Guest Editorial Special Issue on Unmanned Aerial Vehicle (UAV)-Enabled Green Communications and Networking

SUPPORTING explosive data traffic and massive connections is the most critical challenge of 5G and beyond networks. To overcome this challenge, an unmanned aerial vehicle (UAV) can be exploited as a promising communication platform in future wireless networks due to its inherent advantage of flexibility, mobility, hovering and low cost. In particular, the air-to-air and air-to-ground channels are much better than the ground-to-ground channels when a UAV is used as a base station. In many cases, the communication between a UAV base station and a user equipment can benefit from the line-of-sight (LoS) channel in between. Under such circumstances, mmWave transmission becomes practicable for UAV communications, which could provide much higher data rate.

However, the most challenging issue for UAV enabled communications and networking is the short endurance for UAVs due to the limited on-board energy storage. For example, the endurance for rotary-wing UAVs with batteries is usually less than one hour, while the charging process could be several hours. This is because UAVs need additional propulsion energy consumption to maintain airborne and support movement, which is even hundreds of times higher than the communication-related energy. Thus, energy efficiency (EE) should be optimized including the propulsion power to make the utilization of UAVs more practical. As the propulsion power is closely related to the velocity and acceleration of the UAV, the EE optimization problem becomes extremely intractable for UAVs. In addition, to prolong the endurance of UAVs, energy-saving techniques for battery life of UAVs are also attracting more and more interest from both academia and industry. On the other hand, wireless power transfer (WPT) is a promising solution to provide perpetual energy supplies to low-power devices, which has substantial applications for future Internet-of-Things (IoT) networks. Until now, the efficiency of WPT is still its bottleneck mainly due to the severe terrestrial propagation loss over long distance with fading. UAVs can fly close to the ground energy receivers with excellent LoS air-to-ground channels, and the WPT efficiency can be significantly improved. Nevertheless, the propulsion power of UAVs should also be considered as the cost for WPT, and the whole EE of WPT by UAVs needs to be further improved. In addition, to make WPT by UAVs more effective, the beamforming and trajectory should also be carefully designed. As UAVs can be flexibly combined with most of the latest wireless advances to achieve better performance, e.g., intelligent reflecting surfaces, edge computing, covert communication, etc., the green issue of UAV-enabled communications and networking should be emphasized with great effort. Therefore, it is imperative to conduct thorough investigation and research on UAV-enabled green communications and networking, i.e., to achieve sustainable, energy-efficient, energy-aware, and environment-aware communications and networking assisted by UAVs.

This special issue collects together some of the latest ideas and research on UAV-enabled green communications and networking. Particularly, 14 original articles have been accepted and included in the collection on the following pages. The topics of these works on UAV-enabled green communications and networking are mainly concerned with energy efficiency, wireless power transfer, energy management, green edge computing, and so forth. We believe that these articles will play a role in inspiring our readers.

I. Summaries of Accepted Articles

The first invited article titled "Trajectory Optimization for UAV Emergency Communication With Limited User Equipment Energy: A Safe-DQN Approach" authored by Zhang *et al.* proposes a framework for UAV-based emergency communication networks, where the special challenges in post-disaster communication scenarios including obstacles and the limited energy of affected user equipment are both considered. Aiming to maximize the uplink throughput, a trajectory optimization problem is transformed into a CMDP and solved by a safe-DQN algorithm.

The second article titled "Green MEC Networks Design Under UAV Attack: A Deep Reinforcement Learning Approach" authored by Zhao *et al.* proposes a novel optimization framework for the secure MEC network, based on deep reinforcement learning. Under this framework, four optimization criteria are proposed to reduce the system latency, energy consumption and price, which outperform the conventional schemes substantially.

The third article titled "Trajectory and Resource Optimization in OFDM Based UAV-Powered IoT Network" authored by Lu *et al.* proposes a UAV-powered IoT network

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based on OFDM. In the proposed network, two UAVs supply energy for the two ground nodes through wireless power transfer (WPT), and receive information from them. An optimization problem that involves UAV trajectory, time allocation, power allocation and subcarrier allocation is solved to maximize the sum average transmission rate.

The fourth article titled "Flocking Control Algorithms Based on the Diffusion Model for Unmanned Aerial Vehicle Systems" authored by Chen *et al.* presents a diffusion model to characterize the flock generation process of a UAV system, for which the system capacity is analyzed. Furthermore, two flocking control algorithms are put forward based on the diffusion model. The first one can regulate the packet exchange between UAVs, while the second one can be adopted by a follower to determine its flight status.

The fifth article titled "Cooperative Transmission of Wireless Information and Energy in Anti-Eavesdropping UAV Relay Network" authored by Ning *et al.* focuses on UAV-assisted wireless MIMO interference networks, where a scheme for energy harvesting and physical layer secure transmission in wireless communication networks based on interference alignment is proposed. Power division technology and artificial noise technology are used to collect energy and ensure the confidentiality of communication, and interference alignment technology is employed to manage the interference between users and artificial noise.

The sixth article titled "Robust Design for UAV-Enabled Multiuser Relaying System With SWIPT" authored by Wang *et al.* investigates how to maximize the sum harvested energy of users while satisfying the quality of service. Specifically, they propose an alternating optimization scheme to tackle the intractable non-convex problem. Furthermore, a low-complexity scheme based on the singular value decomposition-zero forcing (SVD-ZF) technique is designed to reduce the computational cost.

The seventh article titled "An Energy-Efficient Selection Mechanism of Relay and Edge Computing in UAV-Assisted Cellular Networks" authored by Liu *et al.* investigates how to minimize the energy consumption of users served by the UAV relaying network, where a selection mechanism of relay and edge computing is proposed, and the transmission mode, the location, the transmission power of the UAV are optimized jointly.

The eighth article titled "Trajectory Design for Throughput Maximization in UAV-Assisted Communication System" authored by Gupta *et al.* investigates the problem of UAV 3D deployment to provide on-demand coverage to the users to maximize their sum rate. Particularly, the optimal UAV location in 3D space is first obtained, followed by a trajectory optimization problem that finds an optimal UAV path from the initial to the final location by maximizing the sum rate averaged over time in the presence of on-board energy and flight duration constraints.

The ninth article titled "UEE-RPL: A UAV-Based Energy Efficient Routing for Internet of Things" authored by Yang *et al.* proposes a feasible attempt to integrate RPL into UAV application scenarios to implement MP2P and support P2P transmission. By taking advantage of the highly modular nature of RPL, they integrate on-demand routing into the RPL and design a routing metric which optimizes link quality and balances network load simultaneously.

The tenth article titled "Heterogeneous Mobile Networking for Lightweight UAV Assisted Emergency Communication" authored by Zhang *et al.* presents a novel heterogeneous mobile networking scheme for energy-friendly UAV assisted emergency networks. By creating the interesting areas (IAs), the UAVs support the mobile nodes to achieve lower delay and higher delivery ratio. Particularly, the social relationship-based message splitting algorithm is utilized to guarantee the message's timeliness value.

The 11th article titled "Energy and Spectrum Efficient Blind Equalization With Unknown Constellation for Air-to-Ground Multipath UAV Communications" authored by Liu *et al.* proposes a low-overhead blind equalization method to combat frequency-selective fading in air-ground multipath UAV channels. The proposed method requires less information and no training sequences and pilots, and therefore, it achieves energy and spectrum efficient Air-to-Ground multipath UAV communications.

The 12th article titled "Cellular-Connected UAV Trajectory Design With Connectivity Constraint: A Deep Reinforcement Learning Approach" authored by Gao *et al.* proposes a novel approach based on deep reinforcement learning (DRL) to minimize the total outage duration by optimizing the UAV's trajectory. Specifically, the outage time of the UAV with different on-board energy and communication quality of service (QoS) requirements is investigated to evaluate the effectiveness of the proposed method.

The 13th article titled "Contract and Lyapunov Optimization-Based Load Scheduling and Energy Management for UAV Charging Stations" authored by Lv *et al.* proposes an online algorithm based on Lyapunov optimization to schedule the charging of UAVs and the energy management of the charging station. To reduce the power purchase cost as much as possible, contract theory is used to design the optimal charging strategy in the case of information asymmetry. Through the incentive system, users can spontaneously charge at low peak times and avoid the risk of grid overload.

The 14th article titled "On the Influence of Charging Stations Spatial Distribution on Aerial Wireless Networks" authored by Qin *et al.* aims to accurately capture the influence of the battery limitation on the performance of a UAV-enabled wireless network. Specifically, queuing theory and stochastic geometry are exploited to investigate the effect of the limited capacity of each charging station and spatial density on the performance of the network.

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NAN ZHAO, *Lead Guest Editor*
Dalian University of Technology
Dalian, China
(e-mail: zhaonan@dlut.edu.cn)

DANIEL B. DA COSTA, *Guest Editor*
National Yunlin University of Science and Technology
Douliu 64002, Taiwan
(e-mail: danielbcosta@ieee.org)

JIE TANG, *Guest Editor*
South China University of Technology
Guangzhou, China
(e-mail: eejtang@scut.edu.cn)

XIANBIN WANG, *Guest Editor*
University of Western Ontario
London, ON N6A 3K7, Canada
(e-mail: xianbin.wang@uwo.ca)

JONATHON A. CHAMBERS, *Guest Editor*
University of Leicester
Leicester LE1 7RH, U.K.
(e-mail: jonathon.chambers@leicester.ac.uk)

Nan Zhao (Senior Member, IEEE) received the Ph.D. degree in information and communication engineering from the Harbin Institute of Technology, Harbin, China, in 2011. He is currently a Professor with the Dalian University of Technology, China. His research interests include UAV communications, green communications, NOMA, interference management, and physical-layer security. He won the Best Paper Awards in IEEE VTC 2017 Spring, ICNC 2018, WCSP 2018, and WCSP 2019. He also received the IEEE Communications Society Asia–Pacific Board Outstanding Young Researcher Award in 2018, the IEEE TCGCC Best Journal Paper Award in 2019, and the Youth Science and Technology Award of China Institute of Communications in 2018. He is serving on the editorial boards of IEEE WIRELESS COMMUNICATIONS and IEEE WIRELESS COMMUNICATIONS LETTERS.

Daniel B. da Costa (Senior Member, IEEE) is currently a Full Professor with the National Yunlin University of Science and Technology (YunTech), Taiwan, and an Associate Professor with the Federal University of Ceara, Brazil. He is the recipient of four conference paper awards. He was included in the World's Top 2% Scientist list from Stanford University in 2020. He is the Executive Editor of the IEEE COMMUNICATIONS LETTERS, an Area Editor of IEEE OPEN JOURNAL OF THE COMMUNICATION SOCIETY—Area: Green, Cognitive, and Intelligent Communications and Networks, an Editor-at-Large of the IEEE TRANSACTIONS ON COMMUNICATIONS—Area: Communication Theory & Systems II, and the Specialty Chief Editor of the *Frontiers in Communications and Networks*—Wireless Communications Section. He is also an Editor of the IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY and IEEE TRANSACTIONS ON COGNITIVE COMMUNICATIONS AND NETWORKING. He is a Distinguished Lecturer of the IEEE Vehicular Technology Society.

Jie Tang (Senior Member, IEEE) received the B.Eng. degree in information engineering from the South China University of Technology, Guangzhou, China, in 2008, the M.Sc. degree (with Distinction) in communication systems and signal processing from the University of Bristol, U.K., in 2009, and the Ph.D. degree from Loughborough University, Leicestershire, U.K., in 2012. From 2013 to 2015, he was a Research Associate with the School of Electrical and Electronic Engineering, University of Manchester, U.K. He is currently a Full Professor with the School of Electronic and Information Engineering, South China University of Technology. He is a co-recipient of the 2018 IEEE ICNC, 2018 CSPS, 2019 IEEE WCSP, and 2020 6GN Best Paper Awards. He is currently serving as an Editor for IEEE WIRELESS COMMUNICATIONS LETTERS and IEEE SYSTEMS JOURNAL. He also served as a Track Co-Chair for IEEE VTC-Spring 2018, EAI GreeNets 2019, ICCC Workshop 2019, and ICCC 2020.

Xianbin Wang (Fellow, IEEE) is a Professor and the Tier-1 Canada Research Chair with Western University, Canada. He has over 450 highly cited journal and conference papers, in addition to 30 granted and pending patents and several standard contributions. His current research interests include 5G/6G technologies, Internet of Things, communications security, machine learning, and intelligent communications. He serves/has served as an editor-in-chief, associate editor-in-chief, and editor/associate editor for over ten journals. He was involved in over 50 IEEE conferences in different roles, such as the symposium chair, tutorial instructor, track chair, session chair, TPC co-chair, and keynote speaker. He is currently serving as the Chair of IEEE London Section and the ComSoc Signal Processing and Computing for Communications Technical Committee. He is a Fellow of CAE and EIC.

Jonathon A. Chambers (Fellow, IEEE) received the Ph.D. and D.Sc. degrees in signal processing from the Imperial College of Science, Technology and Medicine, Imperial College London, London, U.K., in 1990 and 2014, respectively. He served as the Head of the School of Engineering, University of Leicester from 2017 to 2019, and became an Emeritus Professor of Signal and Information Processing in 2020. He is also an International Honorary Dean of the College of Intelligent Systems Science and Engineering, Harbin Engineering University, China. He has advised almost 100 researchers through to Ph.D. graduation and published more than 600 conference papers and journal articles. His research interests include adaptive signal processing and machine learning and their applications, including in navigation and wireless communications.