Guest Editorial Introduction to the Special Section on Intelligence-Empowered Collaboration Among Space, Air, Ground, and Sea Mobile Networks Towards B5G

PROVIDING ubiquitous network accessibility is one of the most essential goals in the Beyond 5G (B5G) mobile networks. To achieve this goal, it is vital to integrate the space, air, ground, and sea networks (SAGS) to form such heterogenous B5G networks. Although the above networks exhibit different types of technical issues, they should be connected seamlessly with collaborated networking functionalities and management. Besides, recently, the application and innovation of artificial intelligence (AI) have also been attracting significant research attentions to enable intelligent networking and communication, where the network quality can be ensured by meeting the key performance metrics. However, it remains unclear if there is a fundamental science and engineering paradigm that can integrate networking with heterogeneous communication network applications efficiently and effectively on a large scale.

This special section is one of the first publication venues focusing on this timely topic. We intend to foster innovative work that employs AI to design new techniques in B5G-SAGS. There are 24 accepted and published out of 117 submissions, which is the acceptance rate of 20.5%. To give you a better review of all articles in this section, we clarify the accepted papers into Space-Air-Ground, Space-Ground, UAV-Ground, Satellite Network, UAV Network, Sea Network, and Security, based on the topics of this section and collected papers.

Space-Air-Ground: This topic studies the integration of satellites, aerial nodes, and ground nodes. In this special section, Deb *et al.* in "XiA: Send-it-Anyway Q-Routing for 6G-Enabled UAV-LEO Communications" propose Q-Learning-based routing algorithm, namely, XiA, by involving UAVs to send the data to ground vehicles or access points via Low Earth Orbit (LEO).

Space-Ground: Direct space-ground networking is to support the communications of ground nodes via LEOs, or the communications among LEOs via the relay of ground stations. Chen *et al.* in "Dynamical Control Domain Division for Software-Defined Satellite-Ground Integrated Vehicular Networks" investigate the integration of SDN and satellite-ground vehicular networks. Dynamic controller domain division problem is studied particularly where a two-phase dynamic control graph-based control domain division algorithm is proposed.

UAV-Ground: In this special section, the UAV-Ground related topic has been studied in four aspects. First, UAVs are supposed to be placed in the right positions and optimal altitudes to achieve the maximized coverage. Shehzad *et al.* in "Backhaul-Aware Intelligent Positioning of UAVs and Association of Terrestrial Base Stations for Fronthaul Connectivity" employ the UAVs as the hubs to enable the B5G internet connections. In particular, genetic algorithm is applied to optimize the multi-objective problem of joint positioning of UAVs and terrestrial small-cell base stations. Li *et al.* in "Many-Objective Deployment Optimization for a Drone-Assisted Camera Network" consider how to apply the UAVs in the camera network in order to satisfy the ubiquitous deployment scenarios. Considering the UAV positions and camera visual axis vectors, this problem is formulated as a multi-objective optimization model where it is solved by the proposed method. Sharma *et al.* in "Aerial Base Station Assisted Cellular Communication: Performance and Trade-off" focus on finding the optimal altitude of a UAV base station using the criteria of maximum cell coverage area and minimum symbol error rate.

Second, to realize the UAV-assisted terrestrial applications, the design of routing scheme is a key to enable the transmissions multi-hoply. Seng *et al.* in "Energy-Efficient Communications in Unmanned Aerial Relaying Systems" propose a joint communication and placement design for achieving the energy-efficient UAV relaying communications. A new approximation algorithm is developed to deal with the formulated multi-hop relaying problem. Manogaran *et al.* in "Non-recurrent Classification Learning Model for Drone Assisted Vehicular Ad-Hoc Network Communication in Smart Cities" employ the UAVs in diverse smart city applications. Authors

Digital Object Identifier 10.1109/TNSE.2021.3109386

propose a latency-less data transfer model to support UAV-assisted VANETs.

Third, UAVs can provide alternate computation and storage resources via offloading or caching, in which edge computing and fog computing can involve UAVs as computing servers. Wang *et al.* in "Intelligent Ubiquitous Network Accessibility for Wireless-Powered MEC in UAV-Assisted B5G" deploy the UAVs as mobile edge computing servers to provide task offloading and energy harvesting services to ground devices. Intelligent charging-offloading schemes is designed to minimize the system service latency and resources. Liu *et al.* in "Joint Resource Optimization for UAV-Enabled Multichannel Internet of Things Based on Intelligent Fog Computing" propose an architecture that deploys UAV to relay IoT data to the data center with the management of fog computing base station in order to optimize the terrestrial channel fading. Subcarrier allocation, power of IoT and UAV, as well as the trajectory of UAV are optimized jointly in this work.

In addition, there are also architecture-level studies of UAV-Ground topic in this special section. Miao *et al.* in "Unlocking the Potential of 5G and Beyond Networks to Support Massive Access of Ground and Air Devices" introduce a general architecture of B5G cellular network to support both ground users and UAVs. The features of UAV are analyzed to see their impact on B5G network design. UAV can be employed to assist the ground IoT and fault diagnosis. Wan *et al.* in "Fair-Hierarchical Scheduling for Diversified Services in Space, Air and Ground for 6G-Dense Internet of Things" propose a data-driven scheduling method for supporting dense Internet of Things in SAGS. This work applies Wi-Fi 6 to enable diverse data and applications in the B5G scenario. Wang *et al.* in "Intelligent Drone-assisted Fault Diagnosis for B5G-enabled Space-Air-Ground-Space Networks" employ deep reinforcement learning to implement the fault diagnosis in SAGS-enabled mobile edge computing which further improves the reliability of SAGS.

Satellite Network: Routing in Satellite Constellation is fundamental for providing the communication in the space in order to get better connectivity supports in SAGS. To overcome the traffic congestion caused by the geographical features, Tao *et al.* in "Congestion-Aware Scheduling for Software-Defined SAG Networks" introduce the software-defined networks into satellites. In particular, authors consider the placement of SDN routers among satellites to minimize the traffic overloading. Liu *et al.* in "DRL-ER: An Intelligent Energy-aware Routing Protocol with Guaranteed Delay Bounds in Satellite Mega-constellations" study the energy efficient routing scheme for satellite networking. A novel deep reinforcement learning-based routing protocol is proposed to avoid the energy imbalance inside of the constellations.

UAV Network: To realize the SAGS, UAV should be navigated efficiently and effectively with self-localization in a collaborative manner. Ji *et al.* in "ECONOMY: Point Clouds-based Energy-efficient Autonomous Navigation for UAVs" investigate another essential factor in SAGS, i.e., autonomous navigation of UAV is to lead the aerial vehicles to the right place. An energy-efficient and cloud-assisted system is proposed for the autonomous navigation by considering the limited energy of UAVs. Wang *et al.* in "Optimal Routing for Beamforming-Constrained Swarm UAS Networking" propose a novel on-demand distance vector routing scheme to improve the capacity of beamforming on swarm UAV networking, where it is design for large swarms particularly. Li *et al.* in "Global Visual and Semantic Observations for Outdoor Robot Localization" introduce the improved Gaussian Process into observation models with visual information by combining the local and global semantic information to deal with the localization of both unmanned ground vehicles and UAVs.

Sea Network: This is another important component of B5G-SAGS to realize the ubiquitous connectivity. Autonomous underwater vehicle (AUV) based mobile networks (AUV-MNs) is promising to explore the various underwater world for military and civil applications. Zhang *et al.* in "Fast Calculation of Underwater Acoustic Horizontal Range: A Guarantee for B5G Ocean Mobile Networks" develop an underwater range acquisition method with involving AI techniques. In particular, an equation is proposed for fast calculation of the underwater horizontal range with accurate determination of horizontal range.

Draz *et al.* in paper "Energy Efficient Proactive Routing Scheme for Enabling Reliable Communication in Underwater Internet of Things" investigate how to reduce the interference and collision with consideration of energy efficiency in the underwater world. A proactive routing scheme is proposed to support reliable and collision-free communication for underwater IoTs. The Raleigh fading channel model is chosen to exam the link consistency for reliable communication.

Security: Since UAVs are mostly energy constrained, light-weight and secure communication protocols and schemes should be designed to avoid the threats and attacks. Xu *et al.* in "Hierarchical Bidirectional RNN for Safety-enhanced B5G Heterogeneous Networks" study the security issues of B5G network purely, where malicious detection is investigated by using the hierarchical bidirectional recursive neural network. Gupta *et al.* in "BATS: A Blockchain and AI-empowered Drone-assisted Telesurgery System towards 6G" apply the UAVs to transport the light-weight healthcare items in the telesurgery system in emergent situation. In this scenario, blockchain is employed to ensure the secure, trusted telesurgery system. Al-Hawawreh *et al.* in "Deep Learning-enabled Threat Intelligence Scheme in the Internet of Things Networks" also study the security and resilient connectivity of SAGS, to provide safe access for B5G IoT. Deep learning techniques are involved to discover the cyber threats. Zhang *et al.* in "Intelligent Drone-assisted Anonymous Authentication and Key Agreement for 5G/B5G Vehicular Ad-hoc Networks" design an intelligent UAV-based assistant communication scheme to realize the secure communication among vehicles. Li *et al.* in "I/Q Imbalance Aware

Nonlinear Wireless-Powered Relaying of B5G Networks: Security and Reliability Analysis" introduce an analysis framework to evaluate the reliability and security of wireless-powered decode-and-forward B5G multi-relay networks in physical layer. Two relaying node selection strategies are proposed, including suboptimal relay selection and optimal relay selection to enhance the secure performance.

To sum up, by involving AI, the collected papers in this special section present the innovative designs of SAGS towards B5G. It carves new paths to find the principles in order to enable the diverse applications in B5G-SAGS in the future. At the end, we hope this timely special section can give new ideas and inspirations to the researchers and engineers in this area.

LIANG ZHAO *Lead Guest Editor*
Shenyang Aerospace University
Shenyang 110136, China
(e-mail: lzhao@sau.edu.cn)

NEERAJ KUMAR, *Guest Editor*
Thapar Institute of Engineering and Technology
Patiala 147004, India
(e-mail: neeraj.kumar@thapar.edu)

CELIMUGE WU, *Guest Editor*
University of Electro-Communications
Tokyo 182-8585, Japan
(e-mail: celimuge@uec.ac.jp)

JIA HU, *Guest Editor*
University of Exeter
Exeter EX4 4RN, U.K.
(e-mail: j.hu@exeter.ac.uk)

AHMED AL-DUBAI, *Guest Editor*
Edinburgh Napier University
Edinburgh EH10 5DT, U.K.
(e-mail: al-dubai@napier.ac.uk)

Liang Zhao (Member, IEEE) received the Ph.D. degree from the School of Computing, Edinburgh Napier University, Edinburgh, U.K., in 2011. From 2012 to 2014, he was an Associate Senior Researcher with Hitachi, China, a Research and Development Corporation. He is currently an Associate Professor with Shenyang Aerospace University, Shenyang, China. He has authored or coauthored more than 100 articles. His research interests include ITS, VANET, WMN, and SDN.

Neeraj Kumar (Senior Member, IEEE) received the Ph.D. degree in CSE from SMVD University, Katra (J & K), India. He was a Postdoctoral Research Fellow with Coventry University, Coventry, U.K. Since 2014, he has been an Associate Professor with the Department of Computer Science and Engineering, Thapar Institute of Engineering & Technology, Patiala, India. He is an Internationally Renowned Researcher in the areas of VANET & CPS Smart Grid & IoT Mobile Cloud computing & Big Data and Cryptography.

Celimuge Wu (Senior Member, IEEE) received the Ph.D. degree from The University of Electro-Communications, Japan in 2010. He is currently an Associate Professor with The University of Electro-Communications. His research interests include vehicular networks, edge computing, IoT, intelligent transport systems, and application of machine learning in wireless networking and computing. He is an Associate Editor for the IEEE TRANSACTIONS ON NETWORK SCIENCE AND ENGINEERING, IEEE TRANSACTIONS ON GREEN COMMUNICATIONS AND NETWORKING, IEEE Open Journal of the Computer Society, *Wireless Networks*, and *IEICE Transactions on Communications*. He was the recipient of the 2021 IEEE Communications Society Outstanding Paper Award, and IEEE Computer Society 2019 Best Paper Award Runner-Up.

Jia Hu (Member, IEEE) received the B.Eng. and M.Eng. degrees in electronic engineering from the Huazhong University of Science and Technology, Wuhan, China, in 2004 and 2006, respectively, and the Ph.D. degree in computer science from the University of Bradford, Bradford, U.K., in 2010. He is currently a Senior Lecturer of computer science with the University of Exeter. His research interests include edge-cloud computing, resource optimization, applied machine learning, and network security.

Ahmed Al-Dubai (Senior Member, IEEE) received the Ph.D. degree in computing from the University of Glasgow, Glasgow, U.K., in 2004. He is currently a Professor of networking and communication algorithms with the School of Computing, Edinburgh Napier University, Edinburgh, U.K. His research interests include communication algorithms, mobile communication, Internet of Things, and future internet. He was the recipient of the several international awards.