Guest Editors' Introduction: Special Section on Novel Techniques for Managing Softwarized Networks

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I. Introduction

THE SOFTWARIZATION of networks is enabled by the SDN (Software-Defined Networking), NV (Network Virtualization), and NFV (Network Function Virtualization) paradigms, and offers many advantages for network operators, service providers and datacenter providers. Given the strong interest in both industry and academia in the softwarization of telecommunication networks and cloud computing infrastructures, a series of special section was established in IEEE Transactions on Network and Service Management, which aims at the timely publication of recent innovative research results on management of softwarized networks.

The first special section in this series was titled "Efficient Management of SDN/NFV-Based Systems" and published in 2015 in two parts [item 1) in the Appendix], [item 2) in the Appendix]. The main reported research contributions were: efficient resource allocation and management of softwarized network functions, design of high-performance platforms to allow network function virtualization on commodity machines, enabling efficient collaboration between providers in softwarized networks, optimizations to flow-based software-defined networks to address the scalability and energy consolidation requirements, programming abstractions in wireless software-defined networks, and improved network virtualization to efficiently support latency sensitive applications.

The second special section in this series was published in 2016 with the title "Management of Softwarized Networks" [item 3) in the Appendix]. The main reported research contributions were: SDN control planes optimizations, improvements of OpenFlow network traffic balancing and resilience, SDN traffic management optimizations, novel virtual network embedding algorithms, including algorithms for reliable embedding, efficient NFV resource management and advanced platforms for management of softwarized network systems.

The third special section in this series was published in 2017 with the title "Advances in Management of Softwarized Networks" [item 4) in the Appendix]. The main reported research contributions were: management of softwarized datacenter networks, VNF (Virtual Network Function) management in NFV-based networks, performance characterization and optimization of NFV-based networks, novel techniques for SDN, advanced softwarized wireless networks, security and verification in softwarized networks, and management of softwarized content distribution networks.

There are many more interesting challenges currently being addressed by the research community, which aim at efficient management of softwarized networks and the ability to use the technologies and their enabling paradigms in any combination to their full potential, including network and service dynamics, slicing, resilience and security as well as techniques for optimization in wired and wireless networks.

The current special section reports upon recent advances in management of softwarized networks, addressing amongst others the above mentioned challenges.

In parallel to the IEEE TNSM series on softwarized networks, the IEEE NetSoft conference was established and dedicated to research on network softwarization. The first four editions were respectively held in London, U.K., in 2015, in Seoul, South Korea in 2016, in Bologna, Italy in 2017, and in Montreal, Canada in 2018. Each of these editions attracted 180+ participants from academia and industry. IEEE NetSoft 2019 will be organized in Paris, France, on June 24-28, 2019, with the overall theme "*Unleashing the Power of Network Softwarization*".

II. Special Section Overview

This special section welcomed submissions addressing the important challenges and presenting novel research and

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experimentation results on management of softwarized networks. Survey papers that offer a perspective on related work and identify key challenges for future research have also been considered.

Eighty-eight papers were submitted for this special section. The submitted papers were thoroughly reviewed and, when needed 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 twenty-four papers for inclusion in this special section.

The time between initial submission and online publication of the revised papers in this special section was at most six months.

The selected papers in this special section are addressing the following topics that currently play a very important role in the efficient management of softwarized networks: novel techniques for management of SDN-based networks addressing resilience, security, load balancing, configuration and monitoring, VNF management in NFV-based networks for orchestration and resource allocation, advanced softwarized switching and routing incl. virtual network routing and traffic estimation, management of softwarized wireless and cellular networks, in particular, and management of data center networks.

III. Accepted Papers

From the selected papers in this special section, four papers deal with management of SDN control plane (Section III-A), three papers focus on monitoring and configuration in Software- Defined Networks (Section III-B), six papers report upon novel techniques for the management of NFV-based networks (Section III-C), five papers focus on advanced techniques for softwarized switching and routing (Section III-D) and, finally six papers present recent results on softwarized wireless networks (Section III-E).

A. Advances in SDN Control Plane Management

Efficient operation and management of the SDN control plane is a basis for successful network operation. The papers in this category focus on different aspects of advances in SDN control plane management. The first two papers address distributed SDN controllers. The other two papers focus on resilience and security aspects.

In "A Load-Balancing Mechanism for Distributed SDN Control Plane Using Response Time", Cui *et al.* [item 5) in the Appendix] propose a new method for load balancing for distributed SDN controllers considering the response time rather than the controller load aiming at avoiding unnecessary migration costs within the control plane.

In "ZeroSDN: A Highly Flexible and Modular Architecture for Full-Range Distribution of Event-Based Network Control", Kohler *et al.* [item 6) in the Appendix] propose a new architecture for a distributed SDN control plane based on lightweight control modules to ease distribution and to improve manageability.

In "RASCAR: Recovery-Aware Switch-Controller Assignment and Routing in SDN", Savas *et al.* [item 7) in the Appendix] focus on the optimization problem of SDN switch to controller assignment minimizing the time required for data path recovery to avoid performance degradations.

In "BWManager: Mitigating Denial of Service Attacks in Software-Defined Networks Through Bandwidth Prediction", Wang *et al.* [item 8) in the Appendix] address an important security issue for SDN controllers. Their proposal supports the forecasting of the users' bandwidth requirement and trust values leading to different priority queues handled by a BWManager to be able to deal with DoS attacks.

B. Monitoring and Configuration in Software-Defined Networks

In network management, special attention should be given to monitoring and configuration. In this section, the authors focus on Software-Defined Networking and propose solutions for network configuration and monitoring, in particular.

In "Fast Network Configuration in Software-Defined Networking", Achleitner *et al.* [item 9) in the Appendix] provide solutions targeting the minimization of the time to deploy a set of flow rules, which leads to a significant reduction of the total network configuration time.

In "Reducing the Monitoring Footprint on Controllers in Software-Defined Networks", Hark *et al.* [item 10) in the Appendix] propose a so-called Statistic Request Relay (SRR) that forms a logically centralized relay for statistics between SDN controllers and the data-plane. They show how the SRR helps to reduce the number of statistics processed on controllers and requests on switches.

In "Self-Adaptive Decentralized Monitoring in Software-Defined Networks", Tangari *et al.* [item 11) in the Appendix] present a framework for resource monitoring in SDN that supports the collection of statistics with low impact on the network resources via automatically adjusting the settings based on the traffic dynamics.

C. Novel Techniques for the Management of NFV-Based Networks

Management and Orchestration of NFV-based networks is receiving increasing importance. The six papers in this section focus on NFV orchestration, resource allocation, function placement and interworking aspects.

In "z-TORCH: An Automated NFV Orchestration and Monitoring Solution", Sciancalepore *et al.* [item 12) in the Appendix] present an approach named zero Touch Orchestration (z-TORCH) that optimizes the orchestration process while minimizing the monitoring load for an NFV MANO system based on machine learning techniques.

In "ClusPR: Balancing Multiple Objectives at Scale for NFV Resource Allocation", Woldeyohannes *et al.* [item 13) in the Appendix] propose a mechanism considering the dependencies between flow routing and network function placement in NFV networks taking several objectives into account, such as minimizing path stretch and Network Function (NF) load balancing, to maximize the overall network utilization.

In "In Broker We Trust: A Double-Auction Approach for Resource Allocation in NFV Markets", Borjigin *et al.* [item 14) in the Appendix] present

a double-auction based study considering the maximization of the stakeholders' profits: the NFV operator, the NFV customers and the NFV service providers.

In "Cost and Availability Aware Resource Allocation and Virtual Function Placement for CDNaaS Provision", Yala *et al.* [item 15) in the Appendix] address the joint optimization of computing resource assignment and function placement for an on-demand content delivery network service provisioning scenario.

In "Optimization Model for Designing Multiple Virtualized Campus Area Networks Coordinating with Wide Area Networks", Kurimoto *et al.* [item 16) in the Appendix] focus on the planning of NFV-based Campus Area Networks to minimize both the total network cost for including the data transmission cost in wide area networks, and the data synchronization cost for failure recovery.

In "NFV Architecture for the Interworking Between WebRTC and IMS", Nguyen *et al.* [item 17) in the Appendix] propose an NFV-based interworking architecture between WebRTC and IMS and its analytic system model taking resource constraints, QoS and service costs into account.

D. Advanced Techniques for Softwarized Switching and Routing

Switching and routing constitute core network functions. Novel techniques are presented that consider new routing paradigms as well as softwarized switching mechanisms and their performance modeling.

In "SDN Architecture and Southbound APIs for IPv6 Segment Routing Enabled Wide Area Networks", Ventre *et al.* [item 18) in the Appendix] describe the implementation of a Linux-based node for IPv6 Segment Routing (SRv6) supported by Software-Defined Networking and the realization of the controller to SRv6 node interface, in particular.

In "Automated Inter-Domain Cut-Through Switching for the Future Internet", Lara *et al.* [item 19) in the Appendix] present a control plane design for the MobilityFirst Future Internet architecture aiming at replacing the Internet Protocol to improve content delivery and mobility. In that work, the focus is on cut-through switching to be able to automatically bypass certain functions for flows that do not need them.

In "An Accurate and Efficient Modeling Framework for the Performance Evaluation of DPDK-Based Virtual Switches", Begin *et al.* [item 20) in the Appendix] present an analytical queueing model to evaluate the performance of a DPDK-based vSwitch and demonstrate its accuracy.

In "An Efficient Route Management Framework for Load Balance and Overhead Reduction in SDN-Based Data Center Networks", Wang and You [item 21) in the Appendix] propose their L2RM framework to adaptively optimize the flow routes in data centers based on an SDN controller that configures the switches dynamically.

In "An SDN-Based Traffic Matrix Estimation Framework", Tian *et al.* [item 22) in the Appendix] present an approach for traffic matrix estimation in SDN-based networks exploiting the observation that an added flow increases the rank of the linear equation system underlying the traffic matrix estimation.

E. Advanced Softwarized Wireless Networks

The six papers in this category focus on mobile and wireless networks as an important application domain for management solutions for softwarized networks. More specifically, they address controller and function placement in edge clouds and edge networks, service composition of 5G network functions, Cloud-RAN and softwarized Device-to-Device Communication.

In "SDN Controller Placement with Delay-Overhead Balancing in Wireless Edge Networks", Qin *et al.* [item 23) in the Appendix] present a proof-of-concept realization of a wireless edge system with multiple controllers and provide solutions for controller placement in edge nodes.

In "A Benders Decomposition Approach for Resilient Placement of Virtual Process Control Functions in Mobile Edge Clouds", Zhao and Dán [item 24) in the Appendix] focus on the placement of virtualized industrial process control functions on 5G Mobile Edge Computing resources taking resilience requirements into account.

In "RDNA: Residue-Defined Networking Architecture Enabling Ultra-Reliable Low-Latency Datacenters", Liberato *et al.* [item 25) in the Appendix] address Mobile Edged Computing in micro data centers and provide novel solutions for supporting latency constraints as well as reliability requirements.

In "Coordinated Service Composition and Embedding of 5G Location-Constrained Network Functions", Spinnewyn *et al.* [item 26) in the Appendix] present techniques for a combined optimization of service function placement and service chain composition in a 5G context.

In "How to Migrate From Operational LTE Networks to C–RAN with Minimal Investment?", Harutyunyan and Riggio [item 27) in the Appendix] address the migration problem from a legacy RAN architecture to a C–RAN architecture by proposing a mapping algorithm that selects central unit (CU) pools, and provide the CU to distributed unit (DU) assignment in a most cost-efficient manner.

In "A Routing Framework for Offloading Traffic from Cellular Networks to SDN-Based Multi-Hop Device-to-Device Networks", Abolhasan *et al.* [item 28) in the Appendix] propose a new routing framework for Device-to-Device networks that aims to reduce traffic overhead in LTE networks based on the management of an SDN controller.

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APPENDIX
RELATED WORK

1) F. De Turck, R. Boutaba, P. Chemouil, J. Bi, and C. Westphal, "Guest editors' introduction: Special issue on efficient management of SDN/NFV-based systems—Part I," *IEEE Trans. Netw. Service Manag.*, vol. 12, no. 1, pp. 1–3, Mar. 2015.

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3) F. De Turck *et al.*, "Guest editors' introduction: Special issue on management of softwarized networks," *IEEE Trans. Netw. Service Manag.*, vol. 13, no. 3, pp. 362–365, Sep. 2016.
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5) J. Cui, Q. Lu, H. Zhong, M. Tian, and L. Liu, "A load-balancing mechanism for distributed SDN control plane using response time," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1197–1206, Dec. 2018.
6) T. Kohler, F. Dürr, and K. Rothermel, "ZeroSDN: A highly flexible and modular architecture for full-range distribution of event-based network control," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1207–1221, Dec. 2018.
7) S. S. Savas *et al.*, "RASCAR: Recovery-aware switch-controller assignment and routing in SDN," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1222–1234, Dec. 2018.
8) T. Wang, Z. Guo, H. Chen, and W. Liu, "BWManager: Mitigating denial of service attacks in software-defined networks through bandwidth prediction," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1235–1248, Dec. 2018.
9) S. Achleitner *et al.*, "Fast network configuration in software defined networking," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1249–1263, Dec. 2018.
10) R. Hark *et al.*, "Reducing the monitoring footprint on controllers in software-defined networks," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1264–1276, Dec. 2018.
11) G. Tangari, D. Tuncer, M. Charalambides, Y. Qi, and G. Pavlou, "Self-adaptive decentralized monitoring in software-defined networks," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1277–1291, Dec. 2018.
12) V. Sciancalepore, F. Z. Yousaf, and X. Costa-Perez, "z-TORCH: An automated NFV orchestration and monitoring solution," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1292–1306, Dec. 2018.
13) Y. T. Woldeyohannes, A. Mohammadkhan, K. K. Ramakrishnan, and Y. Jiang, "ClusPR: Balancing multiple objectives at scale for NFV resource allocation," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1307–1321, Dec. 2018.
14) W. Borjigin, K. Ota, and M. Dong, "In Broker We Trust: A double-auction approach for resource allocation in NFV markets," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1322–1333, Dec. 2018.
15) L. Yala, P. A. Frangoudis, G. Lucarelli, and A. Ksentini, "Cost and availability aware resource allocation and virtual function placement for CDNaaS provision," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1334–1348, Dec. 2018.
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18) P. L. Ventre, M. M. Tajiki, S. Salsano, and C. Filsfils, "SDN architecture and southbound APIs for IPv6 segment routing enabled wide area networks," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1378–1392, Dec. 2018.
19) A. Lara, S. Mukherjee, B. Ramamurthy, D. Raychaudhuri, and K. K. Ramakrishnan, "Automated inter-domain cut-through switching for the future Internet," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1393–1406, Dec. 2018.
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21) Y.-C. Wang and S.-Y. You, "An efficient route management framework for load balance and overhead reduction in SDN-based data center networks," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1422–1434, Dec. 2018.
22) Y. Tian, W. Chen, and C.-T. Lea, "An SDN-based traffic matrix estimation framework," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1435–1445, Dec. 2018.
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25) A. Liberato *et al.*, "RDNA: Residue-defined networking architecture enabling ultra-reliable low-latency datacenters," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1473–1487, Dec. 2018.
26) B. Spinnewyn, P. H. Isolani, C. Donato, J. F. Botero, and S. Latré, "Coordinated service composition and embedding of 5G location-constrained network functions," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1488–1502, Dec. 2018.
27) D. Harutyunyan and R. Riggio, "How to migrate from operational LTE/LTE—A networks to C–RAN with minimal investment?" *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1503–1515, Dec. 2018.
28) M. Abolhasan *et al.*, "A routing framework for offloading traffic from cellular networks to SDN-based multi-hop device-to-device networks," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1516–1531, Dec. 2018.

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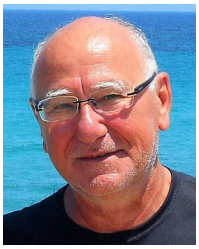

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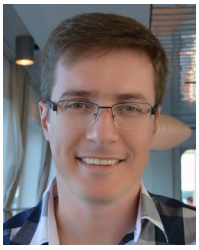

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He served as the Vice Chair for Operations, Technical Committee of Communications Quality and Reliability, IEEE Communications Society from 2016 to 2018, the Co-Chair of Communication Quality, Reliability, and Modeling Symposium of the IEEE ICC in 2014, 2016, and 2017 and Communication Quality, Reliability, and Modeling Symposium of the IEEE Globecom in 2014, 2015, and 2016, an Associate Editor for the IEEE TRANSACTIONS ON NETWORK AND SERVICE MANAGEMENT from 2016 to 2017, a Guest Co-Editor for the IEEE TRANSACTIONS ON NETWORK AND SERVICE MANAGEMENT, Special Issue on Management of Softwarized Networks, an Associate Editor for the *Journal of Network and Systems Management* from 2011 to 2016, a Guest Co-Editor for the IEEE TRANSACTIONS ON NETWORK AND SERVICE MANAGEMENT Special Issue on Management of Softwarized Networks, a Guest Co-Editor for *IEEE Communications Magazine* on Network and Service Virtualization (Part I and Part II).