Guest Editorial Introduction to the Special Section on Cybertwin-Driven 6G for V2X Applications

DIGITAL twin is envisioned to enhance functionalities of future electric and autonomous vehicles. Serving as the digital representation of a vehicle on the application layer, digital twin models the entire lifecycle of processes and services of the vehicle. To provide fundamental support for digital twin from network and transport layers, an agent service, namely Cybertwin, acts as the communication, mobility, and security agent for each user entity (either human or thing) at the edge of the network. Specifically, Cybertwin, serving as a communication anchor, is the only entrance point of the user for the Internet and records all the user states and behaviors. In addition, Cybertwin can become the personal AI assistant and act as a security agent through customizing the visibility of recorded data. By enhancing edge intelligence and providing composite edge services, Cybertwin can support advanced vehicle-to-everything (V2X) applications in the future intelligent and secure vehicular 6G network.

By enhancing edge intelligence and providing composite edge services, Cybertwin can support advanced vehicle-to-everything (V2X) applications in the future intelligent and secure vehicular 6G network. With the help of Cybertwin, vehicles can seamlessly upgrade the on-board functionalities, e.g., advanced driver assistance, autonomous driving, and energy optimization. This special section aims to promote and develop the great potentials of Cybertwin and seeks for novel and prominent research works on Cybertwin-driven 6G for V2X applications.

Although the concept of Cybertwin is raised shortly, the special section attracts 26 high-quality submissions from distinguished researchers from all over the world. The review is conducted through a multi-round process, with qualified reviewers expertizing each paper, and the final decisions are made in a discreet manner. Thanks to the great support from the past Editor-in-Chief, Prof. Nei Kato, and current Editor-in-Chief, Prof. Abbas Jamalipour, and the dedicated work of all reviewers, we were able to accept 9 excellent research works covering various topics in Cybertwin-driven 6G for V2X Applications. In the following, we will introduce these articles and highlight their main contributions.

The paper "SecCDV: A Security Reference Architecture for Cybertwin-driven 6G V2X" introduces the architecture and applications of Cybertwin-driven 6G V2X and analyzes its essential data security and privacy preservation requirements. The migration of Cybertwin caused by vehicle mobility is investigated as a typical case, where a handover authentication scheme is proposed to create new Cyberwtin between vehicle and edge server based on proxy ring signature technique. Moreover, several open research directions for achieving more secure Cybertwin-driven 6G V2X are discussed.

In the paper "Traffic Routing-Based Computation Offloading in Cybertwin-Driven Internet of Vehicles for V2X Applications," Ma *et al.* investigate the conflict between the resource-hungry V2X applications and the resource-constrained vehicles. A traffic routing-based computation offloading scheme in cybertwin-driven IoV for V2X applications is proposed to adapt the dynamic network conditions caused by the mobility of vehicles, in which cybertwin represents the network hardware devices and the network software functions. Performance evaluation results validate that the proposed scheme is indeed capable of reducing latency.

The paper "Physical Layer Security in Cybertwin-enabled Integrated Satellite-terrestrial Vehicle Networks" exploits the secure vehicle communications in cybertwin-enabled integrated satellite-terrestrial networks, where the digital twins in the cybertwin space reflects the physical entities. Specifically, the problems of maximizing the secrecy rate of satellite-to-vehicle link and the terrestrial BS-to-vehicle link are formulated and solved with two beamforming optimization approaches, respectively.

The paper "Low-Complexity Phased-Array Physical Layer Security in Millimeter-Wave Communication for Cybertwin-Driven V2X Applications" proposes a low-complexity phased-array physical layer security (PLS) scheme in mmWave wireless communications for cybertwin-driven V2X applications. The simulation demonstrates that the proposed scheme achieves good security performances in terms of symbol error rate (SER) and secrecy outage probability.

The paper "Efficient Multi-Vehicle Task Offloading for Mobile Edge Computing in 6G Networks" studys a hybrid energy-powered multi-server Mobile Edge Computing (MEC) system with cybertwin. An efficient multi-vehicle task offloading (EMT) algorithm is designed to achieve the trade-off between system cost and task queue length. Both theoretical analysis and experimental evaluation show that EMT algorithm can optimize the total cost of the MEC system and guarantee the system performance.

The paper "Hybrid RSU Management in Cybertwin-IoV for Temporal and Spatial Service Coverage" aims to

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mitigate the gap between the stringent V2X requirements and the limited available resources with a cybertwin-based internet of vehicle (IoV) architecture. The utility maximization problem with coverage constraints is formulated to evaluate the performance of cybertwin-based roadside unit (RSU) deployment and scheduling. Considering the different granularities of service loads, a three-stage hybrid RSU management strategy is proposed to facilitate the RSU management and achieve always-on V2X services.

In the paper "Cybertwin-driven Adaptive Transmission Scheduling for Software Defined Vehicular Networks," Quan *et al.* present a cybertwin-driven adaptive transmission scheduling architecture in software-defined vehicular networks (SDVN) to well adapt to the time-varying vehicular environment. A deep reinforcement learning based transmission control approach is designed to learn the optimal transmission policy and dynamically adjust the transmission scheduling mechanism in SDVN. Simulation results show that the proposed approach outperforms other well-known transmission control approaches.

In the paper "CyberChain: Cybertwin Empowered Blockchain for Lightweight and Privacy-preserving Authentication in Internet of Vehicles," Chai *et al.* present a Cybertwin empowered blockchain framework for authentication, namely CyberChain, to reduce both the communication and storage cost while maintaining vehicular privacy. The evaluation results demonstrate that the proposed cyberchain empowered framework significantly improves the authentication performance in terms of authentication latency, privacy, communication overhead and storage cost.

In the paper "Cybertwin-driven Federated Learning based Personalized Service Provision for 6G-V2X," Prathiba *et al.* propose a Federated Learning and edge Cache-assisted Cybertwin (FLCC) framework for personalized service provision in 6G-V2X. The Federated Multi-agent Deep Reinforcement Learning based (FM-DRL) algorithm is proposed and applied to balances the FLCC's learning accuracy by jointly considering the edge cooperation and optimizations. Besides, the Federated Reinforcement Learning-based Edge Caching (FREC) algorithm is used to obtain the desired datasets.

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 Prof. Nei Kato, the former Editor-in-Chief, and Prof. Abbas Jamalipour, the current Editor-in-Chief of the IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, for their great support throughout the whole review and publication process of this special section, 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 Cybertwin-driven 6G for V2X Applications.

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