Guest editorial: Time-critical communication and computation for intelligent vehicular networks

GUEST EDITORIAL

TIME-CRITICAL COMMUNICATION AND COMPUTATION FOR INTELLIGENT VEHICULAR NETWORKS

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Vehicular networks are expected to empower auto mated driving and intelligent transportation via vehicle-to-everything (V2X) communications and edge/cloud-assisted computation, and in the meantime Cellular V2X (C-V2X) is gaining wide support from the global industrial ecosystem. The 5G NR-V2X technology is the evolution of LTE-V2X, which is expected to provide ultra-Reliable and Low-Latency Communications (uRLLC) with 1ms latency and 99.999% reliability. Nevertheless, vehicular networks still face great challenges in supporting many emerging time-critical applications, which comprise sensing, communication and computation as closed-loops.

On the one hand, compared with conventional mobile services, road and driving-related applications pose more strict latency requirements, beyond the air-interface delay, for road safety and efficiency. On the other hand, context information (e.g., the conditions of surrounding vehicles and pedestrians, dynamic high-precision maps, availability of parking lots, and traffic congestion) can be outdated due to high dynamics over various time scales, as measured by recently proposed new information timeliness/freshness metrics (e.g., age of information). In this regard, fundamental issues of time-critical communication (e.g., timely delivering the context information) and computation (e.g., making driving decisions with low response time) should be investigated to support emerging applications like intelligent connected automated driving.

Inspired by these, this feature topic aims to bring new theories, frameworks, algorithms, mechanisms, applications, and tools of time-critical communications and computations for intelligent vehicular networks. The Call for Papers generated considerable erests in the research community, and after impartial and rigorous reviews, we have accepted eight papers covering the state-of-the-art work from transmission, scheduling, computing to applications.

The feature topic begins with the article by Lu et al., "MARVEL: multi-agent reinforcement learning for VANET delay minimization". This article proposes a Multi-Agent Reinforcement Learning (MARL) based decentralized routing scheme, where the inherent similarity between the routing problem in vehicular ad hoc network and the MARL problem is exploited. The proposed routing scheme models the interaction between vehicles and the environment as a multi-agent problem in which each vehicle autonomously establishes the communication channel with a neighbor device regardless of the global information. Simulation performed in the 3GPP Manhattan mobility model demonstrates less than 45.8ms average latency and high stability of 0.05 % averaging failure rate with varying vehicle capacities.

The article by Zhao et al., "Q-greedyUCB: a new exploration policy to learn resource-efficient scheduling," proposes a Reinforcement learning (RL) algorithm to find an optimal scheduling policy to minimize the delay for a given energy constraint in vehicular communication systems where the environments such as traffic arrival rates are not known in advance and can change over time. The problem is formulated as an infinite-horizon Constrained Markov Decision Process (CMDP). The Lagrangian relaxation technique and a variant of Q-learning, Q-greedyUCB that combines ε-greedy and Upper Confidence Bound (UCB) algorithms are used to solve the problem. The proposed Q-greedyUCB algorithm is proved to converge to an optimal solution and is thus superior to other existing methods. The algorithm can also learn and adapt to the environment changes, showing good robustness.

The article by Zhu et al., "On latency reductions in vehicle-to-vehicle networks by random linear network coding" investigates the latency reduction problem of a multi-source single-sink Vehicle-to-Vehicle (V2V) network with wireless broadcasting channels. The random linear network coding is applied to reduce latency and overcome the impact of non-ideal channels. The generation-by-generation packet sending method is used, and it is found that the increase of the generation size helps the transmission in terms of speed. The coding scheme is further optimized by reducing the Galois field size of random linear network coding as much as possible, which can further reduce the delay and computational overhead.

The article by Bao et al., "Edge computing-based joint client selection and networking scheme for federated learning in vehicular IoT" proposes an edge computing-based joint client selection and networking scheme for vehicular IoT. The proposed scheme assigns some vehicles as edge vehicles by employing a distributed approach, and uses the edge vehicles as federated learning clients to conduct the training of local models, which learns optimal behaviors based on the interaction with environments. The client selection considers the vehicle velocity, vehicle distribution, and the wireless link connectivity between vehicles using a fuzzy logic algorithm, resulting in an efficient learning and networking architecture. Simulations are conducted to evaluate the performance of the proposed scheme, in terms of the communication overhead and the information covered in learning.

A mobile edge computing (MEC)-based cooperative positioning approach is proposed by Yang et al. in the article, "Multi-vehicle cooperative positioning based on edge-computed multidimensional scaling". In the proposed scheme, all the vehicles only need to communicate with the base stations, while the MEC node is responsible for all the computations. The proposed two-stage cooperative positioning algorithm combines multidimensional scaling and Procrustes analysis for vehicles with GPS information, which can achieve centimeter level positioning with accurate GPS information and can achieve relative positioning in GPS-unavailable scenarios.

The article by Hou et al., "Joint allocation of wireless resource and computing capability in MEC-enabled vehicular network", investigates the problem of minimizing the total delay in MEC-enabled vehicular networks. A Joint Allocation of Wireless resource and MEC Computing resource (JAWC) algorithm is proposed, including the V2X clustering step and the MEC computation resource scheduling step is introduced. In the V2X clustering step, the SINR requirement of vehicles is transformed into a matrix spectral radius constraint to ensure the reliability, and a heuristic clustering algorithm is proposed to divide V2X links into different clusters. In the MEC computation resource scheduling step, the original optimization problem is transformed into a convex problem to obtain the optimal solution. Simulation results validate the effectiveness of the proposed JAWC algorithm.

A simulator is developed by Fu et al. for connected autonomous driving leveraging communication between vehicles and Roadside Units (RSUs) with C-V2X PC5, presented in the article "A network-level connected autonomous driving evaluation platform implementing C-V2X technology". The simulation platform is comprised of SUMO and CARLA, aiming at verifying the feasibility of some advanced autonomous driving applications, such as multi-intersection vehicle scheduling and remote driving. To demonstrate its effectiveness, this article implements a hybrid multi-intersection scheduling scheme on the platform, and shows the advantages of the scheme in terms of traffic efficiency and fault tolerance. A remote driving application is implemented based on CARLA, wherein the interplay between communication and computation is also investigated.

The article by Fu et al., "A real-time multi-vehicle tracking framework in intelligent vehicular networks", proposes a real-time multi-vehicle tracking framework in intelligent vehicular networks in the traffic monitoring scenario, which consists of multi-vehicle detection, multi-vehicle association, and miss-detected vehicle tracking. The miss-detected vehicles can be re-tracked with occlusions for better multi-vehicle tracking. The proposed approach is evaluated with several experiments, and the results show that it outperforms the state-of-the-art methods.

In conclusion, the Guest Editors of this feature topic would like to thank all the authors for their contributions, and the anonymous reviewers for their constructive comments and suggestions. We also would like to acknowledge the guidance from Ms. Fan, Ms. Nie and the editorial team of China Communications.

Biographies

Shanzhi Chen received the bachelor's degree from Xidian University in 1991 and the Ph.D. degree from Beijing University of Posts and Telecommunications, China, in 1997. He joined the Datang Telecom Technology and Industry Group and the China Academy of Telecommunication Technology (CATT) in 1994, and has been serving as the EVP of Research and Development since 2008. He is currently the Director of the State Key Laboratory of Wireless Mobile Communications, CATT, where he conducted research and standardization on 4G TD-LTE and 5G. He has authored and co-authored four books [including the well-known textbook Mobility Management: Principle, Technology and Applications (Springer Press)], 17 book chapters, more than 100 journal papers, 50 conference papers, and over 50 patents in these areas. He has contributed to the design, standardization, and development of 4G TD-LTE and 5G mobile communication systems. His current research interests include 6G mobile communications, network architectures, vehicular communication networks, and Internet of Things. He has served as a member and a TPC Chair of many international conferences. His achievements have received multiple top awards and honors by the China central government, especially the Grand Prize of the National Award for Scientific and Technological Progress, China, in 2016 (the highest Prize in China). He is an Area Editor of IEEE Internet of Things, an editor of IEEE Network, and a Guest Editor of IEEE Wireless Communications, IEEE Communications Magazine, and IEEE Transactions on Vehicular Technology.

Tommy Svensson is full Professor in Communication Systems at Chalmers University of Technology in Gothenburg, Sweden, where he is leading the Wireless Systems research on air interface and wireless backhaul networking technologies for future wireless systems. He received a Ph.D. in Information theory from Chalmers in 2003, and he has worked at Ericsson AB with core networks, radio access networks, and microwave transmission products. He was involved in the European WINNER and ARTIST4G projects that made important contributions to the 3GPP LTE standards, the EU FP7 METIS and the EU H2020 5GPPP mmMAGIC and 5GCar projects towards 5G and currently the Hexa-X, RISE-6G and SEMANTIC projects towards 6G, as well as in the ChaseOn antenna systems excellence center at Chalmers targeting mm-wave and (sub)-THz solutions for 5G/6G access, backhaul/ fronthaul and V2X scenarios. His research interests include design and analysis of physical layer algorithms, multiple access, resource allocation, cooperative systems, moving networks, and satellite networks. He has co-authored 5 books, 97 journal papers, 130 conference papers and 55 public EU projects deliverables. He is Chairman of the IEEE Sweden joint Vehicular Technology/ Communications/ Information Theory Societies chapter, founding editorial board member and editor of IEEE JSAC Series on Machine Learning in Communications and Networks, has been editor of IEEE Transactions on Wireless Communications, IEEE Wireless Communications Letters, Guest editor of several top journals, organized several tutorials and workshops at top IEEE conferences, and served as coordinator of the Communication Engineering Master's Program at Chalmers.

Sheng Zhou received the B.E. and Ph.D. degrees in electronic engineering from Tsinghua University, Beijing, China, in 2005 and 2011, respectively. In 2010, he was a Visiting Student with the Wireless System Lab, Department of Electrical Engineering, Stanford University, Stanford, CA, USA. From 2014 to 2015, he was a Visiting Researcher with the Central Research Lab, Hitachi Ltd., Japan. He is currently an Associate Professor with the Department of Electronic Engineering, Tsinghua University. His research interests include cross-layer design for multiple antenna systems, mobile edge computing, vehicular networks, and green wireless communications. He received the IEEE ComSoc Asia–Pacific Board Outstanding Young Researcher Award in 2017, and the IEEE ComSoc Wireless Communications Technical Committee (WTC) Outstanding Young Researcher Award in 2020.

Shan Zhang received Ph.D. degree in electronic engineering from Tsinghua University, Beijing, China, in 2016. She is currently an associate professor in the School of Computer Science and Engineering, Beihang University, Beijing, China. She was a post-doctoral fellow in Department of Electronical and Computer Engineering, University of Waterloo, Ontario, Canada, from 2016 to 2017. Her research interests include mobile edge caching, wireless network virtualization and intelligent management. She received the Best Paper Award at the Asia-Pacific Conference on Communication in 2013. She is now serving as an associated editor of IEEE Internet of Things Journal and Peer-to-Peer Network-