Guest Editorial: Special Issue on Latest Developments for the Management of 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 issues 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 issue in this series was entitled "Efficient Management of SDN/NFV-Based Systems" and published in 2015 in two parts [item 1)–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, optimization of 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 issue 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 optimization, improvements of OpenFlow network traffic balancing and resilience, SDN traffic management optimization, 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 issue 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.

The fourth special issue was published in 2018 with the title "Novel Techniques for Managing Softwarized Networks" [item 5) in the Appendix]. Here, the reported advancements in network softwarization addressed resilience, security, load balancing, configuration and monitoring, VNF management in NFV-based networks for orchestration and resource allocation, advanced softwarized switching and routing including virtual network routing and traffic estimation, management of softwarized wireless and cellular networks, in particular, and management of data center networks.

There are many more interesting challenges currently being addressed by the research community, which target service function chaining, network slicing, edge computing, application-oriented management of network components and middleboxes, as well as improvements for the SDN control plane. Moreover,

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artificial intelligence approaches provide new solution opportunities. The current special issue reports upon latest developments for the 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 five editions were respectively held in London, U.K. in 2015, in Seoul, South Korea in 2016, in Bologna, Italy in 2017, in Montreal, Canada in 2018, and in Paris, France in 2019. Each of these editions attracted 180+ participants from academia and industry. IEEE NetSoft 2020 will be organized in Ghent, Belgium on June 29–July 3, 2020 with the overall theme "Bridging the Gap Between AI and Network Softwarization."

II. Special Issue Overview

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

Sixty-nine papers were submitted for this special issue. The submitted papers were thoroughly reviewed and, when needed some authors were given the time to update their paper and to address in detail the concerns raised by the reviewers. It was finally decided to accept twenty-two papers for inclusion in this special issue.

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

The selected papers in this special issue are addressing the following topics that currently play a very important role in the efficient management of softwarized networks: the latest developments for the management of service functions and service function chains as well as network edge environments, application-oriented management of software-defined network components and middleboxes, network virtualization and slicing as well as advances on SDN control plane mechanisms. In particular, many of the proposed solutions are based on artificial intelligence and machine learning methods.

III. Accepted Papers

From the selected papers in this special issue, seven papers deal with advanced management aspects for Network Function Virtualization (NFV) and NF chaining (Section III-A), five papers deal with the management and control of network edge environments (Section III-B), five papers report on advanced management of software-defined network components and middleboxes for selected network applications (Section III-C), three papers focus on managing network virtualization and network slicing (Section III-D) and, finally two papers present advancements of the SDN control plane (Section III-E).

A. Advanced Management Aspects for NFV and NF Chaining

Efficient operation and management of virtualized network functions poses a number of challenges with respect to, e.g., function placement, graph embedding, resource allocation, energy efficiency and dependability. The papers in this category focus on different aspects of NFV management and operation. The first two papers focus on network function placement and forwarding graph embedding. The third paper addresses the use case of routing layer services. The two next papers address energy efficiency in Service Function Chain deployment and operation. One paper focuses on resource allocation and the last paper addresses dependability analysis.

In "Placing Traffic-Changing and Partially-Ordered NFV Middleboxes via SDN," Ma *et al.* [item 6) in the Appendix] study placement challenges of NFV middleboxes in SDNs, presenting hardness results and optimal algorithms to place non-ordered or totally-ordered middleboxes.

In "A Deep Reinforcement Learning Approach for VNF Forwarding Graph Embedding," Quang *et al.* [item 7) in the Appendix] explore the potential of reinforcement learning (DRL) techniques for the placement of Virtual Network Functions-Forwarding Graphs (VNF-FGs). The authors first provide a lightweight solution that enables efficient VNF-FG embedding while meeting QoS requirements. The initial solution is then complemented with a module that enhances the exploration space of the learning algorithm resulting in an approach outperforming ILP-based and simple DRL solutions.

In "Change in Continuity: Chaining Services With an Augmented IGP," Wion *et al.* [item 8) in the Appendix] propose to augment the routing layer with the notion of services. In this paper, their solution leverages on existing distributed routing protocols where, in addition, autonomous nodes announce information about the virtual services they provide.

In "ESSO: An Energy Smart Service Function Chain Orchestrator," Bari *et al.* [item 9) in the Appendix] aim at reducing the overall carbon footprint of a telecommunication network. To this aim, they propose a network orchestrator employing together a technique of migration of network services between different geographic locations, a technique of intelligent topology-aware placement and consolidation of network services, and a policy to put into low-power consumption state networking elements.

In "A Fast Near-Optimal Approach for Energy-Aware SFC Deployment," Farkiani *et al.* [item 10) in the Appendix] focus on energy-aware Service Function Chaining (SFC) deployment, and present a fast and scalable algorithm to calculate a near-optimal solution that is able to take into account traffic processing capacity of instances and VNF management concerns.

In "Profile-Based Resource Allocation for Virtualized Network Functions," Van Rossem *et al.* [item 11) in the Appendix] address the problem of a tailored resource allocation for virtualized network functions in order to fulfil their SLAs. To solve this issue, the authors propose to use VNF profiles and to build VNF performance models based upon these profiles. The applicability of the proposed approach is demonstrated with experiments illustrating the potential of the proposed method for initial orchestration of the VNFs and when scaling the VNFs too.

In "Network-Aware Availability Modeling of an End-to-End NFV-Enabled Service," Tola *et al.* [item 12) in the Appendix]

propose a model to estimate the end-to-end NFV-deployed service availability, and present a quantitative assessment of the network factors that affect it, numerically highlighting the significant impact of the robustness of each node in the network.

B. Management and Control of Network Edge Environments

The network edge receives an increased interest in emerging networked systems to run services close to the users and poses new challenges for their management and control. In this section, the authors address orchestration and resource allocation aspects for different edge computing infrastructures and applications including Mobile Edge Computing (MEC).

In "A Service-Defined Approach for Orchestration of Heterogeneous Applications in Cloud/Edge Platforms," Castellano *et al.* [item 13) in the Appendix] propose a method for a distributed orchestration of cloud/edge services, where applications can define their own strategy. A Distributed Resource AssiGnment and OrchestratioN algorithm (called DRAGON) seeks optimal partitioning of shared resources between the different actors.

In "An NFV-Based Service Framework for IoT Applications in Edge Computing Environments," Shih *et al.* [item 14) in the Appendix] propose an idea of virtual local hub (VLH), which applies NFV technology on edge computing environment for IoT applications. To handle the complicated call graphs of IoT applications with better resource utilization, the VLH system adapts the technologies of container-based virtualization and microservice architecture which enables remote function module sharing on the edge computing environment.

In "Latency and Reliability-Aware Workload Assignment in IoT Networks With Mobile Edge Clouds," Kherraf *et al.* [item 15) in the Appendix] propose a method of assigning the workloads to the available Mobile Edge Computing (MEC) nodes by solving a Mixed Integer Program (MIP) with the Tabu meta-heuristic for IoT services.

In "A MEC-based Extended Virtual Sensing for Automotive Services," Avino [item 16) in the Appendix] present a flexible, yet full-fledged, MEC architecture for the support of Ultra-Low Latency Services, which is implemented building on the popular OpenAir Interface (OAI), present the algorithm for collision detection, and describe the implementation within the MEC platform.

In "SDN-Managed Provisioning of Named Computing Services in Edge Infrastructures," Amadeo *et al.* [item 17) in the Appendix] propose a new framework that brings out the SDN centralized intelligence to take decisions and inject rules for service allocation, and the adaptive NDN forwarding plane and its native in-network caching to request and deliver services by name.

C. Advanced Management of Software-Defined Network Components and Middleboxes for Selected Network Applications

Softwarization paves the way for an advanced management of a plethora of use cases. The five papers in this section address management aspects of software-defined components for applications including Internet Exchange Points, IP Multimedia Subsystem, video telemetry, network transport and mobility management.

In "Enhancing Security Management at Software-Defined Exchange Points," Kumar *et al.* [item 18) in the Appendix] propose that an Internet Exchange Point (IXP) is an appropriate place for managing security of an enterprise, and then design, implement, and evaluate a geo-blocking and IP-spoofing protection solution for a Software-Defined IXP.

In "Statistical Assessment of IP Multimedia Subsystem in a Softwarized Environment: A Queueing Networks Approach," Di Mauro and Liotta [item 19) in the Appendix] focus on the virtualization of service provisioning platforms and study the impact of virtualization on their performance. They hence consider a container-based IP Multimedia Subsystem (cIMS) and leverage queueing theory to assess its performance under a wide range of scenarios with different workloads and capacity constraints.

In "iTeleScope: Softwarized Network Middle-Box for Real-Time Video Telemetry and Classification," Gharakheili *et al.* [item 20) in the Appendix] present a softwarized network middle-box solution for identifying and classifying video flows in real-time, combining dynamic flow rules with telemetry and machine learning.

In "XTRA: Towards Portable Transport Layer Functions," Bianchi [item 21) in the Appendix] propose XTRA (eXtended finite state machines for TRAnsport), a platform-agnostic programming abstraction tailored to the deployment of transport layer functions. They show how XTRA is able to implement TCP protocol logic and ensure its code portability across different platforms such as NetFPGA board, User-space SW over Linux' Open Data Plane, and NS3 emulator.

In "ABRAHAM: Machine Learning Backed Proactive Handover Algorithm Using SDN," Zeljković *et al.* [item 22) in the Appendix] propose ABRAHAM, a machine learning based, proactive, handover algorithm that uses multiple metrics to predict the future state of the network and optimize the AP load to ensure the preservation of QoS.

D. Managing Network Virtualization and Network Slicing

With emerging network slicing, efficient management of network virtualization receives high interest. The first paper surveys fault management aspects of network virtualization. The other two papers in this category address optimization problems in virtual link and slice embedding.

In "A Survey of Fault Management in Network Virtualization Environments: Challenges and Solutions," Cherrared *et al.* [item 23) in the Appendix] provide an overview and comparison of the state-of-the-art of fault management techniques, addressing the impact of virtualization in fault management and proposing a new classification of the recent fault management research achievements in the network virtualization environments.

In "Probabilistic Virtual Link Embedding Under Demand Uncertainty," Hosseini *et al.* [item 24) in the Appendix] address the issue of virtual link embedding in case of demand uncertainty. Presented as a non-linear optimization problem, the contribution presents an algorithm which is based on an

approximate formulation of the problem, allowing for deriving a solution in polynomial time. The method is shown to achieve near-optimal performance, while easily scaling to large networks.

In "Distributed Network Slicing in Large Scale IoT Based on Coalitional Multi-Game Theory," Dawaliby *et al.* [item 25) in the Appendix] tackle scalability limitations in the management of Long Range Wide Area Networks (LoRaWAN) for network slicing optimization in large scale IoT deployments, and propose a distributed slicing strategy based on coalitional game and matching theory, demonstrating the achieved gain in terms of delay, throughput, energy consumption and improving reliability while providing complete isolation between LoRa slices.

E. Advancements of SDN Control Plane

The two papers in this category address the improvement of the SDN control plane with respect to flow table updates and garbage collection.

In "RuleTailor: Optimizing Flow Table Updates in OpenFlow Switches With Rule Transformations," Zhao *et al.* [item 26) in the Appendix] present an efficient, measurement-based optimization framework for SDN flow updates, accounting for the diversity of instruction types and switch behavior.

In "Software Defined Network's Garbage Collection With Clean-Up Packets," ul Huque *et al.* [item 27) in the Appendix] present a problem that consists of determining the appropriate point in the rule update where it is safe to garbage collect old rules. They proposed a solution that significantly reduces the rule update time with a guarantee that no data packet is lost due to the rule alteration through the use of dedicated clean-up packets.

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APPENDIX
RELATED WORKS

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, P. Chemouil, R. Boutaba, M. Yu, C. Rothenberg, and K. Shiomoto, "'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) W. Kellerer *et al.*, "'Guest editors' introduction: Special section on novel techniques for managing softwarized networks," *IEEE Trans. Netw. Service Manag.*, vol. 15, no. 4, pp. 1192–1196, Dec. 2018.
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7) P. T. A. Quang, Y. Hadjadj-Aoul, and A. Outtagarts, "A deep reinforcement learning approach for VNF forwarding graph embedding," *IEEE Trans. Netw. Service Manag.*, vol. 16, no. 4, pp. 1318–1331, Dec. 2019.
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10) B. Farkiani, B. Bakhshi, and S. A. Mirhassani, "A fast near-optimal approach for energy-aware SFC deployment," *IEEE Trans. Netw. Service Manag.*, vol. 16, no. 4, pp. 1360–1373, Dec. 2019.
11) S. Van Rossem, W. Tavernier, D. Colle, M. Pickavet, and P. Demeester, "Profile-based resource allocation for virtualized network functions," *IEEE Trans. Netw. Service Manag.*, vol. 16, no. 4, pp. 1374–1388, Dec. 2019.
12) B. Tola, G. Nencioni, and B. E. Helvik, "Network-aware availability modeling of an end-to-end NFV-enabled service," *IEEE Trans. Netw. Service Manag.*, vol. 16, no. 4, pp. 1389–1403, Dec. 2019.
13) G. Castellano, F. Esposito, and F. Risso, "A service-defined approach for orchestration of heterogeneous applications in cloud/edge platforms," *IEEE Trans. Netw. Service Manag.*, vol. 16, no. 4, pp. 1404–1418, Dec. 2019.
14) Y.-Y. Shih, H.-P. Lin, A.-C. Pang, C.-C. Chuang, and C.-T. Chou, "An NFV-based service framework for IoT applications in edge computing environments," *IEEE Trans. Netw. Service Manag.*, vol. 16, no. 4, pp. 1419–1434, Dec. 2019.
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27) M. T. I. ul Huque, G. Jourjon, C. Russell, and V. Gramoli, "Software defined network's garbage collection with clean-up packets," *IEEE Trans. Netw. Service Manag.*, vol. 16, no. 4, pp. 1595–1608, Dec. 2019.

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