Activity Report 2014

Team DIANA

Design, Implementation and Analysis of Networking Architectures

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Networks and Telecommunications

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Team DIANA

Keywords: Software Defined Networks, Monitoring, Network Protocols, Wireless Networks, Privacy

Creation of the Team: 2013 January 01.

1. Members

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2. Overall Objectives

2.1. Presentation of the team

The overall objective of the DIANA project-team is to provide network architectural support for improving citizen rights in the Internet. To do so, we 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. The mPlane FP7 project (http://www.ict-mplane.eu) is 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 between 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. New Software and Platforms

4.1. ns-3

Participants: Walid Dabbous [correspondant], Thierry Turletti.

ns-3 is a discrete-event network simulator for Internet systems, targeted primarily for research and educational use. ns-3 includes a solid event-driven simulation core as well as an object framework focused on simulation configuration and event tracing, a set of realistic 802.11 MAC and PHY models, an IPv4, UDP, and TCP stack and support for nsc (integration of Linux and BSD TCP/IP network stacks). ns-3 is free software, licensed under the GNU GPLv2 license, and it is publicly available for research, development, and use. Our team has been involved in ns-3 project since 2006 and we are founding member of the ns-3 consortium.

See also the web page http://www.nsnam.org.

- Version: ns-3.21
- Keywords: networking event-driven simulation
- License: GPL (GPLv2)
- Type of human computer interaction: programmation C++/python, No GUI
- OS/Middleware: Linux, cygwin, osX
- Required library or software: standard C++ library: GPLv2
- Programming language: C++, python
- Documentation: doxygen

4.2. DCE

Participants: Thierry Turletti [correspondant], Walid Dabbous.

DCE enables developers and researchers to develop their protocols and applications in a fully controllable and deterministic environment, where tests can be repeated with reproducible results. It allows unmodified protocol implementations and application code to be tested over large and possibly complex network topologies through the ns-3 discrete-event network simulator. The single-process model used in the DCE virtualization core brings key features, such as the possibility to easily debug a distributed system over multiple simulated nodes without the need of a distributed and complex debugger. Examples of tested applications over DCE include Quagga, iperf, torrent, thttpd, CCNx and various Linux kernel versions (from 2.6.36 to 3.12 versions). DCE was initially developed by Mathieu Lacage during his PhD thesis and is maintained by engineers in the team in collaboration with Hajime Tazaki from University of Tokyo. DCE/ns-3 is an important component of the Reproducible Research Lab. DCE is free software, licensed under the GNU GPLv2 license, and is publicly available for research, development, and use.

See also the web page https://www.nsnam.org/overview/projects/direct-code-execution/

- Version: DCE-1.2
- Keywords: emulation, virtualization, networking event-driven simulation
- License: GPL (GPLv2)
- Type of human computer interaction: programmation C/C++, No GUI
- OS/Middleware: Linux
- Required library or software: standard C++ library: GPLv2
- Programming language: C++, python
- Documentation: doxygen

4.3. NEPI

Participants: Thierry Turletti [correspondant], Alina Quereilhac, Julien Tribino, Lucia Guevgeozian Odizzio.

NEPI, the Network Experimentation Programming Interface, is a framework to describe and orchestrate network experiments on a variety of network experimentation platforms, including simulators, emulators, live testbeds, and testbed federations. NEPI is capable of supporting arbitrary platforms through the use of a generic network experiment description model, based on abstracting network experiments as a collection of arbitrary resource objects, and through the generalization of the experiment life cycle for all resources. The common resource life cycle consist on the sequence of operations deploy, start, stop, and release. Different resource objects can implement specific versions of those operations to adapt to any platform. NEPI resolves experiment orchestration as an online scheduling problem that consists on executing the deploy, start, stop, and release operations for every resource in the correct order.

During the year 2013 we fully re-implemented NEPI's core libraries to adopt the scheduling-based experiment orchestration approach, improving the flexibility and extensibility of the framework compared to the previous static stage-based orchestration approach. By the end of 2013 the new NEPI framework supported describing and orchestrating experiments on live testbeds, including SSH enables Linux testbed, PlanetLab Internet testbed, and OMF wireless testbed (version 5.4).

In 2014 the framework was extended to support simulation and emulation, using the ns-3 simulator and its direct code execution (DCE) emulation extension. Additionally, automated translation of a same experiment scenario to different platforms, i.e. multi platform experimentation, was incorporated into the framework to provide an unified environment for the development and evaluation of production quality networking software, meant to be deployed on real networks. This unified development and evaluation environment simplifies the transition from a realistic live platform to a controlled emulation platform, and vice-versa, in order to take advantage of the complementary features offered by them. The environment was demonstrated at ACM ICN 2014 for the case of Content Centric Networking (CCNx) development, combining PlanetLab and DCE platforms.

Finally, NEPI now supports OMF experiment control protocol version 6.0, which is the new mainstream release of OMF control framework for testbeds, and SFA (Slice Federation Architecture), for resource discovery and provisioning across federated testbeds. The combination of OMF 6.0 and SFA was adopted as the standard for federated experiment orchestration in the European federation projects OpenLab and Fed4FIRE. NEPI's ability to support federated experiment orchetsration was demonstrated at the OpenLab Final Review. Information about this demo is available at http://nepi.inria.fr/UseCases/VLCCCNStreamingExperiment.

See also the web page http://nepi.inria.fr.

- Version: 3.2
- ACM: C.2.2, C.2.4
- Keywords: networking experimentation, simulation, emulation
- License: GPL (3)
- Type of human computer interaction: python library
- OS/Middelware: Linux
- Required library or software: python – http://www.python.org
- Programming language: python

4.4. OpenLISP

Participant: Damien Saucez [correspondant].

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.

See also the web page http://www.lisp.ipv6.lip6.fr/a/Download.html.

- 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/Middelware: POSIX
- Required library or software: Expat 2
- Programming language: C
- Documentation: Unix man
- Deployment: ddt-root.org

4.5. ACQUA

Participants: Chadi Barakat [correspondant], Salim Afra, Damien Saucez.

ACQUA is an Application for Predicting User Quality of Experience at Internet Access. It was supported by the French ANR CMON project on collaborative monitoring. 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 if run at the access. An application in ACQUA is a function that links the network-level measurements to its 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 applications (see section 5.2 for more details).

See also the web page https://team.inria.fr/diana/acqua/.

- Version: 1.0
- ACM: C.2.2, C.2.3
- Keywords: Internet measurement, Internet Access, Quality of Experience
- License: GPL (3)
- Type of human computer interaction: C#
- OS/Middelware: 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

4.6. ElectroSmart

Participants: Arnaud Legout [correspondant], Inderjeet Singh, Maksym Gabielkov.

The ElectroSmart project is based on a large crowd sourcing collection of electromagnetic radiations measured by the ElectroSmart application running on real users smartphones. We target a large number of users and many scientific exploitation of the collected data, exploitation that we describe in the following.

Exposure of human beings to electromagnetic radiations is a growing worldwide health concern. While the biological impact of electromagnetic radiations is not fully understood, there are reports of hypersensitivity to such radiations and hints toward a possible correlation between high exposition and cancer. However, the biological impact of electromagnetic radiations is just one half of the problem, the other half is the exploration of the real exposure of the population to electromagnetic radiations. Indeed, whatever the biological impact, it will be function of the level of exposure, and this level of exposure is unknown.

Collecting the real exposure of human beings to electromagnetic radiations is a complex task. It is possible, but costly and time consuming, to ask auditing organizations to make one-shot measurements. However, there is no way accessible to the general audience to make long term measurements.

The goal of this project is to create the first long term measurement of the electromagnetic exposure of a large worldwide population. This project is supported by the Inria ADT ElectroSmart.

- Version: 1.0alpha
- 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

4.7. Platforms

4.7.1. Reproducible research laboratory ($\mathrm{R^2LAB}$*)*

Scientific evaluation of network protocols requires that experiment results must 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. Indeed, anechoic chambers with RF absorbers preventing radio waves reflections and with Faraday cage blocking external interferences represent an ideal environment for experiments reproducibility. This year witnessed the realization of such experimental platform (called $\mathrm{R^2LAB}$ or Reproducible Research Laboratory) at Inria Sophia-Antipolis, in the context of the FIT 'Equipment of Excellence' project. The objectives of this platform are twofold : on the one hand, we need to achieve highly controllable wireless experiments (e.g. control plane for 5G), and to this end, the testbed features an anechoic chamber. On the other hand, we need to make it possible to deploy experiments that have demanding resource requirements, as this is typically the case with e.g. ICN-based research, or when involving simulation. For that reason, the platform features some powerful servers of its own; in addition, these experiments can be either hybrid-experiments (as NEPI will be deployed) or federated experiments through several testbeds such as PlanetLab. As the final objective is to provide an environment to easily run realistic and reproducible wireless experiments and simulations, it is important to be able to increase the testbed realism by injecting noise and interfering signals in a controllable way. Experimentation results done in $\mathrm{R^2LAB}$ could also be used to augment the realism of propagation models in simulators, which are able to run large scale scenarios. We are currently deploying the wireless nodes. The next step will to extend the testbed to support software defined networking (SDN) and LTE experimentations and to install specific tools for operating the platform.

5. New Results

5.1. Highlights of the Year

Arnaud Legout and Thierry Parmentelat designed and realized the very first Inria Mooc hosted on the FUN platform. This Mooc is devoted to the study of the Python language, and targets undergrandudate students. The objective of the course is to give students a thorough understanding of the internal mechanisms of language, and lead them to small and realistic applications. This Mooc was a big success: 9166 persons registered to the course, out of them five hundred followed the whole course and more than a hundred finished the project. For more details on this Mooc see https://www.france-universite-numerique-mooc.fr/courses/inria/41001/Trimestre_4_2014/about.

5.2. From network-level measurements to expected QoE: the Skype use case

Contributors: Salim Afra, Chadi Barakat and Damien Saucez. Applications rely on rich multimedia contents and experience of end users is sensitive to network conditions. Consequently, network operators must design their infrastructure to ensure high Quality of Experience (QoE) for their customers. However, applications are usually over-the-top services on which network operators have no control and users have no mean to tune the network when they undergo poor QoE. In this project, called ACQUA for Application for the Prediction of Quality of Experience at Internet Access, we propose a new approach that allows network operators to determine how their network performance will influence QoE and end users to predict the QoE even before launching their applications. We predict the subjective QoE users will undergo based on the knowledge of objective network performance parameters obtained with active measurements (e.g., delay, loss) and machine learning. With the particular case of Skype calls and using a decision tree, we show that our approach achieves 83% of accuracy when estimating QoE from the delay, bandwidth, and loss. Our approach can be seen as a new way of performing measurements at the Internet access, where instead of expressing the expected performance in terms of network-level measurements, the performance of the access is expressed in clear terms related to the expected quality for the main applications of interest to the end user. The strength of the approach is in

its capacity of expressing directly the QoE as a function of network-level measurements, which is an enabler for QoE prediction, and in reusing the same network-level measurements as input to different models for the QoE of end user applications. More details on this approach and on our application ACQUA can be found in section 4.5, in the report summarizing the results [24] and on the application web page http://team.inria.fr/diana/acqua/.

5.3. Understanding of modern web traffic

Contributors: Salim Afra, Chadi Barakat, Byungchul Park and Damien Saucez.

Mobile devices are everywhere nowadays but little is known about the way they differ from traditional non-mobile devices in terms of usage and the characteristics of the web traffic they generate. In this contribution, we propose a first study of the differences that exist between mobile and non-mobile Web traffic seen from the lorgnette of a university campus network. The study is performed at different levels starting from users' behavior to transport protocol configurations. Our main findings are that mobile users often browse websites tailored to their devices. They show a significant adoption of Apps to browse the web and a preference for multimedia content. The different way of conceiving the web for mobiles is reflected at the HTTP and TCP levels with much less HTTP redirections and abrupt TCP connection terminations. Interestingly, mobile traffic carries larger contents and have larger TCP flows than non-mobile traffic. By cross-analysis of protocols and users' behavior, we explain why TCP flows in mobile traffic are larger than those of non-mobiles. Further details on this study can be found in [30].

5.4. Characterizing ICMP Rate Limitation on Routers

Contributors: Chadi Barakat and Ricardo Ravaioli.

In the last decade, path discovery has been extensively covered in the literature. In its simplest form, it generally works by sending probes that expire along the path from a host to a destination. It is also known that network administrators often configure their routers to limit the amount of ICMP replies sent, a common practice typically referred to as ICMP rate limitation. In this contribution we attempt to characterize the responsiveness of routers to expiring ICMP echo-request packets. Our contribution is twofold: first, we provide a detailed analysis of how routers are most commonly configured to respond to expiring packets; next, we show that for the vast majority of routers the measured round-trip time is not affected by the probing rate. This contribution is published in ICC'2015 [21]. It is the result of a collaboration with the SIGNET group at I3S in the context of a PhD thesis funded by the UCN@SOPHIA Labex.

5.5. Studying Social Networks at Scale: Macroscopic Anatomy of the Twitter Social Graph

Contributors: Maksym Gabielkov and Arnaud Legout.

Twitter is one of the largest social networks using exclusively directed links among accounts. This makes the Twitter social graph much closer to the social graph supporting real life communications than, for instance, Facebook. Therefore, understanding the structure of the Twitter social graph is interesting not only for computer scientists, but also for researchers in other fields, such as sociologists. However, little is known about how the information propagation in Twitter is constrained by its inner structure. We have performed an in-depth study of the macroscopic structure of the Twitter social graph unveiling the highways on which tweets propagate, the specific user activity associated with each component of this macroscopic structure, and the evolution of this macroscopic structure with time for the past 6 years. For this study, we crawled Twitter to retrieve all accounts and all social relationships (follow links) among accounts; the crawl completed in July 2012 with 505 million accounts interconnected by 23 billion links. Then, we proposed a methodology to unveil the macroscopic structure of the Twitter social graph. This macroscopic structure consists of 8 components defined by their connectivity characteristics. Each component group users with a specific usage of Twitter. For instance, we identified components gathering together spammers, or celebrities. Finally, we presented a

method to approximate the macroscopic structure of the Twitter social graph in the past, validate this method using old datasets, and discuss the evolution of the macroscopic structure of the Twitter social graph during the past 6 years. This study was published in ACM Sigmetrics 2014 [17].

5.6. When AIMD meets ICN: a bandwidth sharing perspective

Contributors: Chadi Barakat and Damien Saucez.

Information-centric networking (ICN) leverages content demand redundancy and proposes in-network caching to reduce network and servers load and to improve quality of experience. In this contribution, we study the interaction between in-network caching of ICN and Additive Increase Multiplicative Decrease (AIMD) end-to-end congestion control with a focus on how bandwidth is shared, as a function of content popularity and cache provisioning. As caching shortens AIMD feedback loop, the download rate of AIMD is impacted. Supported by an analytical model based on Discriminatory Processor Sharing and real experiments, we observe that popular contents benefit from caching and realize a shorter download time at the expense of unpopular contents, which see their download time inflated by a factor bounded by $1/(1-\rho)$, where ρ is the network load. This bias can be removed by redefining congestion control to be delay independent or by over-provisioning link capacity at the edge so that to compensate for the greediness of popular contents. Further details on this study, which is the result of a collaboration with Politecnico di Bari, can be found in [23].

5.7. On the incentives and incremental deployments of ICN technologies for OTT services

Contributors: Chadi Barakat and Damien Saucez.

With the explosion of broadband Over-The-Top (OTT) services, the Internet is autonomously migrating toward overlay and incrementally deployable content distribution infrastructures. Information-Centric Networking (ICN) technologies are the natural candidates to efficiently distribute popular content to users. However, the strategic incentives in exploiting ICN, for both users and ISPs, are much less understood to date. We hence studied in [15] the strategic incentives for ICN overlay adoption in OTT services based on a game theoretical approach and discussed how OTTs shall shape their prices to motivate ICN overlay usages.

5.8. On ICN Cache Allocation to Content Providers

Contributor: Damien Saucez
Cross-Team Contributors: Mahmoud El Chamie (Maestro)
External contributors: Sahar Hoteit and Stefano Secci from Sorbonne Universités, UPMC Univ Paris 06.

Information Centric Networks (ICNs) allow offloading content distribution from content service providers by means of in-network caching. Despite a rather high maturation in the definition of ICN forwarding techniques, minor attention has been given to the strategic interaction among the multiple ICN stakeholders. We decided to focus on situations involving multiple Content Providers (CPs) and one ICN provider having to give them access to its caches. Intuitively, this situation is prone to high cache contention, in particular at the appealing topology cross-points. To address this problem we propose a resource allocation and pricing framework to support the network provider in the cache allocation to multiple CPs, for situations where CPs have non-overlapping sets of files and untruthful demands need to be avoided. As cache imputations to CPs need to be fair and robust against overclaiming, we evaluated common proportional and max-min fairness (PF, MMF) allocation rules, as well as coalitional game rules, the Nucleolus and the Shapley value. We found that the naive least-recently-used-based ICN approach provides proportional fairness. Moreover, the game-theoretic rules outperform in terms of content access latency the naive ICN approach as well as PF and MMF approaches, while sitting in between PF and MMF in terms of fairness. This paper is under submission [27].

5.9. Demonstrating a unified ICN development and evaluation framework

Contributors: Walid Dabbous, Alina Quereilhac, Damien Saucez and Thierry Turletti.

Information-Centric Networking solutions target world-wide deployment in the Internet. It is hence necessary to have access to a development and evaluation environment which enables both controllable and realistic experimentation to thoroughly understand how ICN solutions would behave in real life deployment. Such solution can be obtained with NEPI that we demonstrated at the ACM Information Centric Networking 2014 conference. In this demonstration, we presented a development and evaluation framework that combines emulation and live prototyping environments to provide ICN designers and implementers the means to build beyond-prototype ICN solutions. This framework is built upon NEPI. We demonstrated the benefits of such integrated approach by showing how complete experimental studies can be carried out with minimum manual intervention and experiment set-up overhead, in both emulation and live environments. More precisely, we demonstrated how to deploy the same experiment in different environment and how NEPI can help to minimise the implementation and operational overhead. This demonstration is summarised in [31].

5.10. Optimizing rules placement in OpenFlow networks: trading routing for better efficiency

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

The idea behind Software Defined Networking (SDN) is to conceive the network as one programmable entity rather than a set of devices to manually configure, and OpenFlow meets this objective. In OpenFlow, a centralized programmable controller installs forwarding rules onto switches to implement policies. However, this flexibility comes at the expense of extra overhead as the number of rules might exceed the memory capacity of switches, which raises the question of how to place most profitable rules on board. Solutions proposed so far strictly impose paths to be followed inside the network. We advocate instead that we can relax routing requirements within the network to concentrate on the final destination to which the traffic should forwarded, not how to route to this destination. In [19] we illustrate the concept, with an optimization problem that gets the maximum amount of traffic delivered according to policies and the actual dimensioning of the network. The traffic that cannot be accommodated is forwarded to the controller that has the capacity to process it further. [19] also demonstrates that our approach permits a better utilization of scarce resources in the network. We extended the work by stating that in many situations (e.g., data-center networks), the exact path followed by packets has not significant impact on performances as long as packets are delivered to their final destination decided by the endpoint policy. It is thus possible to deviate part of the traffic to alternative paths so as to better use network resources without violating the endpoint policy. In [20], we propose a linear optimization model of the rule allocation problem in resource constrained OpenFlow networks with loose routing policies. We show that the general problem is NP-hard and propose a polynomial time heuristic, called OFFICER, that aims at maximizing the amount of carried traffic in under-provisioned networks. Our numerical evaluation on four different topologies show that exploiting various paths allows to increase the amount of traffic supported by the network without significantly increasing the path length.

5.11. A Survey of Software-Defined Networking

Contributors: Bruno Astuto Arouche Nunes, Xuan Nam Nguyen and Thierry Turletti.

We wrote a survey of the emerging field of Software-Defined Networking (SDN). SDN is currently attracting significant attention from both academia and industry. Its field is quite recent, yet growing at a very fast pace. Still, there are important research challenges to be addressed. We look at the history of programmable networks, from early ideas until recent developments. In particular we described the SDN architecture in detail as well as the OpenFlow standard. We provided an overview of current SDN implementations and testing platforms and examined network services and applications that have been developed based on the SDN paradigm. We concluded with a discussion of future directions enabled by SDN ranging from support for heterogeneous networks to Information Centric Networking (ICN). The survey has been published in the IEEE Surveys and Tutorials journal [9]. This paper is among the top downloads on IEEE Exlpore in December 2014. See http://ieeexplore.ieee.org/xpl/browsePopular.jsp?reload=true.

5.12. Software-Defined Networking Enabled Capacity Sharing in User Centric Networks

Contributors: Bruno Astuto Arouche Nunes and Thierry Turletti.

We proposed to use SDN to deploy capacity sharing mechanisms in the context of User Centric Networking (UCN). We consider user-centric networks as a way of considerably mitigating the problem of sharing limited network capacity and resources efficiently and in a fairly manner. UCNs are self-organizing networks where the end user plays an active role in delivering networking functions such as providing Internet access to other users. We propose to leverage the SDN paradigm to enable cooperation between wireless nodes and to provide capacity sharing services in UCNs. Our proposed approach allows coverage of existing network infrastructure (e.g., WiFi or 3GPP) to be extended to other end users or ad hoc networks that would otherwise not be able to have access to network connectivity and services. Moreover, it takes into account current network load and conditions, and QoS requirements of applications. This work has been published in a special issue of Communications Magazine [14].

5.13. Decentralizing SDN's Control Plane

Contributors: Bruno Nunes Astuto and Thierry Turletti.

Motivated by the internets of the future that will likely be considerably larger in size as well as highly heterogeneous and decentralized, we sketched out a framework aiming to enable not only physical, but also logical distribution of the Software-Defined Networking (SDN) control plane. This framework will accomplish network control distribution by defining a hierarchy of controllers that can "match" an internet's organizational– and administrative structure. The main idea is to delegate control between main controllers and secondary controllers in order to accommodate administrative decentralization and autonomy. This work has been presented in a short paper at the IEEE LCN conference [22].

5.14. Extending DCE to emulate Wireless Software Defined Networks.

Participants: Emilio Mancini, Hardik Soni, Thierry Turletti and Walid Dabbous.

Today it is not possible to simulate and evaluate in a realistic way wireless Software Defined Networking solutions. Indeed, the most used SDN emulator tool, Mininet, can only emulate point-to-point physical links using virtual Ethernet pairs (e.g., MAC layer is ignored), and it cannot provide mobility models for wireless nodes. To make the Direct Code Execution module (DCE) able to run Software Defined Networks we started to support OpenFlow NOX controller and Open vSwitch. The actual NOX binary is executed on a simulated ns-3 node. OpenFlow wireless routers are simulated using the Open vSwitch distribution with data-path kernel module support as it is widely used. DCE provides a mechanism to incorporate such a kernel module based application execution. A demonstration has been done at the 17th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems [29].

5.15. On the Performance of the LISP Beta Network

Contributor: Damien Saucez

The future Internet has been a hot topic during the past decade and many approaches towards this future Internet, ranging from incremental evolution to complete clean slate ones, have been proposed. One of the proposition, LISP, advocates for the separation of the identifier and the locator roles of IP addresses to reduce BGP churn and BGP table size. Up to now, however, most studies concerning LISP have been theoretical and, in fact, little is known about the actual LISP deployment performance. In [16], we report the measurement campaigns carried out on the LISP Beta Network. More precisely, we evaluated the performance of the two key components of the infrastructure: the control plane (i.e., the mapping system) and the interworking mechanism (i.e., communication between LISP and non-LISP sites). Our measurements highlight that performance offered by the LISP interworking infrastructure is strongly dependent on BGP routing policies. If we exclude

misconfigured nodes, the mapping system typically provides reliable performance and relatively low median mapping resolution delays. Although the bias is not very important, control plane performance favors USA sites as a result of its larger LISP user base but also because European infrastructure appears to be less reliable.

This work resulted in a collaboration with Telecom ParisTech starting in mid-2014 a PhD thesis on the feasibility of large scale measurement of LISP networks with Luigi Iannone as advisor and Damien Saucez as co-advisor.

5.16. Standardization: Contributions to the IETF LISP WG

Contibutor: Damien Saucez

In the context of the LISP WG, we contributed to an Internet-draft called "An Architectural Introduction to the LISP Location-Identity Separation System" [25] that describes the architecture of the Locator/ID Separation Protocol (LISP), making it easier to read the rest of the LISP specifications and providing a basis for discussion about the details of the LISP protocols. This document is used for introductory purposes, more details can be found in RFC6830, the protocol specification. This internet-draft is in RFC queue, for imminent publication as RFC.

In the context of the LISP WG, we contributed to an Internet-draft called "LISP Threats Analysis" [33] that proposes a threat analysis of the Locator/Identifier Separation Protocol (LISP). This internet-draft is under discussion in the Working Group.

In the context of the LISP WG, we contributed to an Internet-draft called "LISP-Security (LISP-SEC)" [28] that specifies LISP-SEC, a set of security mechanisms that provides origin authentication, integrity and anti-replay protection to LISP's EID-to-RLOC mapping data conveyed via mapping lookup process. LISP-SEC also enables verification of authorization on EID-prefix claims in Map-Reply messages. This internet-draft is under discussion in the Working Group.

In the context of the LISP WG, we contributed to an Internet-draft called "LISP Impact" [32]. The Locator/Identifier Separation Protocol (LISP) aims at improving the Internet scalability properties leveraging on three simple principles: address role separation, encapsulation, and mapping. In this internet-draft, based on implementation, deployment, and theoretical studies, we discuss the impact that deployment of LISP can have on both the Internet in general and for the end-users in particular. This internet-draft is adopted as Working Group document on December 2014.

6. Bilateral Contracts and Grants with Industry

6.1. Bilateral Contracts with Industry

In the context of the common Inria - Alcatel Lucent Bell-Labs laboratory on Communication networks of the future, we participate to the Content Centric Networking ADR (Action de Recherche). We are currently discussing with Diego Perino team from Alcatel Lucent Bell-Labs to define a research program for a post-doctoral position.

6.2. Bilateral Grants with Industry

We are collaborating with the startup Novathings to deploy early stage privacy leaks monitoring and control solutions. We have proposed in Meddle a VPN based infrastructure performing SSL-bumping in order to capture all the mobile data traffic and to inspect even the SSL flows. The biggest advantage is that, as most mobile platforms support VPNs, we don't need any installation or root access on the devices to perform traffic redirection and inspection. We have a Carnot funding for one year engineer position that will start in April 2015 to implement a new solution on a home appliance sold by Novathings to improve transparency and control for personal devices.

7. Partnerships and Cooperations

7.1. Regional Initiatives

Plate-forme Télécom (PFT) (2011-2014) 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, Pôle SCS, ST Ericsson, Telecom Valley. Our contribution is centred around providing a test methodology and tools for wireless networks experimentation.

7.2. National Initiatives

7.2.1. 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 "Équipements d'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** (2013-2016): 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 will study 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.
- **ANR REFLEXION** (2015-2016): 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.

7.3. European Initiatives

7.3.1. FP7 & H2020 Projects

Program: FP7 FIRE programme

Project acronym:

Project title: Fed4Fire

Duration: mois October 2012 - October 2016

Coordinator: iMinds (Belgium)

Other partners: 17 european partners including iMinds (Belgium), IT Innovation (UK), UPMC (Fr), Fraunhofer (Germany), TUB (Germany), UEDIN (UK), NICTA (Australia), etc.

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

Abstract: Fed4FIRE will deliver open and easily accessible facilities to the FIRE experimentation communities, which focus on fixed and wireless infrastructures, services and applications, and combinations thereof. The project will develop a demand-driven common federation framework, based on an open architecture and specification. It will be widely adopted by facilities and promoted internationally. This framework will provide simple, efficient, and cost effective experimental processes built around experimenters' and facility owners' requirements. Insight into technical and socio-economic metrics, and how the introduction of new technologies into Future Internet facilities influences them, will be provided by harmonized and comprehensive measurement techniques. Tools and services supporting dynamic federated identities, access control, and SLA management will increase the trustworthiness of the federation and its facilities. A FIRE portal will offer brokering, user access management and measurements. Professional technical staff will offer first-line and second-line support to make the federation simple to use. The project will use open calls to support innovative experiments from academia and industry and to adapt additional experimentation facilities for compliance with Fed4FIRE specifications. A federation authority will be established to approve facilities and to promote desirable operational policies that simplify federation. A Federation Standardization Task Force will prepare for sustainable standardization beyond the end of the project. The adoption of the Fed4FIRE common federation framework by the FIRE facilities, the widespread usage by both academic and industrial experimenters, and the strong links with other national and international initiatives such as the FI-PPP, will pave the way to sustainability towards Horizon 2020.

7.3.2. EIT KIC funded activities

Program: **FNS Future Networking Solutions Action Line**

Project acronym: **NFMD**

Project title: Networks for Future Media Distribution (14082)

Duration: January 2014 to December 2014

Coordinator: Acreo, Sweden

Other partners: VTT (Finland), Ericsson, Lund University, SICS (Sweden).

Abstract: The EIT ICT Labs' Networks for Future Media Distribution (NFMD) activity 14082 has as a specific innovation object set out in the application: "Information centric networking is a novel approach of distributing content based on information rather than traditional host routing. The impact foreseen is novel content distribution networks. This is high risk but gives potentially very high impacts. Solutions for media distribution, based on caching in the network and with advanced tools for quality of experience monitoring, as well as optimization for user demand content patterns as monitored in live services, will be considered." The expected outcomes envisioned also in the application were seen over the total length of the project of 2-3 years and would give:

- Building blocks for high performance media service distribution at low cost
- Optimized caching strategies
- Information centric networking solutions
- Quality of Experience tools
- Prototypes, standardization and open source
- Greater mobility, better performance of media services and reduced cost
- Sharing of experience; increased cooperation; new or extended partnerships

Program: **FNS Future Networking Solutions Action Line**

Project acronym: **SDN**

Project title: Software Defined Networking (13153)

Duration: January 2014 to December 2014

Coordinator: Aalto University, Finland

Other partners: Helsinky University (Finland), Thales (France), Deutsche Telecom, Fraunhofer, TU München, TU Berlin (Germany).

Abstract: SDN still requires improvements to be used in mobile networks considering aspects such as security, resilience/robustness and efficient usage of resources in the mobile access. This activity addresses the design of security in mobile access networks (Distributed FW for attack detection and mitigation), Efficient resource usage in mobile access networks (redistribution of traffic based on congestion, mobility patterns) and Resilient control-plane (supporting high speed carrier mobile networks). The expected outcomes are the following:

- Security outcome: Dynamically allocate resources to countermeasure the cyber attack. Isolation of the part of the network under attack so rest is not compromised.
- Efficient resource usage in mobile access networks outcome: Optimal redirection of flows following optimized caching policy and pattern based mobility.
- Resilient control-plane outcome: Understand QoS and make that information available in routing to ensure resiliency.

7.4. International Initiatives

7.4.1. Inria International Labs

We collaborate with Javier Bustos from Inria Chile and his group on the measurements of users' quality of experience and its interpretation in terms of measurements carried on within the devices of the end-users. This collaboration comes to extend Adkintun Mobile with experience-level measurements, and to leverage the results to obtain for the analysis and calibration of users' experience new models and to develop network troubleshooting techniques in case of service degradation. This collaboration fits within our project ACQUA on predicting quality of user experience at Internet access. In 2014, we started integrating the feedback of users revealing their experience into Adkintun Mobile, and the work is currently focusing on obtaining the targeted measurements.

7.4.2. Inria Associate Teams

7.4.2.1. SIMULBED

Title: SIMULBED: Large-Scale Simulation Testbed for Realistic Evaluation of Network Protocols and Architectures

International Partner (Institution - Laboratory - Researcher):

NICT and University of Tokyo (Japan), Hitoshi Asaeda and Yuji Sekiya.

Duration: 2012 - 2014

Participants from Inria in 2014: Walid Dabbous, Emilio Mancini, Alina Quereilhac, Hardik Soni, Julien Tribino and Thierry Turletti.

Participants from NICT in 2014: Hitoshi Asaeda, Ruidong Li and Kazuhisa Matsuzono.

Participants from Univeristy of Tokyo in 2014: Yuji Sekiya and Hajime Tazaki.

Web site: http://planete.inria.fr/Simulbed/

Abstract: Simulators and experimental testbeds are two different approaches for the evaluation of network protocols and they provide a varying degree of repeatability, scalability, instrumentation and realism. Network simulators allow fine grained control of experimentation parameters, easy instrumentation and good scalability, but they usually lack realism. However, there is a growing need to conduct realistic experiments involving complex cross-layer interactions between many layers of the communication stack and this has led network researchers to evaluate network protocols on experimental testbeds.

The use of both simulators and testbeds to conduct experiments grants a better insight on the behavior of the evaluated network protocols and applications. In this project, we focus on the design of SIMULBED, an experimentation platform that aims at providing the best of both worlds. Our project builds on the following state-of-the-art tools and platforms: the open source ns-3 network simulator and the PlanetLab testbed. ns-3 is the first network simulator that includes a mechanism to execute directly within the simulator existing real-world Linux protocol implementations and applications. Furthermore, it can be used as a real-time emulator for mixed (simulation-experimentation) network scenarios. PlanetLab is the well-known international experimental testbed that supports the development and the evaluation of new network services. It is composed of nodes connected to the Internet across the world, and uses container-based virtualization to allow multiple experiments running independently on the same node while sharing its resources.

The overall objective of the project is to make available to networking research community, the SIMULBED platform that will: (1) allow to conduct easily mixed simulation-experimentation evaluation of networking protocols and (2) scale up the size of the PlanetLab experimental testbed, while maintaining a high degree of realism and increasing controllability and reproducibility. We will use the NEPI unified programming environment recently developed in the Planète project-team to help in simplifying the configuration, deployment and run of network scenarios on the platform. See the 2014 Update on the Simulbed web site.

7.4.2.2. Community

Title: COMMUNITY: Message delivery in heterogeneous networks

International Partner (Institution - Laboratory - Researcher):

University of California Santa Cruz (United States) - School of Engineering - Katia Obraczka

Duration: 2009 - 2014

Participants from Inria in 2014: Thierry Turletti, Chadi Barakat, Damien Saucez, Xuan Nam Nguyen, Hardik Soni and Bruno Nunes.

Participants from USCS in 2014: Katia Obraczka and Mateus Santos, PhD Student, USP (research intern at UCSC in 2014).

Participants from USP in 2014: Cintia Borges Margi.

Web site: http://inrg.cse.ucsc.edu/community/

Abstract: This Inria - UC Santa Cruz Team investigates a number of research challenges raised by message delivery in environments consisting of heterogeneous networks that may be subject to episodic connectivity.

During the first three years of the COMMUNITY associate team, we have explored solutions to enable efficient delivery mechanisms for disruption-prone and heterogeneous networks (i.e. challenged networks). In particular, we have designed the MeDeHa framework along with the Henna naming scheme, which allow communication in infrastructure and infrastructure-less networks with varying degrees of connectivity. We have also proposed efficient routing strategies adapted to environment with episodic connectivity that take into account the utility of nodes to relay messages. The various solutions have been evaluated using both simulations and real experimentations in testbeds located at Inria and UCSC. These solutions have demonstrated good performance in challenged networks.

However, the ossification of the Internet prevents the deployment of such solutions in large scale. So, in 2012 we decided to extend our collaboration in two research directions: (1) The exploration of the software-defined networking paradigm to facilitate the implementation and large scale deployment of new network architectures to infrastructure-less network environments, and (2) the design of innovative information-centric communication mechanisms adapted to challenged networks. In particular, we are designing mechanisms to p rovide flexible, efficient, and secure capacity sharing solutions by leveraging SDN in hybrid networked environments, i.e., environments that consist of infrastructure-based as well as infrastructureless networks. We are also investigating solutions to optimize caching in infrastructure and infrastructureless networks using SDN. We have also designed a content-optimal delivery algorithm, called CODA, for distributing named data over challenged networks. See the 2014 Update on the Community web site.

7.5. International Research Visitors

7.5.1. Visits of International Scientists

7.5.1.1. Visiting PhDs

PhD Student: Sahar Hoteit
Date: from May 12th 2014 until May 21st 2014
Subject: On ICN Cache Allocation to Content Providers
Institution: LIP6, University of Pierre and Marie Curie

7.5.1.2. Internships

Student: Salim Afra
Date: from March 2014 until August 2014
Institution: Polytech Nice Sophia, Ubinet Master

Student: Nicolas Aguilera Miranda
Date: from October 2014 February 2015
Subject: Measurements of users' quality of experience over Adkintun Mobile
Institution: University of Chile

Student: Lelio Renard-Lavaud
Date: from April 2014 until July 2014
Subject: Popularity and placement of content in Delay Tolerant Networks
Institution: Ecole Polytechnique - Palaiseau

Student: Hardik Soni
Date: from March 2014 until August 2014
Subject: On managing wireless mesh networks using an SDN architecture
Institution: Polytech Nice Sophia, Ubinet Master

Student: Mahdi Shoja
Date: from March 2014 until August 2014
Subject: Evaluation of network protocols with Direct Code Execution
Institution: Polytech Nice Sophia, Ubinet Master

Student: Phuong Tran Huu
Date: from May 2014 until October 2014
Subject: A Future Internet Technologies benchmark
Institution: Polytech Nice Sophia

7.5.2. Visits to International Teams

Bruno Astuto A. Nunes and Thierry Turletti, visited UCSC in March in the context of the Community associated team.

Hardik Soni and Thierry Turletti, visited NICT and Univ. of Tokyo in november in the context of the Simulbed associated team.

8. Dissemination

8.1. Promoting Scientific Activities

Walid Dabbous is member of the ns-3 consortium. He co-organizes the ns-3 workshop in May 2015. He is member of the scientific council of the Inria Bell-Labs laboratory on Communication networks of the future.

Thierry Turletti, Senior ACM and IEEE member, served in 2014 in the program committees of the following international workshops: 1st ACM Workshop on Wireless and Mobile Technologies for Smart Cities (WiMobCity) at MobiHoc, the 2nd Workshop on Emulation Tools, Methodology and Techniques at SIMUTools, the 5th Workshop on ns-3 and the 5th ICCE, Special Session on Software Defined Networking. He co-chaired the 1st Workshop on Software-Defined Internets of the future (WSDIF'14), Philadelphia, Pennsylvania on October 28 2014. He 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.

Chadi Barakat is on the editorial board of the Computer Networks journal, on the Technical Program Committee for the Traffic Monitoring and Analysis (TMA) 2015 workshop and Publicity Co-Chair for ACM SIGCOMM 2015. He is currently the scientific referee for international affairs at Inria Sophia Antipolis and member of the Conseil d'Orientation Scientifique et Technologique (COST) at Inria within the working group of international affairs (COST-GTRI).

Arnaud Legout on the editorial board of the Computer Networks journal, and was PC member of the ACM/Usenix IMC'2014 conference. Arnaud Legout is the president of the Commission of the users of IT resources of Sophia Antipolis Inria research center.

Damien Saucez is member of the TPC of CCNC 2015, BMSGS' 2015, and AINA-2015. Damien Saucez is secretary and document shepherding at the IETF LISP working group (details about the secretary and shepherd roles can be found in RFC 2418 and RFC 4858). Damien Saucez is secretary of the Project Committee (CP) at Inria Sophia Antipolis Méditerranée.

8.2. Teaching - Supervision - Juries

8.2.1. Teaching

Master Ubinet: Chadi Barakat and Walid Dabbous, Evolving Internet, 31.5 hours, M2, université, 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, 27 hours, M1, University of Nice-Sophia Antipolis, France.

Master CAR: Chadi Barakat, Information Centric Networking, 4.5 hours, Telecom Paris Tech, 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, Scientific Communication, 22.5 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

Mooc: Arnaud Legout and Thierry Parmentelat, Python : des fondamentaux à l'utilisation du langage, 7 weeks, FUN (https://www.france-universite-numerique-mooc.fr/), Inria, 9166 registered persons (for elementary school to PhD), 500 finished the course, 100 did the miniproject.

8.2.2. Supervision

PhD in progress: Riccardo Ravaioli works on "Active and Passive Inference of Network Neutrality" since October 2012. His thesis is co-supervised by Chadi Barakat.

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.

PhD in progress: Maksym Gabielkov works on "Information propagation in social networks" since October 2012. His thesis is supervised by Arnaud Legout.

PhD in progress: Alina Quereilhac works on "Unified Evaluation environment of Networking Protocols for Simulators and Testbeds", since 2011. Her thesis is co-supervised by Walid Dabbous and Thierry Turletti.

PhD in progress: Xuan Nam Nguyen works on "Software Defined Networking in challenged environments", since October 2012. His thesis is co-supervised by Thierry Turletti and Walid Dabbous.

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

8.2.3. Juries

Walid Dabbous served as jury member of Vincent Roca HDR thesis, "Codes AL-FEC et protocoles de diffusion robustes de contenus" defended in June 2014 at University of Grenoble.

Chadi Barakat served as president and jury member of Rachad Maallawi PhD thesis, "Mechanisms, Protocols, and Architectures for the Offloading control in the heterogeneous networks context" defended in January 2014 at Orange Labs Issy-les-Moulineaux.

Walid Dabbous served as reviewer of Wei You PhD thesis, "A Content-Centric Networking Node for Realistic Efficient Implementation and Deployment" defended in January 2014 at Telecom Bretagne, Lannion.

Chadi Barakat served as jury member of Wissam Chahin PhD thesis, "Réseaux hétérogènes tolérants aux délais" defended in March 2014 at IUP Avignon.

Walid Dabbous served as reviewer of Nada Sbihi PhD thesis, "Gestion du trafic dans les réseaux orientés contenus" defended in March 2014 at UPMC, Paris.

Walid Dabbous served as jury member of Tien-Thinh Nguyen PhD thesis, "Optimization of Mobility Mechanisms for IP based Multicast Flows" defended in May 2014 at Eurecom, Sophia Antipolis.

Walid Dabbous served as reviewer of Alexandru-Florin Tatar PhD thesis, "Predicting user-centric behavior: Content popularity and mobility" defended in July 2014 at UPMC, Paris.

Arnaud Legout served as reviewer of Arnaud Jégou PhD thesis, "Harnessing the power of implicit and explicit social networks through decentralization" defended in 2014 at University of Rennes.

Walid Dabbous served as jury member of Mahmoud El Chamie PhD thesis, "Optimization, Control, and Game Theoretical Problems in Consensus Protocols" defended in October 2014 at University of Nice Sophia Antipolis.

Thierry Turletti served as reviewer of Rosa Vilardi PhD thesis, "Traffic Monitoring and Measurements in modern Networks", defended in January 2014 at Politecnico di Bari.

Thierry Turletti served as reviewer of Shubhabrata Roy PhD thesis, "A Complete Framework for Modelling Workload Volatility of a VoD System: a Perspective to Probabilistic Management", defended in May 2014 at ENSL.

Thierry Turletti served as examiner of Rui Pedro Ferreira da Costa PhD thesis, "Mobility Architecture for Next Generation Networks", defended in May 2014 at Eurecom.

Thierry Turletti served as reviewer of Tara Ali Yahiya HDR thesis, "Allocation des Ressources et Gestion d'Interférences dans les Réseaux 4G", defended in May 2014 at Université de Paris Sud.

Thierry Turletti served as examiner of Siwar en Hadj Said PhD thesis, "Contextual Connectivity in Multi-Access Architectures", defended in December 2014 at Télécom Bretagne.

8.3. Popularization

Walid Dabbous presented Future Internet challenges to high school students at Lycée de Valabre Gardanne in April 2014 and at CIV in October at CIV for the Science Week (Fête de la science).

Walid Dabbous made a presentation on Software Defined Networking and Network Functions Virtualization at the Inria Industry Day in Paris on the theme "Télécoms du futur".

Chadi Barakat presented ACQUA at the Inria Industry Day in Paris on the theme "Télécoms du futur". See http://www.inria.fr/en/centre/paris-rocquencourt/innovation/rii-telecoms-du-futur/program.

9. Bibliography

Major publications by the team in recent years

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[3] M. GABIELKOV, A. RAO, A. LEGOUT. *Studying Social Networks at Scale: Macroscopic Anatomy of the Twitter Social Graph*, in "ACM Sigmetrics 2014", Austin, United States, June 2014, https://hal.inria.fr/hal-00948889

[4] Y.-H. KIM, A. QUEREILHAC, M. A. LARABI, J. TRIBINO, T. PARMENTELAT, T. TURLETTI, W. DABBOUS. *Enabling Iterative Development and Reproducible Evaluation of Network Protocols*, in "Computer Networks", January 2014, forthcoming, https://hal.inria.fr/hal-00861002

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Articles in International Peer-Reviewed Journals

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