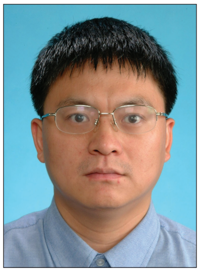
AI-Powered Telco Network Automation: 5G Evolution and 6G


Yan Xin


Kai Yang


Chih-Lin I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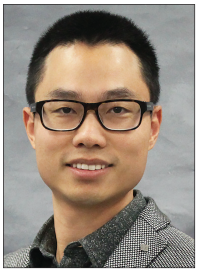
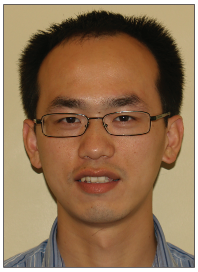

Xingqin Lin


Lifeng Lai

The fifth generation (5G) of cellular networks is significantly more complex than its predecessors due to several factors, such as increased cell density, differentiated service requirements, and coexistence with legacy networks. As a result, traditional operation and management (O&M) solutions, which heavily rely on human intervention, are no longer feasible to support such complex networks at reasonable operating expense (OPEX). Over the past few years, the telecommunication industry has come to the realization that leveraging artificial intelligence (AI) technology to enable a fully automated network O&M is a must to lowering OPEX and enhancing network key performance indicators (KPIs) for 5G, Beyond 5G (B5G), and the sixth generation (6G) of cellular networks. There have been numerous research efforts from both industry and academia to develop AI-powered network automation solutions. Many telecommunication operators and vendors have already adopted AI technology to automate some repetitive operational tasks and reduce reliance on personnel experience, such as cell planning, network deployment simplification, fault detection, and KPI optimization. While there has been notable progress for certain network O&M applications, the development of network automation solutions still faces several unique technical challenges that arise from telecommunication fields, including overwhelming network complexity, massive and diverse proprietary data, lack of industry-wide standards for radio access network (RAN) interfaces, and scarcity of labeled datasets.

This Special Issue (SI) aims to bring together state-of-the-art research contributions that address fundamental challenges and opportunities associated with the development of AI-powered network automation technology for 5G, B5G, and 6G networks. Our call for papers (CFP) received many submissions worldwide. After a rigorous peer review process, seven papers, which best align with the theme of this special issue, and cover a broad spectrum of research topics, including Open RAN (O-RAN), network slicing, distributed learning, fault management, and intelligent RAN, were selected for publication.

The first article, "AI Testing Framework for Next-G O-RAN Networks: Requirements, Design, and Research Opportunities" by Bo Tang *et al.*, proposes an AI-enabled testing framework that aims to evaluate the performance, vulnerability, and security of AI models deployed in O-RAN in realistic environments. The proposed testing framework adopts a master-actor architecture to manage a number of end devices for distributed testing. It leverages AI technologies to automatically and intelligently explore the decision space of AI models in O-RAN. The proposed framework supports both software simulation testing and software-defined radio hardware testing, thus, enabling rapid proof of concept and experimental research on a wireless platform.

In the second article, "Field Trial of Network Slicing in 5G and PON Enabled Industrial Networks" by Yuanqiu Luo *et al.*, the authors present a novel abstraction model of end-to-end network slicing for future industrial networks. The proposed model enables multi-service applications over a converged industrial network with access from both 5G and passive optical network (PON) users. The performance of the proposed model is investigated via a field trial on a manufacturing industrial network operated by China Telecom. The outcome of the trial demonstrates that network slicing not only provides resource sharing among different services but also improves qualities of the services.

The third article, "Artificial Intelligence Enabled NOMA Towards Next Generation Multiple Access" by Xiaoxia Xu *et al.*, aims to exploit AI technologies for non-orthogonal multiple-access (NOMA) to achieve automated, adaptive, and efficient multi-user communications. The authors propose an AI-enabled downlink cluster-free NOMA framework to enable flexible successive interference cancellation operations and scenario-adaptive NOMA communications towards next generation multiple access (NGMA). The article also highlights some open issues in certain research directions for AI-enabled NGMA, including model-based constrained machine learning (ML) for NGMA, ML-empowered dynamic multi-objective optimization for NGMA, and accelerating AutoML for NGMA.

In the fourth article, "An Open Approach to Autonomous RAN Fault Management" by Shubhabrata Mukherjee *et al.*, the authors propose an AI-based framework, called openFM, to support autonomous multi-vendor multi-domain fault management for O-RAN. The proposed framework consists of three stage, such as false alarm detection, pattern classifications and suggestive actions, and auto recovery. The authors investigate the performance of the proposed framework using raw alarm data from a live network, and provide a detailed comparison between classical ML and deep-learning-based algorithms.

The fifth article, "Artificial Intelligence Augmentation for Channel State Information in 5G and 6G" by Yang Li *et al.*, presents an AI-augmentation framework for physical layer communication applicable to both 5G and future 6G networks. Exploiting AI/ML technology, the proposed framework classifies the channel state information (CSI) and applies the classified CSI knowledge to adapt transmission configurations, perform resource optimization, and improve essential signal processing modules.

The authors emphasize that the proposed framework uses AI as a powerful tool to enhance system performance on top of the valuable understanding of the physics of wireless communication systems from past research. The authors also shed light on several technical challenges to commercialize AI-based algorithms in 5G and B5G networks.

In the sixth article, "Distributed Learning Meets 6G: A Communication and Computing Perspective" by Shashank Jere *et al.*, the authors provide a comprehensive overview on the role of distributed learning technology, specifically federated learning (FL), in 6G networks. The article demonstrates a practical use case of FL in wireless networks, where multi-agent reinforcement learning algorithms within the FL architecture are applied to dynamic spectrum access. The authors also summarize several challenges and open problems in the application of distributed learning technology in 6G networks.

Finally, the last article, "QoE Sustainability on 5G and Beyond 5G Network" by Hsiao-Wen Kao *et al.*, presents an AI-enabled quality of experience (QoE) prediction and sustainability architecture that can be used to support QoE-demanding services, create business innovation, and improve energy efficiency for 5G and B5G networks. The proposed architecture adopts 5G network data analytics function, network slicing, and multi-access edge computing technologies to collect cross-layer performance data in real time and allocate network resources accordingly. The authors introduce a ML-based QoE prediction model for live video streaming service and demonstrate that the model can predict the live video severe stalling issues with high accuracy in driving scenarios of a field trial.

In conclusion, the Guest Editors would like to thank all the authors who submitted their papers to this SI and all the reviewers for their time and effort. Their careful reviews and constructive comments helped us select the appropriate papers and improve the overall quality of this SI. We would also like to thank the past Editor-in-Chief, Yi Qian, and the current Editor-in-Chief, Nirwan Ansari, for supporting this SI. Last but not least, we hope that this SI will serve as a useful and informative resource for readers interested in AI-powered network automation technologies, and inspire further research and development activities in this field.

Biographies

Yan Xin [SM'10] (yan.xin@samsung.com) received his Ph.D. in electrical engineering from the University of Minnesota, Minneapolis, MN, USA. From 2004 to 2008, he was an assistant professor in the Department of Electrical and Computer Engineering, National University of Singapore. He is now a Research Director at the Standards and Mobility Innovation Lab, Samsung Research America Inc., USA. His research interests include intelligent RAN automation and optimization, MIMO communications, OFDM modulation, cognitive radio, and LTE/5G-NR/6G. He received the 2004 IEEE Marconi Prize Paper Award in wireless communications from the IEEE Communications Society. Currently, he is the Industry Liaison Officer of IEEE Communications Society Machine Learning for Communications Emerging Technologies Initiative. He served as an associate editor for *IEEE Transactions on Vehicular Technology* and served as an editor for *IEEE Transactions on Wireless Communications*.

Kai Yang [M'10,SM'19] (kaiyang@tongji.edu.cn) received his Ph.D. from Columbia University, USA. He is now a Distinguished Professor with Tongji University, China. He was a technical staff member with Bell Laboratories, Murray Hill, NJ, USA. He has also been an adjunct faculty member with Columbia University since 2011. He holds over 30 patents and has been published extensively in leading IEEE journals and conferences. His research interests fall into the area of applied machine learning, optimization, wireless communications, and signal processing.

Chih-Lin I [F] (icl@chinamobile.com) is CMCC Chief Scientist of Wireless Technologies. She received her Ph.D. EE from Stanford University. She has won the 2005 IEEE ComSoc Stephen Rice Prize, 2018 IEEE ComSoc Fred W. Ellersick Prize, the 7th IEEE Asia-Pacific Outstanding Paper Award, and the 2015 IEEE Industrial Innovation Award for Leadership and Innovation in Next-Generation Cellular Wireless Networks. She is the chair of O-RAN Technical Steering Committee and an O-RAN Executive Committee member, the chair of Future 5G/6G SIG, the chair of Wireless AI Alliance (WAIA) Executive Committee, an executive board member of GreenTouch, a Network Operator Council founding member of ETSI NFV, a steering board member and vice chair of WWRF, a Steering Committee member and the publication chair of IEEE 5G and Future Networks Initiatives, the founding chair of IEEE WCNC Steering Committee, the director of IEEE ComSoc Meetings and Conferences Board, a senior editor of *IEEE Trans. Green Comm. & Networking*, an area editor of *IEEE Trans. Networking*; executive cochair of IEEE Globecom 2020, IEEE WCNC 2007, IEEE WOCC 2004 and 2000; a member of IEEE ComSoc SDB, SPC, and CSCN-SC, and a scientific advisory board member of Singapore NRF. She has published over 200 papers in scientific journals, book chapters, and conferences, and holds over 100 patents. She is co-author of the book "Green and Software-defined Wireless Networks – From Theory to Practice" and has also coedited two books: "Ultra-dense Networks – Principles and Applications" and "5G Networks – Fundamental Requirements, Enabling Technologies, and Operations Management." She is also a fellow of WWRF. Her current research interests center around ICDT Deep Convergence: "From Green & Soft to Open & Smart."

Sanyogita Shamsunder (sanyogitas@gmail.com) heads Global Edge Networking at Google, where her team is responsible for various cloud networking products, solutions, and systems supporting Google's Global Network. Previously, she was the Vice President of Product Strategy and Operations at Verizon, where she was responsible for incubating enterprise and consumer products driven by emerging technologies. Previously, she led the industry leading 5G network and technology development. Sanyogita's work experience spans all areas of the wireless business, including silicon, network technology development, and spectrum strategy. Earlier in her career, she held various R&D and development roles at Lucent- Bell Labs, Sandbridge Technologies and Stanford Telecom. A sought-after speaker, Sanyogita has spoken at many industry conferences, including Mobile World Congress, Fierce Wireless events, CES, and various IEEE conferences and workshops. She also actively mentors and advocates for women in technology. She is on the Board of Industry Leaders of Consumer Technology Association, technical advisory board of Maxilinear, and the non-profit Manavi. Sanyogita received her MBA from the Wharton School and Ph.D. in electrical engineering and math from the University of Virginia.

Xingqin Lin (linxingqin2008@gmail.com) is a Senior Standards Engineer at NVIDIA, leading 3GPP standardization and conducting research at the intersection of 5G/6G and AI. Before joining NVIDIA, he was with Ericsson, leading 5G/6G research and standardization in focus areas. He is an expert in wireless communications and technology strategy and a key contributor to 5G NR, NB-IoT, and LTE standards. He has garnered several awards, including the IEEE Communications Society Fred W. Ellersick Prize (2021), IEEE Vehicular Technology Society Early Career Award (2021), and IEEE Communications Society Best Young Professional Award in Industry (2020). He is an IET fellow.

Lifeng Lai [M'07-SM'19] (lflai@ucdavis.edu) received the B.E. and M. E. degrees from Zhejiang University, Hangzhou, China in 2001 and 2004, respectively, and a Ph.D. from The Ohio State University at Columbus, OH, in 2007. He was a postdoctoral research associate at Princeton University from 2007 to 2009, an assistant professor at University of Arkansas, Little Rock from 2009 to 2012, and an assistant professor at Worcester Polytechnic Institute from 2012 to 2016. He joined the Department of Electrical and Computer Engineering at University of California, Davis was an associate professor in 2016, and was promoted to professor in 2020. His current research interest includes information theory, stochastic signal processing, and machine learning and their applications. He was a Distinguished University Fellow of the Ohio State University from 2004 to 2007. He is a co-recipient of the Best Paper Award from IEEE Global Communications Conference (Globecom) in 2008, the Best Paper Award from IEEE Conference on Communications (ICC) in 2011, and the Best Paper Award from IEEE Smart Grid Communications (SmartGridComm) in 2012. He received the National Science Foundation CAREER Award in 2011, and Northrop Young Researcher Award in 2012. He served as a Guest Editor for *IEEE Journal on Selected Areas in Communications*, special issue on Signal Processing Techniques for Wireless Physical Layer Security from 2012 to 2013, an editor for *IEEE Transactions on Wireless Communications* from 2013 to 2018, and an associate editor for *IEEE Transactions on Information Forensics and Security* from 2015 to 2020. He is currently serving as an associate editor for IEEE Transactions on Mobile Computing, *IEEE Transactions on Signal and Information Processing over Networks* and *IEEE Transactions on Information Theory*.