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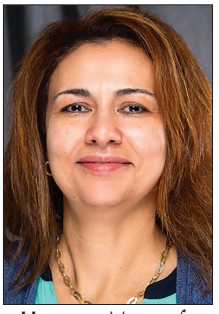
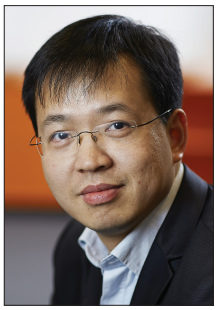

Hassnaa Moustafa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Multi-Access Networking for Extended Reality and Metaverse

With the advent of multimedia content, sensing, imaging technologies, compute capabilities, and networking and Cloud solutions, the XReality (XR) technologies and solutions are continuously evolving. XR is used as an umbrella term to describe Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). Recent advances in XR and immersive technologies pave the way to the paradigm of the metaverse. The metaverse is considered the next evolution of the Internet and IoT. Users can traverse a virtual world that mimics aspects of the physical world, to provide varying immersive experiences. In this context, immersive experience refers to developing a seamless and wirelessly connected extended reality between virtual and real worlds to the users. Indeed, the metaverse has received much attention across several industry segments. Recent technologies in human–computer interaction, IoT, Cloud and Edge Computing, Blockchain, NFT, and high- performance computing infrastructures have enabled many new application scenarios for the XR and metaverse. For instance, IoT is helping to map data from real life, in real-time, into a digital reality. Thus, IoT's primary role will be to bring the outside world into the digital realm. In addition, multi-Access networking, the envisioned future of 6G technologies, and artificial intelligence could support such massive and immersive virtual environments by connecting billions of users and creating a shared world where virtual and reality merge. However, limited by resources, computing power, and sensory devices, metaverse is still far from realizing its entire vision of immersion, materialization, and interoperability. In addition, achieving these objectives requires synergistic techniques from different fields, including deep learning, optimization, game theory, wireless communications, and graph/network theory. There is also a need for considerable synergy between the device, the network infrastructure, and the applications across multiple players to enable end-to-end solutions.

This Special Issue (SI) called for research contributions on B5G/6G networking for metaverse from many perspectives, including algorithm design and analysis, fundamental theories, and practical considerations. Thanks to the extensive efforts of the reviewers and the tremendous support from the Editor-in-Chief, Dr. Rath Vannithamby, we could accept six contributed articles covering several aspects related to the metaverse paradigm on top of B5G/6G networks. A brief review follows:

The first article "Metaverse: Requirements, Architecture, Standards, Status, Challenges, and Perspectives" by Rawat *et al.* provides standards, architecture, requirements, open challenges, and potential solutions for metaverse. In particular, they present metaverse requirements and architecture, in addition to the various standards that serve as the basis for the deployment and development of metaverse. Furthermore, we provide open challenges such as integrating metaverse and AI, privacy and security in metaverse, etc.

In the second article "Standard Evolution of 5G-Advanced and Future Mobile Network for Extended Reality and Metaverse" by Huang *et al.* presents the evolution of 5G-Advanced future technologies to enable Extended Reality and the metaverse. The article provides an overview of the technology enablers for audio and video content in the 5G architecture evolution to accommodate metaverse use cases with the required performance needs.

The third article "Autonomous UAV Edge Architecture for Road Hazards Extended Reality Warnings" by Benhelal *et al.* introduces a novel extended reality and edge server-based architecture to provide a fast response when detecting potential anomalies about road hazards. This architecture enables use cases for Unmanned Aerial Vehicles (UAV) to track road hazards by gathering information about them and offloading them to the edge server. The solution applied reinforcement learning to efficiently deploy UAVs at the spot of potential anomalies.

The fourth article "Metaverse for 6G and Beyond: The Next Revolution and Deployment Challenges" by Aslam *et al.* discusses the emerging vision of metaverse in wireless networks, including 6G networks. They first design a framework of metaverse-enabled wireless networks, including the fundamental and requirements technologies to be integrated with 6G to realize the metaverse vision. Then, they focus on a use case for autonomous vehicles' remote assistance system that leverages 360° live stream, VR technology, and a mobile edge-enabled distributed computing paradigm.

The fifth article "Robot-Based Uniform-Coverage and High-Resolution LIDAR Mapping for Physically-Grounded Metaverse Applications" by Gonzalez-Aguirre *et al.* presents a nee LIDAR Mapping solution for Physically grounded metaverse applications bringing a unique solution showing a prototype for LIDAR hardware and software technologies leveraged to create a 3D world. This solution serves use cases that connect the tangible world bidirectionally with its digital counterparts in Physically-grounded metaverse Applications (PMAs) such as visually-guided human assistance, space-time analytics, and XR.

The sixth article "Non-Fungible Tokens: A Review" by Hammi *et al.* focuses on the Non-Fungible Tokens (NFT) topic showing

the opportunity in metaverse use cases. The article provides a technical overview of NFT and offers its current challenges that require more research solutions. It brings a business and services angle for metaverse applications that helps opens the thought on how NFT can help the metaverse deployment widely and how NFT can help services monetization and security.

In summary, the collected articles offer innovative application scenarios related to metaverse and shed light on the underlying principles, standards, and architecture of the metaverse paradigm on top of modern wireless networks such as 6G. We hope that this timely special issue will trigger more future work in the emerging area.

Biographies

Bouziane Brik (bouziane.brik@gmail.com) is currently working as an associate professor at Bourgogne University, France. He has been working on B5G network slicing in the context of H2020 European project. His research interests also include 5G and Beyond networks, Explainable AI, and machine/deep learning for wireless networks.

Hassnaa Moustafa [SM] (hassnaa.moustafa@intel.com).is a Principal Engineer at Intel Corporation, working on Edge Computing and AI solutions across IoT segments and network edge infrastructure. Previously at Intel, Hassnaa led Car-to-Cloud solutions for connected/autonomous vehicles and connectivity technologies across IoT segments. Before joining Intel, Hassnaa was a Senior R&D engineer at Orange in France. She contributed to wireless network solutions for the EMEA region and led engineering efforts on optimizingvideo and multimedia services over wireless networks. She has over 80 publications in international conferences, journals, and books and over 300 filed patents (over 100 granted). Hassnaa obtained her Ph.D. in Wireless and Mobile Networks from Telecom Paris Tech and her master's degree in distributed systems from the University of Paris XI. She also holds a research director qualification from the University of Paris XI.

Yan Zhang (yanzhang@ifi.uio.no) is currently a Full Professor with the Department of Informatics, University of Oslo, Oslo, Norway. He received the Ph.D. degree from the School of Electrical and Electronics Engineering, Nanyang Technological University, Singapore. 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).

Abderrahmane Lakas (alakas@uaeu.ac.ae) is a Professor of Computer and Network Engineering in the College of Information Technology (CIT) at UAE University. He is the director of CAST (Connected Autonomous Intelligent Systems) research team and the head of ASIL (Autonomous Systems and IoT Lab) at the CIT. He has several years of both academic and industrial experience. Prior to joining UAE University in 2003, Dr Lakas worked in the telecommunication industry holding various technical and managerial positions including Netrake (USA, 2000), Nortel Networks (Canada, 1998), and Newbridge (Canada, 1996).

Sriram Subramanian (sris@fb.com) in his current role at Meta Connectivity drives System Integration and Private Network, 5G initiatives including community engagements for the Telecom Infra Projects on OpenRAN, 5G Private Network among other end to end technologies. In addition, he drives Metaverse related initiatives at Meta connectivity for Network readiness to support next generation Metaverse applications including edge strategy and evolution.