Activity Report 2013

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: Network Protocols, Wireless Networks, Security, Privacy, Monitoring, Peer-to-peer

Creation of the Team: 2013 January 01.

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2. Overall Objectives

2.1. Presentation of the team

The DIANA team conducts research in the domain of networking, with an emphasis on designing, implementing, and analysis of new network architecture with a special focus on Internet users rights. The main objective of the team is to propose and study new architectures, services and protocols that will enable service transparency and better control on user data in the context of hundred billions mobile connected devices. The main research directions are :

- Internet citizen rights observatory
- Open Network architecture

We envision that mobile devices will become the primary Internet access for most users and foresee a convergence between desktops, laptops and those mobile devices. In the DIANA team, we focus our research effort taking into account this new and disruptive context where the main usage is accessing contents and services rather than connecting to well defined hosts.

2.2. Highlights of the Year

Our paper , got the Best Paper Award at the ns-3 Workshop (WNS3) at SimuTools, March 2013, Workshop ns-3, Cannes, France.
BEST PAPER AWARD :
[26] **DCE Cradle: Simulate Network Protocols with Real Stacks in Workshop on NS3 (WNS3)**. H. TAZAKI, F. URBANI, T. TURLETTI.

3. Research Program

3.1. Experimental approach to Networking

The main consequence of the complexity of the Internet is that modeling and understanding the network and services are harder and harder to achieve. Our team has an experimental approach built around measurements and observation of the current behavior of Internet users and available technology and come up with models for the ways information are exchanged. Then we will design and evaluate protocols and system solutions that allow this seamless, open, efficient, and secure access to information and services. We will in particular focus on whether to follow a clean-slate approach or leverage on existing technologies towards the solutions of the above two challenges. Evaluation of our proposals will be performed by leveraging on networking platforms and simulators developed by the team such as OneLab, FIT and ns-3.

We develop experimental code to evaluate the ideas we propose. As an example, we developed recently the Meddle platform to address the problem of opaqueness and lack of control on the Internet. Meddle uses traffic indirection to diagnose mobile devices independently of the OS, ISP, and access technology. We used the platform to observe personal information leakages by popular iOS and Android applications. We also used it to analyze in detail the network characteristics of video streaming services, the most popular Web-service in the current Internet.

3.2. User Centric Networking

Billions of people are using the Inernet with different levels of satisfaction concerning the performance. This means that the past research challenges such as efficiency and scalability of Internet protocols are no longer perceived by the users as important challenges to address. However, as the number of Internet devices and bandwidth requirements continue to explode, they still need to be addressed and represent mandatory properties of any new protocol proposed. Apart those well-known research problems, new research challenges are appearing on the design of services centered on the user needs. Thus, we envision a shift from network-centric research challenges to user-centric networking research challenges.

The main consequence of the Internet complexity for the users is the opacity. Users do not have any way to understand and control what their Internet services are doing, which clearly violate their citizen rights. We are witnessing currently a strong interest of Internet providers in this domain along with a growing number of projects funded by service providers (such as Google or Microsoft) on transparency. We define in the following two different rights that we consider as the ones to be addressed for the next decade. DIANA will articulate its research effort around these two rights.

- **Service transparency**

  The first consequence of Internet complexity is its opacity. The second consequence is the non-predictability of the quality it offers to end-users. It is fundamental for users to be aware of what is going-on on their Internet access and to evaluate the quality they are experiencing, or they can expect, in terms of the different applications they run. For that, some fundamental questions must be answered: What quality can I expect from my Internet access? Why is my service not running properly? Are there any private data sent on the Internet and where? Whereas these questions could be answered with classical measurement techniques (such as ping, traceroute, and tcpdump) in the past, they are vastly more complex today. Indeed, nowadays, mobile device providers, applications/services designers and mobile operators all have conflicting interests and no incentive for real transparency. Regular measurement techniques are either blocked (e.g., traceroutes are blocked by mobile providers to prevent topology discovery which is considered as an industrial secret) or impossible (e.g., tcpdump cannot run on mobile devices because the necessary APIs are not exposed to the application programmer, or simply not implemented in the device drivers). As a consequence, new dedicated measurement platforms are required to work around the existing limitations, and in particular (i) to reveal the reality of the network behind our device and the services we connect to, (ii) to shed light on the quality we can expect from our access in terms of the different applications we run, and (iii) in case of a problem, to help the end user diagnosing its root causes. For instance, to diagnose privacy leaks, we need to perform OS instrumentation and build dedicated experimental platforms to break SSL encryption widely used by services to hide their functioning.

- **Open content access, sharing and control**

  Users must, at any time, keep the control on their content, that is, seamlessly retrieve them and control who can access them. Today proprietary solutions, such as Google Drive or iCloud, partially solve the problem of accessing content seamlessly on heterogeneous devices, but at the cost of losing control on them. However, several important questions must be answered in this context: where my data is localized physically, who has the right to access my confidential documents, who has actually accessed my photos, how can I be sure that this document is permanently deleted? Having an open access (i.e., independent of a specific vendor) and the possibility to control who is accessing content must be a fundamental right. This means that whatever the device, the operating system, the location, and the available Internet provider, users have the right to seamlessly and efficiently access their content without losing control on them. Protecting users from service misbehaviors and privacy leaks is a difficult task because it requires sophisticated and deployable architectural modifications. One example is the case of a poor video streaming quality. Whereas video streaming is today the most popular application (in terms of aggregate traffic) in the Internet, it is hard for a user to diagnose and solve issues because Internet actors (ISPs and service providers) have conflicting interests and no reason to collaborate. A vivid example is the one of Free, a French ISP, which is limiting the throughput for YouTube streams in order to put pressure on Google to compensate the ISP investments. This is clearly against the citizen rights, and it requires working around the throughput limitations using a dedicated and open indirection infrastructure. Another example is the one of the free application market. Most of free applications embed advertisements that are operated by third parties. Whereas most applications do not need to send data on the Internet, private information are leaked in order to run targeted advertisements only. This issue cannot be solved with simple ad-blocking on the device, because the operating system of mobile devices does not allow interposing on applications behavior. Also, blindly blocking all ads might challenge the market of

free applications. The only solution is to build a dedicated open infrastructure that filters out private information while still making the business of targeted advertisement possible.

4. Application Domains

4.1. Internet Citizen Rights Observatory

Internet users are highly interested in knowing the expected and/or actual quality of experience and in detecting potential privacy leakages. These are two essential Internet citizen rights we plan to address in the Diana team. However, the Internet is based on the best effort model and therefore provides no quality of service support. The perceived quality depends on many factors as network and service provisioning, the behavior of the other users, peering agreements between operators, and the diverse practices of network administrators in terms of security and traffic engineering done manually today and probably automatically on programmable infrastructure tomorrow. The proliferation of wireless and mobile access have complicated further this unpredictability of the Internet by adding other factors such as the mobility of end users, the type of wireless technology used, the coverage and level of interference. In addition, the Internet does not have a standard measurement and control plane. Apart from basic information on routing tables, all the rest (delays, available bandwidth, loss rate, anomalies and their root cause, network topology, ISP commercial relationships, etc.) are to be discovered. Several monitoring tools were developed by projects such as CAIDA or Googleâs M-Lab to understand the performance of the Internet and provide end users with information on the quality of their access. However, existing tools and techniques are mostly host-oriented and provide network-level measurements that can hardly be interpreted by the end users in terms of Quality of Experience (QoE). In fact, as the usage model shifts toward Information-centric networking, there is a need to define solutions to monitor and even predict application-level performance at the access based on objective measurements from the network. In the future Internet, there should be some minimum level of transparency allowing end users to evaluate their Internet access regarding the different services and applications they are interested in, and in case of trouble, to identify its origin. This migration of measurements to contents and services, which can be qualified as âFuture Internet Observatoryâ, requires understanding the traffic generated by the applications, inferring the practices of content providers and operators, defining relevant QoE metrics, finding low cost techniques to avoid measurement traffic explosion and redundancy (based, for example, on crowd sourcing) and leveraging spatiotemporal correlations for better localization of network anomalies.

Unfortunately, the quality of Internet applications as perceived by end users depends on numerous factors influenced directly by the home network, the access link (either wireless or wired), the core network, or even the content provider infrastructure. The perceived quality also depends on the application requirements in terms of network characteristics and path performances. This multiplicity of factors makes it difficult for the end user to understand the reasons for any quality degradation. Understanding the reasons of the degradation is getting even more difficult with the mobility of end users and the complexity of applications and services themselves. Nevertheless, it is essential for end users to understand the quality they obtain from the Internet and in case of dissatisfaction, to identify the root cause of the problem and pinpoint responsibilities. This process implies two major challenges. On one hand, there is a need to have a mapping between the quality obtained and the network performance, and to understand the exact behavior of modern applications and protocols. This phase involves the measurements and analysis of applications' traffic and user feedback, and the calibration of models to map the perceived level of quality to network level performance metrics. On the other hand, there is a need for inference techniques to identify the network part hidden behind the observed problem, e.g. knowing which the part of the network causes a bandwidth decrease or high loss rate event. In the literature, this inference problem is often called network tomography, which consists of inferring internal network behavior from edge measurements. Network tomography can be done in two complementary ways. One approach is to run several tests from the end user access excluding each time different network parts, and by intersecting the observations, find the part very likely causing the problem. The advantage of this approach is that the user controls every point of the inference. Unfortunately, this technique requires extensive measurements from each user, which can be difficult to realize when resources are scarce such as on mobile

wireless networks. Another approach can be to distribute the measurement among different end points and share their observations. The advantage is clearly to reduce the load for every one but it comes at the expense of higher complexity to successfully performing the inference. A first difficulty is in the distribution of the measurement work among users and devices. Another issue is in the combination of observations (i.e., which weight to give to each end user according to its location, type of access, etc.) particularly as network conditions can vary from one to another.

The shift of measurements toward mobile devices and modern applications and services will require a completely new methodology. We have dealt up to know with network-level measurements to infer the performance of the current Internet architecture. This past measurement effort has mostly targeted well-known protocols and architectures that are mostly standardized. It has targeted laptops and desktops that are often easily programmable and not suffering from bandwidth and computing resource constraints. For this new project, we will deal with a large number of proprietary services and applications that require, each from its side, a considerable measurement effort to understand its behavior, and implement the appropriate network-level measurements to predict its quality. And given the large number of these applications and services, we will face a certain problem of measurement overhead explosion that we will have to solve and reduce by either measurement reutilization or crowd-sourcing approach. The consideration of mobiles with their close operating systems and limited resources will increase even further the complexity of this measurement effort.

QoE and user privacy are, in our vision, the most critical issue for end-users. There are daily headlines on issues linked to citizen rights degradation (such as, Google data retention, PRISM, mobile applications privacy leakages, targeted and differentiated advertisements, etc.) The common belief is that it is not possible to improve the situation as all technological choices are in the hands of big Internet companies and states. The long-term objective of our research is to study the validity of this statement and to propose to end-users (and possibly service providers) architectural solutions to improve transparency by exposing potential citizen rights violations. One way to improve this transparency is to leverage on the end-users set-top-box in order to implement an indirection infrastructure auditing and filtering all traffic from each end-user.

4.2. Open Network Architecture

As discussed above, whereas the Internet can successfully interconnect billions of devices, it fails to provide a transparent and efficient sharing between information producers and consumers. Here Information producers and consumers must be considered in their broad definition, for instance a microphone, a speaker, a digital camera, a TV screen, a CPU, a hard drive, but also services such as email, storage in the cloud, a Facebook account, etc. In addition to classical contents, information can include a flow of content updated in real time, a description of a device, a Web service, etc. Enabling a transparent open access and sharing to information among all these devices will likely revolutionize the way the Internet is used today.

This research direction aims at proposing global solutions for easy and open content access and more generally to information interoperability. This activity will leverage on current efforts on information-centric networking (e.g., CCN, PSIRP, NetInf). In a first stage, the goal will consist in offering to users a personal overlay solution to publish and manage their own contents, at anytime and whatever the available network access technology (cable, Wi-Fi, 3G, 4G, etc.). The main challenge will be to design scalable mechanisms to seamlessly publish and access information in an efficient way, while preserving privacy. Another challenge will be to incrementally deploy these mechanisms and ensure their adoption by end users, content providers, and network operators. In the context of the evolution of the Internet architecture and in particular through Software defined Networking (SDN), there is a risk that some network operators or other tenants use the increased flexibility of the network against the benefits of the users. So, one of our concern will be to design innovative solutions to prevent possible violation of the network neutrality or to prevent illegitimate collection of private data. In parallel, we envision using SDN as an enabling technology to adapt the network in order to maximize user QoE. Indeed, virtualized network appliances are an efficient way to dynamically insert at strategic places in-network functionalities such as caching proxies, load balancers, cyphers, or firewalls. On this purpose, we plan to build a dedicated open infrastructure relying on a mix of middle boxes and mobile devices applications to capture, analyze and optimize traffic between mobile devices and the Internet.

SDN will introduce a deep shift in the way to design and deploy communications mechanisms. Traditionally, and mainly due to the ossification of the Internet, we used to enhance communication mechanisms by designing our solutions as overlays to the network infrastructure. Using SDN, we will have the opportunity to implement and use new functionalities within the network. If we make them available through well-defined API, those new network functions could be used to implement interoperable, transparent and open services for the benefit of the user. Indeed, implementing these functionalities within the network is not only more efficient than overlay solutions but this can facilitate the deployment of standard services. Important challenges will have to be solved to make this happen, and particularly, to ensure consistency, stability, scalability, reliability and privacy.

Our long-term objective in this research direction is to contribute to the design of network architecture providing native support for easy, transparent, secure, privacy preserving access to information. For instance, an objective is to enable end-users to leverage on their home infrastructure (set-top-boxes, computers, smartphones, tablets) to sanitize traffic and host information.

5. Software and Platforms

5.1. FIT platform

We have started, since 2011, the procedure of building a new experimental platform at Sophia-Antipolis, in the context of the FIT Equipment of Excellence project. This platform has two main goals : the first one is to enable highly controllable experiments due to its anechoic environment. These experiments can be either hybrid-experiments (as NEPI will be deployed, see section 5.4) or federated experiments through several testbeds. The second goal is to make resource consuming experiments (like CCNx) possible due to some powerful servers that will be installed and connected to the PlanetLab testbed. During 2013, a first call for bids has been made during March/April and has been unfortunately declared unsuccessful due to an overestimation of the building's price. As some premises became vacant at the same time, a second call for bids has been launched during September/October. This latter was a success because three interesting offers have been received and negotiated during the end of the year. The notification is planned for the 14th of January 2014.

5.2. ns-3

Participants: Thierry Turletti [correspondant], Daniel Camara, Walid Dabbous.

ns-3 is a discrete-event network simulator for Internet systems, targeted primarily for research and educational use. ns-3 is free software, licensed under the GNU GPLv2 license, and is publicly available for research, development, and 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 solid 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).
See also the web page http://www.nsnam.org.

- Version: ns-3.19
- 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

5.3. DCE

Participants: Emilio Mancini [correspondant], Daniel Camara, Walid Dabbous, Thierry Turletti.

Direct Code Execution (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 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

5.4. NEPI

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

NEPI stands for Network Experimentation Programming Interface. NEPI is a generic framework to manage network experiments, which allows to describe experiments in a simple way and automates experiment execution and result collection in a variety of experimentation environments, including simulators and live testbeds. NEPI was designed to be extensible for potentially any experimentation environment, which can be done by extending its well defined description and execution API's.

During the year 2013 we fully re-implemented NEPI in order to support new important requirements that arose from our participation in the FED4fire and OpenLab European projects. Among those requirements we can enumerate the ability to dynamically provision experiment resources during the experiment run time (e.i. Add new resources to the experiment at any moment), the interactive experiment execution (i.e. NEPI can be used as an interactive experiment management tool), and the description of experiment work-flows (e.i. Allow to include execution/deployment dependencies across resources).

This re-implementation of NEPI gave place to an improved, more extensible and user friendly framework which was officially released as NEPI 3.0 in December 2013. This new version of NEPI was shipped with support for new testbeds, including any testbeds supporting SSH key authentication and OMF (cOntrol and Management Framework) testbeds. Support for OMF technology is a very important features since it is a key part of the federation control management framework proposed in the FED4Fire project. The version of OMF currently supported by NEPI is 5.4. OMF version 6.0, which is the new mainstream release, will be supported during 2014. In order to comply with the requirements of FED4Fire for a federation framework, work is undergo in NEPI to fully support SFA (Slice Federation Architecture), in its latest version, for resource discovery and provisioning across federated testbeds.

Additional improvements to the NEPI framework during 2013 include out-of-the box support for Future Internet technologies such as CCN and OpenFlow for certain testbeds.

Finally, during 2013 a new NEPI web site was released, including an improved look&feel (http://nepi.inria.fr), user manual and code reference pages, detailed experiment examples and a issue tracking page.

- Version: 3.0
- ACM: C.2.2, C.2.4
- Keywords: networking experimentation
- License: GPL (3)
- Type of human computer interaction: python library, QT GUI
- OS/Middelware: Linux
- Required library or software: python – http://www.python.org – http://rpyc.sourceforge.net
- Programming language: python

5.5. Bake

Participants: Daniel Camara [correspondant], Walid Dabbous, Thierry Turletti.

Bake is an integration tool, which can be used by software developers to automate the reproducible build of a number of projects which depend on each other and which might be developed, and hosted by unrelated parties. Bake was developed to automate the reproducible build of ns-3 taking into account the particular needs of it. However, Bake is not specific for ns-3, it can be used by any open source project composed of a number of interdependent sub projects and that needs to simplify and automatize the assembly of these pieces of software in a coherent and useful way.

Bake is free software, licensed under the GNU GPLv2 license, and is publicly available for research, development, and use.

See also the web page http://planete.inria.fr/software/bake/index.html

- Version: Bake-0.1
- Keywords: Integration tool, distributed project, build and installation version control
- License: GPL (GPLv2)
- Type of human computer interaction: command line tool, No GUI
- OS/Middleware: Linux, Mac Os
- Required library or software: Python, GNU C++, Mercurial, CVS, GIT, Bazaar, Tar, Unzip, Unrar, 7z, XZ, Make, cMake, patch, autoreconf
- Programming language: python
- Documentation: doxygen

5.6. Com4Innov Network Testing Platform

Participants: Emilio Mancini [correspondant], Walid Dabbous.

Developed for the Com4Innov project, the platform integrates a set of tools in a virtual appliance, in order to conduct network experiments, store and share their results, and collect network diagnostic information. The platform's core is developed as a Web Application in the Apache Tomcat application server. It has a web user interface, and a public API accessible to external tools. Its architecture is designed to be integrated with SQL or NoSQL databases, and with HTTP or REST client. The core platform is completed by measurement tools and mobile phone clients.

The implementation is available at the url: http://gforge.inria.fr/projects/com4innov. It is currently in advanced development stage.

- Version: 0.5
- Keywords: network, diagnostic
- License: not yet public
- Type of human computer interaction: Web Interface
- OS/Middelware: Linux
- Required library or software: Apache Tomcat Java, Linux Distribution and standard development environment, GPL.
- Programming languages: Java, C++, C#
- Documentation: latex, javadoc

5.7. Mobile Devicess Network Analyzer Tool

Participants: Emilio Mancini [correspondant], Arnaud Legout.

This tool has been developed as a client for the Com4Innov Network Testing Platform, but it evolved in an autonomous one. It samples the signal's strength of wireless networks, correlating it with the GPS position, and then produces coverage maps. Once the sampling is done, it allows the user to upload such data, completed with diagnostic information to the platform.

The implementation is available at the url: http://gforge.inria.fr/projects/com4innov.

- Version: 1.0
- Keywords: network, diagnostic
- License: not yet public
- Type of human computer interaction: Android Application
- OS/Middelware: Android
- Required library or software: Android, GPL.
- Programming languages: Java
- Documentation: latex, javadoc

5.8. SfaWrap

Participants: Thierry Parmentelat [correspondant], Mohamed Larabi.

The SfaWrap is a reference implementation of the Slice-based Federation Architecture (SFA), the emerging standard for networking experimental testbed federation. We are codeveloping the SfaWrap with Princeton University, and during 2013, we have focused on:

- Implementing the Aggregate Manager (AM) API v3.
- Implementing a compatibility layer between AM API v2 and AM API v3.
- Supporting testbed providers in exposing their testbeds through SFA in order to enlarge the federation of testbeds.
- Maintaning the codebase of SFAWrap.
- Releasing SFAWrap software packages for the latest versions of different Linux Distributions (Namely: Fedora, Debian and Ubuntu).
- Version: sfa-3.1-1, myplc-5.3.1
- Keywords: networking testbed federation
- License: Various Open Source Licenses
- Type of human computer interaction: Web-UI, XMLRPC-based API, Qt-based graphical client
- OS/Middelware: Linux
- Required library or software: python2.7 or superior
- Programming languages: python
- Documentation: http://svn.planet-lab.org/#SFAUser-leveldocumentation
- Codebase: http://git.onelab.eu/?p=sfa.git;a=summary

5.9. Experimentation Software

MonLab Monitoring Lab is a platform for the emulation and monitoring of traffic in virtual ISP networks. It was supported by the FP7 ECODE project and is available for download at the web page of the tool http://planete.inria.fr/MonLab/ under the terms of the GPL licence. MonLab presents a new approach for the emulation of Internet traffic and for its monitoring across the different routers of the emulated ISP network. In its current version, the traffic is sampled at the packet level in each router of the platform, then monitored at the flow level. We put at the disposal of users real traffic emulation facilities coupled to a set of libraries and tools capable of Cisco NetFlow data export, collection and analysis. Our aim is to enable running and evaluating advanced applications for network wide traffic monitoring and optimization. The development of such applications is out of the scope of this research. We believe that the framework we are proposing can play a significant role in the systematic evaluation and experimentation of these applications' algorithms. Among the direct candidates figure algorithms for traffic engineering and distributed anomaly detection. Furthermore, methods for placing monitors, sampling traffic, coordinating monitors, and inverting sampling traffic will find in our platform a valuable tool for experimentation.

ACQUA ACQUA is an Application for Collaborative Estimation of QUality of Internet Access. It was supported by the French ANR CMON project on collaborative monitoring. ACQUA is based on the principle of active measurements to a predefined set of landmarks and on the estimation of the Internet access quality by correlating these measurements together. This correlation will point to the importance of observed problems and to estimates to the quality the end user should expect from its access when running his applications over the Internet (one can see the measurements to the landmarks as samples of the global set of possible paths). In its first version (the version available online), ACQUA was concentring on delay measurements at the access and on the detection and estimation of the impact of delay anomalies (local problems, far away problems, etc). The current work is concentring on using the ACQUA principle in the estimation and prediction of the quality of experience of main applications. More details and code can be found at http://planete.inria.fr/acqua/.

ElectroSmart We are developing the application ElectroSmart as part of the Inria ADT ElectroSmart. The ElectroSmart application will enable crowd sourcing of electromagnetic exposures based on the electromagnetic radiations measured by smartphones.

6. New Results

6.1. Service Transparency

Participants: Chadi Barakat, Walid Dabbous, Maksym Gabielkov, Young-Hwan Kim, Arnaud Legout, Byungchul Park, Ashwin Rao, Riccardo Ravaioli, Damien Saucez, Thierry Turletti.

The Complete Picture of the Twitter Social Graph

We made 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 presented 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 introduced 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 work is accepted in Sigmetrics'14 [23].

Meddle: Middleboxes for Increased Transparency and Control of Mobile Traffic

Meddle is a platform that relies on traffic indirection to diagnose mobile Internet traffic. Meddle is motivated by the absence of built-in support from ISPs and mobile OSes to freely monitor and control mobile Internet traffic; the restrictions imposed by mobile OSes and ISPs also make existing approaches impractical. Meddle overcomes these hurdles by relying on the native support for traffic indirection by mobile OSes. Specifically, Meddle proxies mobile Internet traffic through a software defined middleboxes configured for mobile traffic diagnosis. We use Meddle to tests the limits of the network perspective of mobile Internet traffic offered by traffic indirection. We use this perspective to characterize and control the behavior of mobile applications and provide a first look at ISP interference on mobile Internet traffic. We then performed controlled experiments on 100 popular iOS and Android applications to show how Meddle can be used to identify misbehavior and to block traffic causing this misbehavior. Unlike existing solutions, this activity can be performed without warranty voiding the device and activated on the fly on-demand. This work is done in the context of Aswhin Rao's PhD thesis [11] in collaboration with Northeastern University and Berkeley.

Understanding of modern web traffic

This recent years and with the advent of mobile devices, web traffic has changed and moved from static to dynamic generation. Interestingly, while it is well known that network protocols are intertwined in such a way the characteristics of a layer are affected by those of other layers, most of the measurement work done so far does not pay enough attention to this aspect. We then conducted a cross-layer measurement analysis that confronts all the layers from the very deep technological details to the very high level of users behaviors to shed new light on this issue. To support our study, we analysed an Internet packet traffic trace and showed how this cross-layer analysis approach can explain why TCP flows in mobile traffic are larger than usual. We are currently refining our study to characterises the discrepancies between the different network stack protocol implementations based on the mobile/non-mobile nature of the devices but also their operating system and version. This work is currently under submission.

Checking Traffic Differentiation at the Internet Access

In the last few years, ISPs have been reported to discriminate against specific user traffic, especially if generated by bandwidth-hungry applications. The so-called network neutrality, advocating that an ISP should treat all incoming packets equally, has been a hot topic ever since. We propose Chkdiff, a novel method to detect network neutrality violations that takes a radically different approach from existing work: it aims at both application and differentiation technique agnosticism. We achieve this in three steps. Firstly, we perform measurements with the user's real traffic instead of using specific application traces. Secondly, we do assume that discrimination can take place on any particular packet field, which requires us to preserve the integrity of all the traffic we intend to test. Thirdly, we detect differentiation by comparing the performance of a traffic flow against that of all other traffic flows from the same user, considered as a whole. Chkdiff performance strongly depends on the way routers reply to probe packets. We carried out large scale experiments to understand the way routers reply to our probes and we calibrated models to these replies. The next step will be to evaluate the performance of Chkdiff under these models, before making the tool public and available to the community. Chkdiff is currently the subject of a collaboration with I3S around the PhD thesis of Riccardo Ravaioli (funded by the Labex UCN@Sophia). The work is ongoing and will be submitted soon.

Lightweight Enhanced Monitoring for High-Speed Networks

Within the collaboration with Politecnico di Bari, we worked on LEMON, a lightweight enhanced monitoring algorithm based on packet sampling. This solution targets a pre-assigned accuracy on bitrate estimates, for each monitored flow at a router interface. To this end, LEMON takes into account some basic properties of the flows, which can be easily inferred from a sampled stream, and exploits them to dynamically adapt the monitoring time-window on a per-flow basis. Its effectiveness is tested using real packet traces. Experimental results show that LEMON is able to finely tune, in real-time, the monitoring window associated to each flow and its communication overhead can be kept low enough by choosing an appropriate aggregation policy in message exporting. Moreover,

compared to a classic fixed-scale monitoring approach, it is able to better satisfy the accuracy requirements of bitrate estimates. Finally, LEMON incurs a low processing overhead, which can be easily sustained by currently deployed routers, such as a CISCO 12000 device. This work has been published in [18].

Packet Extraction Tool for Large Volume Network Traces

Network packet tracing has been used for many different purposes during the last few decades, such as network software debugging, networking performance analysis, forensic investigation, and so on. Meanwhile, the size of packet traces becomes larger, as the speed of network rapidly increases. Thus, to handle huge amounts of traces, we need not only more hardware resources, but also efficient software tools. However, traditional tools are inefficient at dealing with such big packet traces. We proposed pcapWT, an efficient packet extraction tool for large traces. PcapWT provides fast packet lookup by indexing an original trace using a Wavelet Tree structure. In addition, pcapWT supports multi-threading for avoiding synchronous I/O and blocking system calls used for file processing, and is particularly efficient on machines with SSD. PcapWT shows remarkable performance enhancements in comparison with traditional tools such as tcpdump and most recent tools such as pcapIndex in terms of index data size and packet extraction time. Our benchmark using large and complex traces shows that pcapWT reduces the index data size down below 1% of the volume of the original traces. Moreover, packet extraction performance is 20% better than with pcapIndex. Furthermore, when a small amount of packets are retrieved, pcapWT is hundreds of times faster than tcpdump. These results, done in collaboration within the CIRIC, have just been submitted to Computer Networks[34].

Impact of new transport protocols on BitTorrent performance

In the paper [27], we address the trade-off between the data plane efficiency and the control plane timeliness for the BitTorrent performance. We argue that loss-based congestion control protocols can fill large buffers, leading to a higher end-to-end delay, unlike low-priority or delay-based congestion control protocols. We perform experiments for both the uTorrent and mainline BitTorrent clients, and we study the impact of uTP (a novel transport protocol proposed by BitTorrent) and several TCP congestion control algorithms (Cubic, New Reno, LP, Vegas and Nice) on the download completion time. Briefly, in case peers in the swarm all use the same congestion control algorithm, we observe that the specific algorithm has only a limited impact on the swarm performance. Conversely, when a mix of TCP congestion control algorithms coexists, peers employing a delay-based low-priority algorithm exhibit shorter completion time.

6.2. Open Network Architecture

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Delay Tolerant Networks

Delay Tolerant Networks (DTNs) stand for wireless networks where disconnections may occur frequently. In order to achieve data delivery in such challenging environments, researchers have proposed the use of store-carry-and-forward protocols: there, a node may store a message in its buffer and carry it along for long periods of time, until an appropriate forwarding opportunity arises. Multiple message replicas are often propagated to increase delivery probability. This combination of long-term storage and replication imposes a high storage and bandwidth overhead. Thus, efficient scheduling and drop policies are necessary to: *(i)* decide on the order by which messages should be replicated when contact durations are limited, and *(ii)* which messages should be discarded when nodes' buffers operate close to their capacity. We worked on a content-centric dessemination algorithm for delay-tolerant networks, called for short CEDO, that distributes content to multiple receivers over a DTN. CEDO assigns a utility to each content item published in the network; this

value gauges the contribution of a single content replica to the network's overall delivery-rate. CEDO performs buffer management by first calculating the delivery-rate utility of each cached content-replica and then discarding the least-useful item. When an application requests content, the node supporting the application will look for the content in its cache. It will immediately deliver it to the application if the content is stored in memory. In case the request cannot be satisfied immediately, the node will store the pending request in a table. When the node meets another device, it will send the list of all pending requests to its peer; the peer device will try to satisfy this list by sending the requester all the matching content stored in its own buffer. A meeting between a pair of devices might not last long enough for all requested content to be sent. We address this problem by sequencing transmissions of data in order of decreasing delivery-rate utility. A content item with few replicas in the network has a high delivery rate utility; these items must be transmitted first to avoid degrading the content delivery-rate metric. The node delivers the requested content to the application as soon as it receives it in its buffer. We implemented CEDO over the CCNx protocol, which provides the basic tools for requesting, storing, and forwarding content. Detailed information on CEDO and the implementation work carried out herein can be found in this publication [22] and at the following web page: http://planete.inria.fr/Software/CEDO/.

Predicting nodes spatial node density in mobile ad-hoc networks

User mobility is of critical importance when designing mobile networks. In particular, "waypoint" mobility has been widely used as a simple way to describe how humans move. This paper introduces the first modeling framework to model waypoint-based mobility. The proposed framework is simple, yet general enough to model any waypoint-based mobility regimes. It employs first order ordinary differential equations to model the spatial density of participating nodes as a function of (1) the probability of moving between two locations within the geographic region under consideration, and (2) the rate at which nodes leave their current location. We validate our models against real user mobility recorded in GPS traces collected in three different scenarios. Moreover, we show that our modeling framework can be used to analyze the steady-state behavior of spatial node density resulting from a number of synthetic waypoint-based mobility regimes, including the widely used Random Waypoint (RWP) model. Another contribution of the proposed framework is to show that using the well-known preferential attachment principle to model human mobility exhibits behavior similar to random mobility, where the original spatial node density distribution is not preserved. Finally, as an example application of our framework, we discuss using it to generate steady-state node density distributions to prime mobile network simulations. This work was done in collaboration with Dr. Katia Obraczka, from UC Santa Cruz, and was published in WINET [12].

Software Defined Networking in Heterogeneous Networked Environments

We worked on the exploration of the software defined networking paradigm to facilitate the implementation and large scale deployment of new network protocols and services in heterogeneous networked environments. Our activities related to this research thrust are described hereafter. 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 presented 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 will be published in 2014 in the IEEE Surveys and Tutorials journal [32].

We have also specified a number of use cases motivating the need for extending the SDN model to heterogeneous networked environments. Such environments consist of infrastructure-based and infrastructure-less networks. These specifications and use cases were summarized in a recent publication [19].

We have also implemented a Capacity Sharing platform by leveraging SDN in hybrid networked environments, i.e., environments that consist of infrastructure-based as well as infrastructureless networks. The proposed SDN-based framework provides flexible, efficient, and secure capacity sharing solutions in a variety of hybrid network scenarios. In the paper published at the Capacity Sharing Workshop CSWS 2013 [40], we identify the challenges raised by capacity sharing in hybrid networks, describe our framework in detail and how it addresses these challenges, and discuss implementation issues.

The aforementioned capacity sharing work is just one application and a preliminary of our longer term effort. We have also started to specify the H-SDN protocols based on the use cases mentioned above, including the capacity sharing use case. These efforts are part of a broader work where we propose a framework to enable the implementation and deployment of more generic H-SDN networks and applications. This framework contemplates important issues regarding H-SDN deployment, such as: security, increased scalability and performance by distribution of SDN control and seamless handover of mobile stations, to name a few. We have targeted Mobisys2014 as a venue for publishing our proposal and results regarding this topic [39].

Rule Placement in Software-Defined Networking

OpenFlow is a new communication standard that decouples control and data planes to simplify traffic management. More precisely, OpenFlow switches populate their forwarding tables by opportunistically querying a centralized controller for flows whose rules (i.e., forwarding actions) are not yet installed. However, the flexibility offered by this new paradigm comes at the expense of extra signaling overhead as, in practice, switches might not be able to store all rules in their local forwarding tables. The question of which rules to install then becomes essential. In our research, we leverage the fact that some flows are more important to manage than others, and thus construct an optimal placement problem of rules in OpenFlow switches that ensures the most valuable traffic is matched by its appropriate rules while respecting switches and links capacity constraints. The rest of the traffic with no installed rules follows a default, yet less appropriate, path within the network. We have formulated and solved this optimisation problem in the case of realistic operational needs, and prove that the optimal placement of rules is NP-hard. The intrinsic complexity of the problem led us to design a greedy heuristic that we evaluated with two representative use cases: BGP multihoming and Access Control Lists. On one hand, the evaluation shows the versatility and the generality of the optimization problem, and on another hand, it demonstrates that heuristics with apparent simplicity are still efficient. We are now extending this work to support traffic dynamics and mobility. This work is currently under submission.

Information-Centric Networking and economical aspects

With the explosion of broadband Over-The-Top (OTT) services all around the world, the Internet is autonomously migrating toward overlay and incrementally deployable content distribution infrastructures. Information-Centric Networking (ICN) technologies are the natural candidates to more efficiently bind and distribute popular contents to users. However, the strategic incentives in exploiting ICN, for both users and ISPs, are much less understood to date. In this work, we shed light on how OTTs shall shape prices and discounts to motivate ICN usage, depending on their awareness over content distribution costs. Actually, the Internet ecosystem is fast and dynamic and new ideas can rapidly reach millions of users spread worldwide without having to rely on special involvement of intermediate transit networks. In this context, Over-The-Top broadband content providers can leverage their customer resources to allowing, from one hand, to improve access performance, and, from the other hand, to reduce operational costs the OTT provider would incur on by directly serving the customers. In this context, Information-Centric Networking appears as an adequate offloading technique, if incrementally deployed as an overlay network. This paper analyses the incentive compatibility in the adoption of a ICN overlay for OTT services and is, as of our knowledge, we are the first in addressing the topic by following a non-cooperative game theory reasoning, we believe adequate in its non-cooperative nature due to independency between the involved ICN stakeholders. Our analysis allows us to assess that the business model currently standing for legacy CDNs does

not make strategic sense for ICN overlays and that, hover, it exists incentives for OTT customers to get involved in the distributions process via an ICN overlay reducing so server load. These unique specifications for the design of an ICN overlay for OTT content distribution do also have relevant implications for ICN protocol design. The OTT provider would need a form of control over the ICN overlay operations. We identify the usage of a OTT- set policy metric for ICN routing as the most appropriate way to ensure ICN users follow the equilibrium strategy suggested by our incentive compatibility framework. We highlight moreover the need of a scalable way of building and controlling ICN overlays over the legacy TCP/IP Internet to support related signaling, forwarding rule registration, and positive strategic behaviour.

Information-Centric Networking and rate control implications

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. We have studied 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 caches provisioning. As caching shortens AIMD feedback loop, the download rate of AIMD is impacted. We earlier shed light on the potential negative impact of in-network caching on instantaneous throughput fairness. The work accomplished in 2013 precisely quantify the issue thanks to an analytic model based on Discriminatory Processor Sharing and real experiments, we observe that popular contents benefit from caching and realize shorter download times at the expense of unpopular contents which see their download times inflated by a factor bounded by $\frac{1}{1-\rho}$, 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. The experimentation study has been supported by the work of Ilaria Cianci internship on the CCN-Jocker emulator. This work is currently under submission.

Routing in Information-Centric Network

The idea behind Information-Centric Networking (ICN) is to omit the notion of host and location and use contents as direct routing and forwarding primitives, instead of IP addresses. This shift of paradigm allow ICN to natively offer in-network caching, i.e., to cache content on the path from content providers to requesters. Actually our studies shows a large spatial and temporal locality of contents amongst users in the same network which proves that in-network caching can achieve good overall performance. However, caching contents strictly on their paths is far from being optimal when paths are not shared among content consumers as contents may be replicated on routers so reducing the total volume of contents that can be cached. To overcome this limitation, we introduced the notion of off-path caching in [21] where we allocate content to well defined off-path caches within the network and deflect the traffic off the optimal path toward these caches that are spread across the network. Off-path caching improves the global hit ratio by efficiently utilizing the network-wide available caching capacity and permits to reduce egress links bandwidth usage.

Locator/Identifier Separation Protocol (LISP)

The future Internet has been a hot topic during the past decade and many approaches proposed towards this future Internet, ranging from incremental evolution to complete clean state 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. We filled this gap through 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 (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 favours USA sites as a result of its larger LISP user base but also because European infrastructure is unreliable. Finally, the LISP Map-versioning RFC mentioned in the last year activity report was published this year [33]. All details are reported in [17], [29].

Running Live CCNx Experiments on Wireless and Wired Testbeds with NEPI

CCNx has long left the early development stage where simulation and emulation frameworks, like ccnSim and mininet, were enough to validate new approaches and improvements. It has now reached a level of maturity which calls for evaluation in more realistic environments. If it is to be deployed in the wild Internet or even in private network settings, a framework that provides proper validation in comparable environments is required. For this purpose we demonstrate the capabilities of the NEPI framework to run CCNx experiments in realistic environments. NEPI can run CCNx experiments directly on Internet settings as well as wireless or wired private network environments. This framework allows to automate host con guration, software installation, result collection and to define execution sequence between applications. Furthermore, it provides the ability to conduct interactive experiments where researchers are free to modify the experiment scenario on the fly. These results were demonstrated at CCNxCon'2013 [38].

Evaluating costs of CCN overlays

We are currently involved in a collaboration with PARC (Palo Alto research center) regarding the evaluation of the CCN (Control Centric Networking) technology. Early results of this work were presented in the poster session at the CCNxConf 2013 meeting. In this work we present a set of scenarios to evaluate the performance of CCN overlays on top of the Internet, for worse case conditions. We used the NEPI experiment API to construct different overlay topologies on PlanetLab, for which we varied the topology configuration (e.g. number and degree of nodes), the CCN parameters (e.g. pipeline, cache usage, prefix routes) and the traffic patterns (e.g. single stream, prefix independent chunks). The objective of this study is to find correlations between these variables and the time to deliver content and the overlay network utilization. Our contribution is twofold. In one hand we provide a benchmark which can be used as reference for comparison of new CCNx versions and for other ICN solutions, and as input traces for CCN simulations. In the other hand, we provide results that can be used to improve the CCNx implementation and that can help Internet providers or end users to better design CCN overlays to satisfy their needs. The work is still ongoing and will be submitted soon.

Enabling Iterative Development and Reproducible Evaluation of Network Protocols

Over the last two decades several efforts have been made to provide adequate experimental environments, aiming to ease the development of new network protocols and applications. These environments range from network simulators providing highly controllable evaluation conditions, to live testbeds providing realistic evaluation environment. While these different approaches foster network development in different ways, there is no simple way to gradually transit from one to another, or to combine their strengths to suit particular evaluation needs. We believe that enabling a gradual transition from a pure simulated environment to a pure realistic one, where the researcher can decide which aspects of the environment are realistic and which are controllable, allows improving network solutions by simplifying the problem analysis and resolution. We have designed a new network experimentation framework, called IDEV, where simulated and real components can be arbitrarily combined to build custom test environments, allowing refining and improving new protocols and applications implementations by gradually increasing the level of realism of the evaluation environment. Moreover, we proposed a testbed architecture specifically adapted to support the proposed concept, and discuss the design choices we made based on our previous experience in the area of network testbeds. These choices address key issues in network testbed development, such as ease of experimentation, experiment reproducibility, and testbed federation, to enable scaling the size of experiments beyond what a single testbed would allow. This work has been described in a paper that will be published in the Computer Networks journal in 2014, see [15].

Direct Code Execution: Revisiting Library OS Architecture for Reproducible Network Experiments

We proposed Direct Code Execution (DCE), a framework that dramatically increases the number of available protocol models and realism available for ns-3 simulations. DCE meets the goals recently proposed for fully reproducible networking research and runnable papers, with the added benefits of 1) the ability of completely deterministic reproducibility, 2) the scalability that simulation time dilation offers, 3) capabilities supporting automated code coverage analysis, and 4) improved debuggability via execution within a single address space. We reported on packet processing benchmark and showcased key features of the framework with different use cases. Then, we reproduced a previously published Multipath TCP (MPTCP) experiment and highlight how code coverage testing can be automated by showing results achieving 55-86% coverage of the MPTCP implementation. We also demonstrated how network stack debugging can be easily performed and reproduced across a distributed system. Our first benchmarks are promising and we believe this framework can benefit the network community by enabling realistic, reproducible experiments and runnable papers. This work has been published in the ACM CoNext conference 2013 [25], in Santa Barbara, CA, USA and will be published in IEEE Communication Magazine in 2014 [14]. DCE has been demonstrated at the ACM MSWiM conference at Barcelona, Spain in November 2013 [42] In the same context, we designed DCE Cradle, a framework that allows to use any features of the Linux kernel network stack with existing ns-3 applications. DCE Cradle uses DCE to address the brittleness of Network Simulation Cradle (NSC). We carefully designed DCE Cradle without breaking the existing functionality of DCE and ns-3 socket architecture by considering the gaps between the asynchronous ns-3 socket API and the general POSIX socket API. We validated the implementation of DCE Cradle with the behavior of TCP implementation in congested links, and then studied its performance by focusing on the simulation time and network scale. We showed that DCE Cradle is at most 1.3 times faster than NSC, while it is about 2.2 times slower than the ns-3 native stack. Then we showcased an actual implementation of the DCCP transport protocol to verify how easy it is to simulate a real implementation using DCE Cradle. We believe that this tool can highly benefit the network community by enabling more realistic evaluation of network protocols. This work has been published in the ns-3 workshop in 2013 in Cannes and got the best paper award [26].

The ns-3 Consortium

We have founded in 2012 a consortium between Inria and University of Washington. The goals of this consortium are to (1) provide a point of contact between industrial members and the ns-3 project, to enable them to provide suggestions and feedback about technical aspects, (2) guarantee maintenance of ns-3's core, organize public events in relation to ns-3, such as users' day and workshops and (3) provide a public face that is not directly a part of Inria or NSF by managing the http://www.nsnam.org web site. The Consoritum started his activities in March 2013. Two European institutions (Centre Tecnològic de Telecomunicacions de Catalunya - CTTC and INESC Porto)) and two Amercian universities (Georgia Tech and Bucknell) joined the consortium as Executive members in 2013. For more details see the consortium web page https://www.nsnam.org/consortium/.

Contiki over ns-3

This year we worked on the adaptation of Contiki OS over ns-3. Contiki is a popular, and highly optimized, operating system for sensor nodes. We developed a proof of concept adaptation layer that, even though simple and limited, was able to show that such interaction is indeed possible. The adaptation layer was capable of transferring data from different sensors using ns-3 to interconnect them. Sensor nodes were controlled by the ns-3 scheduler, respecting the ns-3 clock and executing over simulated time. In fact, the sensors were not even aware they were placed over a simulated network.

Federation of experimental testbeds

We are involved in the F-Lab (French ANR) project, the FED4FIRE (E.U. IP) project and have the lead of the "Control Plane Extensions" WorkPackage of OpenLab (E.U. IP) project. Within these frameworks, as part of the co-development agreement between the DIANA team and Princeton University, we kept contributing into one of the most visible and renown implementations of the

Testbed-Federation architecture known as SFA for Slice-based Federation Architecture. As a sequel of former activities we also keep a low-noise maintenance activity of the PlanetLab software, which has been running in particular on the PlanetLab global testbed since 2004, with an ad-hoc federated model in place between PlanetLab Central (hosted by Princeton University) and PlanetLab Europe (hosted at Inria) since 2007. During 2013, as a step forward to our contribution to the specification of the Aggregate Manager (AM) API v3, which is the control plane interface through which experimenters discover and reserve resources at testbeds, we have focused on coming up with a separate implementation of SFAWrap that supports AM API v3 and brings a more elaborate lifecycle for slices provisioning. Secondly, we implemented a AM API v2 to AM API v3 adapter, which represents the glue between the already existing AM API v2 compliant testbed drivers and the AM API v3 compliant interfaces of SFAWrap. The v2 to v3 adapter provides AM API v3 compatibility to already existing AM API v2-based testbed drivers until their authors find the time to adapt their driver for a native support of AM API v3 if they want to take full advantage of the new lifecycle. Thirdly, within the contexts of the formerly listed projects, and as a consequence of the growing need for testbeds federation, the providers of testbeds such as: BoneFire, SmartSantander decided to adopt SFAWrap in order to join the global federation of testbeds by exposing their testbeds through SFA. Thus, we had to provide to those partners a close support to achieve this goal. Finally, as for any kind of software development project, and due to the growing usage of SFAWrap, we had to be active on both operational and maintanace tasks. See [37] and [41] for more details. We also contributed, in the context of the Fed4FIRE project, to the definition and early implementation of an architecture for heterogeneous federation of future internet experimental facilities. The results of this work were presented at the FutureNetworkSummit 2013 conference. In this work, requirements involving different aspects of the federation of heterogeneous facilities where collected and analysed, and a multilayer architecture was proposed to address them. Our contribution mainly focuses on the experiment control plane of the federation architecture [28]. The experiment control plane involves the interface between the experimenter and the facilities, and it covers tasks such as federation of the resource discovery, provisioning, reservation, configuration and deployment. The proposed architecture combines the use of SFA (Slice Federation Architecture) and OMF (cOntrol and Management Framework) into a common middle-ware that allows to federate resource control within an experiment across facilities.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

- **ADR on Content Centric Networking** (2013-2016):
  The goal of this study in the context of the Inria - Alcatel Lucent Bell Labs laboratory is to work on the definition and the experimental evaluation of ICN mechanisms that use monitoring data to optimize network resource management and user Quality of Experience in today's networks. Massimo Gallo started his post-doc working on this topic early 2013. He was hired by AL-BL in march so he resigned from his post-doc position. The collaboration is currently in stand-by.

8. Partnerships and Cooperations

8.1. Regional Initiatives

- **PFT** (2011-2014) is a DGCIS funded project, in the context of the competitivity cluster SCS, whose aim is to provide 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.

8.2. National Initiatives

8.2.1. ANR

- **ANR FIT** (2011-2018): FIT (Future Internet of Things) aims to develop 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 F-Lab** (2011-2013): ANR funded project on the federation of computation, storage and network resources, belonging to autonomous organizations operating heterogeneous testbeds (e.g. PlanetLab testbeds and Sensors testbeds). This includes defining terminology, establishing universal design principles, and identifying candidate federation strategies. Other partners : UPMC, A-LBLF and Thales.
- **ANR DISCO** (2013-2016): DISCO (DIstributed SDN COntrollers for rich and elastic network services) aims to explore 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.

8.3. European Initiatives

8.3.1. FP7 Projects

8.3.1.1. NOVI

Title: Networking innovations Over Virtualized Infrastructures

Type: COOPERATION (ICT)

Defi: CAPACITIES programme.

Instrument: Specific Targeted Research Project (STREP)

Duration: September 2010 - February 2013

Coordinator: NTUA (Greece)

Others partners: 13 european partners including GARR, ELTE, Cisco, etc.

See also: http://www.fp7-novi.eu/

Abstract: NOVI (Networking innovations Over Virtualized Infrastructures) research concentrates on efficient approaches to compose virtualized e-Infrastructures towards a holistic Future Internet (FI) cloud service. Resources belonging to various levels, i.e. networking, storage and processing are in principle managed by separate yet interworking providers. NOVI will concentrate on methods, information systems and algorithms that will enable users with composite isolated slices, baskets of resources and services provided by federated infrastructures.

8.3.1.2. Fed4Fire

Title: Federation for Future Internet Research and Experimentation

Type: COOPERATION (ICT)

Defi: FIRE programme.

Instrument: Integrating Project (IP)
Duration: October 2012 - October 2016
Coordinator: iMinds (Belgium)
Others partners: 17 european partners including iMinds, IT Innovation, UPMC, Fraunhofer, TUB, UEDIN, NICTA, etc.
See also: 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.

8.3.1.3. OPENLAB

Title: OpenLab: extending FIRE testbeds and tools
Type: COOPERATION (ICT)
Defi: ICT 2011.1.6 Future Internet Research and Experimentation (FIRE)
Instrument: Integrated Project (IP)
Duration: September 2011 - January 2014
Coordinator: Université Pierre et Marie Curie (France)
Others partners: 18 European partners (including ETH Zurich, Fraunhofer, IBBT, TUB, UAM, etc.) and Nicta from Australia.
See also: http://www.ict-openlab.eu/
Abstract: OpenLab brings together the essential ingredients for an open, general purpose and sustainable large scale shared experimental facility, providing advances to the early and successful prototypes serving the demands of Future Internet Research and Experimentation.OpenLad partners are deploying the software and tools that allow these advanced testbeds to support a diverse set of applications and protocols in more efficient and flexible ways. OpenLab's contribution to a portfolio that includes: PlanetLab Europe (PLE), with its over 200 partner/user institutions across Europe; the NITOS and w-iLab.t wireless testbeds; two IMS telco testbeds that can connect to the public PSTN, to IP phone services, and can explore merged media distribution; an LTE cellular wireless testbed; the ETOMIC high precision network measurement testbed; the HEN emulation testbed; and the ns-3 simulation environment. Potential experiments that can be performed over the available infrastructure go beyond what can be tested on the current internet. OpenLab extends the facilities with advanced capabilities in the area of mobility, wireless, monitoring, domain interconnections and introduces new technologies such as OpenFlow. These enhancements are transparent to existing users of each facility. Finally, OpenLab will finance and work with users who propose innovative experiments using its technologies and testbeds, via the open call mechanism developed for FIRE facilities.

8.3.2. EIT KIC funded activities

Our project team was involved in 2013 in **three activities** funded by the EIT ICT Labs KIC:

Fitting, Future InterneT (of ThINGs) facility

The goal of this activity is to develop a testbed federation architecture that combines wireless and wired networks.

Software-Defined Networking (SDN)

The objective of this activity is to explore software-defined networking at different positions on the axis between basic flow-level processing (using OpenFlow for end-to-end flows) in controlled fixed networks and cooperation between mobile end nodes in the open wireless Internet (using opportunistic networking for resources communicated hop-by-hop).

Information-centric networking (ICN) experimentation

The goal of this activity is to define and implement an early validation environment for ICN proposals.

8.4. International Initiatives

8.4.1. Inria Associate Teams

8.4.1.1. COMMUNITY

Title: Message delivery in heterogeneous networks

Inria principal investigator: Thierry Turletti

International Partner (Institution - Laboratory - Researcher):

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

Duration: 2009 - 2014

See also: http://inrg.cse.ucsc.edu/community/

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.

8.4.1.2. SIMULBED

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

Inria principal investigator: Walid DABBOUS

International Partner (Institution - Laboratory - Researcher):

Keio University (Japan) - Shonan-Fujisawa Campus - Osamu Nakamura

Duration: 2012 - 2014

See also: http://planete.inria.fr/Simulbed

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 to provide 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 design a platform to make easier the evaluation of network protocols, applications and proposals for the future Internet architecture, and to make this platform available to the networking research community. The SIMULBED evaluation platform aims to conduct easily mixed simulation-experimentation evaluation of networking protocols in a scalable way, while maintaining a high degree of realism and increasing controllability and reproducibility. It is based on the PlanetLab testbed, the ns-3 network simulator and the NEPI unified programming environment developed in our team to help in simplifying the configuration, deployment and run of network scenarios on the platform. Within this collaboration, we are enhancing the support of emulation in the ns-3 network simulator through Direct Code Execution (DCE) and are extending the functionalities of NEPI to fit the needs of SIMULBED. For example, we extended the DCE and NEPI frameworks to conduct easily and in a more reaslitic way evaluation of the CCNx information-centric networking architecture through ns-3 and the PlanetLab testbed.

8.4.2. Inria International Labs

- CIRIC: Our project-team was involved in the definition of the topics for the Network and Telecom R&D line of the (the Communication and Information Research and Innovation Center - CIRIC), the Inria research and innovation centre in Chili. In this context, we will extend our collaboration with Universidad Diego Portales, Chile.

8.5. International Research Visitors

8.5.1. Visits of International Scientists

8.5.1.1. Visiting PhDs

Ilaria Cianci, Visiting PhD student (from Nov 2012 until Aug 2013)

Subject: Content Centric Networking

Institution: Politecnico di Bari, Italy

8.5.1.2. Internships

Alexandros Kouvakas (from May 2013 until Oct 2013)

Subject: An OpenFlow framework for integrated simulation and live experimentation

Institution: National and Kapodistrian University of Athens

Adel Aljalam (from Mar 2013 until Aug 2013)

Subject: Assessing Internet access quality by active measurements

Institution: Ubinet Master, University of Nice Sophia-Antipolis

Takai Eddine Kennouche (from Feb 2013 until May 2013)

Subject: Realistic Simulation of Sensor Networks - Contiki over ns-3

Institution: Institut National des Télécommunications et des TIC - Oran, Algeria.

Nicoleta Oita (from Mar 2013 until Aug 2013)

Subject: Privacy in mobile networks

Institution: Ubinet Master, University of Nice Sophia-Antipolis

Xiuhui Ye (from May 2013 until Nov 2013)

Subject: How to Network in Online Social Networks

Institution: Politecnico di Torino

8.5.2. Visits to International Teams

Alina Quereilhac, Visiting PhD student PARC in Palo Alto, USA

Period: From June to September 2013

Subject: Evaluating costs of CCNx overlays on the Internet

Thierry Turletti and Bruno Nunes Astuto, Visiting researchers to University of California at Santa Cruz

Period: One week in March 2013

Subject: Community Associated team

Bruno Nunes Astuto Visiting researchers to University of California at Santa Cruz

Period: One month in July 2013

Subject: Community Associated team

Thierry Turletti, Alina Quereilhac and Emilio Mancini, Visitors to NICT, Japan

Period: One week in October 2013

Subject: Simulbed associated team

9. Dissemination

9.1. Scientific Animation

- **Walid Dabbous** served in the programme committees of ACM MM'2013 and CCNxCon'2013. He is member of the ns-3 consortium and has organized the kick-off meeting for the consortium in March 2013. He co-organized the Rescom summer school on Information Centric Networking in Porquerolles in May 2013. He is member of the scientific council of the Inria Bell-Labs laboratory on Self Organizing Networks.

- **Thierry Turletti** Senior ACM and IEEE member, served in 2013 in the program committees of the following international conferences: 20th International Packet Video Workshop and 5th ACM Workshop on mobile Video Delivery (Movid). 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 and served on the Technical Program Committee for the Traffic Monitoring and Analysis (TMA) 2013 workshop and the Passive and Active Measurement (PAM) 2013 conference. 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** is on the editorial board of the Computer Networks journal. He was also reviewer of journals (IEEE/ACM Transactions on Networking, IEEE/ACM Transactions on Computers, IEEE Network, Computer Communications, ACM SIGCOMM CCR), and conferences (IEEE Infocom, ACM Sigmetrics). He also served as an expert to the European Commission to evaluate EC funded projects.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Undergraduate course at IUP GMI Avignon on Peer-to-peer networks, by Arnaud Legout (38h), France.

Master Ubinet: course on Evolving Internet - architectural challenges by Walid Dabbous and Chadi Barakat 42 hours, University of Nice-Sophia Antipolis, France.

Master Ubinet: course on Peer-to-peer networks, by Arnaud Legout (21), University of Nice-Sophia Antipolis.

Master 1 International in Computer Science: course on algorithms for networking, by Chadi Barakat (18h), University of Nice.

Master CAR: course on Internet monitoring by Chadi Barakat, 3h, Telecom Paris Tech, France.

Master TSM: course on Voice over IP by Chadi Barakat, (6h),University of Nice-Sophia Antipolis, France.

Master RISM: course on mobility and wireless networking, by Chadi Barakat (7h), University of Avignon.

Master RISM: course on peer-to-peer networks and privacy, by Arnaud Legout (30), University of Avignon.

9.2.2. Supervision

PhD : Ashwin Rao defended his PhD titled "Improving Transparency and End-User Control in Mobile Networks" on June 30th, at University of Nice Sophia-Antipolis. His thesis was co-supervised by Arnaud Legout and Walid Dabbous.

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: 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: 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: Maksym Gabielkov works on “Propagation of data in social networks” since 2012. His work is supervised by Arnaud Legout.

9.2.3. Juries

Walid Dabbous served as a reviewer and jury member of Mohamed Diallo PhD thesis, defended in March 2013, at University Pierre and Marie Curie.

Walid Dabbous served as a reviewer and jury member of Bilel Ben Romdhanne PhD thesis, defended in December 2013, at Eurecom.

Thierry Turletti served as an external examiner and presides the jury of Bilel Ben Romdhanne PhD thesis, defended in December 2013, at Eurecom.

Thierry Turletti served as reviewer and jury member of Nicolas Kuhn PhD thesis, defended in November 2013 at INP Toulouse.

Thierry Turletti served as reviewer and jury member of Emmanuel Chaput HDR thesis, defended in November 2013, at INP Toulouse.

Thierry Turletti served as reviewer and jury member of Jean Vella PhD thesis, defended in September 2013, at University of Malta.

Chadi Barakat served as a reviewer and jury member of Xavier Miseri PhD thesis, defended in October 2013 at Telecom ParisTech.

Chadi Barakat served as jury member of Vincenzo Ciancaglini PhD thesis, defended in July 2013 at Inria Sophia Antipolis.

Chadi Barakat served as a reviewer and jury member of Heng Cui PhD thesis, defended in April 2013 at Eurecom.

Arnaud Legout served as a jury member for the Ph.D. thesis of Roberto Roverso defended in December 2013 at KTH.

Arnaud Legout served as an opponent for the Ph.D. thesis of Raul Jimenez defended in December 2013 at KTH.

9.3. Popularization

Arnaud Legout made a presentation on “Exploration macroscopique du graphe social de Twitter”to a user group interested in network security called OSSIR. See http://www.ossir.org/paris/supports/index/2013.shtml.

10. Bibliography

Major publications by the team in recent years

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