Guest Editorial: Introduction to the Special Section on Aerial Computing Networks in 6G

AERIAL computing has garnered significant attention from both academia and industry in recent years. Unlike traditional computing models, aerial computing offers comprehensive coverage, high flexibility, and enhanced scalability by leveraging computing resources across space, air, and ground networks. With its potential to support new applications in 6G Space-Air-Ground integrated networks, aerial computing promises to revolutionize global communication. However, adopting aerial computing also presents various challenges, such as managing dynamic network topologies, ensuring resource efficiency, and addressing security concerns. Overcoming these challenges will require the integration of advanced computing, communication, and networking technologies to realize a genuinely seamless and intelligent aerial computing ecosystem.

The special issue "Aerial Computing Networks in 6G" highlights the latest advancements in this rapidly evolving field. Thanks to the dedicated efforts of the reviewers and the valuable support from the Editor-in-Chief, Prof. Jianwei Huang, we were able to include 19 outstanding articles that cover a wide range of critical topics. These include **resource scheduling and allocation in aerial computing**, **AI-enabled aerial communication systems**, **security and privacy issues in the aerial environment**, and **the application of blockchain and federated learning in aerial networks**. We briefly summarize the key contributions of the articles in this special issue as follows.

Integrating Low Earth Orbit (LEO) satellites and uncrewed aerial vehicles (UAVs) into 6G networks presents a promising solution for expanding network capacity, particularly in remote areas. However, task offloading and resource management challenges arise due to the high mobility of LEO satellites and the limited resources of energy-harvesting UAVs (EH-UAVs). In response, the paper "Intelligent Self-Optimization for Task Offloading in LEO-MEC-Assisted Energy-Harvesting-UAV Systems" by D.S. Lakew et al. proposed a joint optimization model for LEO-MEC server selection, power allocation, and task offloading. Using a novel mixed discrete-continuous control deep reinforcement learning (MDC2-DRL) algorithm, the authors address connectivity and energy constraints, achieving superior results over existing methods. This research offers practical solutions for managing resources in LEO-MEC-assisted EH-UAV systems.

LEO satellite networks hold great potential for supporting mobile communications. However, accommodating time-sensitive services, especially for Internet of Things (IoT) and industrial IoT devices, remains challenging due to resource limitations and the dynamic nature of LEO constellations. The paper "Time-Sensitive Scheduling Mechanism Based on End-to-End Collaborative Latency Tolerance for Low-Earth-Orbit Satellite Networks" by Wang et al. addresses these challenges by introducing a latency-scheduling architecture optimized for multi-hop scenarios. Their proposed time-sensitive scheduling algorithm (CoLT-TSA), leverages collaborative latency tolerance to enhance scheduling capabilities without sacrificing the timeliness of services. Simulation results show that CoLT-TSA effectively reduces packet loss and improves throughput while decreasing the time-out ratio compared to conventional methods. This work contributes to advancing LEO-based time-sensitive networking by tackling fundamental scheduling inefficiencies and offers promising improvements for mission-critical applications in next-generation networks.

In the paper "Quantum-Assisted Joint Caching and Power Allocation for Integrated Satellite-Terrestrial Networks," Zhang et al. proposed an innovative approach to enhance content delivery in LEO satellite networks, which work alongside terrestrial networks for global coverage. They introduce an Integrated Satellite-Terrestrial Network (ISTN) architecture to optimize content delivery, cache placement, and power allocation. To solve the complex optimization problem, the authors present a Hybrid Quantum-Classical Generalized Benders' Decomposition (HQCGBD) algorithm. Leveraging quantum annealing, the algorithm efficiently accelerates the process, and simulations demonstrate its superiority over traditional methods, validating the proposed ISTN architecture.

In the paper "Hybrid Multi-Server Computation Offloading in Air-Ground Vehicular Networks Empowered by Federated Deep Reinforcement Learning," Song et al. address the challenges of computation-intensive and delay-sensitive services in intelligent transportation systems for resource-limited vehicular users (VUs). They explore using multi-access edge computing to mitigate computation delays within an air-ground integrated framework. The authors introduce a multi-agent twin delayed deep deterministic policy gradient (MATD3) algorithm for UAV trajectory optimization and a federated upgraded dueling double deep Q network (FUD3QN) algorithm for efficient resource allocation. These approaches aim to minimize delays and energy consumption while ensuring quality of service (QoS). Their MATD3-FUD3QN algorithm significantly outperforms traditional methods, highlighting the benefits of UAV integration in improving transmission quality and overall system performance.

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In "Umix: Sustainable Multi-UAV Coordination for Aerial-Terrestrial Networks," Ding et al. address the growing trend of deploying UAVs within wireless communication networks in remote areas; they highlight the importance of 6G technologies for enhancing the performance of Aerial-Terrestrial Networks (ATNs) in communication relaying and data transmission. The authors present Umix, an innovative approach based on DRL that optimizes UAV trajectories and operational dynamics while tackling energy management and coordination challenges. Umix features an encoder-decoder architecture for capturing historical trajectory data and employs a weight assignment network for efficient task distribution. The extensive experiments demonstrate that Umix outperforms existing benchmarks, effectively conserving energy and time in various UAV and sensor configurations, thus advancing the sustainable coordination of UAVs in challenging environments.

In the paper "UAV T-YOLO-Rice: An Enhanced Tiny Yolo Networks for Rice Leaves Diseases Detection in Paddy Agronomy," A.K. Sangaiah et al. examine the pivotal role of paddy agronomy in the Asia-Pacific region and the integration of cutting-edge technologies to enhance agricultural practices. The authors focus on leveraging aerial computing techniques, particularly UAVs and the IoT combined with Deep Learning (DL), to improve data availability and predictive analytics. They proposed the UAV Tiny YOLO Rice (UAV T-YOLO-Rice) architecture, which incorporates enhancements like a YOLO detection layer for better small object detection and various feature extraction modules to increase accuracy while minimizing computational resource usage. By training their model on a comprehensive rice leaf disease dataset, the authors achieved a mean average precision (mAP) of 86%, surpassing existing models, including the advanced YOLO V7. Their findings highlight the potential of combining DL with UAV technologies to address critical challenges in paddy agronomy, fostering more innovative and efficient farming practices.

In "FAR-Net: Semantic Segmentation of Large-Scale Point Clouds Based on Feature Aggregation and Recoding for Aerial Computing," Zhang et al. address the challenges of semantic segmentation in large-scale point clouds within aerospace remote sensing. They focus on mitigating feature loss during down-sampling and balancing segmentation performance with computational efficiency. The proposed FAR-Net utilizes local difference attention coding and a hierarchical feature aggregation module that combines key points and voxels to enhance detail retention. Additionally, a binary feature recoding module improves segmentation accuracy. Experimental results demonstrate that FAR-Net achieves competitive performance on various 3D point cloud datasets, highlighting its potential in remote sensing applications.

In "Deep Convolutional Linear Precoder Neural Network for Rate Splitting Strategy of Aerial Computing Networks," Wang et al. address the challenge of massive node access in aerial computing networks, where user devices demand low latency and high robustness. They introduce Rate Splitting Multiple Access (RSMA), which enhances interference management by dividing user messages into shared and private components. The authors proposed a deep convolutional neural network for optimizing the linear precoder design for RSMA, significantly reducing optimization time and improving communication efficiency. They also present two methods for integrating the linear precoder with Channel State Information (CSI) feedback models, either using the decoder output or extracting features from the feedback codeword, thereby reducing the computational effort. Simulations show that these models achieve communication rates similar to traditional strategies while offering greater time efficiency, representing a notable advancement in aerial communication technology.

In "Blind Recognition Method for Non-Cooperative Communication Signals Based on Aerial Computing," Wang et al. proposed a significant advancement in the realm of 6G space-air-ground integrated networks. By combining aerial computing with deep learning, they develop a method that simultaneously identifies encoding methods and modulation types for non-cooperative communication signals. This integrated approach conserves computing and communication resources, addressing the inefficiencies in traditional methods that treat these processes separately. The simulation results show superior recognition accuracy, demonstrating the potential of this method in enhancing communication efficiency across aerial computing networks.

The exponential growth of IoT devices and emerging applications has posed challenges for traditional computing architectures. In "Computation Offloading via Multi-Agent Deep Reinforcement Learning in Aerial Hierarchical Edge Computing Systems," Wang et al. proposed an aerial hierarchical mobile edge computing system composed of high-altitude platforms (HAPs) and UAVs to address the limitations of terrestrial edge computing. The system optimizes task offloading for non-divisible tasks by minimizing long-term processing costs. Using a multi-agent DRL algorithm, the authors enable devices to make offloading decisions based on local observations while a convolutional Long Short Term Memory (ConvLSTM) network estimates future task loads. A prioritized experience replay (PER) method also accelerates convergence and enhances training stability. Their results show that this approach significantly outperforms existing benchmarks, contributing to more efficient computation offloading in aerial edge computing.

In this paper, "Blockchain-Aided Secure Access Control for UAV Computing Networks," Wang et al. proposed a blockchain-based solution to improve security in UAV clusters. Unlike traditional centralized methods, their scheme allows UAVs to manage identities and access policies autonomously, reducing communication overhead and security risks. They address blockchain scalability and communication issues by integrating committee elections and clustering optimizations. The security analysis shows that the method effectively defends against attacks while maintaining low energy use and scalability, providing a robust solution for secure access in UAV networks.

Mobile data has proliferated in recent years due to the Internet of Vehicles (IoV) development, leading to resource limitations. In the paper "A Novel Proactive Cache Decision Algorithm Based on Prior Knowledge and Aerial Cloud Assistance in Internet of Vehicles," Chen et al. proposed a solution that integrates aerial cloud and ground edge nodes to enhance caching efficiency. Their proactive caching algorithm uses a dynamic request graph, temporal graph networks, and LSTM models to predict user requests and optimize cache locations. Simulation results demonstrate that the proposed method significantly improves caching efficiency, reduces latency, and lowers energy consumption, outperforming existing algorithms like Dueling Double Deep Q-Network (D3QN), Dueling Deep Q-Network (DQN), and Double DQN. This work presents a critical advancement in managing resources for IoV systems.

In the paper "A Tri-Phases Message Oriented Trust Model in FANET," Du et al. proposed a comprehensive security model to address the vulnerabilities in Flying Ad Hoc Networks (FANETs) formed by UAVs. Given the dynamic topology and limited bandwidth of FANETs, ensuring message security is critical. The proposed Tri-Phases Message Oriented Trust Model (TPMOTM) enhances message security through three distinct phases: generation, transmission, and integration. Trust values are assigned based on detection factors such as timeliness, accuracy, and message loss, which the Ground Station (GS) uses to assess the reliability of messages. Simulations demonstrate high attack detection rates (up to 95%) and event detection accuracy (above 85%), highlighting the model's effectiveness in safeguarding communication within FANETs.

In the paper "Adaptive Task Offloading with Spatiotemporal Load Awareness in Satellite Edge Computing," Zhou et al. address the challenge of balancing computational workloads across LEO satellites, which face constraints due to their mobility and limited resources. To tackle this, the authors proposed Adaptive Task Offloading with Spatiotemporal Load Awareness (ATO-SLA), an adaptive task offloading approach designed to optimize user-perceived delays and energy consumption by leveraging spatiotemporal load awareness. By modeling the offloading problem as a Markov decision process and employing a proximal policy optimization strategy, the approach dynamically manages task allocation to avoid satellite overload. Experimental results show that ATO-SLA effectively reduces average delays and energy consumption, outperforming existing methods and making it a promising solution for satellite edge computing networks.

The paper "UAV-assisted Heterogeneous Multi-Server Computation Offloading with Enhanced Deep Reinforcement Learning in Vehicular Networks," by Song et al., tackles the challenges of computation-intensive and latency-sensitive applications in intelligent transportation systems for resource-constrained task vehicles (TVEs). The authors introduce a UAV-assisted heterogeneous multi-server computation offloading (HMSCO) scheme designed to minimize delay and energy consumption costs while meeting reliability and resource constraints. They decompose the complex, non-convex problem into two sub-problems: first, using a game-based binary offloading decision (BOD) to assess task offloading, and second, applying a multi-agent enhanced dueling double deep Q-network (ED3QN) for optimal resource allocation. Simulation results demonstrate the algorithm's robustness and convergence in dynamic vehicular environments, showcasing its potential to improve computation offloading in future intelligent transportation systems.

In the paper "Federated Learning With Privacy-Preserving Incentives for Aerial Computing Networks," Wang et al. address challenges in integrating artificial intelligence (AI) with aerial computing, focusing on federated learning (FL) amid energy and data limitations. They highlight privacy concerns that hinder user incentives, including risks of eavesdropping on learning quality and potential attacks on cost information. To resolve these issues, the authors proposed a privacy-preserving incentive mechanism that utilizes differential privacy to protect user costs and a Combinatorial Multi-Armed Bandit (CMAB) algorithm to evaluate learning quality without revealing participant details. Simulation results show their approach effectively encourages high-quality participation while ensuring privacy and advancing federated learning in aerial computing networks.

The major work of the paper "Adaptive Multi-UAV Trajectory Planning Leveraging Digital Twin Technology for Urban IIoT Applications" by Zhao et al. is as follows: The replication and prediction capabilities of digital twins (DTs) are utilized to assist UAVs in planning optimal trajectories, and an incremental and distributed updating (IDU) model that combines DTs to optimize their energy consumption is proposed. To cope with the dynamic changes in demand, an adaptive trajectory decision (STD) scheme is proposed, which utilizes DT to plan different classes of trajectories based on the prediction results to cope with the dynamic demand. The UAV simply receives this trajectory model and makes a simple trajectory selection based on the real-time scenario. In order to plan the optimal trajectory by DT, we consider a Dueling Deep Q Network (Dueling DQN) with Prioritized Experience Replay (PER) for training, taking into account the characteristics of the demand. Simulation results demonstrate the effectiveness of DT optimization, and the STD scheme can cope with different demand variations and each trajectory is optimal in the corresponding scenario.

In the paper "Multi-Time-Scale Markov Decision Process for Joint Service Placement, Network Selection, and Computation Offloading in Aerial IoV Scenarios," S.S. Shinde et al. address the challenges faced by Vehicular Edge Computing (VEC) in enhancing multi-service vehicular 6G networks. They highlight the limitations of terrestrial edge servers and propose a multi-time-scale optimization process for effective service placement. By leveraging a Markov Decision Process (MDP) framework and Reinforcement Learning (RL), the authors aim to improve latency and energy efficiency in VEC-enabled vehicular networks. Their advanced deep Q-learning method shows significant performance improvements compared to benchmark approaches, offering valuable solutions for optimizing resource utilization in dynamic aerial IoV environments.

In the paper "Frisbee: An Efficient Data Sharing Framework for UAV Swarms," Chen et al. present an innovative solution to the critical challenge of data sharing within UAV swarms, particularly in emergency, disaster, and military contexts. Frisbee, the proposed framework, addresses intra-cell and inter-cell data-sharing complexities by organizing UAVs into cells with designated head UAVs. Through the use of the Dynamic Cuckoo Summary for efficient intra-cell indexing and a 2-dimensional virtual plane for inter-cell communication, Frisbee optimizes data localization and transmission across the swarm. Experimental results demonstrate its superiority, achieving higher throughput, lower response delay, and reduced overhead compared to traditional ground network solutions. This work is a significant step in enabling real-time data sharing in dynamic UAV environments.

In summary, the collected articles present innovative approaches to aerial computing networks and provide insights into the foundational principles driving their design and optimization for 6G space-air-ground integrated networks. We hope this special section will inspire further research and development in this rapidly evolving field, paving the way for enhanced performance and efficiency in next-generation communication systems.

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