sep 2019]
Muhammad Jawad Khokhar [Inria, PhD Student]
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Vitalii Poliakov [Univ de Nice - Sophia Antipolis, PhD Student, until Jan 2019]
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Mathieu Thiery [Inria]
Thibaud Trolliet [Inria, PhD Student, until Sep 2019]

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Mondi Ravi [Inria, Engineer, until May 2019]

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Visiting Scientists

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Florinda Fragassi [Univ Côte d'Azur, from Nov 2019]
Rossella Franco [Univ Côte d'Azur, from Nov 2019]
Angelo Rodio [Univ Côte d'Azur, from Nov 2019]
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External Collaborators

Mondi Ravi [Self employed, from Jun 2019 until Aug 2019]
Mondi Ravi [Inria, Consultant, from Sep 2019]

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 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 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. Highlights of the Year

4.1. Highlights of the Year

4.1.1. Ekinops

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.

4.1.2. ACM CoNEXT 2019 Artefact Evaluation Committee

As a continuation of our long lasting efforts in encouraging reproducibility [17], Damien Saucez and Mohamed Naoufal Mahfoudi from our project-team have co-chaired the ACM CoNEXT 2019 Artefact Evaluation Committee. In 2019, 11 papers out of the 32 accepted at the conference have requested for being evaluated, resulting in 10 artefacts being awarding with a badge. Interestingly, we are witnessing an important improvement in the quality of the artefacts proposed by the SIGCOMM community.

5. New Software and Platforms

5.1. ACQUAmobile

KEYWORDS: Android - Internet access - Performance measure - Quality of Experience

FUNCTIONAL DESCRIPTION: ACQUA is an Application for prediCting QUality of Experience (QoE) at Internet Access [21]. 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).

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 [26] on YouTube Quality of Experience, or by soliciting the crowd (i.e. crowdsourcing) for combinations (i.e. tuples) of measurements and corresponding application-level Quality of Experience. Our current work is concentrating on using the ACQUA principle in the estimation and prediction of the Quality of Experience for main user's applications. We refer to the web site of the project for further details.

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.

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

- Authors: Thierry Spetebroot and Chadi Barakat
- Contact: Chadi Barakat
- URL: http://project.inria.fr/acqua/

5.2. ElectroSmart

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

FUNCTIONAL DESCRIPTION: 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 2016/2017/2018 (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) 2017/2020.

In August 2016, we released the first stable public release of ElectroSmart. On the 07th January 2020, we acquire 1000 new daily users, and have 20k weekly active users.

Assessment: A-5, SO-4, SM-4, EM-3-up4, SDL-1

We are in a process of creating a startup to commercialize the exposition maps we can build with the data we are collecting.

- Participants: Arnaud Legout, Abdelhakim Akodadi, Hackob Melconian, Inderjeet Singh and Mondi Ravi
- Contact: Arnaud Legout
- URL: https://es.inria.fr/home/index?path_prefix=en

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

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.

`nepi-ng` is currently made of two separate Python libraries:

- asynciojobs:
  - URL: http://asynciojobs.readthedocs.io/en/latest/
  - Version: asynciojobs v0.5.4
  - 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
- apssh:
  - URL: http://apssh.readthedocs.io/en/latest/
  - Version: apssh v0.7.1
  - 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

Assessment: A-2, SO-3, SM-3, EM-3, DSL-4

- Contact: Thierry Parmentelat
- URL: http://nepi-ng.inria.fr

5.4. 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 is now extremely complicated and researchers massively resort to prototyping techniques. Two experimental techniques are mainly used when it comes to testing a network: simulation and emulation. Emulation provides a good accuracy and allows to test the applications directly in an environment that is similar to a real one. Most of the emulators do not take into account the scalability, because usually they are designed to be executed in a single machine. Among other tools, Mininet is the most popular when it comes to evaluate SDN propositions. It allows to emulate SDN networks on a single computer. Unfortunately, Mininet 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. Distrinet uses the same API than Mininet, meaning that it is compatible with Mininet programs. It is generic and can deploy experiments in Linux clusters or in the Amazon EC2 cloud.

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.

RELEASE FUNCTIONAL DESCRIPTION: First release

- Participants: Damien Saucez, Giuseppe Di Lena, Andrea Tomassilli, Frédéric Giroire, Thierry Turletti and Walid Dabbous
- Partner: Orange Labs
- Contact: Walid Dabbous
- URL: https://distrinet-emu.github.io

5.5. Platforms

5.5.1. 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 for 4 years now, 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 is now 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 [33], [34].

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.

Access to R2lab is open 24/7. We currently have around 200 active users from all over the world among them 40 new users registered in 2019. For more details see http://r2lab.inria.fr.

5.5.2. Network simulator for aircrafts

- Keywords: network, simulation, real-time
- Functional Description: In collaboration with Safran Electrical and Power we produced a network design tool for aircrafts. This tool simulates aircraft networks. The tool is about 10,000 lines of code, out of which we produced 2,000.
- Assessment: A-2up,SO-3,SM-2up,EM-4,SDL-3,OC-DA-CD-TPM
- Licence: confidential
- URL: confidential
- Contact: Damien Saucez

6. New Results

6.1. Service Transparency

6.1.1. From Network Traffic Measurements to QoE for Internet Video

Participants: Muhammad Jawad Khokhar, Thibaut Ehlinger, Chadi Barakat.
Video streaming is a dominant contributor to the global Internet traffic. Consequently, monitoring video streaming Quality of Experience (QoE) is of paramount importance to network providers. Monitoring QoE of video is a challenge as most of the video traffic of today is encrypted. In this work, we consider this challenge and present an approach based on controlled experimentation and machine learning to estimate QoE from encrypted video traces using network level measurements only. We consider a case of YouTube and play out a wide range of videos under realistic network conditions to build ML models (classification and regression) that predict the subjective MOS (Mean Opinion Score) based on the ITU P.1203 model along with the QoE metrics of startup delay, quality (spatial resolution) of playout and quality variations, and this is using only the underlying network Quality of Service (QoS) features. We comprehensively evaluate our approach with different sets of input network features and output QoE metrics. Overall, our classification models predict the QoE metrics and the ITU MOS with an accuracy of 63-90% while the regression models show low error; the ITU MOS (1-5) and the startup delay (in seconds) are predicted with a root mean square error of 0.33 and 2.66 respectively. The results of this work were published in [26] and can be found with further details in the PhD manuscript of Muhammad Jawad Khokhar graduated in October 2019.

6.1.2. When Deep Learning meets Web Measurements to infer Network Performance

Participants: Imane Taibi, Chadi Barakat.

Web browsing remains one of the dominant applications of the internet, so inferring network performance becomes crucial for both users and providers (access and content) so as to be able to identify the root cause of any service degradation. Recent works have proposed several network troubleshooting tools, e.g, NDT, MobiPerf, SpeedTest, Fathom. Yet, these tools are either computationally expensive, less generic or greedy in terms of data consumption. The main purpose of this work funded by the IPL BetterNet is to leverage passive measurements freely available in the browser and machine learning techniques (ML) to infer network performance (e.g., delay, bandwidth and loss rate) without the addition of new measurement overhead. To enable this inference , we propose a framework based on extensive controlled experiments where network configurations are artificially varied and the Web is browsed, then ML is applied to build models that estimate the underlying network performance. In particular, we contrast classical ML techniques (such as random forest) to deep learning models trained using fully connected neural networks and convolutional neural networks (CNN). Results of our experiments show that neural networks have a higher accuracy compared to classical ML approaches. Furthermore, the model accuracy improves considerably using CNN. These results were published in [28].

6.1.3. On Accounting for Screen Resolution in Adaptive Video Streaming: A QoE-Driven Bandwidth Sharing Framework

Participants: Othmane Belmoukadam, Muhammad Jawad Khokhar, Chadi Barakat.
Screen resolution along with network conditions are main objective factors impacting the user experience, in particular for video streaming applications. Terminals on their side feature more and more advanced characteristics resulting in different network requirements for good visual experience. Previous studies tried to link MOS (Mean Opinion Score) to video bit rate for different screen types (e.g., CIF, QCIF, and HD). We leverage such studies and formulate a QoE-driven resource allocation problem to pinpoint the optimal bandwidth allocation that maximizes the QoE (Quality of Experience) over all users of a provider located behind the same bottleneck link, while accounting for the characteristics of the screens they use for video playout. For our optimization problem, QoE functions are built using curve fitting on data sets capturing the relationship between MOS, screen characteristics, and bandwidth requirements. We propose a simple heuristic based on Lagrangian relaxation and KKT (Karush Kuhn Tucker) conditions for a subset of constraints. Numerical simulations show that the proposed heuristic is able to increase overall QoE up to 20% compared to an allocation with TCP look-alike strategies implementing max-min fairness. Later, we use a MPEG/DASH implementation in the context of ns-3 and show that coupling our approach with a rate adaptation algorithm can help increasing QoE while reducing both resolution switches and number of interruptions. Our framework and the first validation results were published in [20].

6.1.4. Tuning optimal traffic measurement parameters in virtual networks with machine learning

Participants: Karyna Gogunska, Chadi Barakat.
With the increasing popularity of cloud networking and the widespread usage of virtualization as a way to offer flexible and virtual network and computing resources, it becomes more and more complex to monitor this new virtual environment. Yet, monitoring remains crucial for network troubleshooting and analysis. Controlling the measurement footprint in the virtual network is one of the main priorities in the process of monitoring as resources are shared between the compute nodes of tenants and the measurement process itself. In this paper, first, we assess the capability of machine learning to predict measurement impact on the ongoing traffic between virtual machines; second, we propose a data-driven solution that is able to provide optimal monitoring parameters for virtual network measurement with minimum traffic interference. These results were published in [25] and are part of the PhD manuscript of Karyna Gogunska graduated in December 2019.

6.1.5. Collaborative Traffic Measurement in Virtualized Data Center Networks

Participants: Houssam Elbouanani, Chadi Barakat.

Data center network monitoring can be carried out at hardware networking equipment (e.g. physical routers) and/or software networking equipment (e.g. virtual switches). While software switches offer high flexibility to deploy various monitoring tools, they have to utilize server resources, esp. CPU and memory, that can no longer be reserved fully to service users' traffic. In this work we closely examine the costs of (i) sampling packets ; (ii) sending them to a user-space program for measurement; and (iii) forwarding them to a remote server where they will be processed in case of lack of resources locally. Starting from empirical observations, we derive an analytical model to accurately predict ($R^2 = 99.5\%$) the three aforementioned costs, as a function of the sampling rate. We next introduce a collaborative approach for traffic monitoring and sampling that maximizes the amount of collected traffic without impacting the data center's operation. We analyze, through numerical simulations, the performance of our collaborative solution. The results show that it is able to take advantage of the uneven loads on the servers to maximize the amount of traffic that can be sampled at the scale of a data center. The resulting gain can reach 200% compared to a non collaborative approach. These results were published in [23].

6.1.6. Distributed Privacy Preserving Platform for Ridesharing Services

Participants: Damien Saucez, Yevhenii Semenko.
The sharing economy fundamentally changed business and social interactions. Interestingly, while in essence this form of collaborative economy allows people to directly interact with each other, it is also at the source of the advent of eminently centralized platforms and marketplaces, such as Uber and Airbnb. One may be concerned with the risk of giving the control of a market to a handful of actors that may unilaterally fix their own rules and threaten privacy. Within the Data Privacy project of the UCAJedi Idex Academy 5 and House of Human and Social Sciences, Technologies and Uses Theme, we have proposed a holistic solution to address privacy issues in the sharing economy. We considered the case of ridesharing and proposed a decentralized architecture which gives the opportunity to shift from centralized platforms to decentralized ones. Digital communications in our proposition are specifically designed to preserve data privacy and avoid any form of centralization. A blockchain is used in our proposition to guarantee the essential roles of a marketplace, but in a decentralized way. Our evaluation shows that privacy protection without trusted entities comes at the cost of harder scalability than an approach with a trusted third party. However, our numerical evaluation on real data and our Android prototype shows the practical feasibility of our approach. The results obtained in this activity are published in 12th International Conference on Security, Privacy, and Anonymity in Computation, Communication, and Storage (SpaCCS) 2019, Atlanta [31] and documented in a research report [35].

6.1.7. Missed by Filter Lists: Detecting Unknown Third-Party Trackers with Invisible Pixels

Participants: Imane Fouad, Arnaud Legout, Natasa Sarafijanovic-Djukic.
Web tracking has been extensively studied over the last decade. To detect tracking, previous studies and user tools rely on filter lists. However, it has been shown that filter lists miss trackers. In this paper, we propose an alternative method to detect trackers inspired by analyzing behavior of invisible pixels. By crawling 84,658 webpages from 8,744 domains, we detect that third-party invisible pixels are widely deployed: they are present on more than 94.51% of domains and constitute 35.66% of all third-party images. We propose a fine-grained behavioral classification of tracking based on the analysis of invisible pixels. We use this classification to detect new categories of tracking and uncover new collaborations between domains on the full dataset of 4,216,454 third-party requests. We demonstrate that two popular methods to detect tracking, based on EasyList & EasyPrivacy and on Disconnect lists respectively miss 25.22% and 30.34% of the trackers that we detect. Moreover, we find that if we combine all three lists, 379,245 requests originated from 8,744 domains still track users on 68.70% of websites. This work will appear in PETS 2020 [24].

6.1.8. Privacy implications of switching ON a light bulb in the IoT world

Participants: Mathieu Thiery, Arnaud Legout.

The number of connected devices is increasing every day, creating smart homes and shaping the era of the Internet of Things (IoT), and most of the time, end-users are unaware of their impacts on privacy. In this work, we analyze the ecosystem around a Philips Hue smart white bulb in order to assess the privacy risks associated to the use of different devices (smart speaker or button) and smartphone applications to control it. We show that using different techniques to switch ON or OFF this bulb has significant consequences regarding the actors involved (who mechanically gather information on the user's home) and the volume of data sent to the Internet (we measured differences up to a factor 100, depending on the control technique we used). Even when the user is at home, these data flows often leave the user's country, creating a situation that is neither privacy friendly (and the user is most of the time ignorant of the situation), nor sovereign (the user depends on foreign actors), nor sustainable (the extra energetic consumption is far from negligible). We therefore advocate a complete change of approach, that favors local communications whenever sufficient. The preprint documenting this work has been published as research report [40].

6.1.9. ElectroSmart

Participants: Arnaud Legout, Mondi Ravi, David Migliacci, Abdelhakim Akodadi, Yanis Boussad.
We are currently evaluating the relevance to create a startup for the ElectroSmart project. We are quite advanced in the process and the planned creation is June 2020. There is a "contrat de transfer" ready between Inria and ElectroSmart to transfer the PI from Inria to the ElectroSmart company (when it will be created). Arnaud Legout the future CEO of the company obtained the "autorisation de création d'entreprise" from Inria. ElectroSmart has been incubated in PACA Est in December 2018.

The three future co-founder of ElectroSmart (Arnaud Legout, Mondi Ravi, David Migliacci) followed the Digital Startup training from Inria/EM Lyon.

The goal of ElectroSmart is to help people reduce their exposure to EMF and offer a solution to reduce symptoms associated with exposure to EMF. Electrosensitivity, is known to be a complex and multifactorial syndrome that impacts hundreds of millions of persons worldwide. We aim to commercialize the first treatment of electrosensitivity based on non-deceptive placebo (called open-label placebo). It is known today that placebo are an effective treatment to subjective symptoms (which is the case for several symptoms associated with electrosensitivity). The problem with placebo was that is was assumed that it must be deceptive to be efficient. Kaptchuk et al. showed recently that non-deceptive placebo are as effective as deceptive placebo, so the ethical usage of placebo is now possible. ElectroSmart want to be the first company to commercialize non-deceptive placebo for electrosensitive persons. For details, see https://electrosmart.app/.

6.2. Open Network Architecture

6.2.1. Constrained Software Defined Networks

Participant: Damien Saucez.
The objective of the ANR JCJC DET4ALL project was to offer the ability to multiplex constrained networks with real time and safety requirements on Ethernet network not initially thought for strict constraints. The reason for this move to Ethernet is to reduce the cost of networking solutions in automotive and industrial applications. We advocate that this move requires to rely on Software Defined Networking (SDN) that enables a programmatic approach to networking, hence offering modularity and flexibility. The challenge with SDN is to be able to certify the behaviour of the system while keeping the solution generic. Within DET4ALL we put the first element in place to show that the previous works that proposed programming languages and abstractions for best-effort network could be leveraged to offering safety properties and determinism in real-time industrial and automotive networks. More precisely, we have demonstrated that Linear Temporal Logic (LTL) can be used in real-time networks to demonstrate the that real-time constraints are always respected. We built a strawman to show that the Temporal NetKat language was adapted to express real-time constraints of networks even though it was not initially design for that purpose. Given that Temporal NetKat relies on LTL and an algebra, it is a good candidate to prove the correct behaviour of a SDN network which logic would be implemented with such a language. In the continuation of this work, we have determined what would be necessary to be able to provide provable live network updates in real time network without service degradation.

This work is published in [30] and will be detailed in the next subsection. Due the leave of Damien Saucez to Safran for one year starting October 1st 2019, the activity on this project had to be stopped as it was in the context of an ANR JCJC project.

6.2.2. NUTS: Network Updates in Real Time Systems

Participants: Damien Saucez, Walid Dabbous.
Recent manufacturing trends have highlighted the need to adapt to volatile, fast-moving, and customer-driven markets. To keep pace with ever quicker product lifecycles, shorter order lead times and growing product variants, factories will become distributed modular cyber-physical systems interconnected by complex communication networks. We advocate that the Software Define Networking (SDN) concept with its programmatic approach to networking is a key enabler for the so-called Industry 4.0 because it provides flexibility and the possibility to formally reason on networks. We have identified that a critical point to address is how to support safe network updates of deterministic real-time communication SDN. To achieve this goal 4 elements are required. First a declarative language with LTL support is needed to express the constraints. Second, a programmable data-plane with the ability to provide real-time constraints indications must be provided in order to assess the behaviour of the forwarding elements. Such language does not exist yet however among the data-plane languages currently on the market some provide the ability to add annotations that could be used to reach our objective. Third, we have identified that deterministic algorithms had to be used to provide a verifiable sequence of network updates in order to make live updates without service degradations. Finally, mathematical techniques must be used to provide bounds on the network updates. Network Calculus can be used for that objective. This study was published as a poster in SOSR'19 [30].

6.2.3. A Joint range extension and localization for LPWAN

Participants: Mohamed Naoufal Mahfoudi, Gayatri Sivadoss, Othmane Bensouda Korachi, Thierry Turletti, Walid Dabbous.
We have proposed Snipe, a novel system offering joint localization and range extensions for LPWANs. Although LPWAN systems such as Long Range (LoRa) are designed to achieve high communication range with low energy consumption, they suffer from fading in obstructed environments with dense multipath components, and their localization system is sub-par in terms of accuracy. In this work, MIMO techniques are leveraged to achieve a higher signal-to-noise ratio at both the end device and the gateway while providing an opportunistic accurate radar-based system for localization with limited additional cost. This work has been published at Internet Technology Letters [15].

6.2.4. Online Robust Placement of Service Chains for Large Data Center Topologies

Participants: Ghada Moualla, Thierry Turletti, Damien Saucez.
The trend today is to deploy applications and more generally Service Function Chains (SFCs) in public clouds. However, before being deployed in the cloud, chains were deployed on dedicated infrastructures where software, hardware, and network components were managed by the same entity, making it straightforward to provide robustness guarantees. By moving their services to the cloud, the users lose their control on the infrastructure and hence on the robustness. We propose an online algorithm for robust placement of service chains in data centers. Our placement algorithm determines the required number of replicas for each function of the chain and their placement in the data center. Our simulations on large data-center topologies with up to 30,528 nodes show that our algorithm is fast enough such that one can consider robust chain placements in real time even in a very large data center and without the need of prior knowledge on the demand distribution. This work has been published at IEEE Access [16].

6.2.5. Bandwidth-optimal Failure Recovery Scheme for Robust Programmable Networks

Participants: Giuseppe Di Lena, Damien Saucez, Thierry Turletti.

With the emergence of Network Function Virtualization (NFV) and Software Defined Networking (SDN), efficient network algorithms considered too hard to be put in practice in the past now have a second chance to be considered again. In this context, we rethink the network dimensioning problem with protection against Shared Risk Link Group (SLRG) failures. In this work, we consider a path-based protection scheme with a global rerouting strategy, in which, for each failure situation, there may be a new routing of all the demands. Our optimization task is to minimize the needed amount of bandwidth. After discussing the hardness of the problem, we develop a scalable mathematical model that we handle using the Column Generation technique. Through extensive simulations on real-world IP network topologies and on random generated instances, we show the effectiveness of our method. Finally, our implementation in OpenDaylight demonstrates the feasibility of the approach and its evaluation with Mininet shows that technical implementation choices may have a dramatic impact on the time needed to reestablish the flows after a failure takes place. This work has been presented at the IEEE International Conference on Cloud Networking (CloudNet), November 2019, at Coimbra in Portugal [29] and documented in a research report [36]. A poster version is published in IFIP-Networking in Warsaw [41].

6.2.6. *Efficient Pull-based Mobile Video Streaming leveraging In-Network Functions*

Participants: Indukala Naladala, Thierry Turletti.

There has been a considerable increase in the demand for high quality mobile video streaming services, while at the same time, the video traffic volume is expected to grow exponentially. Consequently, maintaining high quality of experience (QoE) and saving network resources are becoming crucial challenges to solve. In this work, we propose a name-based mobile streaming scheme that allows efficient video content delivery by exploiting a smart pulling mechanism designed for information-centric networks (ICNs). The proposed mechanism enables fast packet loss recovery by leveraging in-network caching and coding. Through an experimental evaluation of our mechanism over an open wireless testbed and the Internet, we demonstrate that the proposed scheme leads to higher QoE levels than classical ICN and TCP-based streaming mechanisms. This work will be presented at the IEEE Consumer Communications & Networking Conference (CCNC), in January 2020 at Las Vegas, USA [27]. The following link https://github.com/fit-r2lab/demo-cefore includes the artefacts that allows to reproduce performance results shown in the paper.

6.2.7. *Low Cost Video Streaming through Mobile Edge Caching: Modelling and Optimization*

Participants: Luigi Vigneri, Chadi Barakat.

Caching content at the edge of mobile networks is considered as a promising way to deal with the data tsunami. In addition to caching at fixed base stations or user devices, it has been recently proposed that an architecture with public or private transportation acting as mobile relays and caches might be a promising middle ground. While such mobile caches have mostly been considered in the context of delay tolerant networks, in this work done in collaboration with Eurecom with the support of the UCN@Sophia Labex, we argue that they could be used for low cost video streaming without the need to impose any delay on the user. Users can prefetch video chunks into their playout buffer from encountered vehicle caches (at low cost) or stream from the cellular infrastructure (at higher cost) when their playout buffer empties while watching the content. Our main contributions are: (i) to model the playout buffer in the user device and analyze its idle periods which correspond to bytes downloaded from the infrastructure; (ii) to optimize the content allocation to mobile caches, to minimize the expected number of non-offloaded bytes. We perform trace-based simulations to support our findings showing that up to 60 percent of the original traffic could be offloaded from the main infrastructure. These contributions were published in the IEEE Transactions on Mobile Computing journal [18].

6.2.8. *Quality of Experience-Aware Mobile Edge Caching through a Vehicular Cloud*

Participants: Luigi Vigneri, Chadi Barakat.

Densification through small cells and caching in base stations have been proposed to deal with the increasing demand for Internet content and the related overload on the cellular infrastructure. However, these solutions are expensive to install and maintain. Instead, using vehicles acting as mobile caches might represent an interesting alternative. In this work, we assume that users can query nearby vehicles for some time, and be redirected to the cellular infrastructure when the deadline expires. Beyond reducing costs, in such an architecture, through vehicle mobility, a user sees a much larger variety of locally accessible content within only few minutes. Unlike most of the related works on delay tolerant access, we consider the impact on the user experience by assigning different retrieval deadlines per content. We provide the following contributions: (i) we model analytically such a scenario; (ii) we formulate an optimization problem to maximize the traffic offloaded while ensuring user experience guarantees; (iii) we propose two variable deadline policies; (iv) we perform realistic trace-based simulations, and we show that, even with low technology penetration rate, more than 60% of the total traffic can be offloaded which is around 20% larger compared to existing allocation policies. These results were published in the IEEE Transactions on Mobile Computing journal [19].

6.2.9. Machine Learning for Next-Generation Intelligent Transportation Systems

Participants: Tingting Yuan, Thierry Turletti, Chadi Barakat.

Intelligent Transportation Systems, or ITS for short, includes 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. It is expected that ITS will be an integral part of urban planning and future cities as it will contribute 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 survey, we explore the use of Machine Learning (ML), which has recently gained significant traction, to enable ITS. In the context of the Drive associated team, we did a comprehensive 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 use and benefit from ML technology. The survey is documented in [42].

6.3. Experimental Evaluation

6.3.1. Exploiting the cloud for Mininet performance

Participants: Giuseppe Di Lena, Damien Saucez, Thierry Turletti.
Networks have become complex systems that combine various concepts, techniques, and technologies. As a consequence , modelling or simulating them is now extremely complicated and researchers massively resort to prototyping techniques. Among other tools, Mininet is the most popular when it comes to evaluate SDN propositions. It allows to emulate SDN networks on a single computer. However, under certain circumstances experiments (e.g., resource intensive ones) may overload the host running Mininet. To tackle this issue, we propose Distrinet, a way to distribute Mininet over multiple hosts. Distrinet uses the same API than Mininet, meaning that it is compatible with Mininet programs. Distrinet is generic and can deploy experiments in Linux clusters or in the Amazon EC2 cloud. Thanks to optimization techniques, Distrinet minimizes the number of hosts required to perform an experiment given the capabilities of the hosting infrastructure, meaning that the experiment is run in a single host (as Mininet) if possible. Otherwise, it is automatically deployed on a platform using a minimum amount of resources in a Linux cluster or with a minimum cost in Amazon EC2. This work has been presented at the IEEE International Conference on Cloud Networking (CloudNet) [22]. Distrinet has been demonstrated both at the IEEE CloudNet conference and at the ACM CoNEXT conference in Orlando USA in December 2019 [39].

6.3.2. Distributed Network Experiment Emulation

Participants: Giuseppe Di Lena, Damien Saucez, Thierry Turletti, Walid Dabbous.

With the ever growing complexity of networks, researchers have to rely on test-beds to be able to fully assess the quality of their propositions. In the meanwhile, Mininet offers a simple yet powerful API, the goldilocks of network emulators. We advocate that the Mininet API is the right level of abstraction for network experiments. Unfortunately it is designed to be run on a single machine. To address this issue we developed a distributed version of Mininet-Distrinet-that can be used to perform network experiments in any Linux-based testbeds, either public or private. To properly use testbed resources and avoid over-commitment that would lead to inaccurate results, Distrinet uses optimization techniques that determine how to orchestrate the experiments within the testbed. Its programmatic approach, its ability to work on various testbeds, and its optimal management of resources make Distrinet a key element to reproducible research. This work has been presented at the Global Experimentation for Future Internet - Workshop (GeFi) workshop November 2019, at Coimbra in Portugal [38].

6.3.3. Evaluating smartphone performance for cellular power measurement. Under submission

Participants: Yanis Boussad, Arnaud Legout.
From crowdsource data collection to automation and robotics, mobile smartphones are well suited for various use cases given the rich hardware components they feature. Researchers can now have access to various sensors such as barometers, magnetometers, orientation sensors, in addition to multiple wireless technologies all on a single and relatively cheap mobile smartphone. In this work, we study the performance of smartphones to measure cellular wireless power. We performed our experiments inside an anechoic chamber in order to compare the measurements of smartphone to the ones obtained with professional spectrum analyzer. We first evaluate the effect of orientation on the received power, then we propose a way to improve the accuracy of smartphone power measurements by using the orientation sensors. We improve the accuracy of the measurements from 25 dBm RMSE to no more than 6 dBm RMSE. We also show how we can exploit the characteristics of the reception pattern of the smartphone to determine the angle of arrival of the signal. The results of this work are described in a research report under submission [32].

6.3.4. Towards Reproducible Wireless Experiments Using R2lab

Participants: Mohamed Naoufal Mahfoudi, Thierry Parmentelat, Thierry Turletti, Walid Dabbous.
Reproducibility is key in designing wireless systems and evaluating their performance. Trying to reproduce wireless experiments allowed us to identify some pitfalls and possible ways to simplify the complex task of avoiding them. In this research report, we expose a few considerations that we learned are instrumental for ensuring the reproducibility of wireless experiments. Then we describe the steps we have taken to make our experiments easy to reproduce. We specifically address issues related to wireless hardware, as well as varying propagation channel conditions. We show that extensive knowledge of the used hardware and of its design is required to guarantee that the inner state of the system has no negative impact on performance evaluation and experimental results. As for variability of channel conditions, we make the case that a special setup or testbed is necessary so that one can control the ambient wireless propagation environment, using for instance, an anechoic chamber like R2lab. This work is published as research report [33].

6.3.5. A step towards runnable papers using R2lab

Participants: Thierry Parmentelat, Mohamed Naoufal Mahfoudi, Thierry Turletti, Walid Dabbous.
In this research report, we present R2lab, an open, electromagnetically insulated research testbed dedicated to wireless networking. We describe the hardware capabilities currently available in terms of Software Defined Radio, and the software suite made available to deploy experiments. Using a generic experiment example, we show how it all fits into a notebook-based approach to getting closer to runnable papers. This work is published as research report [34].

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

7.1.1. Collaboration with Safran

Participant: Damien Saucez.

The research collaboration with Safran on Constrained Software Defined Networks has evolved into a new stage: Damien Saucez took a one year secondment from Inria to join Safran and further develop this activity from "inside".

7.1.2. Collaboration with Ekinops

Participant: Thierry Turletti, Walid Dabbous.
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.

7.1.3. Collaboration with Orange

Participant: Thierry Turletti, Damien Saucez.
We have a collaboration with Orange on the topic of Network Function Virtualization. The activity includes the CIFRE PhD thesis of Giuseppe Di Lena that started his PhD on resilient NFV/SDN environments on April 2018.

7.2. Bilateral Grants with Industry

7.2.1. QWANT

Participant: Arnaud Legout.
The PIA ANSWER project is led by the QWANT search engine and the Inria Sophia Antipolis Méditerranée research center. This proposal is the winner of the "Grand Challenges du Numérique" (BPI) and aims to develop the new version of the search engine http://www.qwant.com with radical innovations in terms of search criteria, indexed content and privacy of users. In the context of this project, we got with Nataliia Bielova from the INDES project-team a funding for a 3 years Ph.D. working on Web tracking technologies and privacy protection.

8. Partnerships and Cooperations

8.1. Inria Internal Funding

8.1.1. IPL Betternet

Participants: Giuilio Grassi, Imane Taibi, Chadi Barakat.
The DIANA team is part of the Inria Project Lab BetterNet (http://project.inria.fr/betternet/). Within this lab, Inria is funding the PhD of Imane Taibi who is hosted by the Dionysos team in Rennes and is co-supervied by Chadi Barakat from the DIANA project-team and Gerardo Rubino and Yassine Hadjadj-Aoul from the DIONYSOS project-team. The PhD of Imane Taibi started on the 1st of November 2017. Further in 2018, Inria funded a PostDoc position to supervise the experiments planned within the IPL and develop the data analysis part. This PostDoc position is occupied by Giulio Grassi who is co-supervised by Chadi Barakat from the Diana project-team and Renata Teixeira from the MIMOVE project-team. Giulio Grassi started on October 1st, 2018 and is currently located in Paris.

8.2. Regional Initiatives

8.2.1. ElectroSmart

Participants: Arnaud Legout, Mondi Ravi, David Migliacci, Abdelhakim Akodadi, Yanis Boussad.

The ElectroSmart project benefits form the following fundings:

- a 39 months engineering position from the UCN@Sophia Labex for the 2016-2019 period (Ravi Mondi was hired on this position)
- 30KEuros from Academy 1 of UCAJedi
- a two years engineering position from an Inria ADT for 2017/2019 (Abdelhakim Akodadi)
- a 18 months business developer from Inria ATT for june 2017-june 2019 (David Migliacci)
- a 3 years 2017/2020 Ph.D. thesis from Academy 1 of UCAJedi (Yanis Boussad)
- 12 months business developper from Inria ATT for june 2019 - mai 2020 (David Migliacci)
- 12 months engineer from Inria ATT for june 2019 - mai 2020 (Mondi Ravi)

8.2.2. D2D Indoor

Participants: Chadi Barakat, Zeineb Guizani.
This project is joint with the NFCOM startup in Nice, specialized in the development of new services for mobile phones. The project aims at leveraging mobile to mobile communications for offloading the cellular infrastructure, and targets a solution based on algorithms previously developed in the DIANA project-team (BitHoc and HBSD) to achieve networking in a sparse scenario following the multi-hop communication principle. The project got a funding for one year engineer from the Labex UCN@SOPHIA. Zeineb Guizani has worked on this project from July 2018 to May 2019 and has proposed an architecture based on NDN-opp to support such communications.

8.3. National Initiatives

8.3.1. ANR

- **ANR JCJC DET4ALL** (2019-2021): Modern factories and industrial system massively rely on cyber physical systems with digital communications (e.g., to allow collaborative robots, for data analytics...). However, industrial networks are still mostly managed and conceived as collections of independent communicating units instead of one unified piece of software.

  The reason why the shift of paradigm did not occur yet to industrial digital communication networks is because industrial processes generally impose strong determinism and real-time constraints. As a result, industrial networks have a propensity of being physically segregated to contain potential malfunctions and simplify conception.

  With the DET4ALL project, we will apply the concept of network programmability to the world of industrial communicating systems. To that aim, we will construct and prove the essential building blocks that will allow to virtualise industrial networks:

  – algorithms to automatically provision the various components constituting industrial networks;
  – Domain Specific Languages (DSLs) to specify real-time communication schemes;
  – mechanisms to update on-the-fly the production infrastructures without service degradation.

  The impact of the DET4ALL project goes beyond technological advances; it will also bring a new vision on what production tools can become, namely agile systems in perpetual evolution.
- **ANR FIT** (2011-2019): 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. The project was extended for one year and will end in december 2019. See also http://fit-equipex.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.

8.4. European Initiatives

8.4.1. 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 as 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.

8.5. International Initiatives

8.5.1. Inria Associate Teams Involved in an Inria International Lab

8.5.1.1. DrIVE

Title: DrIVE: Distributed Intelligent Vehicular Environment - Enabling ITS through programmable networks

Inria International Lab: **Inria@SiliconValley**

International Partners (Institution - Laboratory - Researcher):

UniCamp (Brazil) - Department of Computer Engineering and Industrial Automation - Mateus Augusto Silva Santos

UNICAMP (Brazil) - Department of Computer Engineering and Industrial Automation - Christian Esteve Rothenberg

UC Santa Cruz (USA) - Department of Computer Science and Engineering- Katia Obraczka

Start year: 2018

See also: https://team.inria.fr/diana/drive-associated-team/

Transportation systems are part of our society's critical infrastructure and are expected to experience transformative changes as the Internet revolution unfolds. The automotive industry is a notable example: it has been undergoing disruptive transformations as vehicles transition from traditional unassisted driving to fully automated driving, and eventually to the self-driving model. Communication technology advancements such as support for vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication have been one of the key enablers of next generation transportation services, also known as Intelligent Transport Systems (ITS). However, ITS services and applications pose significant challenges to the underlying communication and network infrastructure due to their stringent low latency, reliability, scalability, and geographic decentralization requirements. The DrIVE associated team proposal aims at addressing such challenges by: (1) developing a programmable network control plane that will dynamically adjust to current environment conditions and network characteristics to support ITS' scalability, quality of service (QoS), and decentralization requirements, and (2) applying the proposed distributed network control plane framework to ITS applications, such as road hazard warning, autonomous- and self-driving vehicles, and passenger-centric services (e.g., infotainment and video streaming).

8.6. International Research Visitors

8.6.1. Visits of International Scientists

Mark Crovella, Professor at Boston University, visited us in March 2019 and gave a talk at Forum Numerica of Université Côte d'Azur. Mark is currently collaborating with Chadi Barakat on network-wide anomaly detection within the IPL BetterNet.

8.6.2. Internships

Houssam Elbouanani

Date: from March 2019 to August 2019

Institution: Ubinet Master 2 program at Université Côte D'Azur

Supervisors: Chadi Barakat and Guillaume Urvoy-Keller

Subject: Measurement as a Service in modern Data Centers

Anas Errahali

Date: from March 2019 to August 2019

Institution: Ubinet Master 2 program at Université Côte D'Azur

Supervisosr: Walid Dabbous and Thierry Turletti

Subject: Enhancing geolocation accuracy in LoRa Low Power Wide Area Networks

Youssef Rachid

Date: from March 2019 to August 2019

Institution: Ubinet Master 2 program at Université Côte D'Azur

Supervisor: Arnaud Legout

Subject: Exploring bias in the YouTube recommendation system.

Tareq Si Salem

Date: from March 2019 to August 2019

Institution: Ubinet Master 2 program at Université Côte D'Azur

Supervisor: Arnaud Legout

Subject: Identifying exposure profiles of Electrosmart users.

8.6.3. Visits to International Teams

Mohamed Naoufal Mahfoudi spent six months (october 2018, March 2019) PhD internship in University of California at San Diego in Professor Xinyu Zhang team. During this period he worked on a new passive localization system based on deep learning.

Tingting Yuan spent a 3-week visit at UNICAMP, Brazil, in the context of the DrIVE associated team (Oct 21 – Nov 8, 2019).

9. Dissemination

9.1. Promoting Scientific Activities

Chadi Barakat is on the editorial board of the Computer Networks journal, and was/is on the Technical Program Committee for the Network Traffic Measurement and Analysis Conference (2019 and 2020), the IEEE Symposium on Measurements and Networking M&N (2019), the International Conference on Network and Service Management (CNSM 2019) and the NetLearn Workshop (2020). He is currently in charge of international affairs at Inria Sophia Antipolis and is member of the COST-GTRI of Inria.

Walid Dabbous is member of the scientific committee of the DS4H Graduate school. He is also member of the Ubinet International Master program steering committee. He served as a Technical Program Committee member of the Artefact Evaluation Committee for the CoNext 2019 conference. He was member of the selection committee for the 2019 ACM SIGOPS France and GDR RSD thesis prize.

Arnaud Legout is the president of the Commission of the users of IT resources of Sophia Antipolis Inria research center.

Damien Saucez has co-chaired the ACM SIGCOMM *Artefact Evaluation Committee* whose role is to assess the reproducibility level of papers accepted to ACM SIGCOMM sponsored conferences and journals. He was TPC co-chair of the 2019 ACM Workshop on ns-3. He is regular reviewer for IEEE, ACM, Elsevier, and Springer journals.

Thierry Turletti, Senior ACM and IEEE member, served in 2019 in the program committees of the following international workshops and conferences: 2nd Workshop on Emerging Trends in Softwarized Networks (ETSN'19), Paris, France, June 28, 2019; 10th Workshop on ns-3, Mangalore, India, University of Florence, Italy, June 19-20 2019; 21st Algotel Conference, Narbonne, France, June 3-7, 2019; and VTC2019-Spring workshop, Kuala Lumpur, Malaysia, 28 April – 1 May 2019. Thierry Turletti is president of the Committee for Technological Development (CDT) and member of the committee NICE that studies postdoc and visiting researcher applications at Inria Sophia Antipolis. 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.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Master 2 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 in Computer Science: Chadi Barakat, Computer Networks, 15 hours, M1, University of Nice Sophia Antipolis, France.

Master 1 in Computer Science: Chadi Barakat, Internet of the Future, 15 hours, M1, University of Nice Sophia Antipolis, France

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

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

Master 1 in Computer Science: 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.

E-learning

Python: Arnaud Legout and Thierry Parmentelat are co-authors of the MOOC Python 3 : "Python 3 : des fondamentaux aux concepts avancés du langage" that lasts 9 weeks on FUN (https://www.france-universite-numerique-mooc.fr/), UCA. For the second session there were 12748 registered persons. In total, this MOOC all on its editions has been followed by 57938 persons.

9.2.2. Supervision

PhD in progress: Othmane Belmoukadam works on “QoE aware content management in the Internet caching and transport”. He is supervised by Chadi Barakat and funded by the doctoral school EDSTIC of Université Côte d’Azur (UCA).

PhD in progress: Yanis Boussad works on “Large scale characterization of the exposition to microwaves”. He is co-supervised with Leonardo Lizzi, LEAT.

PhD in progress: Giuseppe Di Lena works on “Building a resilience methodology for NFV/SDN” in Apr 2018. His PhD is co-supervised by Thierry Turletti, Damien Saucez and Frédéric Giroire from the Coati project-team .

PhD started: Mamoutou Diarra started his PhD on “Multi-access Edge Computing” in november 2019. He is co-supervised by Thierry Turletti, Walid Dabbous and Amine Ismail from Ekinops.

PhD stopped: Thibaut Ehlinger stopped his PhD on “Mapping Quality of Service metrics to user Quality of Experience in the Internet” in April 2019. He was co-supervised by Chadi Barakat and Vassilis Christophides (EPI MiMove, Inria Paris).

PhD started: Houssam Elbouanani started his PhD on “Experiment control for reproducible research” in december 2019. He is co-supervised by Walid Dabbous, Chadi Barakat and Thierry Turletti.

PhD in progress: Iman Fouad started her PhD on on Web tracking technologies and privacy protection in november 2017. Her thesis is co-supervised by Arnaud Legout and Nataliia Bielova (Indes).

PhD: Karyna Gogunska defended her PhD thesis [11] entitled “Empowering Virtualized Networks with Measurement As a Service (MaaS)” in december 2019. Her thesis was co-supervised by Chadi Barakat and Guillaume Urvoy-Keller (I3S) and was funded by the Labex UCN@SOPHIA.

PhD: Muhammad Jawad Khokhar defended his PhD thesis [12] entitled “From Network Level Measurements to Expected Quality of User Experience” in october 2019. His PhD was supervised by Chadi Barakat and was funded by the ANR BottleNet project.

PhD: Mohamed Naoufal Mahfoudi defended his PhD thesis entitled [13] ”Unlocking Wireless Sensing Potential in Wi-Fi and IoT Networks” in ocotber 2019. His thesis was co-supervised by Walid Dabbous and Robert Staraj (LEAT) and was funded by the Labex UCN@SOPHIA.

PhD: Ghada Moualla defended her PhD thesis [14] entitled “Resilient Virtualized Network Functions for Data Centers and Decentralized Environments” in september 2019. Her thesis is co-supervised by Thierry Turletti and Damien Saucez and was funded by the ANR Reflexion project.

PhD in progress: Imane Taibi works on “Big data analysis for network monitoring and troubleshooting”. She is co-supervised by Gerardo Rubino, Yassine Hadjadj-Aoul from the Dionysos project-team and Chadi Barakat.

PhD in progress: Mathieu Thiery works on “Data protection of connected objects and smartphones” in April 2017. He is co-supervised by Vincent Roca from the Privatics project-team and Arnaud Legout.

PhD in progress: Thibaud Trolliet works on “Exploring trust on Twitter”. He is now fully supervised by Frederic Giroire and member of the Coati project team.

9.2.3. Juries

Chadi Barakat served as reviewer of Jingxiu SU PhD thesis, "Recherches sur la mesure de l’analyse du tracking sur le Web", defended in December 2019 at the University Grenoble Alpes and the Chinese Academy of Sciences.

Chadi Barakat served as examiner of Lakhdar Meftah PhD thesis, “Towards Privacy-sensitive Mobile Crowdsourcing”, defended in December 2019 at the University of Lille, France.

Chadi Barakat served as reviewer of Mariem Ben Yahia PhD thesis, “Low Latency Video Streaming Solutions based on HTTP/2”, defended in May 2019 at IMT-Atlantique, France.

Chadi Barakat served as reviewer of Hamza Ben Ammar PhD thesis, “On Models for Performance Evaluationand Cache Resources Placement in Multi-Cache Networks”, defended in May 2019 at the University of Rennes 1, France.

Chadi Barakat served as jury member for the mid-term review of the PhD thesis of Antoine Saverimoutou (Orange Labs) for his thesis entitled "Métrologie de l’Internet du futur: Nouvelles métriques et méthodes de mesure de la qualité de navigation Web" in March 2019.

Walid Dabbous wrote an examiner report on the thesis of Fangzhou Jiang entitled “Towards Characterizing and Exploiting Fine-grained User Behaviors in Mobile System” at the Univeristy of New South Wales.

Walid Dabbous served as reviewer of the PhD thesis of Kim-Hung LE “Mécanismes d’interopérabilité pour les applications industrielles de l’Internet des Objets et la Ville Intelligente”, defended on April 1, 2019 at Eurecom, France.

Walid Dabbous served as reviewer of the PhD thesis of Yoann Desmouceaux “Network-Layer Protocols for Data Center Scalability”, defended on April 10, 2019 at École Polytechnique, France.

Walid Dabbous served as a member of the recruitment committee for a Professor position at Sorbonne University in April 2019.

Thierry Turletti served as reviewer of Romuald Corbel PhD thesis “Évolution des protocoles de transport du point de vue de l’équité”, defended on December 4, 2019 at Université de Rennes 1, France.

Thierry Turletti served as reviewer of Géraldine Texier HDR “Vers un Internet programmable offrant des garanties de qualité de service”, defended on December 3, 2019 at Université de Rennes 1, France.

Thierry Turletti served as reviewer of Jean-Michel Sanner PhD thesis “Architecture du plan de contrôle SDN et placement des services réseaux dans les infrastructures des opérateurs”, defended on July 23, 2019 at Université de Rennes 1, France.

Thierry Turletti served as examiner of Andrea Tomassilli PhD thesis “Vers un Internet programmable offrant des garanties de qualité de service”, defended on June 24, 2019, at UCA, Sophia Antipolis, France.

9.3. Popularization

9.3.1. Internal or external Inria responsibilities

Damien Saucez is part of the MASTIC (https://project.inria.fr/mastic) group at Inria. MASTIC groups all the activities for scientific dissemination for Inria Sophia Antipolis.

9.3.2. Articles and contents

Walid Dabbous wrote an Interstices article [37] on the occasion of the 50th anniversary of the Internet. The article recalls the story of the first France-ARPAnet connection that was established by Christian Huitema’s team in July 1988.

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Major publications by the team in recent years

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