NETWORK SOFTWARIZATION AND MANAGEMENT


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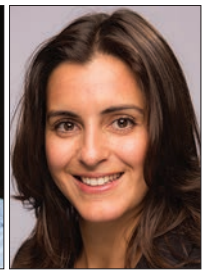
Noura Limam

Welcome to the fourth installment of the *IEEE Communications Magazine* Series on Network Softwarization and Management. We are very excited to introduce this issue and write this first editorial as a new team of Series Editors. We start by expressing our sincere gratitude and appreciation to the past Series Editors, professors Alex Galis, Kohei Shiomoto (lead Editor), and Mohamed Faten Zhani, who were the first group of Editors to be assigned the responsibility of this ComMag Series and brought it to the current high quality level. We are honored to take over the Series from such an outstanding group of experts and will do our best to uphold the quality standards of the series and the magazine.

Owing to the hard work of the past Editors, who also selected a number of the articles appearing in this issue, the Series has become a reference source of in-depth, cutting-edge articles on state-of-the-art technologies and solutions for Network Softwarization and Management. Network Softwarization advocates for architectures where software and programmability aspects in the implementation of network functions, protocols, and services are decoupled from the underlying infrastructure, fostering unprecedented levels of flexibility, abstraction, automation, and intelligence. Network Management aims at integrating fault, configuration, accounting, performance, and security (FCAPS) capabilities in the network, and supporting advanced autonomic and self-management features, often taking advantage of the potential offered by Network Softwarization.

The articles published in this issue cover some of the challenges that must be tackled to run 5G (and beyond) networks on edge computing infrastructures, including application awareness of radio channel conditions, intelligence and self-optimization in disaggregated and open radio access networks, selection of the most convenient edge cloud facilities to run network slices and services, and seamless connectivity among multiple computing clusters. From a more general perspective, the use of advanced management techniques for Blockchain platform selection is also considered, which can benefit the interoperability of distributed services and decentralized applications.

In the first article, "ONIX: Open Radio Network Information eXchange" by Coronado *et al.*, the authors address a key feature offered by emerging Multi-access Edge Computing (MEC) deployments: the awareness at the MEC application level of fine-grained information on radio channel quality. They introduce ONIX, a standard-compliant Radio Network Information Service (RNIS) that brings real-time channel information to MEC applications deployed in 4G and 5G networks. After discussing the requirements of a RNIS-enabled MEC platform, the ONIX system architecture and interfaces are presented, showing the openness and flexibility of the solution to integrate with different radio access network deployment models. An ONIX prototype developed by the authors is also illustrated, and a series of functional tests are reported in terms of end-to-end latency and resource consumption to assess the overall scalability of the platform.

The second article, "Intelligence and Learning in O-RAN for Data-driven NextG Cellular Networks" by Bonati *et al.*, overviews the Open Radio Access Network (O-RAN) architecture and explores means to embed intelligence toward the fulfilment of autonomous and self-optimizing next-generation cellular networks. Insights are provided and are backed up by a proof-of-concept large-scale deployment of a Deep Reinforcement Learning (DRL)-based RAN Intelligent Controller (RIC) on the Colosseum network simulator. The DRL agents are trained to dynamically optimize the scheduling of co-existing network slices based on available resources and current network status, and are shown to outperform static scheduling policies.

The third article, "Edge Cloud Selection: The Essential Step for Network Service Marketplaces" by Dimolitsas *et al.*, proposes a novel framework for realizing network service marketplaces in edge computing. The framework encompasses a new distributed service discovery mechanism for enabling 5G network slicing and cross-service communication at the network edge, and a multi-criteria ranking mechanism for identifying the most suitable edge cloud according to the client's functional, performance, and cost requirements. The proposed framework achieves a service discovery effectiveness similar to existing approaches while significantly decreasing the communication overhead.

The fourth article, "An Efficient Algorithm for Fast Service Edge Selection in Cloud-based Telco Networks" by Baliosian *et al.*, addresses the problem of assigning services with heterogeneous requirements, in terms of throughput, latency, computation and storage, to distributed computing facilities in the context of 5G and beyond cloud-based Telco networks. A heuristic that extends the Successive Shortest Path (SSP) algorithm is proposed and evaluated against a con-

ventional Mixed Integer Linear Programming (MILP) solver. Experiments show that the heuristic achieves comparable results, and its computation time is significantly lower.

The fifth article, "Multi-Cloud Connectivity for Kubernetes in 5G Networks" by Osmani *et al.*, presents a solution for enabling Kubernetes-based multi-cluster workloads with seamless connectivity meeting the requirements for multi-cloud services and the Telco industry in 5G and beyond (5GB) systems. Multi-clustering is achieved by integrating two open-source tools: Network Service Mesh (NSM) for container connectivity across cluster boundaries, and Kubernetes Cluster Federation (KubeFed) for deploying workloads in multiple clusters. In turn, NSM allows Kubernetes to meet 5GB networks' requirements. The paper also presents an early benchmarking study showing that the proposed solution reaches effectiveness regarding latency and throughput similar to popular networking plugins for Kubernetes.

In the sixth and last article, "Policy-based Blockchain Selection" by Scheid *et al.*, the authors propose a framework for applying Policy-based Management (PBM) principles to the selection process of Blockchain (BC) platforms, among the many available, that are most suitable for specific use cases, as well as to facilitate interoperability with decentralized applications. After an overview of the state of the art in BC selection, the authors define a novel refinement flow as a Policy Continuum to translate high-level, abstract requirements into BC selection policies and low-level, BC-specific transactions. The proposed framework and related workflow are then described, reporting also the performance analysis of a reference implementation in terms of execution time of each phase of the workflow. The results show a stable and efficient BC selection process and PBM mechanism.

We hope that the reader will enjoy this Series installment and find the published papers as inspiring and impactful as we do. While we are in the process of selecting the contributions for the next issue, we invite scientists, researchers, practitioners, and professionals to submit new papers on advancements in the state of the art of Network Softwarization and Management. Last but not least, we wish to thank all the authors and reviewers who contributed to the success of this Series, and the *IEEE Communications Magazine* editorial board and staff members for their invaluable and continuous support.

Biographies

Oscar Mauricio Caicedo Rendon [GS'11, M'15, SM'20] is a Full Professor at the Universidad del Cauca, Colombia, where he is a member of the Telematics Engineering Group. He received his Ph.D. degree in computer science (2015) from the Federal University of Rio Grande do Sul, Brazil, and his M.Sc. in telematics engineering (2006) and his degree in electronics and telecommunications engineering (2001) from the University of Cauca. His recent research interests include network and service management, network functions virtualization, software-defined networking, machine learning for networking, and network softwarization. He has served and continues to serve as a Technical Program Co-Chair for IEEE-sponsored international workshops and conferences.

Walter Cerroni [M'01, SM'16] is an Associate Professor of communication networks at the University of Bologna, Italy. His recent research interests include software-defined networking, network function virtualization, edge/fog/cloud computing, service function chaining, and intent-based virtualized infrastructure management. He has co-authored more than 140 articles published in the most renowned international journals, magazines and conference proceedings. He serves as Lead Series Editor for the *IEEE Communications Magazine* Series on Network Softwarization and Management, and as Associate Editor for *IEEE Communications Letters*. He has served as Technical Program Co-Chair for IEEE-sponsored international workshops and conferences.

Noura Limam is a Research Assistant Professor of computer science at the University of Waterloo, Canada. She received the M.Sc. and Ph.D. degrees in computer science from the University Pierre & Marie Curie (now Sorbonne University), France, in 2002 and 2007, respectively. She is an active researcher and contributor in the area of network and service management. Her current interests revolve around network automation and cognitive network management. She is the Chair of the IEEE ComSoc Technical Committee on Network Operations and Management, the Technical Program Chair of the IEEE ComSoc Network Intelligence Emerging Technologies Initiative, and an Associate Editor of *IEEE Communications Magazine*. She has served and continues to serve on the Technical Program Committee as well as the Organizing Committee of several IEEE conferences.