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Internet of Drones: Novel Applications, Recent Deployments, and Integration

Unmanned aerial vehicles (UAVs), also called drones, are extensively being adopted for a wide variety of applications such as traffic surveillance, disaster management, rescue operations, and environment monitoring. With the adoption of the Internet of Things (IoT), UAV networks are quickly transforming into the Internet of Drones (IoD) paradigm. This has opened up opportunities for the exploration of more sophisticated UAV applications.

The UAV as a powerful tool has found applicability in providing advanced communication and computing resources in 5G and 6G networks. However, due to the limited resources on UAVs, multi-access edge computing (MEC) as a powerful offloading technology can be integrated with IoD networks for offloading tasks at the network edge. Further, for securing IoD networks, blockchain technology and cryptography may be leveraged. With the growing volume of data being captured by drones, there is a requirement for real-time and low-latency processing of this data. Thus, artificial intelligence (AI) services can be deployed on drones using advanced machine learning and deep learning algorithms.

This Special Issue focuses on novel works done in the area of IoD networks where state-of-the-art technologies like blockchain, machine learning, deep learning, 5G/6G communication networks, and MEC are leveraged for empowering these networks. It is noteworthy that security is one of the major concerns for IoD network management. Keeping this is mind, around half of the manuscripts in this Special Issue focus on security provisioning for the IoD network using blockchain and other techniques. Approximately 40 contributions were received and peer-reviewed, of which 12 were selected for publication as a part of this Special Issue.

Out of these 12 articles, two propose the use of edge computing for empowering IoD network operation. One article presents a method for extracting content from data lakes in a camera-based IoD environment. One article presents a 5G-empowered drone-assisted remote e-health solution, while yet another proposes the use of drones for analyzing traffic congestion on roads. One article leverages joint provisioning of quality of service (QoS) and security in IoD networks. Five articles propose the use of blockchain and AI to make IoD networks more secure and scalable. One article presents a roadmap of next-generation wireless technology for 6G-enabled vehicular networks. These works are described in short as follows.

In "UAV-Assisted Multiple-Access Edge Computing: Technologies and Challenges," Peiyag *et al.* describe the existing research work on MEC and UAV wireless communication systems. The authors combine the UAV system with the MEC technology and propose a UAV-assisted MEC wireless communication system. Additionally, this article aims to provide new ideas for the proposed architecture for aerial computing [1].

In "Integrating Mobile Edge Computing into Unmanned Aerial Vehicle-Based Networks: An SDN-Enabled Architecture," Chuan *et al.* present various architectures for the UAV-based MEC system. Additionally, they deploy software-defined networking (SDN)-based techniques to improve the network's scalability and controllability. Also, the authors introduce the concept of a smart function table that can be applied to execute the network operation in the proposed framework [2].

In "Fido: A String-Based Fuzzy Logic Mechanism for Content Extraction from UAV Data Lakes," Pallav *et al.* propose a fuzzy-based approach in a camera-based IoD environment, which is capable of efficiently handling spelling variations, out-of-order words, and partial matchings, as compared to conventional string comparison methods. Also, the authors demonstrate the efficacy of Fido with an almost 80 percent similarity ratio between the request and response images and a processing time of 80 μs [3].

In "An Artificial Intelligence Application for Drone-Assisted 5G Remote e-Health," Naercio *et al.* demonstrate an AI and drone-assisted 5G-network-based approach for long-distance patient monitoring and care. The proposed remote e-health application serves as a platform of communication between patients and healthcare staff, where the latter can send standardized video footage or pictures to their primary care doctor [4].

In "Unmanned Aerial Multi-Object Dynamic Frame Detection and Skipping Using Deep Learning on the Internet of Drones," Usman *et al.* present a deep-learning-based system to analyze traffic congestion. The proposed model uses multiple drone video feeds and vehicle information to detect, classify, and count the number of vehicles in the live traffic feed. The model is trained with a deep learning approach to first align the video frame and detect the objects in a top-down aerial drone video. The dynamic skipping method helps process a long video feed and accurately compares the video frame. Then, using a standard vehicle query (i.e., make, model, and year of manufacture), the model detects traffic scenarios in real time. The proposed model is useful in many applications requiring a particular area to be monitored in real time for data analysis and routine drone tasks [5].

In "Joint Provisioning of QoS and Security in IoD Networks: Classical Optimization Meets AI," Fadlullah *et al.* present the trade-off between tightly coupled provisioning of the QoS and security performance of users. Additionally, the authors obtain a synthesized dataset using the solutions derived from an optimizer, which they use to train an adaptive boosting (Adaboost) method so as to address the joint optimization problem of QoS and security. They demonstrate that the Adaboost-based method maximizes the security levels without significantly sacrificing network performance. The effectiveness of the proposed method is demonstrated using computer-based simulation results, which show that it provides higher QoS with higher security ranks in contrast to several conventional methods [6].

In "Blockchain for Internet of Drones: Applications, Challenges, and Future Directions," Singh *et al.* describe the emergence of IoD and its industrial applications. The authors highlight the key security concerns and then propose the use of blockchain as a key solution for these concerns. Additionally, they present these concerns alongside some derived blockchain architectures that tend to resolve these concerns. This article represents a case study for drone-based community delivery in pandemic-like situations using a derived blockchain architecture with some open issues and future challenges [7].

In "Drone-Assisted, Edge-Cloud Computing, and Blockchain-Enabled Networks: Architecture Design, Case Study, and Future Directions," Jianbo *et al.* discuss a drone-assisted and blockchain-enabled edge-cloud computing network (DBECN) framework, where drones can act as moving terminals and moving base stations for different scenarios. Integrated with terrestrial edge nodes and cloud centers, the framework can also provide caching and computation resources for delay-sensitive and resource-intensive task processing, big data analysis, caching, and processing. The authors also present a secure and credible data sharing scheme under the DBECN framework. They deploy blockchain in the edge nodes to provide secure and efficient data storage and sharing among different terminal-based drones [8].

In "GaRuDa: A Blockchain-Based Delivery Scheme Using Drones for Healthcare 5.0 Applications," Gupta *et al.* present a blockchain-based drone delivery scheme for Healthcare 5.0 applications. The proposed scheme integrates IoD and blockchain through 5G-enabled tactile Internet to facilitate low-latency responsive delivery of medical supplies that can be chronologically monitored and tracked among different stakeholders. Also, the authors compare the proposed scheme with the traditional medical delivery scheme with payment gateways to demonstrate its effectiveness in terms of data storage, computation, and communication costs, which shows a reduction in transaction cost and latency [9].

In "Securing Internet of Drones Network Using AI-Envisioned Smart-Contract-Based Blockchain," Bera *et al.* propose an AI-envisioned, smart-contract-based, blockchain-enabled security framework for secure communication in IoD. They provide a security analysis that proves the security of the proposed framework against different potential attacks and results to identify the impact of various components on the system's performance [10].

In "Securing Internet of Drones against Cyber-Physical Attacks," Lv *et al.* present the security performance of drones' communication system and protect the drone network from physical attacks in real time. Also, the authors propose the ECC-GKA key agreement protocol to analyze the accuracy and security of the drone network [11].

In "A Roadmap of Next-Generation Wireless Technology for 6G-Enabled Vehicular Networks," Adhikari *et al.* analyze next-generation 6G-supported technologies and their advantages in terms of adopting 6G in the Internet of Vehicles (IoV). Additionally, they present several 6G-based frameworks for IoV networks with current open research challenges and future directions for solving those challenges in 6G technology [12].

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