# Guest Editors' Introduction: Special Issue on Management of Softwarized Networks

Filip De Turck, *Senior Member, IEEE*, Prosper Chemouil, *Fellow, IEEE*, Raouf Boutaba, *Fellow, IEEE*, Minlan Yu, *Member, IEEE*, Christian Esteve Rothenberg, *Member, IEEE*, and Kohei Shiomoto, *Senior Member, IEEE*

## I. Introduction

THERE is currently a strong interest in both industry and academia in the softwarization of telecommunication networks and cloud computing infrastructures. This evolution is enabled by three paradigms. First, Software-Defined Networking (SDN) allows network control to be separated from the forwarding plane and allows for a flexible management of the network resources. Second, Network Virtualization (NV) brings virtualization concepts to the network, similar to cloud computing, which was enabled by virtualization of servers. Third, Network Function Virtualization (NFV) focuses on virtualization of software-based network functions. Instead of installing and managing dedicated hardware devices for these functions, they are implemented as software components and deployed on commodity hardware infrastructures, in most cases operated by a network operator or cloud infrastructure provider. Service Function Chaining (SFC) consists of building services using virtual network functions (VNFs). These three paradigms are synergetic and reinforce each other when used together. Several initial SDN, NV and NFV deployments are already operational in providers' networks.

In order to efficiently manage softwarized networks and to be able to use them to their full potential, there are many interesting challenges that need to be addressed in the areas of Software-Defined Networks, Network Virtualization, and Network Function Virtualization. In an earlier special issue on "Efficient Management of SDN/NFV-based Systems" in IEEE Transaction on Network and Service Management, published in two parts [1], [2], the main reported research contributions were: efficient resource allocation and management of softwarized network functions [3], [4], design of high-performance platforms to allow network function virtualization on commodity machines [5], enabling efficient collaboration between providers in softwarized networks [6], optimizations to flow-based software-defined networks to address the scalability and energy consolidation requirements [7], [8], programming abstractions in wireless software-defined networks [9], and improved network virtualization to more efficiently support latency sensitive applications [10].

As many more challenges need to be addressed, the current special issue reports upon recent advances in the area of "Management of Softwarized Networks".

In parallel, the IEEE NetSoft conference was established and dedicated to research on network softwarization. The first two editions respectively held in London, U.K., in 2015, and in Seoul, South Korea, in 2016 considered additional management issues in SDN and NFV systems. IEEE NetSoft 2017 that will be organized in Bologna, Italy, on July 3-7, 2017 will extend these considerations towards the design and management of 5G ecosystems.

## II. Special Issue Overview

Based on the above mentioned evolutions, it is clear that efficient management of software-defined virtualized telecommunication systems is of key importance for the future. This special issue welcomed submissions addressing the important challenges and presenting novel research or experimentation results. Survey papers that offered a perspective on related work and identify key challenges for future research have been considered as well.

Fifty four papers were submitted for this special issue. The submitted papers were thoroughly reviewed and some authors were given the time to update their papers and to address in detail the concerns raised by the reviewers. It was finally decided to accept fifteen papers for inclusion in this special issue.

The time between initial submission and publication of the revised papers in this special issue was six months.

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F. De Turck is with Ghent University-iMinds, 9052 Gent, Belgium (e-mail: filip.deturck@ugent.be).

P. Chemouil is with Orange Labs, 92320 Châtillon, France (e-mail: prosper.chemouil@orange.com).

R. Boutaba is with the University of Waterloo, Waterloo ON N2L 3G1, Canada (e-mail: rboutaba@uwaterloo.ca).

M. Yu is with Yale University, New Haven, CT 06520 USA (e-mail: minlan.yu@yale.edu).

C. E. Rothenberg is with the University of Campinas, Campinas, SP 13083, Brazil (e-mail: chesteve@dca.fee.unicamp.br).

K. Shiomoto is with Nippon Telegraph and Telephone Corporation, Tokyo 180-8585, Japan (e-mail: shiomoto.kohei@lab.ntt.co.jp).

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The selected papers in this special issue address critical topics that play a central role in the efficient management of softwarized telecommunication systems: SDN control planes optimizations, improvements of OpenFlow network traffic balancing and resilience, SDN traffic management optimizations, advanced virtual network embedding algorithms, including algorithms for reliable embedding, efficient NFV resource management and advanced platforms for the management of softwarized network systems.

## III. Accepted Papers

From the selected papers, in this special issue, three papers deal with advances in SDN control plane management (Section III-A), four papers focus on optimizations to Openflow networks and SDN traffic management (Section III-B), four papers present techniques for advanced management of virtual networks (Section III-C), and finally four papers report advances in the management of NFV-based systems (Section III-D).

### *A. Novel SDN Control Plane Management*

In "Control Plane Latency with SDN Network Hypervisors: The Cost of Virtualization", Blenk *et al.* [11] present a model-based analysis of SDN hypervisor architectures and introduce mixed integer programming formulations for four different SDN network hypervisor architectures in order to optimize the placement of multi-controller switches in virtualized OpenFlow-enabled SDN networks. Detailed evaluation results are presented, comparing the control plane latencies of the different SDN hypervisor architectures and quantifying the cost of virtualization, i.e., the latency overhead due to virtualizing SDN networks via hypervisors.

In "SDN Partitioning: A Centralized Control Plane for Distributed Routing Protocols", Caria *et al.* [12] focus on hybrid networks, where SDN is deployed to control prioritized traffic and OSPF to assure care-free operation of best effort traffic. The authors propose a new hybrid network architecture, referred to as SDN Partitioning (SDNp), which establishes centralized control over the distributed routing protocol by partitioning the topology into sub-domains with SDN-enabled border nodes. The required network management models for SDNp are detailed and a thorough performance study is presented.

In "The Budgeted Maximum Coverage Problem in Partially Deployed Software Defined Networks", Wu *et al.* [13] study the coexistence of software-defined networking (SDN) nodes with legacy nodes in hybrid networks, from a techno-economical perspective. The upgrade strategy to gradually deploy SDN nodes over time is considered in detail, taking into account budget constraints for the upgrade cycles. Two heuristic solutions are proposed and thoroughly evaluated and compared to other algorithms, in terms of investment cost and achieved hop coverage.

### *B. Optimizations to Openflow Networks and SDN Traffic Management*

Two papers focus on improvements of OpenFlow networks. In "Flexible Traffic Splitting in OpenFlow Networks", Tuncer *et al.* [14] focus on multipath routing coupled with arbitrary traffic splitting in OpenFlow networks. In contrast to existing approaches which mostly focus on equal splitting solutions, the authors present a new approach which exploits the properties of bit-masking operations to enable flexible traffic management in OpenFlow networks. It is shown that a high splitting accuracy can be obtained without requiring complex extensions to the OpenFlow protocol.

In "Optimization of SDN Flow Operations in Multi-Failure Restoration Scenarios", Astaneh and Heydari [15] present techniques for efficient execution of flow operations (i.e., adding or removing flow-entries to/from the flow-tables) to dynamically restore disrupted flows. The authors aim to minimize the number of operations and formulate integer programs to find the most appropriate paths in case of multi-failure scenarios. By means of detailed simulations, the trade-off between path cost and the number of operations is analyzed.

Two papers deal with SDN traffic management optimizations. In "Time4: Time for SDN", Mizrahi and Moses [16] present a new approach for path reconfiguration in SDN networks, while minimizing disruptions during network updates. An important component of the approach is TIME4, a tool designed by the authors to assist in various network update scenarios, including heavily utilized networks. The obtained packet loss in the considered update scenarios is characterized. The design and implementation details of a TIME4-enabled SDN network prototype are presented, together with a characterization of the benefits of the approach.

In "Consistent Network Management for Software-defined Networking based Multicast", Kohler *et al.* [17] introduce a management architecture allowing for an appropriate selection of an update mechanism in software-defined networks and its parameters based on expected inconsistency effects. The update consistency for the case of multicast routing is investigated in detail. An update procedure for multicast routing updates is presented: this procedure identifies critical update steps, which are fed back into the reconfiguration process, along with a lightweight approach that allows for the selection of an update strategy. Furthermore, an optimization of an existing update approach is presented together with an approach for in-network filtering of duplicates.

### *C. Advanced Techniques for Management of Virtual Networks*

In "Resource Slicing in Virtual Wireless Networks: A Survey", Richart *et al.* [18] present a survey of techniques for splitting a wireless network infrastructure into isolated virtual slices under their own management, requirements and characteristics. 5G, LTE and WiFi networks are considered. Because of the dynamicity and shared nature of the wireless medium in these networks, guaranteeing these isolated virtual slices has proven to be difficult. The paper presents the detailed definition of the problem, a discussion of research challenges, and a detailed review of existing works with focus on SDN and NFV-based approaches.

In "Efficient Virtual Network Optimization across Multiple Domains without Revealing Private Information",

Mano *et al.* [19] present algorithms for virtual network embedding in multi-domain networks under the assumption that providers do not share their private information including resource costs. The presented method employs secure multi-party computation for masking sensitive values and is able to optimize virtual networks in a time-efficient way. Experimental evaluations show the low execution times and optimality of the algorithms, even for large virtual networks.

In "A Reliable Embedding Framework for Elastic Virtualized Services in the Cloud", Ayoubi *et al.* [20] detail a novel technique for reliable embedding of virtual network requests given the heterogeneous failure rates of physical network components. The authors propose a framework that consists of two main modules: an availability-aware resource allocation embedding module for VNs, and a reliable reconfiguration module to adapt the embedding of hosted services. By means of numerical results, it is shown that the framework enhances the acceptance rate of virtual network requests and increases the provider's long-term revenue.

In "Generating Virtual Network Embedding Problems with Guaranteed Solutions", Fischer and de Meer [21] introduce a new approach for generating realistic virtual network embedding scenarios. The authors demonstrate how to produce scenarios with a guaranteed exact solution, which is very useful for a thorough evaluation of existing and future virtual network embedding algorithms.

### *D. Advanced Management of NFV-Based Systems*

Two papers in this special issue deal with NFV Resource Management. In "Resource Allocation in NFV: A Comprehensive Survey", Botero and Herrera [22] present a detailed state-of-the-art overview of NFV Resource Allocation (NFV-RA) algorithms. A novel classification is presented of the main approaches for solving NFV-RA. In addition, the authors present their view on future research challenges in the context of NFV-RA.

In "A Scalable Algorithm for the Placement of Service Function Chains", Mechtri *et al.* [23] propose an eigen-decomposition-based approach for the placement of virtual and physical network functions chains in softwarized networks. The performance of the approach is compared in detail to both a custom greedy algorithm and a multi-stage based method from the state of the art. The performance evaluation results show that the proposed approach outperforms the other techniques in terms of request acceptance rate and provider's revenue.

Finally, two papers deal with the design of advanced platforms for management of softwarized networks. In "Towards a Fully Cloudified Mobile Network Infrastructure", Sousa *et al.* [24] focus on the design of a softwarized infrastructure for Mobile Network Operators (MNOs). The authors present in detail the designed architecture, prototype implementations and obtained evaluation results. By means of two proof-of-concept scenarios, the benefits of the designed softwarized infrastructure are demonstrated.

Finally, in "Information Exchange Management as a Service for Network Function Virtualization Environments", Mamatas *et al.* [25] present an Information Exchange Management as a Service facility as an extension to ETSI's NFV Management and Orchestration (MANO) framework, namely the Virtual Infrastructure Information Service (VIS). VIS supports information flow establishment, operation, and optimization and is information-model agnostic. The authors also report an experimental analysis of the main functional and non-functional characteristics of the designed Virtual Infrastructure Information Service.

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**Filip De Turck** leads the Network and Service Management Research Group with the Department of Information Technology, Ghent University, Belgium, and iMinds (Interdisciplinary Research Institute, Flanders). He has (co-)authored over 450 peer-reviewed papers. His research interests include telecommunication network and service management and design of efficient virtualized network systems. In this research area, he is involved in several research projects with industry and academia, serves as the Vice Chair of the IEEE Technical Committee on Network Operations and Management, the Chair of the Future Internet Cluster of the European Commission, and is on the TPC of many network and service management conferences and workshops and serves on the editorial board for several network and service management journals. He is also a member of steering committee of the IEEE NetSoft Conference.

**Prosper Chemouil** received the M.Sc. and Ph.D. degrees in control theory from École Centrale de Nantes, in 1976 and 1978, respectively. He is currently a Research Director with Orange Labs. His research interests are with the design and management of future networks and technologies and their impact on network architecture, traffic engineering and control, and performance. He was a recipient of several awards, including the Blondel Medal in 1996, the Ampère Medal in 2003, the Salah Aidarous Memorial Award in 2014, the Arne Jensen Lifetime Achievement Award in 2015 and the nominee of French Senior Engineer of the Year in 1995. He has served as a Board Member, an Associate, and a Guest Editor for various journals, including the *IEEE Communications Magazine*, the IEEE TRANSACTIONS ON NETWORK AND SERVICE MANAGEMENT, the *IEEE Network*, and *Annals of Telecommunications*. As a Board Member of the IEEE SDN Initiative in charge of the Conference Track, he has launched the IEEE International Conference on Network Softwarization in 2015 and is the Chairman of its steering committee. He is the General Co-Chair of the 2017 IFIP/IEEE Symposium on Integrated Management to be held in 2017, Lisbon, Portugal. He is a fellow of the Electrical and Electronical Society of France (SEE).

**Raouf Boutaba** received the M.Sc. and Ph.D. degrees in computer science from the University Pierre and Marie Curie, Paris, in 1990 and 1994, respectively. He is currently a Professor of Computer Science with the University of Waterloo, Canada, and an Associate Dean Research with the Faculty of Mathematics. His research interests include resource and service management in networks and distributed systems. He was a recipient of several best paper awards and other recognitions such as the Premiers Research Excellence Award, the IEEE Hal Sobol Award in 2007, the Fred W. Ellersick Prize in 2008, the Joe LociCero and the Dan Stokesbury Awards in 2009, the Salah Aidarous Award in 2012, and the McNaughton Gold Medal in 2014. He served as a Distinguished Speaker for the IEEE Computer and the IEEE Communications Societies. He is the Founding Editor-in-Chief of the IEEE TRANSACTIONS ON NETWORK AND SERVICE MANAGEMENT from 2007 to 2010 and on the editorial boards of other journals. He is a fellow of the Engineering Institute of Canada and the Canadian Academy of Engineering.

**Minlan Yu** received the B.A. degree in computer science and mathematics from Peking University in 2006 and the M.A. and Ph.D. degrees in computer science from Princeton University in 2008 and 2011, respectively. She is an Assistant Professor with the Computer Science Department, Yale University. She has actively collaborated with companies such as Google, AT&T, Microsoft, Facebook, and Bell Labs. Her research interests include data networking, distributed systems, enterprise and data center networks, network virtualization, and software-defined networking. She was a recipient of the ACM SIGCOMM Doctoral Dissertation Award in 2011, the NSF CAREER Award in 2015, and the Google Research Awards in 2013 and 2015.

**Christian Esteve Rothenberg** received the Telecommunication Engineering degree from the Technical University of Madrid (ETSIT—UPM), Spain and the M.Sc. (Dipl. Ing.) degree in electrical engineering and information technology from the Darmstadt University of Technology, Germany, in 2006, and the Ph.D. degree from the University of Campinas, Brazil, in 2010, where he is an Assistant Professor with the Faculty of Electrical and Computer Engineering and currently leads the Information and Networking Technologies Research and Innovation Group. His research interests span all layers of distributed systems and his research projects in collaboration with academia and industry (e.g., Ericsson, Samsung, and CPqD) around the world have led to multiple open source system implementations (e.g., RouteFlow, libfluid, ofsoftswitch13, and Mininet-WiFi) in the areas of SDN and NFV, among other scientific results. He was a Senior Research Scientist in the areas of IP systems and networking at CPqD Research and Development Center, from 2010 to 2013.

**Kohei Shiomoto** received the B.E., M.E., and Ph.D. degrees in information and computer sciences from Osaka University, Osaka, in 1987, 1989, and 1998, respectively. He joined Nippon Telegraph and Telephone Corporation (NTT), Tokyo, Japan, in 1989. He is a Senior Manager with the Communication and Traffic Service Quality Project, NTT Network Technology Laboratories, NTT. He has been engaged in Research and Development of high-speed networking including ATM, IP, (G)MPLS, and IP+Optical networking in NTT Laboratories. From 1996 to 1997, he was a Visiting Scholar with Washington University, St. Louis, MO, USA. He has co-authored the book entitled *GMPLS Technologies: Broadband Backbone Networks and Systems (Optical Engineering)* (Marcel Dekker Inc.). He was a recipient of the Young Engineer Award from the IEICE in 1995 and the Switching System Research Award from the IEICE in 1995 and 2001. He is a fellow of IEICE and a member of ACM.