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Abstract

This document contains the report on the PhD course jointly organized by the OFELIA and CHANGE EU-FP7 projects. The CHANGE & OFELIA Summer School on OpenFlow technology and applications was held in Berlin, Germany, between November 7 and November 11, 2011. We could offer a competitive program with 12 presentations by internationally renowned experts and with 3 poster sessions where students presented their own research. Overall, the event attracted more than 50 participants.

All presentations and papers are available from
http://changeofelia.info.ucl.ac.be

Target audience: the general public

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Imprint

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Executive summary

The summer school on flow-based switching and the OpenFlow technology was jointly organized by the EU FP7 projects OFELIA and CHANGE. The event took place in Berlin between November 7 and November 11, directly after the Internet Measurement Conference 2011 (November 2-4, also in Berlin). Overall, we hosted more than 54 PhD students and researchers during this event.

The objective of the summer school was to gather PhD students and researchers who are actively working on OpenFlow and related research topics. The program contained presentations by well-known international experts. The topics of the tutorials covered Future Internet, (optical) network virtualization, NetFPGAs with the focus on OpenFlow as seen by researchers, hardware vendors, and network operators. Moreover, we organized a poster session where students presented their research ideas. The feedback about the summer school was completely positive. Surprisingly, the organizers even received many e-mails in the days after the summer school where students expressed their thanks for the smooth organization and the interesting program. Two students even asked if this event would take place every year from now on.

For registration, students had to submit a 2-page extended abstracts and to mutually review their abstracts. Finally, to foster interaction between PhD students, we organized social events in addition to the scientific programme. The organization committee consisted of participants from both the OFELIA and the CHANGE project.

The website of the summer school is at http://changeofelia.info.ucl.ac.be/ and provides more details about the organization of the summer school.

List of authors

Organisation/Company	Author
ETH Zurich	Wolfgang Mühlbauer
ETH Zurich	Bernhard Plattner

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Abbreviations

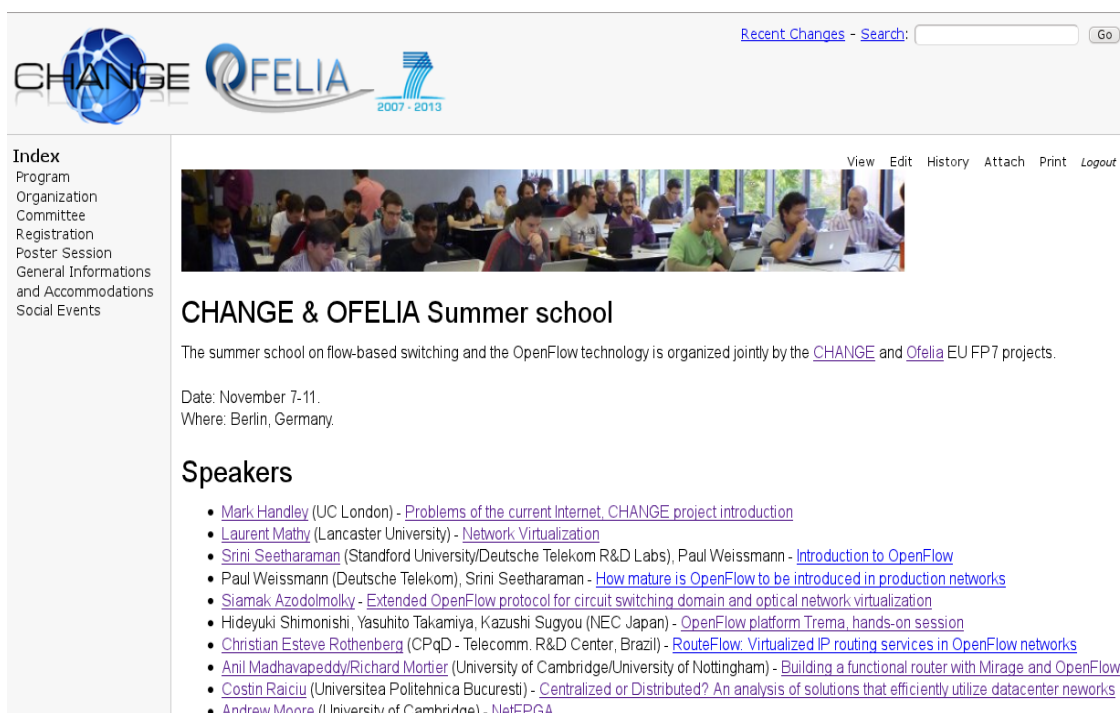|	
CSD	Clean Slate Design
MPTCP	Multi-path TCP
OFELIA	OpenFlow in Europe – Linking Infrastructure and Applications
SDN	Software-defined Networking
TRILL	Transparent Interconnection of Lots of Links
VLAN	Virtual Local Area Network
VPN	Virtual Private Network

2   Introduction

The increasing complexity and its deployment have led to significant research efforts in the area of Future Internet (FI) in Europe and Clean Slate Design (CSD) in the U.S. In this context, the OpenFlow initiative has recently caught the attention of researchers and even router vendors.

The objective of the OFELIA/CHANGE Summer School was to bring together PhD students and researchers who are currently working on future Internet topics such as:

- Principles of evolving future architectures

- New networking paradigms

- OpenFlow-related topics

- Programmable networks, NetFPGAs

- Network virtualization

- Measurements and analyses that characterize and quantify architectural limitations

- Discussions on interworking with the existing Internet and deployability

The summer school was jointly organized by the EU FP7 projects OFELIA and CHANGE. The organization committee consists of participants from both the OFELIA and the CHANGE project. The event took place in Berlin between November 7 and November 11, directly after the Internet Measurement Conference 2011 (November 2-4, also in Berlin). Overall, we hosted more than 54 PhD students, and researchers for this event.

The program contained presentations by well-known international experts on various topics. Moreover, we organized a poster session where students presented their research ideas. For registration, students had to submit 2-page extended abstracts and to mutually review their abstracts. Finally, to foster interaction between PhD students, we also organized social events in addition to the scientific programme.

Figure 1: Website of the OFELIA/CHANGE summer school

The rest of this report is structured as follows. Section 3 lists the members of the organization committee. Section 4 summarizes the scientific program of the summer school. Section 5 explains the organization of the poster session. Finally, Section 6 provides a list of all attendees.

For any further information regarding the summer school, we refer to the course website [1]: http://changeofelia.info.ucl.ac.be

3 Organization Committee

The members of the summer school organization committee were:

- Wolfgang Mühlbauer, ETH Zurich, Switzerland, OFELIA (main organizer)

- Olivier Bonventure, Université Catholique de Louvain, Belgium, CHANGE

- Steve Uhlig, TU Berlin, Germany, OFELIA and CHANGE

- Dominik Schatzmann, ETH Zurich, Switzerland, OFELIA

- Gregory Détal, Université Catholique de Louvain, Belgium, CHANGE

- Saverio Niccolini, NEC Heidelberg, Germany, CHANGE

- Reza Nejabati, University of Essex, OFELIA

4   Summer School Program

According to the feedback we received from the students and the presenters, the summer school was a great success. The competitive program and the diversity of the presentations attracted many peoples from different countries, universities, and backgrounds. Overall, we could achieve an interesting mix of topics including Future Internet, (optical) network virtualization, NetFPGAs, where the focus was on OpenFlow as seen by researchers, hardware vendors, and network operators. The quality of the presentations was remarkably high, and exceeded the standard of many small conferences.

In addition, the students were able to present their ongoing research during three poster sessions with a total of 26 posters. We noticed a lot of interactions among students and renowned expert. Students received valuable feedback about their research, which will help them for their future research.

In the following, we summarize the presentations that were given during the summer school. A detailed summary of the program with pictures from the talks is available on the course website:
http://changeofelia.info.ucl.ac.be/SummerSchool/Program

- ➢ **Mark Handley (UC London)**

  - Title: Problems of the current Internet, CHANGE project introduction

  - Date: Monday, November 7, 12:35-15:00

- ➢ **Laurent Mathy (Lancaster University)**

  - Title: Network Virtualization

  - Date: November 7, 15:30-18:00

  - Abstract: This tutorial present a brief introduction to network virtualization, with the emphasis on defining a framework to compare and contrast various approaches to virtualization. Subjects discussed include VLAN, VPN, virtual routers, virtual programmable routers, and virtual network architectures.

- ➢ **Srini Seetharaman (Stanford University)**

  - Title: Introduction to OpenFlow

  - Date: Tuesday, November 8, 09:00-11:30

  - Abstract: OpenFlow is being widely embraced, both by the industry and academia, to create platforms for innovation. This talk will provide you hands-on experience with building, programming and troubleshooting the platform. Following an introduction to OpenFlow and the Software-defined Networking (SDN) architecture, each participant will learn how to create a flow-based Ethernet switch within a slice in a hands-on approach. Along the way, you'll learn the OpenFlow software suite: you'll view flow tables with dpctl, dissect packets with Wireshark, write a simple NOX-based controller, simulate a multi-switch/multi-host network with Mininet (emulation environment) on your laptop, and slice it using the FlowVisor. The talk will conclude with a short demonstration of using Expedient/Opt-in Manager for slice management.

- ➢ **Paul Weissmann (Deutsche Telekom)**

  - Title: How mature is OpenFlow to be introduced in production networks

  - Date: Tuesday, Tuesday, November 8, 13:30-15:00

  - Abstract: This talk will discuss the importance and relevance of OpenFlow for production networks.

- ➢ **Siamak Azodolmolky (University of Essex)**

  - Title: Extended OpenFlow protocol for circuit switching domain and optical network virtualization

  - Date: Tuesday, Tuesday, November 8, 15:30-17:30

  - Abstract: One of the main promises of Software Defined Networking (SDN) paradigm is to enable the network operators to control and manage their networks in an efficient way and in line with their customer's needs. OpenFlow protocol is a novel mean to materialize this vision, however in its current version the circuit switched (especially optical networking) domain is not comprehensively considered and covered. In this tutorial the extension of OpenFlow protocol to support circuit

switched domain will be presented. In addition to the state-of-the-art, interworking/integration of OpenFlow with GMPLS control plane will be over viewed. The use of Extended OpenFlow protocol for Optical network visualization will be also presented in this session.

➢ **Speaker: Hideyuki Shimonishi, Yasuhito Takamiya, Kazushi Sugyou (NEC Japan)**

- Title: OpenFlow platform Trema, hands-on session

- Date: Wednesday, November 9, 9:00-11:00

- Abstract: Trema is an Open Source modular framework for developing OpenFlow controllers in Ruby/C. The scope of Trema is to help researchers and developers to easily develop their own OpenFlow controllers, and not aiming at providing a specific OpenFlow controller implementation. Trema provides various basic libraries on which users can build their own OpenFlow controllers, as well as integrated network emulator and a lot of sample controllers written in C and Ruby. In this hands-on-session, the architecture and implementation of Trema are introduced, followed by the demonstration of installation, execution on an emulation network, as well as, sample programming of a tiny Trema application.

➢ **Speaker: Christian Esteve Rothenberg (CPqD - Telecomm. R&D Center, Brazil)**

- Title: RouteFlow: Virtualized IP routing services in OpenFlow networks

- Date: Wednesday, November 9, 13:30-15:00

- Abstract: The RouteFlow project proposes a commodity routing architecture that combines the line-rate performance of OpenFlow-enabled hardware with the flexibility of open-source routing stacks (remotely) running on general purpose computers. The outcome is a promising approach in the design space of routing solutions with far-reaching implications towards virtual routers and IP networks as a service. This talk will present the RouteFlow design along its different modes of operation and its main architectural components. We will discuss the prototype implementation and our experiences so far in building an open-source community around the RouteFlow components. The talk will include a demo use case and will conclude by discussing topics of our research agenda.

➢ **Speaker: Andrew Moore (Cambridge University)**

- Title: NetFPGA

- Date: Thursday, November 10, 09:00-11:30

- Abstract: An open platform called the NetFPGA has been developed by a group of developers world-wide, lead by Stanford University. The NetFPGA platform enables researchers and instructors to build high-speed, hardware-accelerated networking systems. The platform can be used in the classroom to teach students how to build Ethernet switches and Internet Prototocol (IP) routers using hardware rather than software. The platform can be used by researchers to prototype advanced services for next-generation networks. The NetFPGA enables new types of packet routing circuits to be implemented and detailed measurements of network traffic to be obtained. During the presentation, we will see the NetFPGA used to determine the amount of memory needed to buffer TCP/IP data streaming through the Gigabit/second router and to measure and plot the occupancy of buffers. Circuits will be downloaded into reconfigurable hardware and tested with live, streaming Internet video traffic. Demonstrations of the new 10Gbps NetFPGA hardware will also be made. Attendees will learn about the NetFPGA platform and what it can do. No knowledge of Verilog/VHDL required.

➢ **Speaker: Richard Mortier (Nottingham University)**

- Title: Building a Functional Router with Mirage and OpenFlow

- Date: Thursday, November 10, 13:30-15:30

- Abstract: Mirage is an exokernel for constructing secure, high-performance network applications across a variety of cloud computing and mobile platforms. Code can be developed on a normal OS such as Linux or MacOS X, and then compiled into a fully-standalone, specialised microkernel that runs under the Xen hypervisor. Mirage is based around the OCaml language, with syntax extensions and libraries which provide networking, storage and concurrency support that are easy to use during development, and map directly into operating system constructs when being compiled for production deployment. The framework is fully event-driven, with no support for preemptive threading. In this tutorial we will introduce the Mirage framework using a range of examples, exploring construction of network services in detail, with reference to OpenFlow controller and datapath implementations.

➢ **Speaker: Costin Raiciu (Universitea Politehnica Bucuresti)**

- Title: Centralized or Distributed? An Analysis of Solutions that Efficiently Utilize Datacenter Networks

- Date: Thursday, November 10, 16:00-18:00

- Abstract: Datacenter network topologies have become multipath, with several paths available between any two servers. The industry standard is to randomly choose a path for any given connection, either via Equal Cost Multipath or the new TRILL IETF standard. However, random choices create collisions where mutiple flows are placed on the same link, wasting capacity elsewhere in the network. The net effect is reduced utilization: in a particularly bad case, 60% of the network capacity is just wasted. In this talk I will analyze two recent solutions to this problem. Hedera [NSDI 2011] uses a centralized approach to compute optimal flow placement and enforces it by leveraging OpenFlow. MPTCP [Sigcomm2011] splits every connection on multiple paths, finding capacity automatically.

> **Speaker: Felipe Huici (NEC, Germany)**

- Title: Flow Processing and the Rise of Commodity Network Hardware

- Date: Friday, November 11, 09:30-10:30

- Abstract: Over the past few years commodity hardware such as x86-based servers have become viable systems for performing flexible yet high-performing flow processing. In this talk we present Flowstream, a flow processing platform based on a set of such servers inter-connected via programmable switches like Openflow and managed by a common platform controller. In addition, we present mechanisms that allow flexible, high-performance and isolated processing on different flows on a single server, as well as light-weight mechanisms for stateful flow migration between servers and platforms.

> **Speaker: Luigi Rizzo**

- Title: Software packet processing on commodity OS: the netmap framwork

- Date: Friday, November 11, 10:30-12:30

- Abstract: This talk will present an overview of mechanisms available for software packet processing on commodity OS, discussing their features and performance. We will then introduce the netmap framework, showing how it can significantly improve the performance of a variety of applications. This will be followed by a discussion of research areas which may benefit from a critical revisitation of software architectures and techniques and strategies used to implement packet processing system, network protocols, and network applications.

5   Poster Sessions

We organized a call for papers to encourage students to present their research. The authors were required to submit a two page paper as an extended abstract of their current research results. We received more than 30 submissions. We decided to accept all papers. Unfortunately, some students finally could not come to the summer school, mainly due to time constraints.

After having submitted their abstracts, the PhD students have been asked to review and comment three extended abstracts of other PhD students. This process encouraged the PhD students to discuss and explain their research with other PhD students before attending the summer school. Moreover, we ensured that the discussion and cooperation when they arrived at the summer school "hit the ground running". Furthermore, this was a good way for the PhD students to discover the standard paper reviewing process and it was the first reviewing experience for many of the students. According to the feedback we received from the participants, this process was successful and PhD students had strongly benefited from this kind of experience.

All submitted abstracts are available on the course website [1] under the following link: http://changeofelia.info.ucl.ac.be/SummerSchool/PosterSession

Overall, we organized three poster sessions, the title of the papers and their authors are listed in the following.

Poster Session 1: Tuesday, 11:30-12:30

- Gaetano Catalli (University of Pisa), Open vSwitch: performance improvement and porting to FreeBSD

- Rodrigo Denicol (CPqD), On IPv6 support in OpenFlow via Flexible Match Structures

- Andrea Di Pietro (University of Pisa), An OpenFlow Compliant Smart Switch for monitoring applications

- Fernando Farias (Federal University of Para), LegacyFlow: Bringing OpenFlow to Legacy Network Environments

- Nikhil Handigol (Stanford University), Aster*x: Load-Balancing as a Network Primitive

- Matteo Landi (Università di Pisa), netmap: framework for very fast access to network devices

- Vladimir Olteanu (Universitatea Politehnica Bucuresti), Scaling middleboxes with OpenFlow

- Octavian Ringciog (University Politehnica of Bucharest), Flow Processing Platform discovery

- Voravit Tanyingyong (KTH Royal Institute of Technology), Offloading Packet Forwarding in a Combined Router/Server

Poster Session 2: Wednesday, 11:30-12:30

- Matteo Gerola (Create-Net), Enabling Network Virtualization in OpenFlow Networks through Virtual Topologies Generalization

- Alexandre Kandalintsev (University of Trento), Advanced Cloud Resource Management For Performance and Power Saving

- Qian Li (Hasselt University), Cognitive Networks for Simultaneous Interaction Spaces

- Matias Jon (University of the Basque Country), The UPV/EHU OpenFlow Enabled Facility

- Charalampos Rotsos (University of Cambridge), Control and Understanding: Owning Your Home Network

- Flavio Silva (Universidade Federal de Uberlândia), Domain Title Service: A Future Internet Enabler

- David Stezenbach (University of Vienna), Federation as a part of Infrastructure as a Service in Transport Networks

- Daniel Philip Venmani (Université Pierre et Marie CURIE), Mobile Network Sharing using OpenFlow

- Yiannis Yiakoumis (Stanford University), Slicing Home Networks

Poster Session 3: Thursday, 11:30-12:30

- Ilaria Cianci (Politecnico di Bari), Data-centric Networking: advanced modeling and design

- Peter Dely (Karlstad University), Towards an Architecture for OpenFlow and Wireless Mesh Networks

- Brandon Heller (Stanford University), Quantitatively Evaluating (and Optimizing) Software-Defined Networks

- Michael Hoefling (University of Tuebingen), Mapping Systems for the Future Internet

- Michael Jarschel (University of Würzburg), OpenFlow Activities in Würzburg

- Juhoon Kim (TU-Berlin), Can TCP and Locator/ID Separation get along?

- Nanfang Li (Politecnico di Torino), A Case Study of Network Virtualization: Implement Multistage Software Routers into Virtual Environment

- Sandeep Pathivada (Trinity College Dublin), Wire Speed Programmable Networks

6 Attendees

The high number of attendees clearly reveals the success of the summer school. Overall, there were 54 students, researchers, and lecturers, coming from diverse countries, universities, and institutions. Due to space contraints, we even had to reject 8 students. Note that the majority of the registered participants are not members of the OFELIA or CHANGE project.

The complete list is given here:

- Abdul Alim, Lancaster University, UK
- Adam Stipkovits, Technical University of Budapest, Hungary
- Alexandre Kandalintsev, University of Trento, Italy
- Andrea di Pietro, University of Pisa, Italy
- Andrew Moore, Cambridge University, UK
- Brandon Heller, Stanford University, USA
- Charalampos, Rotsos, Cambridge University, UK
- Christian Esteve Rothenberg, CPqD - Telecomm. R&D Center, Brazil
- Costin Raiciu, Universitatea Politehnica Bucuresti, Romania
- Daniel Philip Venmani, Université Pierre et Marie Curie, Paris VI, France
- Daniel Turull, KTH Royal Institute of Technology, Sweden
- David Stezenbach, University of Vienna, Austria
- Dominik Klein, University of Würzburg, Germany
- Dominik Schatzmann, ETH Zurich, Switzerland
- Eduardo Jacob, University of the Basque Country, Spain
- Emmanouil Psanis, Lancaster University, UK
- Fabian Duchene, Université Catolique de Louvain, Belgium
- Felipe Huici, NEC, Germany
- Felipe Rizzo, University of Pisa, Italy
- Fernando Farias, Federal University of Parà, Brazil
- Flavio Silva, Federal University of Uberlandia, Brazil
- Gaetano Catalli, University of Pisa, Italy
- Gianni Antichi, University of Pisa, Italy
- Gregory Detal, Universite Catholique de Louvain, Belgium
- Hideyuki Shimonishi, NEC Japan, Japan
- Ilaria Cianci, Politecnico di Bari, Italy
- Jon Matias, University of the Basque Country, Spain
- Juhoon Kim, TU Berlin, Germany
- Kazushi Sugyou, NEC Japan, Japan
- Kurt Baumann, SWITCH, Switzerland
- Laurent Mathy, Lancaster University, UK
- Marek Michalski, Poznan University, Poland
- Mark Handley, UC London, UK
- Matteo Landi, University of Pisa, Italy
- Mehdi Bezahaf, Lancaster University, UK
- Michael Hoefling, University of Tübingen, Germany
- Nanfang Li, Politecnico di Torino, Italy
- Nikhil Handigol, Stanford University, USA
- Paolo Bolloetta, University of Rome – la Sapienza, Italy
- Paul Weissmann, Deutsche Telekom, Germany
- Peter Dely, Karlstad University, Sweden
- Qian Li, Hasselt University, Belgium
- Richard Mortier, University of Nottingham, UK
- Rinciog Octavian, Universitatea Politehnica Bucuresti, Romania
- Rodrigo Denicol, CPqD - Telecomm. R&D Center, Brazil
- Sandeep Pathivada, Trinity College Dublin, Ireland
- Siamak Azodolmolky, University of Essex, UK

- Srini Seetharaman, Stanford University, USA
- Steve Uhlig, TU Berlin, Germany
- Vladimir Olteanu, Universitatea Politehnica Bucuresti, Romania
- Voravit Tanyingyong, KTH Royal Institute of Technology, Sweden
- Wolfgang Mühlbauer, ETH Zurich, Switzerland
- Yasuhito Takamiya, NEC Japan, Japan
- Yiannis, Yiakoumis, Stanford University, USA

References

[1]   OFELIA/CHANGE Summer School: http://changeofelia.info.ucl.ac.be