Advances in Artificial Intelligence (AI) Enabled Vehicular Edge Computing (VEC) for Consumer Electronics

SMART vehicles, especially New Energy Vehicles (NEVs), have evolved into sophisticated information hubs capable of real-time sensing, communication, and computation. These cyber-physical systems transcend conventional transportation roles, emerging as advanced consumer electronics devices with edge computing capabilities. Moreover, Internet of Things (IoT)-enabled smart vehicles continuously generate vast amounts of time-critical or time-insensitive data. Vehicular Edge Computing (VEC) has emerged as a promising paradigm for efficiently processing tasks and data at the source. However, VEC encounters challenges stemming from the dynamic nature of Vehicular Ad Hoc Networks (VANETs), the high mobility of vehicles, and the limited computational resources of edge servers.

Numerous studies are currently exploring the application of Artificial Intelligence (AI) technologies to address the challenges associated with VEC. The deep integration of AI with VEC equips consumers and drivers with exceptional capabilities, including self-organization, self-learning, self-reasoning, and real-time decision-making. However, AI-enabled VEC still faces several critical challenges: i) Standardized datasets and established methodologies are lacking to guide research in this field. ii) Smart vehicles with resource-limited resources struggle with executing complex AI algorithms or training large models. iii) The cloud-based training and edge-based inference model requires further investigation to fully realize its potential. iv) Ongoing concerns persist regarding the security and reliability of AI-enabled VEC systems.

This Special Section of IEEE TRANSACTION ON CONSUMER ELECTRONICS offers a platform to explore the latest advancements in AI-enabled VEC for consumer electronics, bring together cutting-edge and high-quality research to drive substantial progress in this rapidly growing field. Following a rigorous review process, 12 outstanding research papers were accepted, addressing topics such as modeling, resource allocation, and the applications of AI-enabled VEC in the consumer electronics domain.

In [A1] the authors present a secure aggregation framework based on a k-regular graph in the context of VANETs. They design an optimized aggregation scheme that reduces the communication rounds between vehicles and the central server by 2n, while achieving logarithmic overhead when executed among n vehicles. Experimental and security analyses show that the proposed scheme optimizes both computation and communication overheads, achieving logarithmic complexity, which outperforms the state-of-the-art schemes and provides reliable privacy preservation during the secure aggregation process.

The authors of [A2] propose RSMR, a two-phase multipath routing scheme for VEC networks. In the route decision phase, they design an integrated adaptive function that simultaneously considers transmission latency, energy balance and communication quality. During the route maintenance phase, a two-stage mechanism is employed to adjust paths in real-time, ensuring effective data routing. Simulation results show that RSMR outperforms existing schemes in terms of routing reliability and energy balance. The findings provide practical and general guidance for users seeking sustainable routing solutions.

The authors of [A3] explore vehicular crowdsensing from a long-term perspective, rather than concentrating on short-term optimization objectives. They address the challenge of assigning crowdsensing tasks located within a sensing hole, where task requirements may evolve over time, complicating efforts to maintain system stability. To tackle this, the authors formulate a long-term task assignment problem using a Lyapunov optimization model with an upper bound on the utility function. The approach is validated through extensive simulations, demonstrating its efficiency.

In [A4], the authors propose a multi-tier offloading model based on game theory principles to optimize the distribution of resources at edge servers while accounting for server load, ensuring the timely execution of latency-sensitive tasks. The model consists of two stages: the dynamic game offloading stage, where the task offloading problem is formulated as a Stackelberg game to refine the use of edge server resources, and the equilibrium offloading stage, which directs vehicles in task offloading to reduce the task failure rate and maintain service quality. Simulation results demonstrate that the proposed model efficiently utilizes edge server resources and successfully meets task execution requirements.

In [A5], the authors address the issues of potential internal traffic congestion and high time complexity caused by massive route queries in dynamic road networks. They first propose a novel game theory-based algorithm (GTA) to reduce global travel time for these queries, followed by a query clustering technique that leverages the source and destination locations of queries to enhance game efficiency. The combination of these

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approaches results in the GTA-QC algorithm. Experimental results demonstrate that GTA-QC significantly improves route planning efficiency.

The authors of [A6] develop an in-vehicle wireless gesture recognition (GR) system using Channel State Information (CSI) acquired between the In-Vehicle Infotainment System (IVIS) and the driver's smartphone. To reduce the CSI dimension and create a lightweight model, they propose a novel subcarrier grouping selection strategy (SGSS). This strategy reduces the CSI dimension by grouping subcarriers into two sets and performing CSI reshaping across three selection strategies. Experiments conducted in a real vehicle environment show that the proposed model achieves high average accuracy for both large-scale and small-scale gestures.

In [A7], the authors investigate the potential of instant inverse modeling for autonomous vehicles to estimate the behavioral preferences of surrounding vehicles. To determine the driving characteristics of a target vehicle based on its behavioral trajectories, they design a novel workflow for an inference model that leverages a character-aware meta-agent. Simulation results demonstrate that the proposed solution achieves higher inference accuracy than baseline algorithms, even with a shorter inference time.

The authors of [A8] explore the robustness of Graph Neural Networks (GNNs) against label-flipping attacks within the context of the VEC combined with Unmanned Aerial Vehicle (UAV) services, known as the VEC-UAV framework. They propose an advanced adversarial label-flipping attack model called UAVGuard, which employs continuous approximations for complex objectives and a simplified GNN structure to enable effective gradient-based attacks. Experiments conducted on three real-world datasets show that UAVGuard significantly enhances the resilience of traditional GNNs and their variants against label-flipping attacks.

To address the deployment and application challenges faced by resource-constrained Vehicle Edge Devices (VEDs), the authors of [A9] aim to fully optimize the DNN model by combining tensor decomposition, weight quantization, sign flipping, and bitwise shifting. They propose a lightweight tensor linear shift layer and a lightweight tensor convolutional shift layer, introducing two models, LTS-α and LTS-β, based on these lightweight tensor shift layers. Experiments conducted on several real-world datasets show that LTS-α and LTS-β achieve higher performance with lower memory footprint and computational overhead compared to relevant mainstream methods.

The authors of [A10] investigate route planning in consumer electronics supply chains, with a particular focus on collision avoidance in artificial intelligence applications. To address this challenge, they explore variational quantum algorithms that efficiently utilize qubits to adapt to current limitations in quantum computing resources. First, the authors formulate constraints to identify infeasible solutions. They then develop a route planning model that integrates the vehicle routing problem with the collision avoidance problem. A joint optimization algorithm is proposed to solve this model. To reduce the qubit demand and enable the computation of larger-scale problems within the constraints of limited qubits, the algorithm is further enhanced into a stepwise optimization approach, achieving an acceptable computational cost.

In order to solve the executing complex workflow applications through a single-hop offloading paradigm in the Internet of Vehicles (IoV), the authors of [A11] propose a Reinforcement Learning (RL)-based multi-hop computation offloading scheme for workflow applications, aiming to reduce execution latency in VEC networks. Specifically, they design a Deep Q-network algorithm with a Phase-optimal State update (DQPS) to efficiently identify real-time optimal offloading schemes in IoV. Simulation results show that DQPS achieves better convergence and shorter running time compared to other benchmark schemes.

In [A12], the authors formulate task offloading and resource allocation in Multi-access Edge Computing (MEC)-based vehicular networks as a joint optimization problem. To solve this problem, they propose a Load-Balancing Deep Deterministic Policy Gradient (LBDDPG) algorithm. Experimental results show that LBDDPG achieves faster convergence and superior performance compared to other RL algorithms. It effectively meets the requirements for low system consumption and low latency, while ensuring load balancing.

These papers present innovative approaches, including the integration of GNNs, DNNs, RL, federated learning and game theory, all specifically designed to advance AI-enabled VEC for consumer electronics. We would like to express our appreciation to the authors and reviewers for their valuable contributions to this Special Section. Additionally, we are grateful to the Editor-in-Chief for giving us the opportunity to serve as Guest Editors and for his continuous support throughout the entire process.

Appendix: Related Articles

[A1] K. Cui, X. Feng, L. Wang, and Z. Ying, "Secure aggregation with logarithmic overhead for federated learning in VANETs," *IEEE Trans. Consum. Electron.*, early access, Jan. 24, 2025, doi: 10.1109/TCE.2025.3533750.

[A2] Y. Wang, H. Gao, Z. Xiang, Z. Zhu, and A. Al-Dulaimi, "RSMR: A reliable and sustainable multi-path routing scheme for vehicle electronics in edge computing networks," *IEEE Trans. Consum. Electron.*, early access, Aug. 1, 2024, doi: 10.1109/TCE.2024.3436908.

[A3] X. Guo, X. Wang, W. Pan, W. Wu, and K. Liu, "A Lyapunov optimization approach for long-term task assignment in vehicular crowdsensing," *IEEE Trans. Consum. Electron.*, early access, Oct. 9, 2024, doi: 10.1109/TCE.2024.3477472.

[A4] H. Lin, B. Xiao, X. Zhou, Y. Zhang, and X. Liu, "A multi-tier offloading optimization strategy for consumer electronics in vehicular edge computing," *IEEE Trans. Consum. Electron.*, early access, Jan. 8, 2025, doi: 10.1109/TCE.2025.3527043.

[A5] D. Zhang, Y. Zhou, and J. Wang, "Game theory based approach for massive route planning in dynamic road networks," *IEEE Trans. Consum. Electron.*, early access, Aug. 26, 2024, doi: 10.1109/TCE.2024.3449285.

[A6] J. Yuan et al., "In-vehicle wireless gesture recognition system based attention-enhanced lightweight model," *IEEE Trans. Consum. Electron.*, early access, Oct. 16, 2024, doi: 10.1109/TCE.2024.3480954.

[A7] D. Lee and M. Kwon, "Instant inverse modeling of stochastic driving behavior with deep reinforcement learning," *IEEE Trans. Consum. Electron.*, early access, Sep. 20, 2024, doi: 10.1109/TCE.2024.3464566.

[A8] J. Akram, A. Anaissi, A. Akram, R. S. Rathore, and R. H. Jhaveri, "Adversarial label-flipping attack and defense for anomaly detection in spatial crowdsourcing UAV services," *IEEE Trans. Consum. Electron.*, early access, Sep. 20, 2024, doi: 10.1109/TCE.2024.3448541.

[A9] D. Liu et al., "Tensor-empowered hardware-friendly lightweight deep neural networks for vehicular edge computing," *IEEE Trans. Consum. Electron.*, early access, Oct. 15, 2024, doi: 10.1109/TCE.2024.3480139.

[A10] Q. Li, Z. Huang, W. Jiang, Z. Tang, and M. Song, "Quantum algorithms using infeasible solution constraints for collision-avoidance route planning," *IEEE Trans. Consum. Electron.*, early access, Oct. 14, 2024, doi: 10.1109/TCE.2024.3476156.

[A11] B. Lin, Q. Chen, X. Chen, W.-K. Jia, Y. Lu, and N. N. Xiong, "DQPS: An intelligent multi-hop computation offloading scheme for workflow applications in vehicular edge computing networks," *IEEE Trans. Consum. Electron.*, early access, Nov. 19, 2024, doi: 10.1109/TCE.2024.3502408.

[A12] S. Tian, S. Xiang, Z. Zhou, H. Dai, E. Yu, and Q. Deng, "Task offloading and resource allocation based on reinforcement learning and load balancing in vehicular networking," *IEEE Trans. Consum. Electron.*, early access, Feb. 14, 2025, doi: 10.1109/TCE.2025.3542133.

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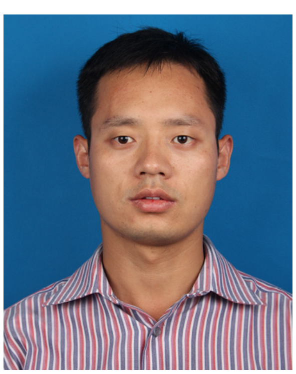

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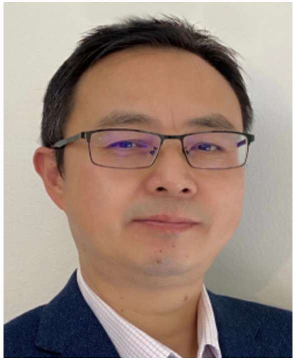

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