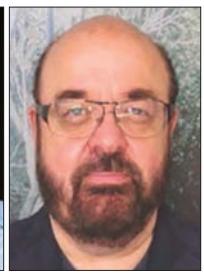
NETWORK SOFTWARIZATION AND MANAGEMENT


Walter Cerroni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This series focuses on softwarization, management, and their integration in communication networks and services. "Network Softwarization" advocates for network architectures that separate the software implementing network functions, protocols and services from the hardware running them. "Network Management" aims to integrate fault, configuration, accounting, performance, and security capabilities in the network and to support self-management features, integral automation, and autonomic capabilities, empowering the network with inbuilt cognition and intelligence. The critical role that software and management are increasingly playing in telecommunications is enabling unprecedented levels of abstraction, disaggregation, operation, integration, robustness, optimization, intelligence, precision delivery, programmability, and cost and complexity reduction in the network infrastructures and services. Such an approach is resulting in even greater attainment of non-functional characteristics (e.g., qualities of the operation of a network, rather than specific behaviors including flexibility, integrability, interoperability, operational guarantees, deployability, auditability and control, reliability, adaptability, elasticity, effectiveness, extensibility, automation and autonomicity).

This series selects and publishes in-depth, cutting-edge articles on state-of-the-art technologies and solutions bringing together the latest advances, technical innovations, open-source projects, case studies, research, and development in Network Softwarization and Management in terms of main paradigms and systems, architectures and methodologies, software approaches, resources, functions, modelling, measurement, performance analysis and cyber-networking. This series also welcomes experience reports from experimental testbeds, Network Softwarization and Management standards, open-source projects, and solutions.

Softwarization and management would help innovate network and cloud-network tasks, accelerate service deployment, and facilitate infrastructure management efficiency. Artificial Intelligence (AI)/Machine Learning (ML) based awareness and resolutions would be applied to address the complexity proliferating rapidly, making current network control and management techniques based on analytical models and simulations impractical. Slicing across access, core and edge networks, multi-domain networks, and cloud would serve vertical industries delivering their services over multiple administrative and technological domains. This series' second issue features six papers considering these trends, grouped per key covered topics as follows: AI/ML-assisted softwarization and management, advances in network functionality, and advances in end-to-end network services.

AI/ML-assisted Softwarization and Management

The complexity of wireless and mobile networks is increasing rapidly, making current network control and management techniques based on analytical models and simulations impractical. The first article, "AI-Empowered Software-Defined WLANs" by Coronado *et al.*, presents an AI-based platform for controlling and managing SD-WLANs. The proposed platform is based on the Telecommunication Standardization Sector (ITU-T) 's in-network AI and the Open Radio Access Network (O-RAN) Alliance's disaggregated radio access networks. This paper examines the evolution, challenges, and scenarios for AI-assisted network automation in the wireless and mobile networking domain.

The second article, "DeepMDR: A Deep-Learning-assisted Control Plane System for Scalable, Protocol-independent, and Multi-domain Network Automation" by Li *et al.*, discusses a multi-domain control plane for programmable data plane to envision the future-proof flexibility. Deep learning (DL) is also adapted to resolve the complexity in path computation. The authors developed a system called DeepMDR based on Open Network Operating System (ONOS) platform that supports protocol-oblivious forwarding (POF) in the data plane and facilitates a DL-assisted hierarchical CP architecture for multi-domain operations. The paper presents simulation results demonstrating that the proposed DL-based method achieves a better tradeoff between path computation time and routing performance than existing approaches.

Advances in Network Functionality

The third article, "Network Tomography for Efficient Monitoring in SDN-enabled 5G Networks and Beyond: Challenges and Opportunities" by Papavassiliou *et al.*, deals with the issue of achieving efficient network monitoring in highly dynamic 5G environments. The authors present an overview of the Network Tomography (NT) approach, which estimates network performance based on traffic measurements

obtained from an accessible subset of network elements, reducing both processing and traffic overhead concerning traditional network monitoring solutions. More specifically, the authors elaborate on the interplay between NT and Software-Defined Networking (SDN), discussing how NT can address several monitoring challenges by taking advantage of SDN features. They also discuss possible applications of current and potential NT solutions to 5G network scenarios, including overlay and virtual networks, cloud networks, data center networks, and vehicular networks, showing how the information inferred by NT can be used to enable traffic engineering, fault detection and management, load balancing, and Service Level Agreement compliance.

The roll-out of the 5G technology has generated a new surge of interest in blockchain's potential to automate various use cases involving cellular networks. The fourth article, "Smart Contracts in the 5G Roaming Architecture: The Fusion of Blockchain with 5G Networks" by Mafakheri *et al*., proposes a roaming architecture for non-standalone mode 5G networks in a local breakout type roaming architecture. It resolves the inefficiency of the data plane in home-routed roaming architecture. The proposed architecture enables quick payment reconciliation and reducing fraudulent transactions by employing permissioned blockchain, e.g., Hyperledger Fabric, to resolve security and trust concerns.

Advances in End-to-end Network Services

The fifth article, "5Growth: An End-to-End Service Platform for Automated Deployment and Management of Vertical Services over 5G Networks" by Li *et al*., proposes a RAN slicing model with an AI-driven closed-loop for automated service management for an automated RAN orchestration and control for Service Level Agreement (SLA) assurance. 5G is a crucial enabler for vertical industries to improve their services and create new ones. Despite the significant progress on 5G standardization and development, a set of specific challenges are yet to be solved. Network slicing enables effective resource sharing by different verticals with disparate requirements. The support for radio access network (RAN) conditions in the network slice information models is an open issue. The paper addresses multiple vertical pilots (Industry 4.0, Transportation and Energy), identifies the 5G requirement and analyzes existing technical and functional gaps compared to current solutions. It presents multi-domain solutions to expand service offerings by aggregating services and resources from different provider domains, thereby enabling integrating private 5G networks with public networks.

Cloud-network slicing is a promising approach to serve vertical industries delivering their services over multiple administrative and technological domains. However, there are numerous open challenges to provide end-to-end slices due to multifaceted business and engineering requirements from service and resource providers. The sixth article, "The NECOS Approach to End-to-End Cloud-Network Slicing as a Service" by Esteve Rothenberg *et al*., presents an orchestration and management system that handles the end-to-end cloud and network slices with lightweight micro-service based architecture. The salient feature of the proposed architecture is a marketplace approach for resource discovery. This paper presents a concrete implementation of slice-as-a-service across multi-domains. The experimental results across Greece, Spain, the U.K., and Brazil from the NECOS (Novel Enablers in Cloud Slicing) project demonstrate the proposed architecture's proof-of-concept.

We hope that you will enjoy this second issue of the series and find these papers as inspiring and impactful as we do. We welcome paper submissions anytime during the year. The call for papers is available at https://www.comsoc.org/publications/magazines/ieee-communications-magazine/cfp/network-softwarization-and-management. The submitted papers will undergo a rigorous peer-review process and, if accepted, they will be published in the first slot available for this series. In our role as Series Editors, we strive to achieve a fast, quality, and selective review process for all submissions to quickly publish high-quality and cutting-edge papers on relevant topics in the Network Softwarization and Management areas.

We would like to thank all the authors and reviewers who contributed to the series and the *IEEE Communications Magazine* editors and staff for their continuous support.

Biographies

Walter Cerroni [M'01, SM'16] (walter.cerroni@unibo.it) is an Associate Professor of communication networks at the University of Bologna, Italy. His recent research interests include software-defined networking, network function virtualization, service function chaining in cloud computing platforms, intent-based northbound interfaces for multi-domain/multi-technology virtualized infrastructure management, modelling, and design inter-and intra-data centre networks. He has co-authored more than 130 articles published in the most renowned international journals, magazines, and conference proceedings. He serves as an Associate Editor for *IEEE Communications Letters* and as Technical Program Co-Chair for IEEE-sponsored international workshops and conferences.

Alex Galis is a Professor in Networked and Service Systems at University College London (UCL) (www.ee.ucl.ac.uk/~agalis/). His current interests are in 5G and beyond networking, management, AI-enabled networking, virtualization and softwarization, deterministic and high-precision networking and servicing, network, and cloud programmability. He has co-authored more than 250 publications in the Future Internet areas and standards, including 11 research books. He is a co-editor of the *IEEE Communications Magazine* Series on Network Softwarization and Management, the *IEEE Communication Magazine* Feature Topic on Advances in Networking Software, the *IEEE JSAC* series on Network Softwarization and Enablers, and Wiley's *ETRI Journal*. He has served as general chair/TPC chair/keynote and panel chair/tutorials for IEEE conferences such as NOMS/IM/CNSM/ICIN/CloudNet/NetSoft.

Kohei Shiomoto [M'90, SM'15] is a Professor at Tokyo City University, Tokyo, Japan. He has been engaged in R&D in the data communication industry for over 25 years since he joined NTT Laboratories in 1989. He has been active in network virtualization, data-mining for network management, and traffic & QoE management since he joined Tokyo City University in 2017. He has served as Guest Co-Editor for a series of special issues established in *IEEE TNSM* on Management of Softwareized Networks. He has served in various roles organizing IEEE ComSoc high profile conferences such as IEEE NOMS, IEEE IM, and IEEENetSoft. He is the lead Series editor for the Network Softwarization and Management Series in *IEEE Communications Magazine*.

Mohamed Faten Zhani is an Associate Professor at ÉTS Montreal, University of Quebec, Canada. His research interests include network function virtualization, software-defined networking, and resource management in large-scale infrastructures. He has co-authored several research papers published in renowned conferences and journals. He has served as the general/technical program chair of several international conferences and workshops. He is a co-editor of *IEEE Transactions on Network and Service Management* and the IEEE softwarization newsletter. He received the IEEE/IFIP IM 2017 Young Researchers and Professionals Award for outstanding research contribution and leadership in network and service management.