Connected and Autonomous Vehicles


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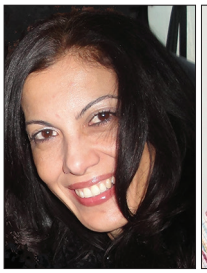
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In this era of rapid technological advancement, characterized by remarkable progress in sensing, communication, networking, and computing, a groundbreaking concept emerges: Connected and Autonomous Vehicles (CAV), representing a beacon of innovation. Imagine a future where vehicles seamlessly monitor their internal health, accessing an array of onboard units to elevate transportation safety to unprecedented levels. Visualize vehicles transcending their mechanical nature, evolving into intelligent entities capable of self-guided navigation, fundamentally transforming user experiences on the road. Moreover, these vehicles orchestrate a symphony of data exchange, intricately weaving networks of interaction — from vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) to vehicle-to-human (V2H) connections — ushering in an era of efficient and sustainable transportation.

Although the horizon appears boundless, within this ambitious vision lie intricate challenges that demand direct confrontation. Crucial challenges encompass efficient network connectivity and achieving network-level autonomy. Vehicular networks grapple with the dynamic shifts in topology and a range of wireless communication methods, necessitating seamless integration to ensure dependable, low-latency data exchange. Simultaneously, the progression toward network-level autonomy calls for heightened intelligence and collaboration among vehicles, humans, and the CAV ecosystem.

Our Special Issue (SI) embarks on the journey to unravel these intricacies, extending an invitation for contributions that shed light on emerging information and communication technologies tailored for the CAV landscape. As guest editors, our enthusiasm propels us forward, inviting researchers to join us in exploring the uncharted domains of CAV, guided by the belief that innovative solutions will pave the path toward a connected and autonomous future.

The Call for Papers for this SI has garnered an astonishing response, attracting 51 submissions from contributors around the globe. The rigorous review process, involving multiple rounds of assessment by esteemed experts in relevant fields, ensured comprehensive evaluation of each manuscript. We extend heartfelt gratitude to Dr. Chonggang Wang, the Editor-in-Chief of IEEE Network, for his invaluable support, which empowered us to curate 18 outstanding articles encompassing diverse aspects of connected and autonomous vehicles.

The article, "A Curbside Parking Planning and Searching Navigation System for Autonomous Vehicles," presents a smart curbside parking system for autonomous vehicles, offering turn-by-turn navigation and parking planning tools. Utilizing GPS, map data, and vehicle routing algorithms, the system provides real-time guidance for safe parking based on street videos captured by a dashcam. The approach effectively reduces curbside parking search times, contributing to efficient and safe autonomous vehicle navigation.

The article, "ECMER: Edge-Cloud Collaborative Personalized Multimodal Emotion Recognition Framework in the Internet of Vehicles," introduces a novel approach called Edge-Cloud Collaborative Multimodal Emotion Recognition Framework (ECMER) to improve driver emotion recognition for safer driving. Current methods relying on physiological signals are inadequate for Internet of Vehicles (IoV) scenarios. ECMER combines facial expression and audio data analysis at the edge, extracting driver personality features that are fused in the cloud. A personality-linked emotion recognition method is proposed using the Big Five Model, enhancing accuracy. Real-time coarse-grained emotion recognition at the edge reduces data transmission and cloud load, leading to improved driver emotion recognition performance as demonstrated in real-world datasets.

The article, "Direct-V2X Support with 5G Network-based Communications: Performance, Challenges and Solutions," explores using 5G Vehicle-to-Network-to-Vehicle (V2N2V) communications for critical V2X services. It analyzes end-to-end latency across different 5G network setups, highlighting the feasibility of supporting V2X services via MEC-based deployments and local peering points. The research suggests that this approach could enhance reliability by complementing direct Vehicle-to-Vehicle (V2V) connections and help manage sidelink network congestion.

The article, "Digital Twins for Maintaining QoS in Programmable Vehicular Networks," proposes employing digital twins for enhancing wireless quality of service (QoS) in non-line-of-sight (NLOS) situations in connected and autonomous vehicles. The method involves using LiDAR sensors on autonomous cars to detect obstacles, triggering a digital twin that employs ray-tracing to determine optimal base station (BS) and reconfigurable intelligent surface (RIS) settings. Real-life LiDAR data and ray-tracing software validate the approach, demonstrating improved QoS through BS and RIS configurations, even in challenging NLOS scenarios.

The article, "An Integrated New Deep Learning Framework for Reliable CSI Acquisition in Connected and Autonomous Vehicles," proposes an integrated framework that addresses these challenges through deep learning, with a focus on optimizing performance and adaptability through continual learning. Simulation results demonstrate the framework's effectiveness in addressing CSI acquisition challenges and adapting to dynamic environments.

The article, "Overcoming Occlusions: Perception Task-Oriented Information Sharing in Connected and Autonomous Vehicles," proposes a perception task-oriented information sharing (PTOIS) network, enabling CAVs to achieve occlusion-free environmental awareness through vehicle-to-everything (V2X) communications. The PTOIS framework includes a game-theoretical computing resource allocation strategy for real-time, reliable perception data fusion, showcased through extensive numerical results that demonstrate high-performance and adaptability in diverse driving scenarios.

The article, "A Novel Generalized Meta Hierarchical Reinforcement Learning Method for Autonomous Vehicles," introduces a novel approach, MHRL-I (meta hierarchical reinforcement learning with imitation learning), which enhances sample efficiency and generalization by leveraging low-level policies and reducing the action space of high-level policies. It also introduces a mechanism with different timescales for high-level and low-level policies, promoting quicker convergence and improved stability and comfort in autonomous driving.

The article, "Auto-CIoV: Autonomous Connected Internet of Vehicles Security Requirements, Open Challenges with Future Research Directions," addresses security challenges and offers insights into interoperability, resource allocation, and communication within the Auto-CIoV framework. This comprehensive approach serves as a valuable resource for researchers and stakeholders in the transportation industry, focusing on robust authentication, data confidentiality, availability, and integrity to ensure secure future Auto-CIoV networks.

The article, "A Hybrid Framework of Reinforcement Learning and Convex Optimization for UAV-Based Autonomous Metaverse Data Collection," focuses on a UAV-assisted Metaverse network, where UAVs expand base station (BS) coverage to gather data from roadside units (RSUs). To enhance data collection efficiency, the system integrates resource allocation and trajectory control. The time-dependent optimization challenge is addressed using a hybrid approach combining reinforcement learning and convex optimization, effectively reducing mission completion time with specified transmission power resources.

The article, "Meta-Networking: Beyond the Shannon Limit with Multi-faceted Information," introduces Meta-Networking, an advanced architecture that surpasses Shannon's communications threshold by leveraging diverse information sources through intelligent collaboration among distributed network entities. It also includes an application scenario in the Internet of Vehicles (IoV), demonstrating substantial performance enhancement over traditional communication methods.

The article, "Multimodal Cooperative 3D Object Detection Over Connected Vehicles for Autonomous Driving," focuses on enhancing small object detection, specifically pedestrians, using shared image and LiDAR data. Evaluation results demonstrate that this method improves 3D pedestrian detection over existing networks.

The article, "Unified Perception and Collaborative Mapping for Connected and Autonomous Vehicles," outlines a strategy for collaborative mapping in a vehicular communication network, involving distributed place recognition, pose optimization within vehicles, and centralized map integration on cloud servers. Real-world dataset experiments illustrate the advantages of unified perception and collaborative mapping.

The article, "Network Optimization Aspects of Autonomous Vehicles: Challenges and Future Directions," provide a comprehensive review, dispel misconceptions, and delineate the future of network optimization for autonomous vehicles. It outlines multidisciplinary approaches, including cooperative perception, to achieve this goal. Drawing on extensive CAV experience, the authors aim to share insights, knowledge, relevant use-cases, and experimental results to contribute to the understanding and progress of autonomous vehicle network optimization.

The article, "DT-SFC-6G: Digital Twins Assisted Service Function Chains in Softwarized 6G Networks for Emerging V2X," introduces a novel business model, followed by the DT-SFC-6G framework design that efficiently researches tailored SFCs by creating digital replicas. Experiments showcase SFC algorithm evaluations within DT-SFC-6G, highlighting its feasibility and advantages. Promising SFC directions in DT-empowered softwarized 6G networks are also discussed.

The article, "Networked Edge Intelligence for Autonomous Farm Vehicles," examines autonomous capabilities for farm vehicles, outlining general requirements and specific needs. It explores a multi-dimensional network architecture, the space-air-ground integrated network (SAGIN), to address coverage and access challenges. Edge computing challenges are also addressed, with experiments demonstrating the efficiency of an AI inference scheduling framework. Additionally, the article delves into the challenges faced by autonomous farm vehicles.

The article, "AI-empowered Management and Orchestration of Vehicular Systems in the Beyond 5G era," addresses challenges in current NFV orchestration solutions for B5G C-V2X edge services, proposes an AI/ML-based closed-loop orchestration framework, discusses the application and implications of AI/ML techniques, and explores AI/ML-based system enablers for B5G C-V2X services.

The article, "Secure and Efficient Lightweight Protocol for Emergency Vehicle Avoidance based on Cloud," proposes a lightweight emergency vehicle authentication protocol for cloud environments, ensuring mutual authentication among vehicles, RSUs, and the cloud. It uses random temporary secrets and re-authentication for efficiency, verifies driver identity, and safeguards against impersonation and vehicle theft attacks. Simulation and security analyses validate the protocol's effectiveness.

The article, "Aerial-Ground Cooperative Vehicular Networks for Emergency Integrated Localization and Communication," introduces an innovative solution, the aerial-ground cooperative vehicular network (AGCVN), which leverages unmanned aerial vehicles (UAVs) and terrestrial emergency vehicles (TEVs) to establish a reliable and flexible integrated localization and communication (ILAC) service in disaster scenarios.

In conclusion, we extend our heartfelt gratitude to the esteemed authors for their exceptional contributions to this SI. Our sincere appreciation also goes to the diligent reviewers who committed their expertise and time to meticulously assess these papers. Their invaluable comments and insightful suggestions have undeniably elevated the caliber of the articles. Furthermore, we would like to express our deep appreciation to Dr. Chonggang Wang, the Editor-in-Chief, and the dedicated team at IEEE Network for affording us this invaluable opportunity. Their unwavering support throughout the preparation of this SI

has been instrumental in its success. In closing, we hold a genuine hope that the readers will find the contents of this special issue both captivating and beneficial.

Biographies

Qing Yang [M'11, SM'17] is an Associate Professor in the Department of Computer Science and Engineering, University of North Texas. He received a Ph.D. degree in Computer Science from Auburn University, in 2011. His current research interests include connected and autonomous vehicles, cooperative perception, and the Internet of Things. His research is funded by the U.S. National Science Foundation, U.S. Federal Highway Administration, PACCAR, and Toyota InfoTech Inc.

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Weisong Shi [F] is a Professor and Chair of the Department of Computer and Information Sciences at the University of Delaware (UD), where he leads the Connected and Autonomous Research (CAR) Laboratory. He is an internationally renowned expert in edge computing, autonomous driving, and connected health. His pioneer paper, "Edge Computing: Vision and Challenges," has been cited over 6,000 times. Before he joined UD, he was a professor at Wayne State University (2002–2022). He has published more than 300 articles in peer-reviewed journals and conferences and served in editorial roles for more than ten academic journals and publications, including EIC of Smart Health, AEIC of *IEEE Internet Computing Magazine*. He is a distinguished member of ACM.

Ye Liu received M.S. and Ph.D. degrees from Southeast University, China, in 2013 and 2018, respectively. He was a visiting scholar with Montana State University, USA. and a visiting Ph.D. Student with RISE Swedish Institute of Computer Science. He is currently a Macao Young Scholar with Macau University of Science and Technology. His research interests include wireless sensor networks, energy harvesting systems, and mobile crowdsensing.

Dinh Thai Hoang [M'16, SM'22] is currently a faculty member at the School of Electrical and Data Engineering, University of Technology Sydney, Australia. He received his Ph.D. in Computer Science and Engineering from the Nanyang Technological University, Singapore, in 2016. His research interests include emerging wireless communications and networking topics, especially machine learning applications in networking, edge computing, and cybersecurity. He is currently an Editor of *IEEE TMC*, *IEEE TWC*, *IEEE TCCN*, *IEEE TVT*, and *IEEE COMST*.

Antonella Molinaro is a Full Professor of Telecommunications at University Mediterranea of Reggio Calabria, Italy, and CentraleSupélec, Paris-Saclay University, France. Her research focuses on V2X future Internet, 5G/6G networks. She was co-editor of the book Vehicular ad hoc Networks: Standards, Solutions, and Research, Springer; she gave tutorials on V2X in IEEE WCNC, IEEE ICC, IEEE GLOBECOM, EuCNC. She serves in the editorial board of *IEEE TVT*, *IEEE VTM*, *IEEE IoTM*, *IEEE Comm. Letters*, *IEEE OJCS*, etc.

Ryokichi Onishi received his Ph.D. in Electrical Engineering and Information Systems from the University of Tokyo, Japan. Since 2001, he has worked at Toyota Motor Corporation, where he is currently Project General Manager of the End-to-End Computing Group, Connected Advanced Development Division. His current interest is in IoT and mobile communication technologies geared for emerging vehicle services. He has been issued 31 patents by the U.S. Patent and Trademark Office.