AI-Empowered Mobile Edge Computing in the Internet of Vehicles


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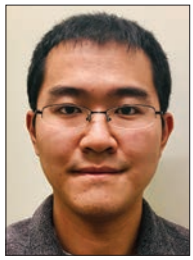
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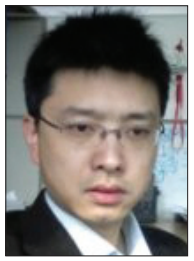
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Mobile Edge Computing (MEC) is promising for computation-intensive applications (such as automatic and cooperative driving) and storage burdens (video caching) on the Internet of Vehicles (IoV). It paves the way for the establishment of intelligent transportation systems and smart cities. Many countries all over the world have devoted themselves to investigating novel equipment and components to support communications and applications based on IoVs.

Artificial Intelligence (AI) has emerged as a promising technique to break through obstacles in various research areas (such as pattern recognition, image processing, and natural language processing) and make the system smart enough to make decisions based on the environment status, even with high-dimensional inputs.

So far AI-empowered MEC in IoVs mainly depends on a centralized approach, because an AI management center is required to collect the information and react according to the environment. With the ever-increasing and complicated contents and frequent communications, the robustness and agility of AI-empowered MEC in IoVs need to be enhanced. Therefore, the distributed AI approach is preferred, while the mobility of vehicles should be considered comprehensively.

For this special issue, we received 47 submissions, of which nine were accepted. The acceptance rate is about 19 percent. Each submission received at least three detailed reviews. Here is the overview of the nine accepted papers.

In "Toward an Optimal MEC Resources Dimensioning for Vehicle Collision Avoidance System: A Deep Learning Approach", the authors point out that collision detection and avoidance between vehicles is one of the key services envisioned in the IoV. Such services are usually deployed at the MEC to ensure low latency communication and thus guarantee real-time reactions to avoid collisions between vehicles. The authors introduce an AI-empowered framework that aims to optimize the computing resources at the MEC hosts in the context of IoV. The proposed framework uses deep learning to (1) predict the vehicle density to be served by a MEC host, and (2) derive the exact computing resources required by the collision detection application to run optimally.

The paper "Edge Intelligence for Plug-in Electrical Vehicle Charging Service" explores the potential of edge intelligence based PEV charging pricing strategies, such that the service providers (SPs) of PEV chargings can respond in a timely manner to the dynamic needs of PEV users and load of the grid. The key factors and parameters that affect the behaviors and interactions of PEV users, charging SPs, and the grid, are introduced. The basic idea of how to apply edge intelligence in vehicular networks is provided. Considering the challenges such as low sampling rate, large variance, slow convergence, etc., the potential of utilizing reinforcement learning (RL) at the network edge to solve the pricing strategy is discussed. Future directions of using edge intelligence for PEV charging pricing strategy are provided.

In "Making a Case for Federated Learning in the Internet of Vehicles and Intelligent Transportation Systems", the authors present the benefits of using federated learning compared to traditional machine learning methods in Intelligent Transportation Systems. In this regard, the authors discuss the various technical considerations related to the implementation of federated learning in such a system. Following this, they present a case study highlighting the efficacy of federated learning for fault recovery during an unforeseen failure scenario. Finally, the authors discuss potential applications of federated learning in the Intelligent Transportation System, such as roadside unit intelligence, intelligent NFV Orchestration, and vehicular intelligence.

The article "Machine-Learning-Enabled Cooperative Perception for Connected Autonomous Vehicles: Challenges and Opportunities" presents the research challenges and opportunities in machine-learning-enabled cooperative perception for connected and autonomous vehicles. Feature map based cooperative perception is proposed, followed by a detailed discussion of feature map processing, feature map transmission, and feature map fusion. To support fast feature map transmission, the paper analyzes the feasibility of applying millimeter wave communications to facilitate feature map transmission among autonomous vehicles and edge servers. Finally, the research issues of cooperative perception in a vehicular edge system are discussed, e.g., vehicular edge system architecture, computing offloading, and resource task scheduling.

In "Imitation Learning-enabled Vehicular Edge Computing: Toward Online Task Scheduling", the authors design an imitation learning-based online task scheduling scheme with the support of vehicular edge computing. To obtain the expert policy, the authors design a heuristic searching algorithm based on full network states, which can be executed offine. Then, the authors train the learning model online to enable the learning agent to mimic the behaviors of experts. It intends to minimize the average age of critical information, referring to the age of information that has significant impacts on vehicle decisions. Performance evaluations show that the proposed scheme outperforms other algorithms in several aspects.

The paper "AI Empowered Content Caching in Vehicular Edge Computing: Opportunities and Challenges" presents a task-based architecture of content caching in Vehicular Edge Computing, where three major tasks are identified, namely, content popularity prediction, content placement in the cache, and content retrieval from the cache. The authors provide an overview of how Artificial Intelligence (AI) techniques such as regression and Deep Q-learning can improve the eficiency of these tasks. The authors also highlight related future research opportunities in the areas such as collaborative data sharing for

improved caching, efficient sub-channel allocation for content retrieval in C-V2X, and secure caching.

To solve the data transmission efficiency problem and improve the scalability of the full network architecture in the Internet of Vehicles (IoV), the article "Federated Learning Empowered Collaborative Data Sharing for Vehicular Edge Networks" investigates the issue of collaborative data sharing in vehicular edge networks (VEN) with the deployment of AI-empowered mobile edge computing (MEC). In particular, this article models the problem of collaborative data sharing as minimizing the system transmission latency of data sharing. As federated learning has many advantages such as alleviation of network bandwidth, protec.tion of privacy, and low latency, an intelligent collaborative data sharing scheme with deep Q-network (DQN) and federated learning is proposed to improve the efficiency and security of data sharing in the VEN.

In "Blockchain-Enabled Intelligent Vehicular Edge Computing", the authors propose a blockchain-based decentralized architecture to enhance transparency in IVEC resource management and leverage edge consumers (e.g., vehicles) with a computation verification option. Additionally, they address the unbalanced load distribution issue and propose a secure IVEC federation model for balancing loads. The authors also outline the main challenges and provide a brief description of promising research directions to draw the attention of concerned stakeholders and parties in both blockchain and edge computing domains.

The article "Network Slicing with MEC and Deep Reinforcement Learning for the Internet of Vehicles" introduces a model-free approach based on deep reinforcement learning (DRL) to solve the resource allocation problem in MEC-enabled IoV networks based on network slicing. Furthermore, the solution uses nonorthogonal multiple access (NOMA) to enable a better exploitation of the scarce channel resources. The considered problem addresses jointly channel and power allocation, slice selection and vehicle selection (vehicle grouping). The authors model the problem as a single-agent Markov decision process. Then, they solve it using DRL using the well known DQL algorithm. They show that their approach is robust and effective under different network conditions compared to benchmark solutions.

Biographies

Jun Huang (M'12-SM'16) received the Ph.D. degree (with honors) from the Institute of Network Technology, Beijing University of Posts and Telecommuni.cations, China, in 2012. He is a full professor of computer science with the Chongqing University of Posts and Telecommunications. He was a visiting scholar at the Global Information and Telecommunication Institute, Waseda University; a research fellow in the Electrical and Computer Engineering Department, South Dakota School of Mines and Technology; a visiting scholar in the Computer Science Department, the University of Texas at Dallas; and a guest professor at the National Institute of Standards and Technology. He received the best paper award from MobiMedia 2019, the outstanding service award from ACM RACS 2017 and 2018, the runner-up of best paper award from ACM SAC 2014, and the best paper award from AsiaFI 2011. He has authored 120+ publications including papers in prestigious journal/conferences. He is an associate editor of *Elsevier Digital Communications and Networks*, *IEEE Access* and *KSII Transactions on Internet and Information Systems*. He has guest-edited several special issues on IEEE journals such as the *IEEE Communications Magazine*, *IEEE Internet of Things Journal*, *IEEE Access*, etc. He has also chaired and co-chaired multiple conferences in the communications and networking areas and organized multiple workshops at major IEEE and ACM events. His current research interests include network optimization and control, machine-to-machine communications, and the Internet of Things. He is a senior member of the IEEE.

Jalel Ben Othman received his B.Sc. and M.Sc. degrees, both in computer science, from the University of Pierre et Marie Curie, (Paris 6) France in 1992 and 1994, respectively. He received his Ph.D. degree from the University of Versailles, France, in 1998. He was an assistant professor at the University of Orsay (Paris 11) and the University of Pierre et Marie Curie (Paris 6), in 1998 and 1999, respectively. He was an associate professor at the University of Versailles from 2000 to 2011. He is now full professor at the University of Paris 13. His research interests are in the area of wireless ad hoc and sensor networks, broadband wireless networks, multi-services bandwidth management in WLAN (IEEE 802.11), WMAN (IEEE 802.16), WWAN (LTE), security in wireless networks in general and wireless sensor and ad hoc networks in particular. His work appears in highly respected international journals and conferences, including, IEEE ICC, Globecom, LCN, VTC, PIMRC, etc. He has supervised and co-supervised several graduate students in these areas. He is widely known for his work on wireless ad hoc and sensor networks, in particular security. He is an editorial board member of *Wiley Wireless Communications and Mobile Computing*, *Inderscience International Journal of Satellite Communications Policy and Management*, and an associate editor of *Wiley International Journal of Communication Systems*. He has served as a member of Technical Committees of more than 40 international IEEE/ACM conferences and workshops, including ICC, Globecom, MSWIM, and LCN. He is a member of IEEE and ACM. He served as Local Arrangement Chair for the 13th IEEE International Symposium on Computer Communication (ISCC 09). He served as a TPC Co-Chair of the IEEE Globecom Wireless Communications Symposium (Globecom 2010) and the 9th international Workshop on Wireless local Networks (WLN09) and 10th International Workshop on Wireless Local Networks (WLN10).

Shiqiang Wang received his Ph.D. from the Department of Electrical and Electronic Engineering, Imperial College London, U.K., in 2015. He has been a research staff member at IBM T. J. Watson Research Center, NY, USA since 2016, where he was also a graduate-level co-op in the summers of 2014 and 2013. In the fall of 2012, he was at NEC Laboratories Europe, Heidelberg, Germany. His current research focuses on the interdisciplinary areas in distributed computing, machine learning, networking, optimization, and signal processing. He served as a technical program committee (TPC) member of several international conferences, including ICML, NeurIPS, ICDCS, AISTATS, IJCAI, IFIP Networking, IEEE GLOBECOM, IEEE ICC, and as an associate editor of *IEEE Transactions on Mobile Computing*. He received the IEEE Communications Society Leonard G. Abraham Prize in 2021, IBM Outstanding Technical Achievement Award (OTAA) in 2019, multiple Invention Achievement Awards from IBM since 2016, Best Paper Finalist of the IEEE International Conference on Image Processing (ICIP) 2019, and Best Student Paper Award of the Network and Information Sciences International Technology Alliance (NIS-ITA) in 2015.

Ricky Y. K. Kwok (F'14) received a B.Sc. degree in computer engineering from the University of Hong Kong in 1991, and the M.Phil. and Ph.D. degrees, both in computer science, from the Hong Kong University of Science and Technology (HKUST) in 1994 and 1997, respectively. His research focus has been on designing efficient communication protocols and robust resource management algorithms toward enabling large scale distributed mobile computing. In these research areas, he has authored one textbook, co-authored another two textbooks, and published more than 200 technical papers in various leading journals, research books, and refereed international conference proceedings. He is a Fellow of the HKIE, the IEEE, and the IET. He is also a member of the IEEE Computer Society and the IEEE Communications Society. From March 2006 to December 2011, he served on the editorial board of the *Journal of Parallel and Distributed Computing* as a subject area editor in Peer-to-Peer Computing. He also served as an associate editor for *IEEE Transactions on Parallel and Distributed Systems* from January 2013 to December 2016. He received the Outstanding Young Researcher Award from HKU in November 2004. In January 2010, one of his journal papers was ranked No. 4 among the top 10 All-Time Most Cited Papers published in the *IEEE Transactions on Parallel and Distributed Systems*, based on Scopus and Google Scholar citation counts as of October 2009. In April 2013, he received the Outstanding Reviewer Service Award from the IEEE Computer Society (under the Reviewer Appreciation Program) because as of 2013 he was the All-Time Most Prolific Reviewer for the *IEEE Transactions on Parallel and Distributed Systems*.

Victor C. M. Leung (F'03) received the B.A.Sc. (Hons.) degree in electrical engineering from the University of British Columbia (UBC) in 1977, and was awarded the APEBC Gold Medal as the head of the graduating class in the Faculty of Applied Science. He attended graduate school at UBC on a Natural Sciences and Engineering Research Council Postgraduate Scholarship and received the Ph.D. degree in electrical engineering in 1982. From 1981 to 1987, he was a Senior Member of Technical Staff at Microtel Pacific Research Ltd. (later renamed MPR Teltech Ltd.), Burnaby, Canada, where he specialized in the planning, design and analysis of satellite communication systems. He also held a part-time position as visiting assistant professor at Simon Fraser University in 1986 and 1987. In 1988, he was a Lecturer in the Department of Electronics at the Chinese University of Hong Kong. He returned to UBC as a faculty member in 1989, where he was a professor and the inaugural holder of the TELUS Mobility Industrial Research Chair in Advanced Telecommunications Engineering in the Department of Electrical and Computer Engineering, and a member of the Institute for Computing, Information and Cognitive Systems when he retired from UBC and became a professor emeritus at the end of 2018. He is the Director of the Laboratory for Wireless Networks and Mobile Systems (WiNMoS). His research interests are in the broad areas of wireless networks and mobile systems. He is a registered member of Engineers and Geoscientists BC, Canada. He is a Fellow of IEEE, a Fellow of the Academy of Science, Royal Society of Canada, a Fellow of the Engineering Institute of Canada, a Fellow of the Canadian Academy of Engineering, and a voting member of ACM.

Wei Sun is leading the research and development of smart mobility technologies and offerings empowered by electric vehicle, autonomous driving and AI technologies in Volkswagen Group China. He was a research technical executive of IBM Research-China leading Internet of Things research initiatives across IBM global research labs. In recent years, he has been driving research projects in the areas of asset management, connected vehicle, transportation research, smarter city, and connected vehicle services through partnerships with partners and clients in selected industries. He was a member of the IBM Academy of Technology, and he was a member of the IBM Academy Leadership Team.