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Guest Editorial: Edge Intelligence for beyond 5G Networks

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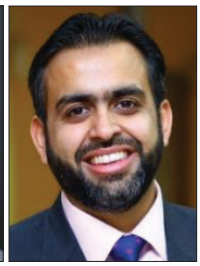
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Beyond fifth-generation (B5G) networks, or so-called "6G", is the next-generation wireless communications systems that will radically change how Society evolves. Edge intelligence is emerging as a new concept and has extremely high potential in addressing the new challenges in B5G networks by providing mobile edge computing and edge caching capabilities together with Artificial Intelligence (AI) to the proximity of end users. In edge intelligence empowered B5G networks, edge resources are managed by AI systems for offering powerful computational processing and massive data acquisition locally at edge networks. AI helps to obtain efficient resource scheduling strategies in a complex environment with heterogeneous resources and a massive number of devices, while meeting the ultra-low latency and ultra-high reliability requirements of novel applications, e.g., self-driving cars, remote operation, intelligent transport systems, Industry 4.0, smart energy, e-health, and AR/VR services. By integrating AI functions into edge networks, radio networks become service-aware and resource-aware to have a full insight into the operating environment and can adapt resource allocation/orchestration in a dynamic manner. Despite the potential of edge intelligence, however, many challenges also need to be addressed in this new paradigm. Until now, limited research efforts have been made on edge intelligence for B5G networks.

The aim of this Special Issue is to promote edge intelligence as the crucial technology and new research field in B5G/6G networks. The Special Issue will also present and highlight the advances and latest implementations and applications in the field of edge intelligence for B5G networks such that the theoretical and practical frontiers can be moved forward for a deeper understanding from both the academic and industrial viewpoints. Through an open call for papers and rigorous peer-review, we selected 10 articles from 42 submissions as representatives of ongoing research and development activities. These accepted articles encompass a wide range of research topics in edge intelligence beyond 5G. Here, we introduce them and highlight their main contributions.

In the article "Learning Empowered Privacy Preservation in Beyond 5G Edge Intelligence Networks", Zhu *et al*. focus on typical privacy concerns in B5G edge intelligence networks. This is a leading study on exploring machine learning and deep learning in edge intelligence 5G networks. The authors creatively divide applications into statistical analysis and personalized analysis. Both local and joint differential privacy are applied for the two cases. Caching is taken as an example to preserve preference privacy of users in B5G edge intelligence networks.

In the article "Deep Learning at the Edge for Channel Estimation in Beyond-5G In Massive MIMO", Belgiovine *et al*. propose to use deep learning via a Multi-Layer Perceptron architecture that exceeds the performance of traditional CSI processing methods like Least Square (LS) and Linear Minimum Mean Square Error (LMMSE) estimation, thus leading to a beyond fifth-generation (B5G) networking paradigm wherein machine learning fully drives networking optimization. The key insight here is to design the learning architecture such that it is implementable on massively parallel architectures, such as GPU or FPGA. The study validated the approach by simulating a 32-element array base station, and a user equipment with a 4- element array operating on millimeter wave (mmWave) frequency band.

In the article "Edge Intelligent Networking Optimization for Internet of Things in Smart City", Chen *et al*. study a learning approach to network optimization for IoT in smart cities with 5G and B5G networks. The proposed learning approach consists of local and global learning phases, which can be asynchronous and distributed using multi-core CPU machines that are more friendly to IoT devices in smart cities.

In the article "Federated Learning-Based Client Scheduling for Low-Latency Wireless Communications", Xia *et al*. study the issues associated with client scheduling to obtain low-latency in the context of federated learning for wireless networks. In this study, the authors propose to reduce the required number of communication rounds and shorten the average time interval per round to achieve fast convergence. Both scenarios have been studied with and without prior information. The MAB theory is introduced in particular to learn the statistical information online without knowing the prior information.

In the article "Edge Intelligence for Autonomous Driving in 6G Wireless System: Design Challenges and Solutions", Yang *et al*. study an autonomous driving framework with a 6G wireless system considered. The proposed framework is empowered by a two-tier process that consists of the autonomous vehicles tier and the edge-intelligence tier to deal with shallow and deep layers in the deep neural network model. A multi-task learning model is applied to obtain the optimal offloading strategy of edge intelligence in near-real-time.

In the article "Digital Twins for Intelligent Authorization in the B5G-enabled Smart Grid", Lopez *et al*. carry out a prospective analysis of the future Smart Grid through the evolution of the Digital Twins. The authors first highlight some of the most relevant challenges. They then introduce artificial intelligence and B5G communication technologies that can drive the progress of the electricity grid toward a fully decentralized and autonomous model governed by intelligent authorization systems.

In the article "Computation Offloading in Beyond 5G Networks: A Distributed Learning Framework and Applications", Chen *et al*. investigate the computation offloading in B5G net-

works. The authors formulate the computation offloading problem using a multiagent Markov decision process (MDP). The studied problem considers the dynamic uncertainties, the sharing of communication and the computation resources. A distributed and autonomous learning framework is proposed to solve the formulated multi-agent MDP problems. An online deep reinforcement learning algorithm is developed to demonstrate the studied framework.

In the article "Security and Privacy for Edge Intelligence in 5G and Beyond Networks: Challenges and Solutions", Li *et al*. study security and privacy issues in edge intelligence for B5G networks with the Blockchain technology. The authors review the main techniques used in B5G and analyze the typical security and privacy issues. The authors also propose a framework that integrates some typical blockchain-based solutions as edge intelligence to deal with these issues.

In the article "Wireless Virtual Reality in Beyond 5G Systems with the Internet of Intelligence", Lin *et al*. study a novel framework for wireless VR in B5G systems with the Internet of Intelligence. The authors focus on key factors such as content correlation, buffer aware caching and quality-of-experience (QoE) aware transmission in the studied wireless VR systems. A novel quantum-inspired reinforcement learning algorithm is proposed to realize online decision making for the multidimensional resource provisioning issue in wireless VR.

In the article "Edge Intelligence-Empowered, Unified Authentication and Trust Evaluation for Heterogeneous B5G Systems", Cui *et al*. study the security and privacy aspects of edge intelligence empowered, heterogeneous, B5G access networks. The network architecture and the corresponding technical challenges of authentication and trust evaluation are presented in this work. Moreover, the authors propose to migrate the authentication functionality to edge servers in a unified authentication framework. Primary authentication procedures, inter access network handover authentication, and a trust-evaluation based compromised user equipment detection are studied.

We believe this special issue is delivering cutting-edge research in edge computing and AI for 5G mobile IoT, and will encourage researchers to devote continuous efforts in addressing remaining open challenges. Finally, we would like to sincerely thank Prof. Yi Qian, the Editor-in-Chief of *IEEE Wireless Communications*, for his support of the special issue, and Joseph Milizzo from the Communications Society publications staff for the great help in the whole production process.

Biographies

Yan Zhang (F'20) is currently a full professor with the Department of Informatics, University of Oslo, Norway. He received the Ph.D. degree from the School of Electrical and Electronics Engineering, Nanyang Technological University, Singapore. He received M.S. and B.S degrees from Beihang University and Nanjing University of Post and Telecommunications, respectively. His research interests include next-generation wireless networks leading to 5G beyond/6G, green and secure cyber-physical systems (e.g., smart grid and transport). He is an editor (or area editor, senior editor, associate editor) for several IEEE transactions/magazines, including *IEEE Network Magazine*, *IEEE Transactions on Network Science and Engineering*, *IEEE Transactions on Vehicular Technology*, *IEEE Transactions on Industrial Informatics*, *IEEE Transactions on Green Communications and Networking*, *IEEE Communications Survey and Tutorials*, *IEEE Internet of Things Journal*, *IEEE Systems Journal*, *IEEE Vehicular Technology Magazine*, and *IEEE Blockchain Technical Briefs*. He is a symposium/track chair for a number of conferences, including IEEE ICC 2021, IEEE Globecom 2017, IEEE PIMRC 2016, and IEEE SmartGridComm 2015. He is the Chair of the IEEE Communications Society Technical Committee on Green Communications and Computing (TCGCC). He was an IEEE Vehicular Technology Society Distinguished Lecturer during 2016-2020. He is a CCF Senior Member, an elected member of the CCF Technical Committee on Blockchain, and a 2019 CCF Distinguished Speaker. Since 2018, he was a recipient of the global "Highly Cited Researcher" Award (Web of Science top 1% most cited worldwide). He is a Fellow of IEEE, Fellow of IET, elected member of Academia Europaea (MAE), elected member of Royal Norwegian Society of Sciences and Letters Academy (DKNVS), and an elected member of Norwegian Academy of Technological Sciences (NTVA).

Zhiyong Feng (M'08-SM'15) received her B.E., M.E., and Ph.D. degrees from Beijing University of Posts and Telecommunications (BUPT), Beijing, China. She is a professor at BUPT, and the director of the Key Laboratory of Universal Wireless Communications, Ministry of Education, P.R.China. She is a senior member of IEEE, and vice chair of the Information and Communication Test Committee of the Chinese Institute of Communications (CIC). Currently, she is serving as Associate Editor-in-Chief for *China Communications Magazine*, and she is a technological advisor for the international forum on NGMN. Her main research interests include wireless network architecture design and radio resource management in 5th generation mobile networks (5G), spectrum sensing and dynamic spectrum management in cognitive wireless networks, and universal signal detection and identification.

Hassnaa Moustafa is a principal engineer at Intel Corporation currently working on Edge AI solutions across IoT segments and network and edge infrastructure. Previously at Intel, she led Car-to-Cloud solutions for connected/autonomous vehicles, and connectivity technologies across IoT segments. Before joining Intel, she was a senior R&D engineer at France Telecom (Orange Labs) in France, where she contributed to low cost wireless network solutions for emerging countries and led engineering efforts on personalization and context-aware video and multimedia services within the NGN effort. She obtained her tenure in computer science from the University of Paris XI, her Ph.D. in computer and networks from Telecom Paris Tech, and her master degree in distributed systems from the University of Paris XI. Her broad experience covers IoT E2E network and services infrastructure, media networks, video delivery optimization, services personalization and content adaptation. She also worked for many years on ad hoc and vehicular network routing and AAA solutions. She contributed to the IETF standardization for 10 years and she is a senior IEEE member. Hassnaa has over 80 publications in international conferences and journals including IEEE and ACM. She has co-authored books published by the CRC press, she is a regular guest editor for several journals, and she is an active member in TPCs for IEEE and ACM conferences. She is also a regular co-chair for several IEEE workshops and conferences symposiums. She has been involved in several European projects with a technical lead role and she served as a consultant for the European Commission (EU) from 2008 until 2012, and contributed in defining the research agenda for Future Internet and Media Networks published in EU white papers.

Feng Ye [S'12, M'15, SM'21] is an assistant professor with the Department of Electrical and Computer Engineering, University of Dayton, Dayton, OH, USA. He received a Ph.D. degree from the University of Nebraska – Lincoln (UNL), Omaha, NE, USA, in 2015, and a B.S. degree from Shanghai Jiao Tong University, Shanghai, China, in 2011. He serves as the Vice Chair (Americas) of the IEEE TCGCC. He is an associate editor of *IEEE Transactions on Vehicular Technology*, *IEEE Internet of Things Journal*, and *IEEE/CIC China Communications*. He is a column editor for the *IEEE Wireless Communications*. He serves and has served as the IEEE ICC 2021 Green Communication Systems and Networks Symposium Co-Chair, IEEE CloudNet 2019 Publicity Co-Chair, ICNC'19 Signal Processing for Communications Symposium Co-Chair, IEEE CBDCom 2018 Publicity Co-Chair, and IEEE ICC 2018 Cognitive Radio and Networking Symposium Co-Chair. He also serves as a TPC member for numerous international conferences, including INFOCOM, GLOBECOM, VTC, ICC, etc. He was awarded the 2020 IEEE Dayton Section Ravi Pallerla Memorial Award for Young Professionals. He is a Distinguished Member of the INFOCOM 2019 TPC, and the recipient of the 2015 Top Reviewer of the IEEE Vehicular Technology Society.

Usman Javaid is Director of EMEA Delivery at Amazon Web Services. Previously, he held the IoT and Emerging Technologies leadership roles. He is helping the largest enterprises and fast growing start-ups to accelerate their digital transformation using the AWS global cloud computing platform and emerging technologies. With a career in the mobile industry spanning across 20 years, he led R&D and strategy functions, global field operations and delivered the world's first 4G network in Europe for Vodafone. Previously, he served as a research scientist with France Telecom leading R&D efforts in collaboration with industry partners in pioneering European and French research programs. He is a named inventor on 10 worldwide patents and has authored over 25 international publications. He holds a Ph.D. and Master's degree in computer science.

Chunfen Cui is the Director of the Future Mobile Technology Lab of the China Mobile Research Institute (CMRI). He received the Ph.D. degree from Beijing University of Posts & Telecommunications in 2003, then joined CMRI to research advanced wireless technologies and networking, green communications, including 4G/5G/6G, C-RAN/O-RAN, energy saving for wireless networks, etc. He has also been involved in many standardization organizations and industry initiatives such as 3GPP/ITU-R/NGMN/O-RAN/CCSA/Future Forum, etc. for more than 15 years.