Introduction to Heterogeneous Robotic Systems in 5G and Beyond Networks


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Remote intelligence in the application of robotics and the autonomous system relies heavily on seamless wireless connections. The 5G mobile network technology meets traditional manufacturing enterprises' application requirements for wireless networks based on robot transformation and upgrading, robot interconnection, and remote interactive applications in production. However, there exists many challenging 5G communication issues, such as different communication protocols in the system varies with different robots and no disruptive changes to the physical layer.

Currently, specialized networked systems consisting of intelligent robots may deploy, repair, and relocate sensors to improve coverage, build routes and fix network partitions to ensure data communication, change network topology to shape routing patterns, balance energy consumption, and respond to reported events in a timely and effective manner. While solving problems, such as interference and mobility management, integrating robotics, and autonomous systems into the communication network is crucial. However, by enabling sensing operations for complex and dynamic scenarios to process the data on edge or offload them toward existing cloud services, these horizontal design approaches can only provide limited performance gains. Consequently, alternative approaches based on the co-design of control systems, inference engines, and communication protocols must be explored. These new approaches are envisioned to enable the rapid deployment of new robotics applications. As an emerging field, robotic systems require new heterogeneous networking techniques and novel cloud/edge architectures for different data gathering and processing procedures that might unlock the potentials of such systems. This special issue uniquely calls for the study of wireless communication solutions both for and through robotic platforms.

A total of 19 papers were submitted to this special issue (SI), and five high-quality articles were selected, resulting in an acceptance rate of 26.3 percent. Each paper was peer reviewed by three or more experts during the assessment process. The selected articles have exceptional diversity in terms of wireless communications, robotics techniques, and applications. They represent the most recent development in both theory and practice. The contributions of these papers are briefly described as follows:

The first article, "5G MEC-based Intelligent Computation Offloading in Power Robotic Inspection," by Z. Zhou *et al.* proposes a 5G mobile edge computing-based intelligent computation offloading framework in power robotic inspection to cope with multi-dimension entity heterogeneity, environment dynamics, and inspection delay guarantee. Specifically, the proposed framework and the implementation procedures of computation offloading are elaborated and the research challenges are outlined.

The second article, "A 5G Cloud Platform and Machine Learning-based Mobile Automatic Recognition of Transportation Infrastructure Objects," by Y. Hou *et al.* proposes a mobile automatic system integrating fifth-generation wireless communication technology (5G), cloud computing, and artificial intelligence (AI) for transportation infrastructure object recognition. With the help of 5G technology, the 'cloud-network-terminal' interconnection can be achieved to provide fast and stable information transmission between transportation infrastructure and road users.

The third article, "Decentralized P2P Federated Learning for Privacy-Preserving and Resilient Mobile Robotic Systems," by X. Zhou *et al.* proposes a Peer-to-Peer (P2P) based Privacy-Perceiving Asynchronous Federated Learning (PPAFL) framework to realize the decentralized model training for secure and resilient modern mobile robotic systems in 5G and beyond networks.

The fourth article, "On Multi-Robot Data Collection and Offloading for Space-Aerial-Surface Computing, " by L. Peng *et al.* proposes a space-aerial-surface computing (SASC) for intelligent data collection and offloading via multiple collaborative robots in massive Internet of Things (IoT) sensor networks. The effectiveness of the proposed architecture is justified, and a number of key issues relevant to the proposed architecture are discussed, including data similarity-aware node selection and clustering, collaborative trajectory planning strategies, the collaboration of heterogeneous robots, and aerial computing-integrated data offloading schemes.

The fifth and final article, "Multi-Robot Distributed Communication in Heterogeneous Robotic Systems on 5G Networking," by Z. Lv *et al.* develops the robot communication network with a robot operation and decision control method driven by Digital Twins. The multi-agent is integrated with the Proximal Policy Optimization (PPO) algorithm, forming the Muti-PPO algorithm for robot path planning. In addition, a consistent hashing algorithm is introduced and optimized as a Weighted Consistent Hash of Multiple Mappings (WCHMM) algorithm with multiple mappings is introduced.

In conclusion, we would like to thank the authors for their contributions to the SI and all the reviewers for their careful reviews. We also appreciate the support and help from the editorial staff and the Editor-in-Chief, Nirwan Ansari.

Biographies

Huimin Lu (dr.huimin.lu@ieee.org) received his Ph. D. in Electrical Engineering from Kyushu Institute of Technology in 2014. From 2013 to 2016, he was a JSPS research fellow at Kyushu Institute of Technology. Currently, he is an Associate Professor in Kyushu Institute of Technology and an Excellent Young Researcher of Ministry of Education, Culture, Sports, Science, and Technology (MEXT), Japan. He serves as Editor-in-Chief for Computers & Electrical Engineering; Cognitive Robotics Journal; Editor for Wireless Networks; Applied Soft Computing; IEEE Transactions on Artificial Intelligence; IEICE Transactions on Information; and Systems and Pattern Recognition. He is the Guest Editor for many journals, such as *IEEE Transactions on Circuits and Systems for Video Technology*; *IEEE Transactions on Network Science and Engineering*; *ACM Transactions on Internet Technology*; *IEEE/CAA Journal of Automatica Sinica*; *IEEE Internet of Things Journal*; and *IEEE Transactions on Intelligent Transportation Systems*. His research interests include artificial intelligence, computer vision, and robotics. He is the Senior Member of The Institute of Electrical and Electronics Engineers (IEEE) and Chair of IEEE Computer Society Technical Committee on Big Data.

Pin-Han Ho (p4ho@uwaterloo.ca) is a Professor in the Department of Electrical and Computer Engineering at the University of Waterloo. His current research interests cover a wide range of topics in broadband wired and wireless communication networks, including survivable network design, wireless communications, cyber-physical systems, and Internet of Things (IoT). Professor Ho and his Ph.D. student, Dr. James She, invented Wireless Media Express™ to rectify the problem of "wireless channel fading." Wireless channel fading is the intrinsic wireless communication systems problem that limits wireless service providers from effectively multicasting to intended receivers. Wireless Media Express™ generates an intelligent multicast signal that maximizes the video quality for all intended receivers, regardless of receiver channel quality status. This technology will allow users to have access to TV channels on handheld devices while watching consistent high quality live broadcasting. It also gives a business owner the capability of conveniently uploading video advertising materials to different digital displays throughout a city (highway billboards, shopping mall displays, subway station terminals) all in one shot and targeted to different "time of day" audiences.

Bassem Khalfi (bkhalfi@qti.qualcomm.com) received a Ph.D. in ECE from Oregon State University, Corvallis, Oregon, USA in 2018. He joined Qualcomm Technologies Inc, CA, USA in 2018 where he has been working on the design and implementation of 4G and 5G physical layer algorithms. He won the IEEE IWCMC 2017 best paper award. He has been actively serving in the reviewing process for various IEEE journals, magazines, and conferences. His research focuses on various topics in wireless communications and networks, including dynamic spectrum access and sensing; resource allocation for wireless communication systems; and content centric networking.

Christos Verikoukis (chverik@gmail.com) received his Bachelor and Master's degree from the Aristotle University of Thessaloniki in 1994 and 1997, respectively; and his Ph.D. in the area of Broadband Indoor Wireless Communications from the Signal Theory and Communications Department of the Technical University of Catalonia (UPC), Barcelona in 2000. Since 2020, he has been an Associate Professor with the University of Patras (Department of Computer Engineering & Informatics) and a Collaborating Faculty member with the Industrial Systems Institute (ISI) in Patras since 2022. From 2004 to 2021 he was with the Catalan Technological Centre of Telecommunications (CTTC) in Barcelona Spain. His research is focused on AI-aided 5G/6G networks, network slicing, resource management, network virtualization, zero-touch networks, and micro-grids design. His other areas of interest include MAC protocols for WiFi and WBAN; cross-layer PHY/MAC design; multi-user MIMO; network coding; cooperative communications; and energy efficiency in infrastructure sharing wireless networks. His research work has been published in 156 journals (75 percent of them in the first quartile) and more than 220 conference papers. He has also co-authored five published books and filled four granted patents. His research work has received more than 8500 citations.