Emerging Information and Communication Technologies for Autonomous Driving


Guangjie Han


Yuanguo Bi


Mohsen Guizani


Jaime Lloret


Muhammad Imran


Ammar Rayes


Kanke Gao

With the great advances in information and communication technology (ICT), autonomous driving is anticipated to significantly improve driving safety by performing intelligent operations including collision avoidance, lane departure warning, traffic sign detection, and so on, which alleviates the burden of human drivers, especially under some hostile traveling environments. In addition, by steering deceleration and acceleration of an autonomous vehicle, autonomous driving can boost fuel economy and lower emissions. With the support of autonomous driving, new transportation services for elderly people and handicapped persons will be fully developed. Autonomous driving has been an emerging area to achieve the ultimate in automobile safety and comfort, which will greatly change the way we work, live, and play.

The developments in multidisciplinary autonomous driving require state-of-the-art technologies in perception, planning, and control. Although an autonomous vehicle is typically equipped with a powerful computing processor and various kinds of sensing devices (e.g., camera, sensor, radar), an inherent drawback of a single ICT in the existing autonomous driving tends to result in suboptimal performance. That necessitates the need to integrate various ICT technologies. For example, coordination among vehicles by vehicle-to-everything (e.g., vehicle, infrastructure, road, human, sensor) communications (V2X) can overcome the limited range of sensors and achieve cooperative maneuvering and sensing. This in turn will enable moving vehicles to quickly and accurately collect real-time road traffic information and notify neighboring vehicles of potential dangerous events. This is expected to meet the imminent demands for reduced traffic accidents and improved road efficiency in intelligent transportation systems (ITS). On the other hand, a deep-learning-based approach can be utilized to detect unexpected obstacles on the road ahead. Reinforcement learning (part of deep learning) can be applied to motion control and decision making for autonomous vehicles. Integrating various ICT technologies can optimize decision making of intelligent vehicles, and improve safety, efficiency, and sustainability of transportation systems.

In this *IEEE Wireless Communications* Feature Topic (FT), the Guest Editors invited researchers from academia, industry, and government to discuss challenging ideas, novel research contributions, demonstration results, and standardization efforts on autonomous driving. After a rigorous review process, 12 papers were selected.

Provisioning of infotainment applications for enjoyable commutes and trips will be the natural next step in the evolution of autonomous driving. Coutinho *et al.*, in ''Guidelines for the Design of Vehicular Cloud Infrastructures for Connected Autonomous Vehicles,“ focus on the design of vehicular cloud computing for supporting connected autonomous vehicles. They give a thorough discussion of vehicular cloud computing and investigate the fundamental challenges to be tackled in order to empower a vehicular cloud computing system capable of supporting CAV applications.

Conventional ITS solutions would fall short due to numerous technical limitations such as reduced flexibility, poor connectivity, limited scalability, and lack of adequate intelligence. Utilizing the potential benefits of software defined networking (SDN), edge computing (EC), and distributed mobility management (DMM) in future autonomous vehicle (AV) networks, Garg *et al.*, in ''MobQoS: Mobility-Aware and QoS-Driven SDN Framework for Autonomous Vehicles,'' present a composite framework with a distributed SDN-DMM approach in ITS ecosystems. Numerical results demonstrate that the proposed MobQoS outperforms existing solutions in overall communication latency and bandwidth utilization.

The current state of technology may not be completely sufficient to realize the aspiration of seamlessly connected vehicles. Jameel *et al.*, in ''Internet of Autonomous Vehicles: Architecture, Features, and Socio-Technological Challenges,'' present a novel paradigm called the Internet of Autonomous Vehicles (IoAV). They first paint the picture of IoAV by discussing salient features and applications of IoAV, followed by a detailed discussion of key enabling technologies. Then they describe the proposed layered architecture of IoAV and uncover some critical functions of each layer, followed by the performance evaluation of IoAV, which demonstrate significant advantages of the proposed architecture in terms of transmission time and energy consumption.

A huge amount of traffic data generated by communicating autonomous vehicles (CAVs) poses challenges for the current networks and even the upcoming 5G communication networks. Li *et al.*, in ''Vehicle-Mounted Base Station for Connected and Autonomous Vehicles: Opportunities and Challenges,'' analyze the communication requirements of CAVs and present the progress of vehicular communication networks. On that basis, they propose a novel concept of vehicular mobile base station (VMBS) and a VMBS-CCNA for CAVs. Simulation results reveal that the proposed VMBS-CCNA can bring significant improvement in terms of throughput, delay, and average number of links.

Loopholes existing in localization and navigation technologies could be utilized by adversaries to manipulate autonomous driving navigation by hijacking valuable vehicles, goods, or even target characters. Luo *et al.*, in ''Localization and Navigation in Autonomous Driving: Threats and Countermeasures," provide a basic guide summarizing the security threats and attack schemes, then propose countermeasures specifically for localization and navigation technologies in autonomous vehicles. Then they present a novel route spoofing attack that could also be implemented against future autonomous driving navigation. The results demonstrate that targeted drivers can be spoofed to arrive at the wrong destination, pass a malicious place, and be tracked in real time.

Designing a MAC protocol for reliable V2X broadcasting is very challenging, as minimal beacon delivery delay and collision avoidance should be achieved simultaneously. Lyu *et al.*, in ''Fine-Grained TDMA MAC Design toward Ultra-Reliable Broadcast for Autonomous Driving," design a TDMA-based MAC protocol to support ultra-reliable broadcast for autonomous vehicles. Three critical issues are identified: mobility-caused time slot collision, time slot shortage, and stiff beacon rate limitation. Accordingly, fine-grained solutions are provided to tackle those issues. Simulation results demonstrate that the fine-grained medium access control (MAC) can work robustly.

The demand for an accurate and reliable object localization and mapping system in driverless cars is higher than ever, and an accurate object detection and positioning system with minimal latency is still challenging. In order to determine the perfect setting for optimal performance, Maiouak *et al.*, in "Dynamic Maps for Automated Driving and UAV Geofencing," introduce a system that satisfies part of the local dynamic map (LDM) and focuses on the latency challenge by measuring it with different inputs and system resources. Finally, the object detection module is tested, and experimental results are presented and discussed.

The traditional vehicular ad hoc network has evolved into a new concept called the Internet of Vehicles (IoV). it is expected to soon transform into the Internet of Autonomous Vehicles (IoAV). Nanda *et al.*, in "Internet of Autonomous Vehicles Communications Security: Overview, Issues, and Directions," give an overview of autonomous vehicle communication layers, its associated properties, and security threats. Further, they also briefly discuss the current research trends and future research issues.

To make the autonomous vehicle a reality, several challenges, such as software heterogeneity, real-time data analytics, verification and validation, and latency need to be resolved. Tanwar *et al.*, in "Tactile Internet for Autonomous Vehicles: Latency and Reliability Analysis," utilize 5G-network-based non-orthogonal multiple access (NOMA) to meet the stringent latency and reliability requirements of autonomous vehicles. The results show that the proposed technique based on 5G-enabled Tactile Internet reduces the end-to-end latency of the conventional techniques and provides reliable and efficient AVs.

There are still challenges for big data analytics in smart transportation that include processing big data in real time, fast processing, and efficient decision and management. Jan *et al.*, in "Designing a Smart Transportation System: An Internet of Things and Big Data Approach," design a model for analyzing transportation data with Hadoop along with Spark to handle real-time transportation data. The proposed system is tested for transportation datasets from various authentic sources, and the results show processing of data and real-time dissemination with citizens in possibly less time.

Vulnerability of software in autonomous driving can lead to vehicle components and systems being attacked, which ultimately affects the work of the autonomous vehicle. *Niu et al.*, in "Detecting Malware on X86-Based IoT Devices in Autonomous Driving," propose a detection of malware on X86-based IoT devices in autonomous driving. They combine fusion features from static analysis and machine learning to solve problems of resource overhead for dynamic analysis and low accuracy of the static analysis. Experimental results show that fusion features can significantly increase the recognition rate.

The NOMA-based autonomous driving vehicular (ADV) network is recognized as a promising application scenario in next generation mobile networks. Liu *et al.*, in "Energy-Efficient Subchannel Matching and Power Allocation in NOMA Autonomous Driving Vehicular Networks," propose an architecture of NOMA-based ADV networks to satisfy the communication requirements. Simulation results prove that the proposed scheme has good feasibility and reliability, and also verify that its algorithm has better energy efficiency.

In closing, we would like to thank all the people who have made significant contributions to this FT, including the contributing authors, the anonymous reviewers, and the *IEEE Wireless Communications* publication staff. We believe that the research results presented in this FT will stimulate further research and development ideas in autonomous vehicles.

Biography

Guangjie Han [S'03, M'05, SM'18] is currently a professor with the Department of Information and Communication Systems, Hohai University, China. His current research interests include sensor networks, computer communications, mobile cloud computing, and multimedia communication and security. He has served on the Editorial Boards of up to 20 international journals, including *IEEE JSAC, IEEE Network*, and *IEEE Systems*. He chas guest edited a number of special issues in IEEE journals and magazines.

Yuanguo Bi received the B.Sc. degree from Liaoning University, Shenyang, China in 2003, and M.Sc. (2006) and Ph.D. (2010) degrees from Northeastern University, Shenyang, China, all in computer science. He is currently a Professor with the School of Computer Science and Engineering, Northeastern University, China. His current research interests focus on medium access control, QoS routing, multihop broadcast, mobility management in vehicular networks, as well as SDN enabled vehicular networks.

Mohsen Guizani [S'85, M'89,SM'99, F'09] received the B.S, M.S. and Ph.D. from Syracuse University. He is currently a Professor at the Computer Science and Engineering Department at Qatar University. His research interests include wireless communications/mobile cloud computing, computer networks, security and smart grid. He is the author of nine books and more than 600 publications. He was the Chair of the IEEE Communications Society Wireless Technical Committee. He served as the IEEE Computer Society and the IEEE ComSoc Distinguished Speaker.

Jaime Lloret [M'07-SM'10] received his M.Sc. in Physics in 1997, his M.Sc. in electronic Engineering in 2003 and his Ph.D. in telecommunication engineering in 2006. He is a Cisco Certified Network Professional Instructor. He is currently Associate Professor in the Polytechnic University of Valencia. He is the head of the research group "communications and remote sensing" of the Integrated Management Coastal Research Institute and he is the head of the "Active and collaborative techniques and use of technologic resources in the education (EITACURTE)" Innovation Group.

Muhammad Imran is working as Assistant Professor in the College of Computer and Information Sciences, King Saud University (KSU) since 2011. He worked as a Postdoctoral Associate on joint research projects between KSU, University of Sydney and Iowa State University. He is a Visiting Scientist with Iowa State University, USA. His research interests include mobile ad hoc and sensor networks, WBANs, Multihop wireless networks and fault tolerant computing.

Ammar Rayes [S'85, M'91, SM'15] is a Distinguished Engineer focusing on the technology strategy for Cisco Services. His research interests include IoT, network management NMS/OSS, machine learning, analytics and security. He authored three books, over 100 publications in refereed journals and conferences on advances in software & networking related technologies and over 25 patents. He received B.S. and M.S. degrees from the University of Illinois at Urbana and D.Sc. degree from Washington University all in EE.

Kanke Gao [M'11] received the Ph.D. degree and the M.S. degree in Electrical Engineering from the State University of New York at Buffalo, Buffalo, NY, in 2011 and 2007, respectively. He is currently a Principle Algorithms & Signal Processing Engineer in Velodyne Lidar, Inc. He is also holding an Adjunct Professor position at University of Electronic Science and Technology of China. His current research interests include autonomous driving, sensor fusion, SLAM algorithms, cross-layer optimization and statistical signal processing.