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CHANGE

CHANGE: Enabling Innovation in the Internet Architecture through Flexible Flow-Processing Extensions

Specific Targeted Research Project FP7 ICT Objective 1.1 The Network of the
Future

D6.5 - Final dissemination and exploitation plan and record

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Executive Summary

This document describes the final dissemination and exploitation plan and record of the CHANGE project.

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1 Introduction

This document constitutes the CHANGE WP6 deliverable *D6.5 - Final dissemination and exploitation plan and record*. It presents the dissemination achievements and exploitation efforts of CHANGE during the complete duration of the project.

CHANGE has put great effort into properly disseminating project results. In summary, dissemination of CHANGE results in the scientific community has been very successful. A large number of scientific publications have been published with CHANGE acknowledgment. In addition to scientific publications, several presentations and demonstrations have been made at industry venues in order to make CHANGE's achievements visible to the public. Also, an international project workshop was organised. Moreover, CHANGE released several tools and software libraries as open source. Finally, CHANGE provided several contributions to key standards bodies.

This deliverable presents the following CHANGE dissemination and exploitation activities, detailing the individual activities and achievements for each of these items in an individual chapter:

- Publications in scientific journals and conferences
- Exploitation activities carried out by the project's industrial partners
- Contributions to standards bodies
- Open Source software released
- Other Dissemination Activities

2 Publications in Scientific Journals and Conferences

CHANGE was very successful with scientific publications at recognised international journals and high-level conferences. Below we list the scientific publications of CHANGE which have been peer reviewed and published at major conferences or journals.

2.1 Journal Papers and Book Chapters

- Benjamin Frank, Ingmar Poese, Georgios Smaragdakis, Anja Feldmann, Bruce M. Maggs, Steve Uhlig, Vinay Aggarwal, Fabian Schneider, Collaboration Opportunities for Content Delivery and Network Infrastructures, ACM SIGCOMM ebook on Recent Advances in Networking, Volume 1, August 2013
- Luigi Rizzo, Revisiting network I/O APIs: the netmap framework Communications of the ACM, 55 (3), 45-51, March 2012 (a version of this paper appears on ACM Queue, January 2012), <http://queue.acm.org/detail.cfm?id=2103536>
- Nikolaos Chatzis, Georgios Smaragdakis, Anja Feldmann, Walter Willinger, There is More to IXPs than Meets the Eye, ACM SIGCOMM Computer Communication Review, 43(5), October 2013
- Benjamin Frank, Ingmar Poese, Yin Lin, Georgios Smaragdakis, Anja Feldmann, Bruce Maggs, Janis Rake, Steve Uhlig, Rick Weber, Pushing CDN-ISP Collaboration to the Limit, ACM SIGCOMM Computer Communication Review, 43(3), July 2013
- Georgios Smaragdakis, Nikolaos Laoutaris, Konstantinos Oikonomou, Ioannis Stavrakakis, Azer Bestavros, Distributed Server Migration for Scalable Internet Service Deployment, IEEE/ACM Transactions on Networking, accepted in 2013, [to appear]
- Nikolaos Laoutaris, Georgios Smaragdakis, Rade Stanojevic, Pablo Rodriguez, Ravi Sundaram, Delay-Tolerant Bulk Data Transfers on the Internet, IEEE/ACM Transactions on Networking, accepted in 2013, [to appear]
- R. Khalili, N. Gast, M. Popovic, J.-Y. Le Boudec, MPTCP is not Pareto-optimal: Performance issues and a possible solution, accepted at IEEE/ACM Transaction on Networking (will be published at October issue, 2013)
- Simon van der Linden, Gregory Detal, and Olivier Bonaventure, Revisiting next-hop selection in multi-path networks, ACM SIGCOMM Computer Communication Review, volume 41, pages 420-421, ACM, 2011

- Gregory Detal, Christoph Paasch, Simon van der Linden, Pascal Merindol, Gildas Avoine, and Olivier Bonaventure, Revisiting flow-based load balancing: Stateless path selection in data center networks, *Computer Networks*, 57(5):1204-1216, April 2013

2.2 International Conferences and Workshops

- Luigi Rizzo, Giuseppe Lettieri, Vincenzo Maffione, Speeding up packet I/O in virtual machines, IEEE/ACM ANCS 2013, San Jose, October 2013, <http://www.ancsconf.org/conference-program>
- Luigi Rizzo, Giuseppe Lettieri, VALE: a switched ethernet for virtual machines, ACM CoNEXT'2012, Nice, France, December 2012, <http://conferences.sigcomm.org/co-next/2012/program.html>
- Luigi Rizzo, netmap: a novel framework for fast packet I/O, Usenix ATC'12 (Best paper award), Boston, USA, June 2012
- Luigi Rizzo, Marta Carbone, Gaetano Catalli, Transparent acceleration of software packet forwarding using netmap, Infocom 2012, Orlando, March 2012, <http://www.ieee-infocom.org/2012/program.html>
- Luigi Rizzo, Matteo Landi, netmap: memory mapped access to network devices, Sigcomm 2011 Poster (Best poster award), Toronto, August 2011
- Francesco Salvestrini, Gino Carrozzo, Nicola Ciulli, Towards a distributed SDN control: Inter-platform signaling among flow processing platforms, Software Defined Networks for Future Networks and Services (SDN4FNS), Trento (Italy), November 2013
- Quang Dung Pham, Florence Massen, Yves Deville, Olivier Bonaventure, A Tabu Search Approach for Online and Offline Network Service Embedding, Submitted to CPAIOR 2014, Cork, Ireland
- Norbert Egia Adam Greenhalgh, Mark Handley, Mickael Hoerd, Felipe Huici, Laurent Mathy, Panagiotis Papadimitriou, Forwarding Path Architectures for Multicore Software Routers, CoNEXT 2010 PRESTO Workshop, Philadelphia, USA, Nov 30th, 2010
- Mark Handley, Flow processing and the rise of the middle, MSN 2011, Abingdon, UK, 11/07/2011
- Simon van der Linden, Gregory Detal, Olivier Bonaventure, Revisiting Next-hop Selection in Multipath Networks, SIGCOMM '11, Toronto, 17/08/2011
- Vladimir Olteanu, Costin Raiciu, Efficiently Migrating Stateful Middleboxes, 23rd ACM Symposium on Operating Systems Principles, Cascais, Portugal, 23-26 Oct. 2011

- Vladimir Olteanu, Costin Raiciu, Efficiently Migrating Stateful Middleboxes, SIGCOMM 2012, Helsinki, Finland, 14-16 Aug. 2011
- Mohamed Ahmed, Felipe Huici, Armin Jahanpanah, Enabling Dynamic Network Processing with ClickOS, SIGCOMM 2012, Helsinki, Finland, 14-16 Aug. 2011
- Christoph Paasch, Gregory Detal, Fabien Duchene, Olivier Bonaventure, Costin Raiciu, Exploring Mobile/WiFi Handover with Multipath TCP, SIGCOMM '12 CellNet workshop, Helsinki, Finland, 13/08/2012
- Michio Honda, Felipe Huici, Luigi Rizzo, MiniStack: Operating System Support for Fast User-space Network Protocols, OSDI 2012, Hollywood, CA, USA, 08-10 Oct. 2012
- Nikola Gvozdiev, Brad Karp, Mark Handley, LOUP: Whos Afraid of the Big Bad Loop?, HotNets 2012, Redmond, US, 29-30 Oct. 2012
- Nikolaos Chatzis, Georgios Smaragdakis, Jan Boettger, Thomas Krenc, Anja Feldmann, On the Benefits of Using a Large IXP as an Internet Vantage Point, ACM IMC 2013
- Florian Streibelt, Jan Boettger, Nikolaos Chatzis, Georgios Smaragdakis, Anja Feldmann, Exploring EDNS-Client-Subnet Adopters in your Free Time, ACM IMC 2013
- Y.-C. Chih, Y.-S. Lim, R. J. Gibbens, E. Nahum, R. Khalili, D. Towsley, A Measurement-based Study of MultiPath TCP Performance over Wireless Networks, ACM Internet Measurement Conference, long paper, ACM IMC 2013
- Arne Ludwig, Stefan Schmid, Anja Feldmann, Specificity vs. Flexibility: On the Embedding Cost of a Virtual Network, In Proc. of 25th International Teletraffic Congress (ITC), 2013
- Philipp S. Schmidt, Theresa Enhardt, Ramin Khalili, Anja Feldmann, Socket Intents: Leveraging Application Awareness for Multi-Access Connectivity, CoNEXT 2013
- Christoph Paasch, Ramin Khalili, Olivier Bonaventure, On the Benefits of Applying Experimental Design to Improve Multipath TCP, CoNEXT 2013
- Gregory Detal, Benjamin Hesmans, Olivier Bonaventure, Yves Vanaubel, and Benoit Donnet, Revealing middlebox interference with Tracebox, Proceedings of the 2013 ACM SIGCOMM conference on Internet measurement conference, ACM, October 2013
- Gregory Detal, Christoph Paasch, and Olivier Bonaventure, Multipath in the middle(box), CoNEXT workshop HotMiddlebox, ACM, December 2013
- Benjamin Hesmans, Fabien Duchene, Christoph Paasch, Gregory Detal, and Olivier Bonaventure, Are TCP extensions middlebox-proof?, CoNEXT workshop HotMiddlebox ACM, December 2013

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- Costin Raiciu, Christoph Paasch, Sebastien Barre, Alan Ford, Michio Honda, Fabien Duchene, Olivier Bonaventure, and Mark Handley. How hard can it be? designing and implementing a deployable Multipath TCP, USENIX Symposium of Networked Systems Design and Implementation (NSDI12), San Jose, USA, 2012
 - HO Trong Viet, Yves Deville, Olivier Bonaventure, and Pierre Francois, Traffic engineering for multiple spanning tree protocol in large data centers, ITC 2011 23rd International Teletraffic Congress, San Francisco, USA, September 2011
 - Joao Martins, Mohamed Ahmed, Costin Raiciu, Vladimir Olteanu, Michio Honda, Roberto Bifulco, Felipe Huici, ClickOS and the Art of Network Function Virtualization, NSDI 2014 (to appear)

3 Exploitation Activities Carried out by the Project's Industrial Partners

This section provides an overview of the exploitation activities carried out by the project's industrial partners. It lists presentations and talks given at industry venues as well as updated exploitation plans of the project's industrial partners.

3.1 Presentations, Talks, and Similar Exploitation Activities

- Enabling Innovation in the Internet Architecture through Flexible Flow-Processing Extensions, ICT 2010, Brussels, Belgium, 27-29 Sept. 2010, Felipe Huici (NEC)
- Enabling Innovation in the Internet Architecture through Flexible Flow-Processing Extensions, EC Future Internet Cluster, Brussels, Belgium, 18-20 Oct. 2010, Felipe Huici (NEC)
- CHANGE requirements for OFELIA, Felipe Huici
- CHANGE: A boost to innovation on the Internet, CHANGE Eurescom Press Release, 08/11/2010, CHANGE partners
- Slides from chairs, Virtualized Programmable Platform, OpenFlow Virtualization Acid Tests Meeting of the IRTF Virtual Networks Research Group (VNRG), Martin Stiemerling is co-chair, Beijing, China, November 12th, 2010, Martin Stiemerling (NEC) for first slides, other slides by externals
- CHANGE: A boost to innovation on the Internet, CHANGE NEC Press Release, 12/11/2010, CHANGE partners
- Programmability of the infrastructure, Smart Infrastructures session, FIA Ghent, Ghent, Belgium, 16/12/2010, Adam Kapovits
- CHANGE + OFELIA press release, NEC Press Release, 07/13/2011, CHANGE partners
- Click Under the Hood - Click Manual, Click's official wiki page, 12/05/2011, Felipe Huici
- Virtualization and Software Networking, CFIP2011, Sainte-Maxime, France, 12/05/2011, contributions from various CHANGE partners
- Virtualization and Software Networking, Seminar@UCLouvain, Louvain-la-Neuve, Belgium, 19/05/2011, contributions from various CHANGE partners
- Software Networking and Flow Processing, Seminar Series, The Institute of Computing Technology, The Chinese Academy of Sciences Beijing, China, 08/06/2011, contributions from various CHANGE partners

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- Flow Processing for Internet Innovation, 3rd Future Internet Testbed & Research (FIT&R) Workshop, Seoul, Korea, 13/06/2011, contributions from various CHANGE partners
 - Virtualization and Software Networking, 6th International Conference on Future Internet Technologies (CFI 2011), Seoul, Korea, 14/06/2011, contributions from various CHANGE partners
 - Virtualization and Software Networking, Keynote at Social Networks and Future Internet Workshop Annecy, France, 27/06/2011, contributions from various CHANGE partners
 - Not your father's Internet, or where did the Internet architecture go? And what can we do about it?, CHANGE/OFELIA Summer School Berlin, Germany, 7-11 Nov. 2011, Mark Handley (UCL)
 - Network virtualization, CHANGE/OFELIA Summer School, Berlin, Germany, 7-11 Nov. 2011, Laurent Mathy (Lancaster U)
 - OpenFlow Tutorial, CHANGE/OFELIA Summer School, Berlin, Germany, 7-11 Nov. 2011, Srinivas Seetharaman, Paul Weissmann (DT)
 - OpenFlow in Production Networks, CHANGE/OFELIA Summer School, Berlin, Germany, 7-11 Nov. 2011, Paul Weissmann, Srinivas Seetharaman
 - The dark forces of the middle and the battle for the future Internet, CONEXT Student Workshop Keynote, Tokyo, Japan, 6 Dec 2011, contributions from various CHANGE partners
 - Why Software-Defined Networking matters, 9th FP7 Concertations: Future Networks - the way beyond 2013, Brussels, Belgium, 14 Feb 2012, contributions from various CHANGE partners
 - The dark forces of the middle and the battle for the future Internet, AIT seminars, Vienna, Austria, 13 Mar 2012, contributions from various CHANGE partners
 - The dark forces of the middle and the battle for the future Internet, Flexible Networks workshop, Guildford, UK, 24-25 Apr 2012, contributions from various CHANGE partners
 - The dark forces of the middle and the battle for the future Internet, Seminar Series, Institute of Computing Technology, The Chinese Academy of Sciences, Beijing, China, 28 Sep 2012, contributions from various CHANGE partners
 - Forwarding Path Architectures for Multicore Software Routers, Huawei Campus, Beijing, China, Oct 9, 2012
 - Towards a distributed SDN control - Inter-platform signalling & Flow-aware Path Computation Element (PCE), SDN and OpenFlow World Congress, Darmstadt, Germany, 23-24 Oct. 2012, Nicola Ciulli (NXW)

- Free your middleboxes down to the data plane with tiny, fast network VMs, EWSDN 2012, Darmstadt, Germany, 25-26 Oct. 2012, Saverio Niccolini, Felipe Huici, Mohamed Ahmed (NEC), Luigi Rizzo (UNIFI)
- Software Defined Networking: which way forward?, IEEE Infocom 2013 Panel, Turin, Italy, Apr. 17, 2013, Laurent Mathy
- Towards a distributed SDN control: Inter-platform signalling & Flow-aware Path Computation Element (PCE), SDN & OpenFlow World Congress, Darmstadt - Denmark, Oct. 22nd-24th 2012, Nicola Ciulli (NXW)
- SDN principles applied to datacenters and metro-core networks: towards a network operating system, SDN & OpenFlow World Congress, Bad Homburg - Frankfurt, Oct. 15th-18th 2013, Nicola Ciulli (NXW)
- Enabling innovation in the Internet: main achievements of the CHANGE project, EWSDN 2013, Friday, October 11th, <http://ewsdn.org>, Invited Speaker Session; Felipe Huici (NEC Laboratories Europe)
- Accelerating software switches with Netmap, EWSDN 2013, Friday, October 11th, <http://ewsdn.org>, Industry Session, Michio Honda (NEC Laboratories Europe)
- Network Functions Virtualization on top of Xen², by Simon Kuenzer (NEC), DENOG, November 14th 2013, <http://www.denog.de/meetings/denog5/agenda.php?lang=en>
- Enabling Fast, Dynamic Network Processing with ClickOS, by Joao Martins (NEC), Xen Summit 2013, October 24-25th, 2013, <http://events.linuxfoundation.org/events/xen-project-developer-summit>
- Enabling CDN-ISP Collaboration, Georgios Smaragdakis, Plenary Talk at RIPE 67. Athens, Greece, October 14-18, 2013
- Client-IP EDNS Option Concerns, Florian Streibelt, RIPE 67, DNS Working Group, Athens, Greece. October 14-18, 2013
- How to explore EDNS-Client-Subnet Supporters in your Free Time, Florian Streibelt, DENOG 5, Darmstadt, November 14, 2013
- Unintended Consequences: Exploring EDNS-Client-Subnet Adopters in your Free Time, Florian Streibelt, IEPG Meeting at IETF 87, Berlin, DE, July 28, 2013
- Enabling CDN-ISP Collaboration, Georgios Smaragdakis, University of Athens, Athens, Greece, June 26, 2013

- Content-aware Traffic Engineering, Georgios Smaragdakis, OTE Labs, Athens, Greece, June 21, 2013
- Content-aware Traffic Engineering, Georgios Smaragdakis, Athens University of Economics and Business, Athens, Greece, May 14, 2013
- Pushing CDN-ISP Collaboration to the Limit, Georgios Smaragdakis, University of Wisconsin, Madison, USA, April 26, 2013
- Flow processing and the rise of the middle, Seventh Future Internet Cluster Workshop, Brussels, Belgium, February 2012, Olivier Bonaventure
- Multipath TCP, IEEE CloudNet 2012, Invited Talk, Paris, France, November 2012, Olivier Bonaventure
- Multipath TCP, GoogleTechTalks, Google, Mountainview, CA, USA, April 2012, Christoph Paasch, Costin Raiciu
- Tracebox, Invited Talk, Universite de Liège, Belgium, October 2013, Gregory Detal
- ClickOS demo at the annual NEC Openhouse Conference, September 2013.

3.2 Industrial Partners' Exploitation Plans and Industrial Adoption

3.2.1 Nextworks

3.2.1.1 Partner profile

Nextworks s.r.l., located in Pisa, Italy, is a R&D SME that was created in 2002 as a spin-off company of the Computer Science and Telecommunications Division of the Consorzio Pisa Ricerche (CPR-DITEL). Nextworks was created by a group of engineers and computer scientists who gained high experience in National and International research projects and industrial consultancies since 1995. Nextworks operates in the TLC sectors, collaborating with some of the major European manufacturers and operators. The company's team boasts long-term experience and proven skills in the frameworks of Control Plane technologies for wired and wireless transport networks, design and development of complex software on both traditional and embedded platforms and in Quality of Service (QoS) in packet networks, IP telephony, digital video encoding and streaming.

The consulting activities carried out by Nextworks range from pure support consulting on one end, up to long-term, third-party software design & developments for equipment vendors on the other end (e.g. Alcatel-Lucent and Ericsson). The specific nature and technical position of these activities require a leading-edge, up-to-date know-how and technical expertise. In order to fulfil this requirement, Nextworks participates actively in EU funded research projects, cooperating with both academic and industrial partners, as an important and preferential investment to develop and update know-how on selected topics. Recent examples include projects dealing with Network Control Plane enhancements (e.g. FP7 ICT GEYSERS, FP7 ICT PHOSPHORUS),

projects dealing with Software-Defined Networking and datacenter network services (e.g. FP7 ICT FIBRE, FP7 ICT LIGHTNESS, FP7 ICT CONTENT) as well as those dealing with clean-slate network architectures (e.g. FP7 IRATI, PRISTINE).

3.2.1.2 Exploitation plans and results

The Nextworks plans for exploiting the CHANGE results are based on two major activities carried out in WP4: the design and the prototyping of the inter-platform signaling framework and the mechanisms and procedures to allow chaining services among different flow processing platforms. The key foreground software obtained from CHANGE is the Inter-platform signaling framework, integrated within the FlowStream platform (the CHANGE reference platform). Primary outcomes from this research activity at Nextworks are the the framework software components (i.e. Service Manager, Signaling Manager) by which the service layer (e.g. a SDN controller) can interface to the network and interact with it for advanced flow processing services provisioning (e.g. LS-NAT, Distributed DPI). These components allow a set of CHANGE platforms to dynamically interact each-other for the joint provisioning of an end-to-end flow processing service. The architecture design pivots around the Flow Processing Route (FPR) concept that encapsulates a concatenation of hops, constituting an explicitly routed path. Using the FPR, the paths taken by flows can be administratively pre-determined, automatically computed by a decision entity or demanded to a hop-by-hop decision. This concept represents the foundation for an extensible signaling framework that allows to chain services among different platforms and could be easily adapted to different deployments and routing models.

Nextworks work on the CHANGE inter-platform signaling mechanisms is part of broader research strategy the company has been undertaking from some years on the Software Defined Networking. The ultimate goal for Nextworks is to build control plane tools to allow the instantiation of network services on-demand and bound to / joint with the IT provisioning phases. Key applicability areas of this research are the data centers and the geographically distributed and virtualized services. In a framework of SDN applications mostly centralized and minimal (down to none) interactions among controllers, the signaling framework provides an important background for an east-west SDN interface, to be used for chaining flow processing services among different controllers. In such contexts, the foreground software obtained in CHANGE can be adapted and extended towards a distributed SDN approach where different SDN controllers talk each other. The SDN strategy at Nextworks has been targeted for a medium/long-term consolidation in the next 3-5 years: in this plan, the CHANGE activities on inter-platform signaling can represent a pragmatic reference solution to be used and further enhanced for an operative SDN environment particularly targeted to data-centers. Another exploitation opportunity that can be generated by CHANGE research activities is the know-how increase of the company R&D team on service chaining approaches and architectures. The company has a growing set of customers who require highly-specialized consulting on very specific network control areas. Software Defined Networking, Network Function Virtualization and Service Function Chaining are hot topics rapidly emerging as customer priorities. Nextworks consulting in this area mostly consists of architect / designer

roles, with Nextworks engineers involved in the design of specific network / software solutions for customers like Network Service Providers (e.g. Interoute) and Content Providers / Producers (e.g. the European Space Agency). The R&D activities in CHANGE can directly and easily turn in an increased competitiveness for Nextworks in this market, leveraging on an updated know-how produced by the project and the amount of contacts exported by the consortium in the IT and network communities.

The current CHANGE-driven exploitation strategy outlined at Nextworks in the consulting area consists of the following two major phases:

- In the short term the company will consolidate its position with the current customers, possibly starting also new activities related to the CHANGE technological themes related to SDN, NFV and the NFV / SFC convergence.
- In a medium and long term perspective, Nextworks will try to differentiate its market coverage, contacting new potential customers for small and medium size consultancy activities. This approach will not only open new business perspectives, but also reduce the economic risk of incidental loss of a specific customer.

A further potential exploitation route could be pursued around the Signaling framework software, delivered as key component of the CHANGE Platform as a whole independent product. Potential business activities for Nextworks around this software product beyond the CHANGE project could consist of software maintenance and customization services.

3.2.2 NEC

The ClickOS work has been showcased to a number of NEC business units, many of which have shown interest. Beyond this, NEC's work on high performance software switches will likely be adopted into business unit projects for fiscal year 2014. In particular, NEC presented a ClickOS demo at the annual 'NEC Openhouse Conference'. The conference showcases selected, outstanding work from any of its Japanese and world-wide research laboratories. The demo was shown to other researchers, managers, and top-level executives, including NEC's CEO. The demo highlighted ClickOS' ability to instantiate large numbers of middlebox virtual machines versus how long it would take using Linux VMs. At the click of a button, a server would instantiate 10 ClickOS VMs, while another would do the same with Linux VMs. A GUI would show that ClickOS finished practically immediately, while the Linux VM server would take seconds/minutes to do the same task. The demo was very well received.

3.2.3 UCL-BE

Part of the MPTCP work carried out in CHANGE has recently been adopted as part of Apple's IOS operating system (see <http://www.networkworld.com/news/2013/091913-ios7-multipath-273995.html>). While it is so far only used for its Siri service, it is a major step towards an actual, real-world deployment.

Gregory Detal received a funding for 2 years by the Walloon Region in Belgium to evaluate the possibility of creating a spin-off based on the MPTCP/TCP converter developed within the project. Two business models are evaluated: bonding Internet connectivities for enterprise networks for a more reliable and efficient Internet service and/or provide WiFi/3G offloading for network operators.

4 Contributions to Standards Bodies

4.1 ONF and ETSI NFV

The Open Networking Foundation (ONF) standardizes the Openflow protocol and further interfaces required to enable Openflow-based networks. NEC contributed to the discussions on Openflow standardization and Northbound API issues. NEC also channelled developments out of ONF back to the CHANGE project. The feedback was used in the research and development of some of the modules of the VALE/mSwitch high-speed software switch (see Deliverable D5.3)

In early 2013, an ETSI Industrial Specification Group (ISG) was founded on the topic of Network Functions Virtualization (NFV). An important part of NFV is reusing the concepts of SDN in terms of steering flows through a network in order to reach various network functions. NEC bridged the gap between the NFV activity and the CHANGE project in order to check if results out of CHANGE could be reused in ETSI NFV. More specifically, the results from the ClickOS work (see Deliverable D5.3) have been used to augment and enhance the discussion and documents coming out of the performance track of the ETSI NFV group.

4.2 IETF

4.2.1 Multipath TCP

Over the course of the CHANGE project UCL-BE published two IETF drafts on topics relevant to MultiPath TCP (MPTCP):

- **MultiPath TCP Low Overhead ([2])** This draft proposes a variant of the MPTCP handshake presented in the initial IETF draft ([4]). The proposed handshake allows to reduce the computational overhead of establishing an MPTCP connection and the associated TCP subflows in controlled environments where security attacks are not a concern. This is achieved by removing the authentication mechanism described in [4]. It is assumed that end-hosts will only use this low-overhead version of MPTCP for non-security critical traffic or in controlled environments like isolated data-centers.
- **Securing the MultiPath TCP handshake with external keys ([3])** MultiPath TCP such as proposed in the initial draft ([4]) addresses the security threats identified in [1] by exchanging keys in clear during the handshake for the initial subflow. These keys are then used in the authentication procedure for the establishment of subsequent TCP subflows. Exchanging keys in clear during the initial handshake has obvious shortcomings from a security viewpoint. Some application-layer protocols like SSL/TLS or ssh already negotiate a shared key between the end-points. This draft proposes a variant of the MPTCP handshake allowing MultiPath TCP to reuse keys negotiated by the Application layer protocol above it such as SSL/TLS to authenticate the establishment of additional subflows.

These contributions have been presented at the IETF-85 meeting in Atlanta (November 2012).

4.2.2 ALTO

NEC contributed to the IETF Application Layer Traffic Optimization (ALTO) WG the following drafts with CHANGE acknowledgement:

- **ALTO Server Discovery** The goal of Application-Layer Traffic Optimization (ALTO) is to provide guidance to applications that have to select one or several hosts from a set of candidates capable of providing a desired resource. ALTO is realized by a client-server protocol. Before an ALTO client can ask for guidance it needs to discover one or more ALTO servers. This document specifies a procedure for resource consumer initiated ALTO server discovery, which can be used if the ALTO client is embedded in the resource consumer. [6]
- **ALTO Deployment Considerations** Many Internet applications are used to access resources, such as pieces of information or server processes, which are available in several equivalent replicas on different hosts. This includes, but is not limited to, peer-to-peer file sharing applications. The goal of Application-Layer Traffic Optimization (ALTO) is to provide guidance to these applications, which have to select one or several hosts from a set of candidates that are able to provide a desired resource. This memo discusses deployment related issues of ALTO. It addresses different use cases of ALTO such as peer-to-peer file sharing and CDNs, security considerations, recommendations for network administrators, and also guidance for application designers using ALTO. [9]

Both drafts have been presented several times at various IETF meetings during the timeframe of the CHANGE project.

4.2.3 CDNI

NEC contributed to the IETF Content Delivery Interconnection (CDNI) WG the following drafts with CHANGE acknowledgement:

- **CDNI Request Routing: Footprint and Capabilities Semantics** This document tries to capture the semantics of the 'Footprint and Capabilities Advertisement' part of the CDNI Request Routing interface, i.e. the desired meaning and what 'Footprint and Capabilities Advertisement' is expected to offer within CDNI. The discussion in this document has the goal to facilitate the choosing of one or more suitable protocols for 'Footprint and Capabilities Advertisement' within CDNI Request Routing. This document is a working group item in the IETF CDNI WG. [7]
- **CDNI Footprint and Capabilities Advertisement using ALTO** Network Service Providers (NSPs) are currently considering to deploy Content Delivery Networks (CDNs) within their networks. As a consequence of this development, there is a need for interconnecting these local CDNs. The necessary interfaces for inter-connecting CDNs are currently being defined in the Content Delivery Networks Interconnection (CDNI) WG. This document focuses on the CDNI Footprint & Capabilities Advertisement interface (FCI). Specifically, this document outlines how the solutions currently being defined in

the Application Layer Traffic Optimization (ALTO) WG can facilitate Footprint & Capabilities Advertisement in a CDNI context, i.e. how the CDNI FCI can be realised with the ALTO protocol. Concrete examples of how ALTO can be integrated within CDNI request routing and in particular in the process of selecting a downstream CDN are given. The examples in this document are based on the use cases and examples currently being discussed in the CDNI WG. [8]

Both drafts have been presented several times at various IETF meetings during the timeframe of the CHANGE project.

5 Open Source Software Released

5.1 Netmap

The following Software has been released by the CHANGE project (for details, please see <http://info.iet.unipi.it/~luigi/netmap/>):

- CHANGE released netmap (source code and demo OS images for FreeBSD and Linux)
 - source code for of Netmap and VALE
 - tinycore (Linux) bootable OS image
 - picobsd (FreeBSD) bootable OS image
- CHANGE released openvswitch patches to make openvswitch work on FreeBSD/libpcap and get good performance in userspace
- CHANGE released the Inter-platform Signaling framework prototype as open source software. The software package has been licensed as GPL-2 material.

netmap is a framework for high speed packet I/O. You can use it to build extremely fast traffic generators, monitors, software switches or network middleboxes. Its companion software switch VALE lets you interconnect virtual machines, and do performance analysis of all the above without expensive 10 Gbit/s links. netmap and VALE are implemented as a non intrusive kernel module, support NICs from multiple vendors, are part of standard FreeBSD distributions and available in source format for Linux too.

5.2 MBtest

MBtest is a netkit/UML and click based tool that let you easily test new transport protocol or TCP extensions through various kind of middleboxes. The code is freely available at <http://bitbucket.org/bhesmans/mbtest>.

- the user chose the linux kernel that he wants to try. MBtest has been used to test MPTCP kernel, and several TCP extensions.
- pseudo language to configure combination of middleboxes on one or several path(s)
- click embedded : new elements can be used to capture new middleboxes' behavior

The tool has been extensively used for [5].

5.3 Multipath TCP

The Linux kernel implementation of Multipath TCP is available at <http://multipath-tcp.org>. The site provides access to the Git-repository, Bug-reporting facilities as well as to the mptcp-dev Mailing List. Furthermore

this site gives access to several slides explaining MPTCP and also gives detailed instructions to install MPTCP as well as statistics on MPTCP usage in the world. Finally explanations on how the researchers from UCL-BE were able to break the record of the fastest TCP connection with MPTCP can be found.

It is the IETF's reference implementation of Multipath TCP. It includes a fully standard-compliant implementation of the Multipath TCP protocol. Within the CHANGE project, the maintenance of this implementation has been accomplished. The maintenance-work included the fixing of bugs as well as aligning the implementation with the upstream Linux kernel.

Further, several new features have been added to the implementation. The support for TCP segmentation offloading (TSO) allowed to achieve up to 53 Gbit/s for a single Multipath TCP session. The addition of dynamic subflow removal and destruction allowed the use of Multipath TCP on mobile devices (e.g., smartphones). On <http://multipath-tcp.org/pmwiki.php?n=Main.50Gbps> a demonstration video showing the goodput achieved with MPTCP can be found.

5.4 Tracebox

'tracebox' is an open-source software developed within the CHANGE project. Middleboxes manipulate traffic for purposes other than simple packet forwarding and often transparently to the end-user (e.g. NAT, transparent proxies, DPI, etc.). Detecting such middleboxes is difficult today.

Tracebox is a tool that allows to detect middleboxes on any paths, i.e., between a source and any destination. Tracebox can be viewed as a tool similar to traceroute as it uses ICMP replies to identify changes in the packets. Tracebox is available at <http://www.tracebox.org>.

6 Other Talks and Dissemination Activities

6.1 Talks

- Luigi Rizzo, netmap: the fast network packet I/O framework, EuroBSDCon 2013, Malta, September 2013
- Luigi Rizzo, From netmap to virtualization through openvswitch, Linux Plumbers 2013, New Orleans, September 2013
- Luigi Rizzo, Evolution of the netmap architecture, Coseners Meeting, Oxford (UK), July 2013
- Luigi Rizzo, Fast network I/O in virtual machines, Microsoft Research, Cambridge, UK, July 2013
- Luigi Rizzo, Fast network I/O in virtual machines, NUIE, Maymoth, Ireland, July 2013
- Luigi Rizzo, Fast network I/O in virtual machines, Zagreb University, Zagreb, Croatia, June 2013
- Luigi Rizzo, Lightning fast networking in your virtual machine, BSDCan 2013, Ottawa, May 2013
- Luigi Rizzo, Moving packets. Fast. OnLAB, Palo Alto, February 2013
- Luigi Rizzo, Fast network I/O in virtual machines, IBM, Yorktown Heights, March 2013
- Luigi Rizzo, High speed networking in a VM Google, Mountain View, February 2013
- Luigi Rizzo, The netmap framework for high speed packet I/O Riverbed, Sunnyvale, May 2012
- Luigi Rizzo, High speed packet I/O: challenges and solutions BSDCan 2012, Ottawa, May 2012
- Luigi Rizzo, Software packet processing in a 10 Gbit/s world, EPFL Summer School, Lausanne, June 2012 <http://memento.epfl.ch/event/software-packet-processing-in-a-10-gbits-w>
- Luigi Rizzo, Netmap: Software packet processing in a 10Gbit/s world, Stanford University, Palo Alto, November 2012 http://netseminar.stanford.edu/11_15_12.html; Video at <http://www.youtube.com/watch?v=LSztB-hpmyM>
- Luigi Rizzo, Netmap: Software packet processing in a 10Gbit/s world, UCSC, Santa Cruz, November 2012
- Luigi Rizzo, Netmap: software packet processing in a 10Gbit/s world, Netapp, Sunnyvale, November 2012
- Luigi Rizzo, netmap: a novel framework for high speed packet I/O, Harvard University, Cambridge (MA), February 2012 (same talk also given at Netapp, Boston, Feb. 2012)

- Luigi Rizzo, The netmap framework for fast packet I/O, Sosp 2011 short talk, Cascais (PT), October 2011
- Luigi Rizzo, Marta Carbone, Gaetano Catalli, Improving the performance of OpenvSwitch?, EuroBS-DCon 2011, Marsseen, NL, October 2011
- Luigi Rizzo, netmap: a novel framework for high speed packet access Google Tech Talk, Mountain View, August 2011 <http://www.youtube.com/watch?v=SPToXNW9yEQ> same talk also given at Apple HQ (Cupertino) and HP (Palo Alto)
- Nicola Ciulli (NXW), Invited talk: SDN & OpenFlow World Congress (Darmstadt - Denmark, 22-24 October 2012) - Towards a distributed SDN control: Inter-platform signalling & Flow-aware Path Computation Element (PCE)
- Nicola Ciulli (NXW), Invited talk: SDN & OpenFlow World Congress (Bad Homburg - Frankfurt, 15-18 October 2013) - SDN principles applied to datacenters and metro-core networks: towards a network operating system

6.2 Other Dissemination Activities

- Nicola Ciulli (NXW), participation to the Future Networks 6th FP7 Concertation meeting (Brussels - Belgium, Nov. 19th-21th 2010)
- Nicola Ciulli (NXW), participation to the 7th FP7 Concertation Meeting (Brussels - Belgium, Feb. 11th 2011)
- Nicola Ciulli (NXW), participation to the FIA - Future Internet Assembly (Budapest - Hungary, May 17th-19th 2011)
- Nicola Ciulli (NXW), participation to the FNMS - Future Network and Mobile Summit (Warsaw - Poland, June 15th-17th 2011)

7 Conclusions

This deliverable described the overall dissemination activities and achievements of the CHANGE project for the whole duration of the project. In summary, CHANGE has put great effort into properly disseminating project results. Consequently, dissemination of CHANGE results has been very successful. A broad dissemination was achieved by using different channels of making project results available to the public: Scientific publications, presentations and demonstrations at research conferences, presentations and demonstrations at industry venues, release of open source software, and contributions to standards bodies.

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