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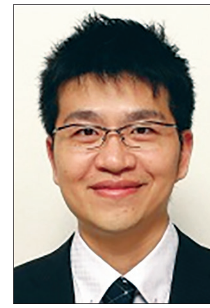
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6G Mission-Critical Internet of Things

With the widespread adoption of diverse IoT applications, various vertical IoT deployments has emerged in recent years. Mission-critical IoT applications have gained substantial traction, showing considerable potential in various vertical markets, such as smart medicine and smart manufacturing. Given the significance of high-value mission-critical tasks, timely and reliable control is essential. The emerging sixth-generation (6G) wireless communications and networking system is expected to create new opportunities by supporting mission-critical IoT applications. Technical solutions to improve wireless communications with low latency capabilities and high reliability are needed.

This Special Issue (SI) looks into several key aspects of enabling technologies that have tremendous potential for the future mission-critical IoT evolution in 6G era. As 6G-based framework will be heterogeneous, different innovations will be applied including, low-latency access for massive devices, network enhancement with relaying, flexible mission-critical architecture with open radio access network, data reliability enhancement with network coding, wide-area resilient access with LEO satellite, and support of zero-energy IoT devices.

In "NOMA-based Grant-Free Massive Access for Latency-Critical Internet of Things: A Scalable and Reliable Framework," Kang, Abebe, and Choi describe the latency-critical access through grant-free Non-Orthogonal Multiple Access (NOMA) mechanisms. Handling a large number of IoT devices accessing the wireless networking system is an essential 6G system design requirement. Grant-free random access protocol is a technical solution to reduce latency for wireless IoT network access. NOMA technique can be applied to increase wireless system capacity. Enhanced NOMA-based grant-free mechanism applies multi-signature spreading design and exploits multi-antenna capabilities for reliability, low latency and efficient resource utilization for 6G mission-critical IoT access.

In "On Advanced Relay Schemes to Support Throughput-Hungry IoT Applications," Lin *et al.* discuss applying relay techniques to better support 6G IoT application requirements. Deploying relay stations and integrating sidelink communications in 6G could expand coverage areas, effectively reduce coverage holes, and improve user perceived throughput in many IoT usage scenarios. 6G sidelink communications could provide flexible network topology configurations and enhanced link quality between IoT Gateways and IoT devices. 6G sidelink communications could also be utilized to provide multi-path transmissions and adaptive resource sharing between sidelink communications and direct communications between IoT devices and base stations. Relaying-based 6G architecture exhibits great potential for enabling reliable communications in various scenarios.

In "Linear Packet Network Coding to Enhance Reliability and Resiliency of Next Generation Wireless Networks with Topological Redundancies," Nikopour and Mao present the network resiliency enhancement by applying network coding. Network coding techniques have been shown to enhance data transmission reliability. The Integrated Access Backhaul (IAB) networking architecture could be utilized to enhance transmission reliability in multi-hop multi-path environments. Applying network coding in IAB network could further improve the reliability. In such a case, route selection strategies are critical to meet the reliability and latency requirements under different traffic loading and radio link blockage environments.

In "Supporting 6G Mission Critical Services on O-RAN," Kaliski and Cheng describe the potential for O-RAN based 6G systems. Open Radio Access Networks (O-RAN) has drawn attention in the 5G community and will continue playing a key role in 6G era. 6G mission-critical IoT services could be deployed with the flexible O-RAN architecture. Traffic steering, localized QoS, proactive cell association, and dynamic spectrum sharing could enhance networking service reliability. In addition, O-RAN based solution could be used for enhancing system security through malicious IoT application detection, IoT Gateway malware detection, and rogue base station detection mechanisms.

In "Enabling Resilient Access Equality for 6G LEO Satellite Swarm Networks," Lin *et al.* discuss the potential of utilizing LEO satellites to improve the 6G service resilience. LEO satellites will become an indispensable part for 6G IoT, especially in the remote area. Network resilience could be achieved with multi-connectivity and multi-path routes in heterogeneous LEO satellite swarm network. In this heterogeneous LEO networking system, software-defined networking edge architecture could provide distributed, multi-tier, multi-domain management framework for machine learning tasks that process distributed data in mission-critical applications.

In "Zero-Energy Devices Empowered 6G Networks: Opportunities, Key Technologies, and Challenges," Naser *et al.* describe the challenges and opportunities of energy-aware 6G IoT operations with zero-energy devices (ZEDs). Leveraging energy harvesting sources and ambient backscatter communication techniques, ZEDs could play pivotal roles in facilitating the advancement of 6G IoT. To realize the energy-efficient operations of ZED-based IoT, energy-aware communications protocol design as well as low-power architecture for efficient machine learning and information security will be needed.

In conclusion, the collected articles in this special issue offer different technical approaches to tackle challenges for 6G mission-critical IoT. Despite recent progress, there remains much to be accomplished to meet the demanding requirements for mission-critical IoT services. We hope that this timely special issue will serve as a catalyst for further research in this emerging area and will lead to many more exciting advancements.

Biographies

Hung-Yu Wei [SM] (hywei@ntu.edu.tw) is a Professor in Department of Electrical Engineering and Graduate Institute of Communications Engineering, National Taiwan University. He received the B.S. degree in electrical engineering from National Taiwan University in 1999. He received the M.S. and the Ph.D. degree in electrical engineering from Columbia University in 2001 and 2005 respectively. He is currently the Chair of IEEE P1935 working group for edge/fog management and orchestration standard. He is now program co-director for MOST 6G research program in Taiwan.

Athul Prasad [SM] (athul.prasad@samsung.com) received his MBA from Massachusetts Institute of Technology (MIT), where he was a Sloan Fellow, and doctoral degree, D.Sc. (Tech) from Aalto University. He is with Samsung since 2023 and is the co-author of numerous scientific publications — including the book: End-to-End Mobile Communications: Evolution to 5G (McGraw-Hill, 2020). He was previously with Nokia, NEC and Huawei. He was an associate editor of IEEE Access and is currently an associate technical editor of *IEEE Communications Magazine*.

Hanna Bogucka received the Ph.D. degree with honors and the Doctor Habilitus degree in Telecommunications from Poznan University of Technology (PUT), Poznan, Poland in 1995 and 2006 respectively. Currently, she is a full professor and the Director of the Institute of Radiocommunications at PUT. Moreover, prof. Bogucka is the co-founder, Board Member and the Head of Cooperation of RIMEDO Labs, a successful startup and the spin-off from PUT. Prof. Bogucka is involved in the research activities in the area of wireless communications: radio resource management, cognitive radio, and green communication. Currently, she is the IEEE ComSoc Fog/Edge Industry Community Regional Chair in Europe and the member of the Polish Academy of Sciences.

Mianxiong Dong received B.S., M.S. and Ph.D. in Computer Science and Engineering from The University of Aizu, Japan. He is the Vice President and Professor of Muroran Institute of Technology, Japan. He was a JSPS Research Fellow with School of Computer Science and Engineering, The University of Aizu, Japan and was a visiting scholar with BBCR group at the University of Waterloo, Canada supported by JSPS Excellent Young Researcher Overseas Visit Program from April 2010 to August 2011. He is Clarivate Analytics 2019, 2021 Highly Cited Researcher (Web of Science) and Foreign Fellow of EAJ.

Alain Mourad has 20+ years of experience in wireless industrial R&D. He is currently a Senior Director at InterDigital and the Head of Future Wireless Europe Lab in London (UK) leading research on 5G evolution towards 6G. Prior to InterDigital, Alain was a Principal Standards Engineer at Samsung Electronics R&D (UK) and previously a Senior Engineer at Mitsubishi Electric R&D Centre Europe (France). Throughout his career, he has been active in the research and standardization of wireless systems (3GPP, IEEE802, DVB, ATSC, ETSI, IETF). He is a prolific inventor with over 50 issued patents and several additional patent applications.

Antonio de la Oliva works as Associate Professor at UC3M since 2018. He has worked in multiple European research projects, including coordination of several of them. He has also participated in several standardisation activities, as Vice-chair of IEEE 802.21b, Technical Editor of IEEE 802.21d and lately contributing to several IEEE 802.11 TGs. Due to his work in SDOs, Antonio de la Oliva has applied for more than 20 patents over the last years.

JaeSeung Song [SM] jssong@sejong.ac.kr) is a professor in the Computer&Information Security Department at Sejong University. He holds the position of oneM2M Technical Plenary Vice Chair. He received a Ph.D. at Imperial College London in the Department of Computing, United Kingdom. He holds B.S. and M.S. degrees in computer science from Sogang University. His research interests span the areas of beyond 5G and 6G, AI/ML enabled network systems, software engineering, networked systems and security, with focus on the design and engineering of reliable and intelligent IoT/M2M platforms.

Shilpa Talwar is an Intel Fellow and Director of Wireless Systems Research in the Intel Labs organization at Intel Corporation. She leads a research team focused on advancements in ultra-dense multi-radio network architectures and associated technology innovations. Her research interests include multi-radio convergence, interference management, mmWave beamforming, and applications of machine learning and artificial intelligence (AI) techniques to wireless networks. While at Intel, she has contributed to IEEE and 3GPP standard bodies, including 802.16m, LTE-advanced, and 5G NR. She graduated from Stanford University in 1996 with a Ph.D. in Applied mathematics and an M.S. in electrical engineering. She is the author of 70 technical publications and holds 60+ patents.