Ultra-Low-Latency and Reliable Communications for 6G Networks



Shahid Mumtaz | Varun G Menon | Muhammad Ikram Ashraf

Recently, extensive research efforts have been dedicated to develop fifth-generation (5G) wireless mobile networks aimed at providing ubiquitous connections for anyone and anything irrespective of time and location. The number of connected devices and data traffic is increasing exponentially every day, and future data-intensive applications like AR/VR, holographic communications, V2X, autonomous driving, high precision manufacturing, and ultra-massive machine-type communications would demand high throughput, ultra-reliable transmission, extremely low latency and high energy efficiency. 6G is expected to extend 5G capabilities to higher levels where millions of connected devices and applications could operate seamlessly with trust, low-latency and high-bandwidth. Thus, major research is now focused on three areas, ultra-reliable and low latency communications (uRLLC), enhanced mobile broadband (eMBB), and massive Internet of Things (mIoT) in 6G wireless communications.

Ultra-reliable and low latency communications is perhaps the most challenging task because of its demanding requirements of low latency combined with ultra-high reliability. Using more resources to increase reliability will in turn increase the latency, and therefore a combination of various technologies like software-defined networking (SDN), virtual network slicing, and physical layer technologies are currently experimented for achieving uRLLC with various applications. This special issue solicited high-quality papers reporting on new techniques and concepts, standards, future applications, novel physical-layer solutions, network architectures, resource allocation schemes, and other issues, challenges, and promising solutions for ultra-high speed, low latency and reliable communications in 6G network.

We received a very good response to our special issue call for papers from around the world. Each submitted article was assigned to and reviewed by at least three experts in the field, with a rigorous multiround review process. Thanks to the dedicated work of the numerous reviewers, we were able to accept 16 excellent articles covering various topics in Ultra-low Latency and Reliable Communications for 6G Networks. In the following, we will introduce these articles and highlight their main contributions.

In the article "UAV-Assisted Vehicular Edge Computing for 6G Internet of Vehicles: Architecture, Intelligence, and Challenges" Hu *et al*. discuss an UAV-assisted network architecture to support 6G vehicular edge computing. The article further presents discussions on leveraging the big data feature of historical information, artificial-intelligence-based solutions that are anticipated to facilitate fast, automatic, and efficient UAV deployment to support 6G V2X applications.

The article "Embedding Security Awareness for Virtual Resource Allocation in 5G HetNets Using Reinforcement Learning" discusses various security threats and vulnerabilities due to the complexity of virtualization in 5G HetNets possibly leading to major performance outbreaks and information leakage and presents a novel secure framework (VRA-RL-SecAwa) based on the emerging reinforcement learning approach.

The article "Secure Virtual Mobile Small Cells: A Stepping Stone toward 6G" presents some key discussions on 6G and a next generation communication platform, which aims to extend the rigid coverage area of fixed deployment networks by considering virtual mobile small cells (MSCs) that are created on demand.

In the article "Research and Analysis of URLLC Technology Based on Artificial Intelligence" Zhu *et al*. introduce the performance indicators and critical technologies of URLLC in the physical layer and list the advantages of deep learning in solving technical problems in the physical layer.

In "Several Key Technologies for 6G: Challenges and Opportunities" Ji *et al*. present a survey that compares the system performance between 5G and 6G, and further discuss the rapid increase in wireless data traffic and the achievable rate that can be reached up to terabits per second to improve the communication quality.

The article "URLLC Key Technologies and Standardization for 6G Power Internet of Things" analyzes the application scenarios and service requirements of URLLC for 6G Power Internet of Things (PIoT), summarizes the key technologies and standardization of 5G/B5G URLLC and end-to-end URLLC guarantee technologies, and outlines the possible evolution directions of URLLC in 6G.

The article "6G Vision: Toward Future Collaborative Cognitive Communication Systems" presents an innovative framework for 3C (collaborative, cognitive, communication) systems that is able to analyze and predict both human and machine behaviors. It proactively diagnoses issues and recommends solutions without requiring any human intervention.

The authors mention that the proposed concept of 3C systems would potentially contribute toward 6G standardization.

The article "Mobile Edge Computing for Ultra-Reliable and Low-Latency Communications" investigates the advantages of MEC in comparison with mobile cloud computing and then introduces several specific themes and the existing techniques in MEC, which are concerned with efficient communication and reliable mechanisms in MEC.

In the article "When Wireless Communications Meet Computer Vision in Beyond 5G" Nishio *et al*. mention that with the recent advances in machine learning and the availability of non-radio-frequency (RF) data, vision-aided wireless networks have shown to significantly enhance wireless communication reliability without sacrificing spectral efficiency. Further, the authors demonstrate how computer vision enables look-ahead prediction in a millimeter-wave channel blockage scenario before the blockage actually occurs.

The article "3D Network Modelling for THz-Enabled Ultra-Fast Dense Networks: A 6G Perspective" discusses the new 6G ultra-cell scenario along with a potential 3D network architecture. Several recent developments in network modeling applying a stochastic geometry-based clustered process are also presented in the article.

In "Sparse Code Multiple Access for 6G Wireless Communication Networks: Recent Advances and Future Directions" Yu *et al*. present an overview and outlook on the application of sparse code multiple access (SCMA) for 6G wireless communication systems, which is an emerging disruptive non-orthogonal multiple access (NOMA) scheme for the enabling of massive connectivity. The authors then propose to apply SCMA to a massively distributed access system (MDAS), whose architecture is based on fiber-based visible light communication (FVLC), ultra-dense network (UDN), and NOMA.

The article "Novel Joint Index Modulation and Physical Layer Network Coding Mechanism for Beyond 5G" discusses a novel mechanism combining Physical Layer Network Coding (PNC) and Index Modulation (IM) to achieve a balance between energy efficiency (EE) and spectral efficiency (SE) for URLLC applications beyond 5G.

The article "Key Technologies for Ultra Reliable and Low Latency Communication (URLLC) in 6G" presents the key technology enablers for deployment in ultra-reliable and low latency communications for 6G networks. In addition, the potential issues related to system security and spectrum management in 6G networks are also discussed in the article.

The article, "Extremely-interactive and Low Latency Services in 5G and Beyond Mobile Systems" provides an overview of extremely interactive and low latency immersive services as well as on the relevant industry and standardization activities, and also presents some insights on the relevant architectures and solutions, and highlights some research challenges and directions.

In the article "Spectrum Sharing for 5G/6G URLLC: Research Frontiers and Standards" Yang *et al*. discuss 3GPP standards, recall the recent advances in spectrum sharing algorithms, and analyze the challenges of spectrum sharing in 5G/6G and also provide potential research fields in future 5G/6G applications.

The article "Reinforcement-Learning-Enabled Massive Internet of Things for 6G Wireless Communications" presents a reinforcement-learning-based and a framework for a wireless channel access mechanism for IEEE 802.11 standards (i.e., Wi-Fi) in mIoT. The proposed mechanism suggests exploiting a practically measured channel collision probability as a collected dataset from the wireless environment to select optimal resource allocation in mIoT for upcoming 6G wireless communications.

We would like to express our sincere thanks to all the authors for submitting their papers and to the reviewers for their valuable comments and suggestions that significantly enhanced the quality of these articles. We are also grateful to the Editor-in-Chief, Zander Lei for the great support throughout the whole review and publication process of this special issue, and, of course, all the editorial staff. We hope that this special issue will serve as a useful reference for researchers, scientists, engineers, and academics in the field of Ultra-low Latency and Reliable Communications for 6G Networks.

Biographies

Shahid Mumtaz is a principal researcher at the Instituto de Telecomunicações, Aveiro, Portugal. He an IET Fellow, IEEE ComSoc and ACM Distinguished Speaker, recipient of the IEEE ComSoC Young Researcher Award (2020), founder and EiC of *IET Journal of Quantum Communication*, Vice-Chair of the Europe/Africa Region-IEEE ComSoc: Green Communications & Computing Society, and Vice-Chair of the IEEE Standard on P1932.1: Standard for Licensed/Unlicensed Spectrum Interoperability in Wireless Mobile Networks. He is the author of four technical books, 12 book chapters, 250+ technical papers (150+ journal/transaction, 80+ conference), and two IEEE best paper awards in the area of mobile communications. Most of his publications are in the field of wireless communication. He is serving as a scientific expert and evaluator for various research funding agencies. He was awarded an Alain Bensoussan Fellowship in 2012. He was the recipient of the NSFC Researcher Fund for Young Scientists in 2017 from China.

Varun G Menon is an associate professor and Head of the Department of Computer Science Engineering, and International Collaborations and Corporate Relations in charge at SCMS School of Engineering and Technology, India. He is a Distinguished Speaker of the Association of Computing Machinery (ACM) and a Senior Member of IEEE. He has completed his Ph.D. in computer science and engineering and holds an M.Tech. degree in computer and communication with University First Rank. He also holds an M.Sc. in applied psychology, an MBA in human resource management, and a diploma in training and development. His research interests include sensor technologies, Internet of Things, green IoT, wireless communication, fog computing and networking. He is currently an associate editor for *Physical Communication*, *IET Networks*, and *IET Quantum Communications*; a series editor for *IEEE Transactions on Intelligent Transportation Systems*; and a technical editor for *Computer Communications*. He is currently the guest associate editor for *IEEE Journal of Biomedical and Health Informatics*, *IEEE Internet of Things Journal*, and *IEEE Transactions on Green Communications and Networking*. He has served as the guest associate editor for *IEEE IoT Magazine*, *IEEE Transactions on Industry Informatics*, and the *Journal of Supercomputing*. He received the Top Peer Reviewer Award from Publons in 2018 and 2019. He is also currently serving on the review boards of many high impact factor journals including *IEEE Transactions on Vehicular Technology*, *IEEE Transactions on Communications*, *IEEE Transactions on Industrial Informatics*, *IEEE Transactions on Intelligent Transportation Systems*, and *IEEE Communications Magazine*. He has served over 20 conferences such IEEE ICC, IEEE CAMAD 2021, IEEE ICC 2020, EAI SmartGov 2021, ICCCN 2020, IEEE COINS 2020, SigTelCom, ICACCI, ICDMAI in leadership capacities including program co-Chair, track Chair, session Chair, and Technical Program Committee member.

Muhammad Ikram Ashraf has more than 12 years of experience in the field of wireless communication including 5G and beyond technologies. He is currently working with the 5G R&D group at Ericsson Finland. Before joining Ericsson, he worked for Nokia Bell-Labs and the Centre for Wireless Communication (CWC), Finland. His areas of research include URLLC, industrial IoT, TSN, resource allocation, D2D, V2X communications, ProSe, social networks, medical ICT, and heterogeneous networks. He has participated in numerous international projects and has written a number of scientific publications. He has also contributed to several 3GPP standardization activities.