Fog Intelligence and Radio Access Networks


Yi Qian

Dear reader,

During this time of uncertainty and change, I hope all is well and that you and your families are staying safe and healthy. In the last issue of *IEEE Wireless Communications Magazine*, we successfully published a special issue on "Intelligent Radio: When Artificial Intelligence Meets Radio Network." In the April 2020 issue, we present a closely related topic, a special issue on "Artificial Intelligence-Driven Fog Radio Access Networks: Recent Advances and Future Trends," with a collection of eight articles compiled by the guest editors, M. Peng, T. Q. S. Quek, G. Mao, Z. Ding, and C. Wang, who have done an excellent job in editing this issue for our readers.

The fifth-generation (5G) wireless communication system and heterogeneous networks enable a multitude of connected Internet-of-Things (IoT) devices to exchange information with the online service providers in a more effective way. With the support of fog computing-based radio access networks (F-RANs), the significant burdens of massive data flow and exchanged information from large groups of IoT 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 assured. F-RANs is an extension of cloud networks, which are a collection of servers comprising a distributed network. Such a network can allow a service provider to greatly exceed the resources that would otherwise be available to it, freeing the service provider from the requirement to keep infrastructure on site. It brings intelligence and processing closer to the data source. As a promising solution, cyberinfrastructure is designed and developed to boost a network with artificial intelligence (AI) by offering powerful computing systems, flexible data storage repositories, and advanced virtualization environments.

The recent trend of Artificial Intelligence-Driven F-RANs has drawn particular attention to research and development from both the wireless communications and AI communities. This special issue focuses on the recent advances and new challenges to enter a promising beyond 5G era that are related to AI-Driven F-RANs, such as how to meet the diverse low-latency and massive-connection desires for the industry of Internet, autonomous driving-based Internet of vehicles, and intelligent recommended applications. Please stay tuned for new developments in this research area of fog intelligence and radio access networks, and read the editorial by the guest editors and the papers in this special issue.

In addition to the eight articles in the special issue, we have also included 20 open call articles in this issue.

The first article, "Reliable Federated Learning for Mobile Networks" by J. Kang *et al*., introduces reputation as a metric and proposes a reputation-based worker selection scheme for reliable federated learning by using a multi-weight subjective logic model for reputation calculation. It leverages blockchain as the enabling technology to manage the reputation of the workers in a decentralized manner. Numerical results demonstrate that the proposed schemes are reliable for federated learning in mobile networks.

The second article, "A Mobile Edge Computing (MEC)-enabled Transcoding Framework for Blockchain-based Video Streaming" by M. Liu *et al*,, proposes a new mobile edge computing (MEC)-enabled transcoding framework for blockchain-based video streaming while an adaptive block size scheme is designed for the underlying blockchains. The system architecture of the proposed framework is presented to enable coordination of different aspects.

In the third article, "MmWave IEEE 802.11ay for 5G Fixed Wireless Access," K. Aldubaikhy *et al*. investigate the mmWave distribution network (mDN) use case that has been standardized recently by the IEEE 802.11ay standard as an alternative 5G FWA solution. They present a comprehensive tutorial view of the considered new protocol specifications and design elements of the mDN and highlight some challenging research issues in the field of the mDN. They also provide a case study based on the investigation of the mDN where a low-complexity concurrent transmission protocol is proposed to enhance the network performance while mitigating the interference.

T. Hong *et al*., in the fourth article, "Space-Air-Ground IoT Network and Related Key Technologies," propose a new Space-Air-Ground IoT network paradigm based on the Space-Air-Ground heterogeneous architecture. In the proposed design, the UAV plays an important role by adopting network slicing and mmWave channel modelling. They conduct an integrated measurement and simulation study for a multi perspective performance evaluation.

In the fifth article, "The Next Generation Heterogeneous Satellite Communication Networks: Integration of Resource Management and Deep Reinforcement Learning," B. Deng *et al*. propose an new resource management framework for the next generation heterogeneous satellite network, which can achieve the cooperation between independent satellite systems and maximizing the resource utilization.

In the sixth article, "Cross-Modal Collaborative Communications," L. Zhou *et al*. propose a cross-modal collaborative communications mechanism among the audio, video, and haptic signals. For cross-modal signal transmission, they design a content-driven scheduling strategy to guarantee the high-quality cross-modal services by taking advantage of the different characteristics of the streams. For the cross-modal signal processing, they develop a complete signal restoration, reconstruction, and rendering scheme via cross-modal information fusion and sharing. They also demonstrate that the proposed collaborative communications can improve the users' immersive experience substantially.

In the seventh article, "Content Dissemination and Routing for Vehicular Social Networks: A Networking Perspective," B. Zhang *et al*. present a survey in content dissemination and routing for vehicular social networks (VSNs). They first discuss how VSNs differ from traditional vehicular ad hoc networks and also mobile social networks from a networking perspective. They introduce typical structures of VSNs and their social properties, which have a big impact on the performance of content dissemination and routing in such networks. They divide existing protocols based on different design criteria. They introduce how each of the protocols works and discuss their merits and deficiencies. They also present some open issues in this topic.

Wireless multimedia big data contains valuable information on users' behavior, content characteristics and network dynamics, which can drive the system design and optimization. The fundamental issue is how to mine data intelligence and further incorporate them into wireless multimedia systems. In the eighth article, "When Wireless Video Streaming Meets AI: a Deep Learning Approach," L. Liu *et al*. propose an integration of wireless multimedia systems and deep learning. They start with decomposing a wireless multimedia system into three components, including end-users, network environment, and servers, and present several potential topics to embrace deep learning

techniques. After that, they present deep learning based QoS/QoE prediction and bitrate adjustment as two case-studies.

In the ninth article, "Enabling Efficient Coexistence of DSRC and C-V2X in Vehicular Networks," K. Z. Ghafoor *et al*. first review DSRC and C-V2X radio access technologies and existing packet relaying mechanisms that are specifically designed for homogenous or heterogeneous vehicular environments. After that, they present a quality of service aware relaying algorithm that incorporates multi-metric to prioritize dual interface vehicles and provide robust communications among vehicles that are equipped with different radio access technologies.

In the tenth article, "Toward Efficient Network Resource Sharing: From One-Sided Market to Two-Sided Market," Y. Zhang *et al*. provide the basic concept of a two-sided market, together with the challenges and applications of using the two-sided market model to tackle the resource sharing problem in various kinds of networks. Potential methodologies to solve resource sharing problems in a two-sided market are also presented sequentially and compared. In the end, future directions for resource sharing under the two-sided market model are discussed.

In the eleventh article, "Integration and Provision for City Public Service in Smart City Cloud Union: Architecture and Analysis," M. Chen *et al*. propose the concept of "city cloud union" to describe the whole city public service and raise the users' satisfaction. In the city cloud union, city public service can be divided into two main categories, individual service and subscription service. Then, a city public service relevance and sharing architecture of the city cloud union is constructed.

In the twelfth article, "Cache-enabled Unmanned Aerial Vehicles for Cooperative Cognitive Radio Networks," J. Yang *et al*. provide an overview of the cooperation technique, including their theoretical schemes and the advanced performance in radio networks. This article also proposes a cache-enabled UAV cooperation scheme in Cognitive Radio Network (CRN), which enhances the CRN's transmission capability and reduces the redundant traffic load of CRN.

In the thirteenth article, "Beam-space Multiplexing: Practice, Theory, and Trends: From 4G TD-LTE, 5G, to 6G and Beyond," S. Chen *et al*. propose the new term, beam-space multiplexing, for the former multi-layer beamforming for 4G TD-LTE in 3GPP releases. They provide a systematic overview of beam-space multiplexing from engineering and theoretical perspectives. They discuss the future trends of beam-space multiplexing in 6G and beyond, including massive beamforming for extremely large-scale MIMO, low earth orbit satellite communication, data-driven intelligent massive beamforming, and multi-target spatial signal processing.

In the fourteenth article, "AI-Enhanced Cooperative Spectrum Sensing for Nonorthogonal Multiple Access," Z. Shi *et al*. propose a new cooperative spectrum sensing framework for non-orthogonal multiple access (NOMA) to further improve the spectral efficiency. Considering the complicated physical layer implementations of NOMA, they introduce an artificial intelligence based solution to cooperatively sense the spectrum with a very good accuracy rate and acceptable complexity.

In the fifteenth article, "Wireless Communications with Programmable Metasurface: New Paradigms, Opportunities, and Challenges on Transceiver Design," W. Tang *et al*. introduce two paradigms to utilize the programmable metasurfaces as radio frequency chain-free transmitter and space-down-conversion receiver, which both have great potential to realize cost-effective and energy-efficient wireless communication networks in the future. The basic principles, design architectures and promising advantages of these novel paradigms are presented. They demonstrate that programmable metasurfaces may bring a paradigm shift in wireless transceiver design, due to their superior capability of manipulating the electromagnetic waves.

In the sixteenth article, "Maritime Internet of Things: Challenges and Solutions," M. Wang *et al*. describe the typical use cases of maritime IoT, address their requirements and challenges, and present a practical solution. Specifically, a space-earth integrated, software-defined, and service-centric network architecture is established, and four variants of Very High Frequency Data Exchange System air interfaces are specified which are tailored for addressing the specific maritime IoT requirements.

In the seventeenth article, "Vehicular Blockchain-based Collective Learning for Connected and Autonomous Vehicles," Y. Fu *et al*. explain why current single-vehicle intelligence and traditional centralized or even distributed machine learning techniques are not sufficient to support large-scale Connected and Autonomous Vehicles (CAVs). In order to make better use of "collective intelligence" in a more efficient and practical manner from the set of CAVs, they propose a blockchain-based collective learning framework. Based on the framework, they refine the collective learning operation, blockchain operation, and global machine learning model update operation.

In the eighteenth article, "Cache-Enabled Coordinated Mobile Edge Network: Opportunities and Challenges," S. He *et al*. provide an overview of the ultra-dense cache-enabled cell-free (UD2CF) architecture from the latency demand perspective. Based on latency-driven evaluation, they demonstrate that the pipelined transmission of in-network caching into the network edge can potentially help reduce transmission latency. They also present a number of promising research opportunities and relevant challenges, particularly related to caching strategy, distributed optimization, coordinated transmission, and cache-enabled mmWave communication.

In the nineteenth article, "Artificial Intelligence-Enabled Cellular Networks: A Critical Path to Beyond-5G and 6G," R. Shafin *et al*. provide an overview of the state-of-the-art research topics, identify key obstacles, and present a roadmap toward fulfilling the potential of artificial intelligence in cellular networks.

Finally, in the twentieth and the last article, "Vision, Requirements, and Technology Trend of 6G: How to Tackle the Challenges of System Coverage, Capacity, User Data-rate and Movement Speed," S. Chen *et al*. provide a comprehensive discussion on 6G based on the review of 5G developments, covering visions and requirements, technology trends and challenges, aiming at tackling the challenge of coverage, capacity, the user data rate and movement speed of mobile communication system. The vision of 6G is to fully support the development of a Ubiquitous Intelligent Mobile Society with intelligent life and industries. The roadmap of the 6G standard is suggested for the future.

I hope you will enjoy reading these articles in the April 2020 issue of *IEEE Wireless Communications Magazine*. Please take care of yourself and your family. Thank you very much!

Biography

Yi Qian [M'95, SM'07, F'19] received a Ph.D. degree in electrical engineering from Clemson University, 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. More specifically, 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 2018 IEEE International Conference on Communications. He serves on the Editorial Boards of several international journals and magazines, including as the Editor-in-Chief of *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.