Metaverse for Connected and Automated Vehicles and Intelligent Transportation Systems [From the Guest Editors]

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The metaverse aims to blur the boundary between the physical world and digital content. To achieve this goal, the metaverse relies heavily on extended reality (XR), the Internet of Things, and communication technologies. Concurrently, connected vehicles and intelligent transportation systems (ITSs) are envisioned as the future paradigm of driving and becoming reality thanks to increasingly powerful onboard vehicular processing capacity and advanced vehicle-to-everything networking technologies.

Observing a large number of overlapping enabling technologies, we expect a convergence between the metaverse and connected vehicles that would eventually benefit both fields. Connected and automated vehicles are mobile platforms equipped with significant sensing and computing capabilities that can broaden metaverse use cases. On the other hand, immersive metaverse applications can improve the driver's experience as well as passengers' in-vehicle entertainment and passenger.

Richer information collected and created from the metaverse has created new challenges, such as information filtering, object positioning, vision transformation, and so on. These challenges are often computation intensive and bring considerable additional delay to connected and automated vehicles, which demand near-real-time reactions. Researchers have thus proposed edge and cloud computing, machine learning, and computer vision solutions to tackle such challenges.

CONNECTED AND AUTOMATED VEHICLES ARE MOBILE PLATFORMS EQUIPPED WITH SIGNIFICANT SENSING AND COMPUTING CAPABILITIES THAT CAN BROADEN METAVERSE USE CASES.

This special issue of *IEEE Vehicular Technology Magazine* aims to present works that apply different techniques to improve the driving experience of automatic/connected vehicle services in terms of facing the coming metaverse era. We received 23 high-quality submissions, of which five were eventually accepted after a rigorous review process. These articles cover several different aspects of the metaverse and connected vehicles.

The first article [A1] highlights the potential of connected automated vehicle (CAV)-assisted mobile crowdsensing in shaping the metaverse. By leveraging edge intelligence, the proposed framework offers enhanced data quality and transmission efficiency. The authors point out that the transition to 6G demands content-aware communication that aligning with the metaverse's nuances. However, the acceleration of mobile crowdsensing in the metaverse raises concerns about data privacy and security, emphasizing the importance of robust anomaly detection and security measures.

The next article [A2] delves into the integration of pretrained foundation models with edge intelligence for the metaverse. The authors present a model caching and inference framework optimized for mobile edge networks. A novel least context algorithm is introduced, leveraging a proposed metric, namely, age of context, to enhance mobile artificial intelligence (AI) service accuracy. This research offers a glimpse into the future interplay between edge AI and the metaverse.

The third article [A3] highlights a multifaceted approach to enhance vehicular automation by harnessing the power of digital twin networks (DTNs), with a keen focus on perception, planning, and control. By integrating diverse learning methodologies, the authors set a new benchmark for traffic management and vehicular safety. This research not only underscores the future of sustainable transportation but also underscores the synergy between CAVs and DTNs for optimized driving experiences.

In the fourth article [A4], the authors introduced a DT- and AI-empowered panoramic video streaming scheme

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THIS RESEARCH OFFERS A GLIMPSE INTO THE FUTURE INTERPLAY BETWEEN EDGE AI AND THE METAVERSE.

for XR-assisted connected AVs that reduces transmission latency and intelligently responds to user requirements. Specifically, the authors proposed a DT-enabled distributed XR service management framework that provides low latency and smooth XR services across different domains in the vehicular metaverse. In addition, they presented a case study on XR streaming-based virtualized resource allocation and a novel deep reinforcement learning-based method that minimizes transmission latency. Quantitative experimental results demonstrated that the positive role of AI in connected AV networks can be enhanced by DTs. Finally, open issues and potential research directions for the XR-assisted vehicular metaverse were discussed.

In the final article [A5], the authors discuss the challenges and requirements of edge caching for metaverse CAVs (meta-CAVs) and ITSs (meta-ITSs). The specific requirements of vehicular applications translate to specific needs for dynamic, secure, and intelligent caching. To address these challenges, the authors propose using AI-assisted content caching for meta-CAVs and meta-ITSs. They survey the techniques commonly found in the literature that can improve caching performance. These techniques, such as long short-term memory, reinforcement learning, and federated learning, allow for predicting the popular content, deciding caching location based on spatial and temporal data, and devising dynamic and secure caching policies. A case study is presented, showcasing the advantages of using multiagent federated reinforcement learning in edge caching for meta-CAVs and meta-ITSs.

In conclusion, the articles featured in this special issue shed light on the intricate interplay and potential synergies among the metvaverse, connected vehicles, and intelligent transportation systems, presenting both the inherent challenges and exciting opportunities at this crossroad. We are deeply grateful to the authors for their trailblazing contributions and to the reviewers for their meticulous and insightful evaluations that have significantly enhanced the quality of each article. Our sincere appreciation also goes out to Prof. Javier Gozalvez, the editor-in-chief, and the committed team at *IEEE Vehicular Technology Magazine*, whose support and guidance were instrumental in bringing this special issue to fruition. It is our earnest hope that readers will find the insights presented in these articles both intriguing and practically valuable.

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Appendix: Related Articles

[A1] X. Yu et al., "When connected and automated vehicles meet mobile crowdsensing: A perception and transmission framework in the metaverse," *IEEE Veh. Technol. Mag.*, vol. 18, no. 4, pp. 22–34, Dec. 2023, doi: 10.1109/MVT.2023.3320865.

[A2] M. Xu et al., "Sparks of generative pretrained transformers in edge intelligence for the metaverse: Caching and inference for mobile artificial intelligence-generated content services," *IEEE Veh. Technol. Mag.*, vol. 18, no. 4, pp. 35–44, Dec. 2023, doi: 10.1109/MVT.2023.3323757.

[A3] Y. Kang, Q. Song, J. Song, F. Pan, L. Guo, and A. Jamalipour, "How does a digital twin network work well for connected and automated vehicles: Joint perception, planning, and control," *IEEE Veh. Technol. Mag.*, vol. 18, no. 4, pp. 45–55, Dec. 2023, doi: 10.1109/MVT.2023.3328107.

[A4] S. Li, X. Lin, J. Wu, W. Zhang, and J. Li, "Digital twin and artificial intelligence-empowered panoramic video streaming: Reducing transmission latency in the extended reality-assisted vehicular metaverse," *IEEE Veh. Technol. Mag.*, vol. 18, no. 4, pp. 56–65, Dec. 2023, doi: 10.1109/MVT.2023.3321172.

[A5] B. Mao, Y. Liu, J. Liu, and N. Kato, "AI-assisted edge caching for metaverse of connected and automated vehicles: Proposal, challenges, and future perspectives," *IEEE Veh. Technol. Mag.*, vol. 18, no. 4, pp. 66–74, Dec. 2023, doi: 10.1109/MVT.2023.3327514.

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MOBILE RADIO

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5G Nonterrestrial Networks

Satellites can enhance 5G networks by solving coverage and challenging use cases beyond ground-based infrastructure. On 4 July 2023, 5G Americas, the voice of 5G and beyond for the Americas, unveiled the white paper "Update on 5G Non-Terrestrial Networks" [3], which provides an update on current developments in the growth of partnerships and technologies relating to nonterrestrial network (NTN) integration with 5G networks, building on a previous white paper on this subject (as we reported in the June 2022 issue of the magazine).

By mid-2023, NTNs are a thriving market with diverse technical and commercial strategies. The 5G NTN delivers high-speed wireless access to remote areas, utilizing satellites on the mobile network's access side to provide ground users with mobile services.

"Update on 5G Non-Terrestrial Networks" examines the growing ecosystem of providers and partnerships between NTN service providers and ground-based cellular providers. In addition, it highlights satellite constellations operating in three key domains: broadband and Internet services, IoT connectivity, and direct-to-cell applications.

Some key topics surrounding NTNs in this 5G Americas report include

- current status of NTNs
- architectural paradigms update
- 5G NTN standardization in 3GPP
- New Radio and IoT support
- NTN in release 17
- NTN enhancements in 3GPP release 18
- potential for new services with 3GPP NTN solutions
- Federal Communications Commission activities related to NTNs
- recommendations and conclusions.

Luiz Abud, head of emerging business and partnerships at Nokia, said, "Today, the integration of 3GPP smartphones with NTN paves the way for exciting advancements in 5G NTN standards. These developments within 3GPP hold tremendous potential to amplify the efficiency and capabilities of LEO satellites, presenting a wealth of opportunities for emerging 5G NTN ecosystems. By revolutionizing Earth's communication landscape with unprecedented reliability, these advancements not only bridge the digital divide but also safeguard lives in challenging scenarios while optimizing global supply chain systems."

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[2] "MEC support towards edge native design," ETSI, Sophia Antipolis, France, White Paper, 2023. [Online]. Available: https://www.etsi.org/images/files/ETSIWhitePapers/ETSI-WP55-MEC_support_towards_Edge_native.pdf

[3] "Update on 5G non-terrestrial-networks," 5G Americas, Bellevue WA, USA, White Paper, 2023. [Online]. Available: https://www.5gamericas.org/wp-content/uploads/2023/07/Update-on-5G-Non-terrestrial-Networks-Id.pdf

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