Smart, Optimal, and Explainable Orchestration of Network Slices in 5G and Beyond Networks

			
Zubair Md Fadlullah	Mostafa M. Fouda	Khaled Rabie	Ruidong Li

Network slicing is a much discussed topic in Fifth Generation (5G) and beyond networks. The network slice feature differentiates the 5G and beyond (B5G) networks from the earlier generations since it replaces the conventional concept of Quality of Service (QoS) with end-to-end multi-service provisioning and multi-tenancy. A diverse set of resources for computing, networking, storage, and power need to be smartly assigned in network slices. Traditional optimization/resource scheduling techniques are typically one-dimensional and may not scale well in large-scale 5G/B5G networks. Therefore, there is a pressing need to smartly address the orchestration and management of network slices. Since beyond 5G networks will heavily use embedded intelligence, how to leverage AI-based techniques, such as machine learning, deep learning, and reinforcement learning, to address and solve the various, complex network slicing problems is emerging as a challenging problem. The guest editors strived hard to reach out to researchers from academia and industry to address these points in this special issue in quest of a genuinely intelligent beyond 5G network rollout that could be both smart and practical.

We had phenomenal support from the Editor-in-Chief of the IEEE WCM, and the IEEE staff to be able to organize the special issue with the tight scheduling and reshuffling of priorities from everyone involved, particularly during the ongoing pandemic. We had 23 submissions, out of which five articles were selected through a rigorous review process with an acceptance ratio of 21.7%. The Guest Editors are thankful to the authors for submitting their articles which addressed how to best leverage IoT and computing resources at the edge with robust security and privacy requirements of COVID-19 data collection, delivery, and processing. As such, we have selected a variety of articles which cover the relevant topics and main research challenges in the direction of smart, optimal, and explainable orchestration and management of network slices in 5G and beyond networks using AI-based techniques.

The first paper by Wen et al. conceptualized an AI-native network slicing technique for 6G networks. They proposed AI-native network slicing involves the information exchange among various network elements, such as end users, access points, and the software-defined network (SDN) controllers in integrated space-air-ground networks. A case study was provided on AI-assisted resource reservation, aiming at reducing long-term overall system cost. Joint design of 6G network planning and operation was highlighted to be a key challenge for network slice provisioning in such complex and large network scenarios.

Next, the second article by Rodrigues et al. considered the combined resource slicing in satellite-ground networks through reinforcement learning in both centralized and decentralized manner. The proposed reinforcement learning technique was compared with conventional methods and demonstrated to provide a significantly high user acceptance ratio for both growing number of users and servers.

In the third article by Babbar et al., three use-cases of network slicing in 5G were discussed. These use-cases demonstrated enhanced Mobile Broadband (eMBB), Ultra Reliable Low Latency Communications (uRLLC), and massive Machine Type Communications (mMTC), respectively. Slice Service Type (SST) values were smartly assigned to the slices reflecting different applications, such as automotive, electric utility, and other consumer uses. The key finding of the article was the improvement of eMBB slices with the increasing number of compact cells. The uRLLC slices were found to have ten times smaller performance than the eMBB slice in a compact cell environment. On the other hand, due to increased interference, the total capacity of the mMTC slice was shown to diminish with the growing number of compact cells.

The fourth article by Jianhang et al. proposed a new and interesting architecture called the slicing-based software-defined Unmanned Aerial Vehicle (UAV)-enabled mobile edge computing. In this work, the authors exploited resource slices to offer customized multi-dimensional resources. With the flexibility and mobility of UAVs or drones, the work identified various resource slicing schemes and key research challenges. Then, a Lyapunov optimization-based offloading algorithm was designed to select the relevant resource slice, performance of which was shown to be encouraging through simulation results. Also, the authors hinted on using emerging tools such as Kubernetes and OpenDaylight to facilitate practical roll-out of this system in the emerging networks in the future.

The fifth and final article by Wang et al. considered the security of network slicing in vehicular networks in 5G and beyond settings. Efforts were given towards presenting the potential of network slicing for security protection and also analyzing its security threats from various perspectives. In addition, a case study of using deep reinforcement learning (DRL) for resilient recovery after attacks was provided to improve the service success rate of slices in 5G/B5G vehicular networks. The comparison of the proposed DRL method with the theoretical optimization reveals a small gap at the advantage of near real-time performance which is required in vehicular networks due to the critical need for accurate road perception and real-time collaborative control.

This special issue has successfully addressed important topics in the area of optimal and smart network slicing in emerging 5G/B5G networks. Besides these studies in the accepted articles, there are still many open challenges in this area. For instance, there are integrated aerial-satellite-terrestrial-underwater networks which have different radio access technologies with inherent requirements and challenges, and slice provisioning in such combined networks may require a robust dataset for investigating application of AI models. While end-to-end communication systems in B5G networks could be assisted by deep learning frameworks, it is important to interpret the results from a communication systems perspective (e.g., over individual blocks of the communication system) without falling into the danger of using these AI models as mere blackboxes. The incorporation of intelligent surfaces, cell-free networks, and other paradigm shifts in the B5G networks can also pose further challenges to obtaining closed-form optimization of network slice provisioning.

To conclude, we would like to thank the authors, numerous reviewers, and the EiC for helping the Guest Editors to organize this timely Special Issue. We anticipate that the breadth and diversity of the articles will encourage researchers and practitioners from academia and industry to come up with intelligent network slicing solutions and applications for emerging networks in the future.

Biographies

Zubair Md Fadlullah [SM'13] (zfadlullah@ieee.org) is currently an Associate Professor with the Department of Computer Science, Lakehead University, and a Research Chair of the Thunder Bay Regional Health Research Institute (TBRHRI), Thunder Bay, Ontario, Canada. He was an Associate Professor at the Graduate School of Information Sciences, Tohoku University, Japan, from 2017 to 2019. He received his Ph.D. degree in Information Sciences from Tohoku University, Japan in 2011. His main research interests span over the cyber physical system layers in sensing, communication, and computing problems and elegant solutions. He is currently editor of IEEE Transactions on Vehicular Technology (TVT), IEEE Access, and IEEE Open Journal of the Communications Society (OJ-COMS). He is a Senior Member of IEEE.

Mostafa M. Fouda [SM'14] (mfouda@ieee.org) received the Ph.D. degree in Information Sciences from Tohoku University, Japan, in 2011. He is currently an Assistant Professor with the

Department of Electrical and Computer Engineering, Idaho State University, ID, USA. He also holds the position of Associate Professor with Benha University, Egypt. He has served as an Assistant Professor with Tohoku University, Japan. He was a Postdoctoral Research Associate with Tennessee Technological University, TN, USA. He has been engaged in research on cybersecurity, communication networks, wireless mobile communications, smart healthcare, smart grids, AI, blockchain, and IoT. He has published more than 70 papers in prestigious peer-reviewed journals and conferences. He has served as the Symposium/Track Chair of IEEE VTC2021-Fall conference. He has also served as a Guest Editor of some special issues of several top-ranked journals such as IEEE WCM and IEEE IoTM. He also serves as a referee of some renowned IEEE journals and magazines such as IEEE COMST, WCM, TWireless, TPDS, TSG, Access, TNSM, TETC, Network, etc. He is an Editor of IEEE Transactions on Vehicular Technology (TVT) and an Associate Editor of IEEE Access. He is a Senior Member of IEEE.

Khaled Rabie [SM'21] (k.rabie@mmu.ac.uk), a Fellow of the U.K. Higher Education Academy, received the M.Sc. and Ph.D. degrees in electrical and electronic engineering from the University of Manchester, in 2011 and 2015, respectively. He is currently a Senior Lecturer with the Department of Engineering, Manchester Metropolitan University (MMU), U.K. His current research interests focus on developing and designing next-generation wireless communication systems. He serves regularly on the technical program committee (TPC) for several major IEEE conferences, such as GLOBECOM, ICC, and VTC. He has received many awards over the past few years in recognition of his research contributions including the Best Paper Award at the 2021 IEEE CITS, the IEEE Access Editor of the Month Award for August 2019; and the Best Student Paper Award at the 2015 IEEE ISPLC. He is currently serving as an Editor for IEEE COMMUNICATIONS LETTERS, an Editor for *IEEE Internet of Things Magazine*, an Associate Editor for IEEE ACCESS and an Executive Editor for the *Transactions on Emerging Telecommunications Technologies* (Wiley). He guest-edited many special issues in several journals including *IEEE Wireless Communications Magazine*, IEEE Access, *Electronics*, and *Sensors*.

Ruidong Li [SM] (liruidong@ieee.org) is an associate professor at Kanazawa University, Japan. Before joining this university, he was a senior researcher at the National Institute of Information and Communications Technology (NICT), Japan. He received the M.Sc. degree and Ph.D. degree in computer science from the University of Tsukuba in 2005 and 2008, respectively. He serves as the vice chair of IEEE ComSoc Internet Technical Committee (ITC), and are the founders and chairs of IEEE SIG on Big Data Intelligent Networking and IEEE SIG on Intelligent Internet Edge. He is the associate editor of IEEE IoT Journal, OJCS, DCN and also served as the guest editors for a set of prestigious magazines, transactions, and journals, such as IEEE communications magazine, IEEE network, and IEEE TNSE. He also served as chairs for several conferences and workshops, such as the general co-chairs for IEEE MSN 2021, AIVR2019, IEEE INFOCOM

2019/2020/2021 ICCN workshop, TPC co-chairs for IWQoS 2021, IEEE MSN 2020, BRAINS 2020, IEEE ICDCS 2019/2020 NMIC workshop, and ICCSSE 2019, and Symposium co-chairs for ICC 2021, Globecom 2021. His research interests include future networks, intelligent Internet edge, Internet of things, quantum Internet, wireless network, and network security. He is a senior member of IEEE and a member of ACM and IEICE.