Guest Editorial: Special Issue on Internet of UAVs Over Cellular Networks

THE EMERGING unmanned aerial vehicles (UAVs) have been widely exploited for sensing purposes due to the larger service coverage compared with the conventional fixed sensor nodes. However, due to the limited computation capability of UAVs, real-time sensory data needs to be transmitted to the BS/server for real-time data processing. In this regard, the cellular networks are necessary to support the data transmission for UAVs, which is called the Internet of UAVs. Very recently, 3GPP has approved a study item on the enhanced support to seamlessly integrate UAVs into future cellular networks.

Unlike terrestrial cellular networks, UAV communications have many distinctive features, such as high dynamic network topologies and weakly connected communication links. Besides, they also suffer from some practical constraints, such as battery power, no-fly zone, sensing requirements, etc. Therefore, it is essential to develop novel communication and signal processing techniques in support of the ultrareliable and real-time sensing applications. This special issue aims to create a platform for researchers from both academia and industry to disseminate state-of-the-art results and to advance the integration of UAVs to cellular networks.

In total, 30 submissions were received from around the world in response to this call for papers. During the review process, each article was assigned to and reviewed by at least three experts in the field, with a rigorous multiround review process. Thanks to the great support from the former Editor-in-Chief, Prof. Xuemin (Sherman) Shen, and the current Editor-in-Chief, Prof. Honggang Wang, and the dedicated work of numerous reviewers, we were able to accept 13 excellent articles covering various topics in this special issue. In the following, we will introduce these articles and highlight their main contributions.

In the article "Joint optimization of UAV 3-D placement and path-loss factor for energy-efficient maximal coverage," Shakoor *et al.* investigate a 3-D UAV placement problem as an aerial base station in emergency or capacity enhancement scenarios. To maximize the user coverage in the uplink transmission, a joint optimization scheme of the 3-D UAV deployment and path-loss compensation is proposed. The proposed optimization scheme demonstrates a significant performance improvement in terms of the coverage and the throughput.

In the article "Joint flight cruise control and data collection in UAV-aided Internet of Things: An onboard deep reinforcement learning approach," Li *et al.* address the challenge that UAV maneuvering gives rise to buffer overflow at the Internet-of-Things (IoT) node and unsuccessful transmission due to lossy airborne channels. A partial observable Markov decision process (POMDP) model is utilized to formulate a joint optimization of flight cruise control and data collection schedule to minimize the network data loss. In consideration of the curse of dimensionality with the growth in the number of IoT nodes, an onboard deep Q-network-based scheme is proposed given outdated knowledge on the network states.

The article "Drone-cell trajectory planning and resource allocation for highly mobile networks: A hierarchical DRL approach" studies a multi-UAV trajectory planning and resource allocation problem where UAVs serve as aerial base stations. To tackle the high uncertainties of the aerial communication environments, two hierarchical schemes are proposed. First, a multiagent deep reinforcement-learning-based algorithm is proposed for global trajectory planning. Second, a deep deterministic policy gradient-based algorithm is proposed to control the movement of UAVs and transmit power allocation according to real-time user traffic.

In the article "LEO-satellite-assisted UAV: Joint trajectory and data collection for Internet of Remote Things in 6G aerial access networks," Jia *et al.* exploit the low-Earth orbit (LEO) satellite-assisted UAV for data collection from the Internet-of-Remote-Things (IoRT) sensors, where delay-sensitive data can be transmitted through UAV-satellite transmission to the ground. The total energy cost of UAVs, including propulsion and transmission, is minimized while satisfying the IoRT demands. An efficient column generation algorithm based on the Dantzig–Wolfe decomposition is designed to address this problem.

In the article "Federated learning in the sky: Aerial-ground air quality sensing framework with UAV swarms," Liu *et al.* focus on the design of an aerial–ground air quality sensing framework for fine-grained 3-D air quality index (AQI) monitoring and forecasting based on federated learning. For aerial systems, a lightweight DenseMobileNet model is leveraged to achieve energy-efficient end-to-end learning from haze features of haze images taken by UAVs for predicting AQI scale distribution. For ground systems, a graph convolutional neural network-based long short-term memory (GC-LSTM) model is

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proposed to achieve accurate, real-time, and future AQI inference.

The article "Robust 60-GHz beamforming for UAVs: Experimental analysis of hovering, blockage, and beam selection" characterizes the impact of GPS inaccuracies, blockages in the line of sight, and suboptimal beam selection on aerial millimeter-wave links. By exploiting the information contained in the angular domain of experimentally collected beam-selection data, device-agnostic algorithms are proposed to jointly optimize UAVs physical movement and the beamforming procedure. Compared to the classical 802.11ad standards-defined approach, experimental results reveal 260% bit-rate improvement.

In the article "UAV-aided cellular operation by user offloading," Ali and Jamalipour deploy a UAV as an aerial base station to assist a terrestrial base station via user offloading. Taking into account the mutual interference between the aerial and terrestrial communication links due to spectrum reuse, the authors present the impact of the UAV altitude and transmit power, as well as the offload portion, on the users' downlink sum rate. The performance of the proposed method with respect to the horizontal UAV position optimization, probabilistic Line-of-Sight (LoS) channel, uplink communication, and orthogonal spectrum allocation is also investigated.

In the article "A novel nonstationary 6G UAV-to-ground wireless channel model with 3-D arbitrary trajectory changes," Chang *et al.* present a 3-D nonstationary geometry-based stochastic model for UAV-to-ground multiple-input–multiple-output (MIMO) channels. Statistical properties, including power delay profile (PDP), stationary interval, space–time correlation function (STCF), and root-mean square (RMS) delay spread, are derived and analyzed for different frequencies and scenarios. The accuracy is also validated by corresponding available channel measurements.

The article "Offloading optimization in edge computing for deep-learning-enabled target tracking by Internet of UAVs" investigates offloading problem from UAVs to a mobile-edge computing (MEC) server to execute deep learning tasks. A hierarchical machine learning tasks distribution (HMTD) framework is proposed to minimize the total weighted-sum cost of the UAVs with the inference error rate constraint. Closed-form optimal offloading ratios are derived analytically for different offloading schemes.

The article "Three-dimensional map-based trajectory design in UAV-aided wireless localization systems" considers the problem of localizing outdoor ground radio users with the help of a UAV on the basis of received signal strength (RSS) measurements in an urban environment. An optimal UAV trajectory is designed to help the UAV accelerate the learning process for a 3-D map of the environment. This proposed scheme is shown to achieve a superior accuracy compared to the map-unaware methods.

In the article "Malware on Internet of UAVs detection combining string matching and Fourier transformation," Niu *et al.* investigate advanced persistent threat (APT) in the Internet of UAVs. Based on the fact that most APT attacks use DNS to locate the C&C server of malware for information transmission periodically, an APT malware on the Internet of UAVs detection method is proposed to handle encrypted and obfuscated traffic due to packet payloads independence. The investigation provides a machine learning method to automatically find the detection threshold setting.

In the article "Dynamic resource allocation in UAV-enabled mmWave communication networks," Kumar *et al.* present a sectoring approach to ensure the coverage in a UAV-enabled millimeter-wave communication network. The expression for the probability distribution of signal-to-interference-plus-noise ratio due to simultaneous transmissions in different sectors is derived. Moreover, the resource allocation problem is formulated aiming to maximize the sum rate subject to the minimum rate constraint for each user.

The article "Location-based robust beamforming design for cellular-enabled UAV communications" proposes a position-based robust beamforming algorithm through complementarily integrating the navigation information and wireless channel information to improve the performance of cellular-enabled UAV communications. To accommodate the high mobility of UAVs, an optimization problem is solved by considering the Direction-of-Arrival (DoA) angle to correct the inherent position error. The results show that the proposed robust beamforming scheme could achieve over 90% DoA estimation error reduction.

We would like to express our sincere thanks to all the authors for submitting their papers and to the reviewers for their valuable comments and suggestions that significantly enhanced the quality of these articles. We are also grateful to Prof. X. Shen, the former Editor-in-Chief, and Prof. H. Wang, the current Editor-in-Chief of IEEE INTERNET OF THINGS JOURNAL, for their great support throughout the whole review and publication process of this special issue, and, of course, all the editorial staff. We hope that this special issue will serve as a useful reference for researchers, scientists, engineers, and academics in the field of the Internet of UAVs over cellular networks.

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