Edge Intelligence for Next Generation Wireless Networks

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In the past decade we have witnessed the development of machine learning and artificial intelligence algorithms with cloud computing in providing intelligence for smart applications. By collecting raw data from a multitude of mobile and wireless devices, the cloud server executes machine learning algorithms to train the data and perform data prediction. However, the growing number of devices has generated a tremendous amount of data. Transmitting massive data to centralized machine learning in the cloud has significant communication overhead and computational complexity. With the support of edge gateways, the significant burdens of massive data flow and exchanged information from large groups of devices can be efficiently alleviated in terms of both communication and computational overhead. Meanwhile, the exchanged information aims to reach the remote online system, in which the continuous and robust online services should be always guaranteed and ensured. As a promising solution, cyberinfrastructure is designed and developed to boost network intelligence by offering powerful computing systems, flexible data storage repositories, and advanced virtualization environments at both the edge and the cloud. Edge intelligence has emerged as a new trend for next generation wireless networks.

In this issue of *IEEE Wireless Communications*, we are pleased to present a special issue on "Edge Intelligence for Beyond 5G Networks" with a collection of 10 articles. Many thanks to the guest editors, Y. Zhang, Z. Feng, H. Moustafa, F. Ye, U. Javaid, and C. Cui, who did an excellent job in editing this special issue for our readers. Please stay tuned for new developments in the research area of edge intelligence for beyond 5G networks and read the editorial and papers in this special issue.

In this issue, we are also very glad to present 12 articles accepted from the open call.

The first article, "Blockchain-Enabled Applications in Next-Generation Wireless Systems: Challenges and Opportunities" by X. Li *et al*., discusses opportunities and challenges of blockchain-enabled wireless applications. Blockchain technology and 5G system architecture are briefly reviewed. An example wireless application use case is presented to illustrate the benefits that blockchain technology can bring to wireless applications. As a potential solution, a wireless blockchain middleware architecture, BlockWare, is proposed, where a blockchain middleware layer is positioned between and connecting wireless applications and underlying blockchain infrastructure. The blockchain middleware layer interacts with various types of blockchain systems on behalf of different wireless applications.

The second article, "Game Theoretical Approaches for Cooperative UAV NOMA Networks" by X. Shao *et al*., proposes a cooperative UAV NOMA network (CUNN) architecture and analyzes its technical challenges. With the goal of cooperatively or competitively utilizing the limited resources effectively in a distributed manner, game theory shows its potential in addressing various technical challenges in wireless networks. The authors further survey game theoretical approaches for NOMA networks and UAV-based relay networks and provide insights on how these game theoretical approaches can be adopted to solve technical challenges in CUNNs. Aiming to achieve high spectrum efficiency and ensure fairness among user equipment, they propose a UAV-iUE association, UAVs' position optimization, and power allocation algorithm in a dynamic cooperative game-theoretic framework.

In the third article, "Dynamic Metasurface Antennas for 6G Extreme Massive MIMO Communications," N. Shlezinger *et al*. present an alternative application of metasurfaces for wireless communications as active reconfigurable antennas with advanced analog signal processing capabilities for next generation transceivers. They review the main characteristics of metasurfaces used for radiation and reception and analyze their main advantages as well as their capability to reliably communicate in wireless networks. They also discuss a list of research and implementation challenges which arise from the application of metasurface antennas for wireless transceivers.

In the fourth article, "Understanding UAV-Based WPCN-Aided Capabilities for Offshore Monitoring Applications," D. Carrillo *et al*. address the technical challenges in the context of versatile maritime and offshore use cases by delivering a conceptual solution based on the convergence of three emerging technologies: unmanned aerial vehicles (UAVs), battery-less sensors, and wireless powered communication networks. They offer a systematic description of the ecosystem related to the proposed solution by identifying its key actors and design dimensions together with the relevant resources and performance metrics. A system-level modeling-based evaluation of an illustrative scenario delivers deeper insights into the considered operation and the associated tradeoffs.

In the fifth article, "Information-Centric Networking in Wireless Environments: Security Risks and Challenges," B. Nour *et al*. present the security issues that may arise and the attacks that may occur from different points of view when Information-Centric Networking (ICN) is deployed in wireless environments. The discussed attacks may target both applications and the ICN network itself by exploiting elements of the ICN architecture, such as content names and in-network content caches. They also discuss potential solutions to the presented issues and countermeasures to the presented attacks. Finally, they identify future research opportunities and directions.

In the sixth article, "Interactive Artificial Intelligence Meets Game Theory in Next-Generation Communication Networks," J. Shen *et al*. propose a new three-step frame-

work combining game theory and ML naturally, involving feature learning for abstracting knowledge, game modelling for making strategies, and strategy learning for online updating. They propose a framework that consists of three existing technologies to solve the network selection problem in ultra-dense heterogeneous networks. The simulation results demonstrate the advantage of the framework to reduce average delay. The combination of game theory and AI can overcome their shortcomings respectively.

In the seventh article, "Reconfigurable-Intelligent-Surface Empowered Wireless Communications: Challenges and Opportunities," X. Yuan *et al*. discuss the fundamental physical-layer issues related to the deployment of reconfigurable intelligent surfaces (RISs) in practical wireless networks, including CSI acquisition, passive information transfer, and low-complexity robust system design. For each of these issues, they explain the main challenges, discuss the state-of-the-art solutions, and identify the open research directions. Other RIS design problems, such as edge intelligence and physical-layer security, are briefly introduced.

In the eighth article, "V2X-Based Vehicular Positioning: Opportunities, Challenges, and Future Directions," S.-W. Ko *et al*. investigate V2X as a pivotal technology and recommend several attractive directions to meet the vehicular positioning's stringent safety requirements. They provide some possible directions to realize fully auto-driving by overcoming current obstacles.

In the ninth article, "Social-Aware Routing in Mobile Opportunistic Networks," J. Zhang *et al*. present an insightful review of social-aware routing in MONs through investigations to provide a comprehensive understanding and inspire more in-depth studies. They first explore the motivations behind social-aware routing and introduce various social metrics commonly used. They investigate existing social-aware routing schemes in terms of design principles, evaluation metrics, taxonomy, relay selection and message distribution, respectively. They summarize emerging challenges and open issues with respect to social metrics, social perception, privacy and security, emerging applications, and experiments in this area.

In the tenth article, "A Novel HTTP Anomaly Detection Framework Based on Edge Intelligence for the Internet of Things (IoT)," Y. An *et al*. propose a new HTTP anomaly detection framework based on edge intelligence for IoT. In this framework, both clustering and classification algorithms are used to detect anomalies quickly and accurately in the HTTP traffic for IoT. Unlike the existing work relying on a centralized server to perform anomaly detection, with the recent advances in edge intelligence, the proposed framework distributes the entire detection process to different nodes. A data processing method is also proposed to divide the detection fields of HTTP data, which can eliminate redundant data and extract features from the fields of a HTTP header.

In the eleventh article, "A Novel Centralized Cloud-Based Mobile Data Rollover Management," Z. Sadreddini and H. Yanikomeroglu propose a new centralized mobile data management system under some circumstances: Internet access can be neither easily accessible for users who use limited plans nor affordable for inbound or outbound travelers. The aim of the proposed method is to provide a centralized cloud data-pool, which provides data rent and release facilities for users anytime anywhere. To offer this opportunity, data-pool management is provided by the centralized controller (CeCo), which is in constant communication with the SP. Therefore, under CeCo and SP coordination, users can transfer unused data into the data-pool or rent data from the data-pool when they need it.

In the twelfth and last article, "B-ReST: Blockchain-Enabled Resource Sharing and Transactions in Fog Computing," Y. Gao *et al*. propose the B-ReST architecture to enable resource sharing and transactions in fog computing networks, where F-RAN and blockchain technology are combined tightly. The willingness and billing issues in the computing resource sharing and transaction applications due to the untrustworthy feature in fog computing networks are discussed in detail. The physical architecture based on FRAN, the workflow based on blockchain technology and the functional architecture of B-ReST are designed and illustrated as well.

I hope you will enjoy reading the articles in this issue of *IEEE Wireless Communications Magazine*.

Biography

Yi Qian [M'95, SM'07, F'19] received a Ph.D. degree in electrical engineering from Clemson University, in Clemson, South Carolina. He is currently a professor in the Department of Electrical and Computer Engineering, University of Nebraska-Lincoln (UNL). Prior to joining UNL, he worked in the telecommunications industry, academia, and government. Some of his previous professional positions include serving as a senior member of scientific staff and a technical advisor at Nortel Networks, a senior systems engineer and a technical advisor at several startup companies, an assistant professor at the University of Puerto Rico at Mayaguez, and a senior researcher at the National Institute of Standards and Technology. His research interests include wireless communications and networks, and information and communication network security. He has research and industry experience in wireless communications and networks, wireless sensor networks, vehicular communication networks, information and communication network security, smart grid communications, broadband satellite communications, optical communications, high-speed communications and networks, and Internet of Things. He was previously Chair of the IEEE Technical Committee for Communications and Information Security. He was the Technical Program Chair for the IEEE International Conference on Communications 2018. He serves on the Editorial Boards of several international journals and magazines, including as the Editor-in-Chief for *IEEE Wireless Communications*. He was a Distinguished Lecturer for the IEEE Vehicular Technology Society. He is currently a Distinguished Lecturer for the IEEE Communications Society. He received the Henry Y. Kleinkauf Family Distinguished New Faculty Teaching Award in 2011, the Holling Family Distinguished Teaching Award in 2012, the Holling Family Distinguished Teaching/Advising/Mentoring Award in 2018, and the Holling Family Distinguished Teaching Award for Innovative Use of Instructional Technology in 2018, all from the University of Nebraska-Lincoln. He is the principal author of the textbook, "Security in Wireless Communication Networks", published by IEEE Press/Wiley in 2021.