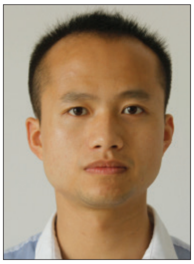
Aerial Computing: Drones for Multi-Access Edge Computing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The employment of multi-access edge computing (MEC) promotes the emergence of novel computation-intensive and time-sensitive applications at the network edge. Resource-limited devices can offload their computing tasks to edge servers, thereby avoiding heavy computing loads and reducing energy consumption. However, the computing servers are usually embedded in the fixed access points (APs) or base stations (BSs) in traditional MEC, which make it difficult to meet the unexpected explosively increasing computing demands and server users in certain emergency scenarios. Due to mobility, flexibility, and maneuverability, aerial computing has drawn extensive attention, where unmanned aerial vehicles (UAVs) equipped with computing servers provide agile computing services to mobile devices. Despite the potential of the aerial computing, however, many challenges also need to be addressed in this new paradigm. Until now, limited research progress has been made toward aerial computing.

The aim of this Special Issue (SI) is to highlight the latest research results and applications on aerial computing and inspire further research endeavors in this promising field. This SI also aims to promote the theory and practical frontiers for aerial computing. Through an open call for papers and rigorous peer-review process, we have selected 13 articles from over 60 submissions as representatives of ongoing research and implementation activities. These accepted articles encompass a wide range of research topics in aerial computing.

Cellular traffic prediction at mobile edges is valuable in 5G. However, accurate prediction for cellular traffic flow is a tough challenge due to irregular and dramatic fluctuations of network traffic. The article entitled "Cellular Traffic Prediction via Deep Multi-reservoirs Regression Learning Network for Multi-Access Edge Computing" by Li *et al*. achieves cellular traffic prediction by a deep multi-reservoirs regression learning network for multi-access edge computing. This is the first attempt to enhance deep neural computing considering a combined regression scheme in the framework of deep belief network.

Since traditional fog nodes are usually fixed, mobile fog nodes can be dispatched to various locations to cope with the variability in resource demand. The article entitled "Evaluation of the Employment of UAVs as Fog Nodes" by Silva *et al*. evaluates the use of UAVs as an alternative to fixed nodes in a fog infrastructure to cope with the variable workload in a metropolitan area. A location algorithm is proposed to deploy multiple battery-constrained UAVs, which aims to support computing services in regions without fixed nodes and replace some redundant fixed nodes.

Control and communication are two important pillars intra autonomous UAV swarm. The article entitled "Joint Optimization of Control and Communication in Autonomous UAV Swarm: Challenges, Potentials, and Framework" by Yao *et al*. investigates the joint optimization of control and communication processes, which aims at improving the swarm's task-handling capability. This article proposes a game model to characterize the UAVs' autonomous cooperation actions and designs a distributed multi-agent cooperative learning algorithm to achieve autonomous swarm.

How to provide robust edge computing is critical in UAV systems. The article entitled "Robust Edge Computing in UAV Systems via Scalable Computing and Cooperative Computing" by Liu *et al*. introduces a scalable aerial computing solution to divide different quality levels of tasks and proposes a cooperation framework for resource-constrained UAVs and ground servers, which opens the possibility to serve more users, and enables the optimal tradeoff between user experience and consumption of both computational and communication resources.

Large-scale sensor networks face energy, space isolation, communication collision and limited computation problems. The article entitled "An Aerial Computing Assisted Architecture for Large-Scale Sensor Networks" by Gu *et al*. proposes an aerial computing assisted architecture for large-scale sensor networks. By designing sensor localization, trajectory planning of drones, communication control between drones and sensors, and intelligent computation on drones, the architecture significantly advances large-scale sensor networks with higher efficiency, smaller delay, larger lifetime and more powerful computing capability.

The high mobility and internal interference of UAVs cause spatial-temporal discontinuity, which renders the network unable to provide users with on-demand coverage. The article entitled "Exploiting Aerial Computing for Air-to-Ground Coverage Enhancement" by Xie *et al*. designs a coverage-oriented computing control architecture for adaptive coverage structure generation. To enable temporally continuous coverage, this article proposes an AI-based aerial computing-based resource management scheme.

How to design a comprehensive resource management framework to adapt to various applications is critical to dynamic vehicular networks. The article entitled "Edge Intelligence for Multi-Dimensional Resource Management in Aerial-Assisted Vehicular Networks" by Peng *et al*. proposes a drone-assisted MEC-enabled vehicular network architecture to facilitate responsive and adaptive multi-dimensional resource management and designs artificial intelligence based resource management schemes to support vehicles with satisfied quality of service in highly dynamic vehicular network scenarios.

UAV-NOMA-MEC networks still involve significant challenges that are nontrivial for conventional approaches, including proactive user association, UAV deployment and long-term joint optimization of task offloading and resource allocation. The article entitled "Artificial Intelligence Driven UAV-NOMA-MEC in Next Generation Wireless Networks" by Yang *et al*. introduces an artificial intelligence enabled UAV-NOMA-MEC framework, where federated learning and reinforcement learning are introduced for intelligent task offloading and computing resource allocation.

Agents that learn the strategy from scratch always incur lots of resource consumption and long training delay, which pose challenges on resource-limited UAVs serving delay-sensitive computing tasks. The article entitled "Transfer Learning for Distributed Intelligence in Aerial Edge Networks" by Zhang *et al*. proposes a transfer learning empowered aerial edge network, which enables the UAVs to share knowledge for saving resource costs and reducing training latency. The article develops efficient transfer learning schemes where the edge resources are optimally orchestrated between knowledge sharing and task offloading.

While using UAVs as flying servers, computation offloading has significant impacts on the operation of aerial multi-access edge computing. The article entitled "MCTS-Enhanced Hybrid Offloading for Aerial Multi-Access Edge Computing" by Xu *et al*. considers multiple task computing strategies of users and designs a Monte Carlo tree search enhanced hybrid strategy in achieving time and energy-aware computation offloading.

Although multiple UAVs can be utilized for efficient multi-modal multi-task processing, great challenges in massive data transmission and dynamic network management arise. The article entitled "Joint Computation Offloading and Trajectory Design for Aerial Computing" by Zhang *et al*. proposes an air-ground integrated aerial computing framework and conducts implementation of the joint computation offloading and trajectory design for providing reliable and efficient edge computing services to ground devices.

When eavesdroppers exist, task transmission becomes vulnerable due to the limited computing power for encryption. The article entitled "A Secure Structure for UAV-Aided IoT Networks: Space-Time Key" by Han *et al*. proposes a secure UAV-aided IoT network structure. The new structure facilitates the trajectory planning and deployment optimization of UAVs to minimize energy consumption among multiple clusters covered by a UAV and maximize the secrecy capacity in each cluster, respectively. The beam hopping is carried out to encrypt multi-access IoT devices within the coverage of a UAV.

The ever-increasing number of devices and emerging applications have triggered the demands for ubiquitous connectivity and more efficient computing paradigms, which pose significant challenges to current wireless networks and computing architectures. The article entitled "An Edge Computing Paradigm for Massive IoT Connectivity over High-Altitude Platform Networks" by Ke *et al*. proposes a high-altitude platform network-enabled aerial cell-free massive multiple-input multiple-output network and further adopts a grant-free massive access scheme to guarantee low-latency and high-efficiency massive IoT connectivity.

Finally, we would like to sincerely thank Prof. Yi Qian, the Editor-in-Chief of *IEEE Wireless Communications*, for his support of this SI. We sincerely thank all the authors who submitted their valuable work. We would also like to thank all the reviewers for their quality reviews. We believe this SI delivers cutting-edge research in the field of aerial computing, and will encourage researchers from related areas to devote continuous efforts in tackling the remaining open challenges.

Biographies

Jianchao Zheng received the B.S. degree in communications engineering and the Ph.D. degree in communications and information systems from the College of Communications Engineering, PLA University of Science and Technology, Nanjing, China, in 2010 and 2016, respectively. From 2015 to 2016, he was a visiting scholar with the Broadband Communications Research Group, Department of Electrical and Computer Engineering, University of Waterloo, Canada. He is currently an associate professor at the National Innovation Institute of Defense Technology, Academy of Military Sciences of PLA. He has authored or co-authored over 40 papers in international conferences and respected journals in his research area. His research interests focus on interference mitigation techniques, green communications and computing networks, game theory, learning theory, and optimization techniques. He has acted as a Technical Program Committees Member for a number of international conferences, including the IEEE Global Communications Conference, and the IEEE Vehicular Technology Conference (VTC). He was a recipient of the Excellent Doctoral Thesis Award of the China Education Society of Electronics in 2017. He was also a recipient of the Best Paper Awards at the IEEE Communications Society Technical Committee on Green Communications and Computing (TCGCC) in 2017 and IEEE WCSP in 2016, respectively. He was granted by the National Post-Doctoral Program for Innovative Talents in 2017 and by the Young Elite Scientist Sponsorship Program in 2018.

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