Emerging Technologies for 5G-IoV Networks: Applications, Trends and Opportunities

Wei Duan, Jinyuan Gu, Miaowen Wen, Guoan Zhang, Yancheng Ji, and Shahid Mumtaz

Abstract

With the evolution of the technologies for IoV to be intelligent and interconnected, V2X communication technology serves as a core technology for information interaction among intelligent connected vehicles, and an important technology to realize environment sensing for future autonomous driving. In order to provide wireless communication services with ultra-low delay, ultra-high reliability and ultra-large bandwidth, this article proposes architectures of 5G-V2X communication networks by exploiting the technologies of 5G new radio (NR), network slicing, and device-to-device communications. We discuss their principles and key features, and foresee the challenges, opportunities, and future research trends. The applications of related technologies of the software defined network (SND) and multi-access edge computing (MEC) are also introduced. Finally, the technologies of information security and privacy protection are identified to support the diverse services and applications in the future 5G-V2X networks.

Introduction

In the past few years, the emergent issues of active safety, traffic efficiency and environmental protection caused by a sharp increase in the number of vehicles have become increasingly prominent [1], resulting in a wide concern for the research and development of the related fields of Internet of vehicles (IoV). Integrating the technologies of the global position system (GPS), sensors radio frequency identification (RFID), data mining and automatic control, the IoV realizes intelligent traffic management, intelligent dynamic information service, as well as vehicle intelligent control. Vehicular-to-everything (V2X) is a core technology for the typical applications of the IoV [2], including vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), and vehicle-to-infrastructure/network (V2I/N). Thanks to V2X technology, the IoV not only breaks the limitations of the non-line-of-sight perception and vehicle information sharing for a single vehicle, but also expects to improve the intelligent level and autonomous driving ability, satisfying the requirements of the intelligent, comfortable, safe, energy-saving and efficient comprehensive services [3]. To date, V2X has been mainly supported by dedicated short range communication (DSRC) and cellular mobile communication system.

The traditional architecture is designed for static networks, which fails to satisfy the requirements of mass management, high-quality service and real-time application, and is hard to adapt to the rapid development of the IoV [4]. With the rapid development and commercial use, the fifth generation (5G) communication technology, fusing the techniques of the massive multi-input multi-output (MIMO), ultra-dense network and device-to-device (D2D), displays a more flexible architecture to meet different performance metrics in diverse application scenarios [5]. Therefore, with benefits of the 5G communication technology in terms of the low latency, high reliability and mobility, problems and challenges of different sorts arising from the IoV are desired to be solved to provide a better performance for the on-board unit (OBU) under the environment of high speed [6]. Moreover, 5G communication technology allows the IoV to operate independently of base stations (BS) and service infrastructure. With its popularization, 5G communication technology will bring historic opportunities for the development of the IoV.

On one hand, as a novel network paradigm, software defined network (SDN) receives extensive attention since it can separate the control plane from the data plane, and allocate the network resources by the logically centralized controller, which significantly improves the scalability of the networks [7]. Meanwhile, it provides a programmable network architecture, significantly simplifies network management, makes customized IoV possible, and greatly improves the flexibility. Hence, the application of SDN in vehicle networks has become a popular research field. On the other hand, multi-access edge computing (MEC) migrates computing storage and business service capabilities to the edge of the network [8]. Moreover, enabling applications, services and contents can realize localization, closed range and distributed deployment, satisfying the requirements of the 5G enhanced mobile broadband (eMBB), massive machine type of communication (mMTC), ultra reliable and low latency communication (uRLLC) services. Predictably, for IoV, constructing the 5G network architecture with MEC based on the long term evolution (LTE) can not only decrease the end-to-end latency by reducing the number of routing nodes for data transmission, but also take advantage of the characteristics of MEC, such as the large-scale regional coverage, to support the geographical deployment of

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vehicle networking services [9]. In [10], a new architecture that combines MEC and SDN is proposed to address the challenge of increased communication traffic volume for data dissemination, which provides a future research trend in this field. With these observations, the goal of this article is to provide a potential solution to further realize 5G-V2X networks by applying techniques of 5G new radio (NR), network slicing, and D2D. Moreover, to satisfy the requirements of ultra-low delay, ultra-high reliability and ultra-large bandwidth, SDN and MEC are introduced into 5G-V2X networks. Information security and privacy protection are also identified to support the diverse services and applications.

The rest of the article is organized as follows. First, we provide the key issues and challenges for 5G-IoV, and the demands for autonomous driving. Next, D2D communication, network slicing, and 5G-NR technologies are introduced to the 5G-IoV networks, providing a theoretical basis and technical support for the development of 5G-IoV technical standards. Then, the applications of SDN and MEC based 5G-IoV, as well as the security and privacy protection for the proposed systems, are respectively discussed. After that, the main challenges and possible solutions are discussed in detail. Finally, we present concluding remarks. For clarity, the whole structure of the article is also shown in Fig. 1.

Key Issues and Challenges for 5G-IoV

Since 5G-IoV is in its infancy, the design of its architecture and corresponding strategies are different from that of the traditional IoV system. In this section, we summarize the key issues and challenges for 5G-IoV as follows.

Scalable and Flexible 5G-IoV Architecture Design: As known, there are mainly three categories for the applications of IoV: information service applications for the user experience, intelligent applications for vehicle driving and intelligent transportation applications for collaboration. Therefore, the research on performance requirements and key technologies of the above applications form the basis of the 5G-IoV architecture design. Since 5G vehicle units, 5G BS(s), 5G mobile terminals, 5G cloud servers, and so on, are involved in 5G-IoV, it has a more flexible architecture than the conventional IoV. In addition to the V2X information interaction, 5G-IoV will also realize the interconnection of the OBU, BS, mobile and cloud server, and support them with special features and communication modes.

Unloading Scheme and Resource Allocation Strategies: Under the latency constraints, unloading the computing task into the MEC server can save energy consumption and improve computing capacity. Due to the rapid movement of the vehicles and frequent BS switching, in the design and calculation of the unloading strategy, it is overarching to track the moving vehicle to ensure no interruption during the uninstallation. In addition, since there are differences in computing power, data size and priority of the MEC server, it is necessary to allocate appropriate communication and computing resources for different computing tasks.

SDN Based 5G-V2X Architecture Design with MEC: The centralized SDN controller is

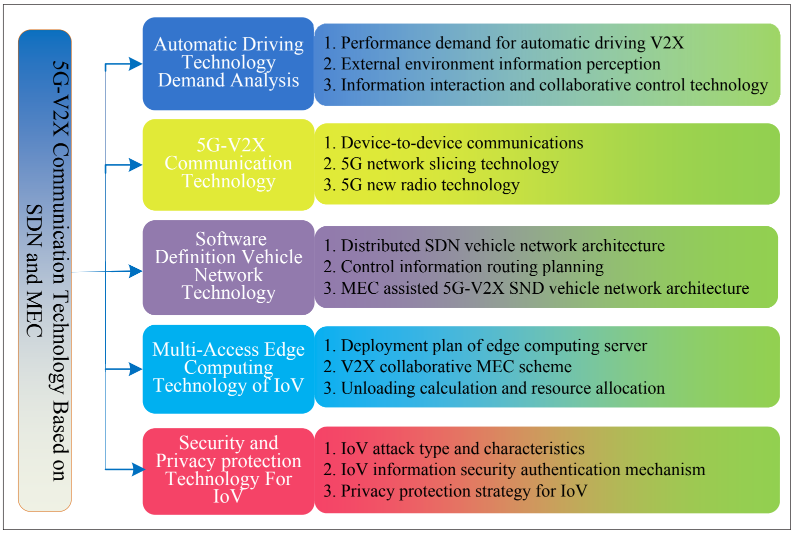

FIGURE 1. Emerging technologies for 5G-IoV networks.

responsible for generating the forwarding rules and program flow entries, which challenges the scalability and increases the possibility of latency and network failure. Specifically, with the increase of vehicle density in vehicular Ad-hoc networks (VANET), the controller has to manage a large number of devices, which may exceed its capacity range and cause bottlenecks, and hence a decline of the network performance. In the meanwhile, due to the increasing number of new mobile applications, the demand for transmission rate and computing power is growing as well. It is therefore necessary to build a distributed SDN vehicle network architecture. The main problems lie in how to deploy different levels of SDN controllers and support the efficient and instant communication between the SDN controllers. Moreover, in order to reduce the service response delay and deploy the MEC server on the edge of IoV, it is also necessary to design the communication protocol and standards between the MEC server and SDN controller.

Identity Authentication and Privacy Protection Strategies: In order to support the increasing data traffic, large capacity and efficient security mechanism are demanded for the 5G wireless communication network. More frequent authentication is required between the users and different access points to prevent the attack of fake terminals and middlemen. Since the data transmission of 5G-IoV users and vehicles are normally performed via the vehicle units, mobile terminals and BS(s), effective measures should be designed to ensure the security of communication and integrity of data.

Demands for Autonomous Driving Technology

Autonomous driving greatly improves vehicle safety, and reduces traffic accidents and congestion, which is designed based on the vehicle intellectualization technology. It is known that there are six levels from the Society of Automotive Engineers (SAE) classifications for autonomous driving, which are $L0$–$L5$. In short, $L0$–$L2$ levels automatic driving assistance is similar to the "escort driver," and the driving action normally should be completed by the driver, while the escort is only assisted. For $L3$, automatic driving becomes a "substituting driver," such that under some certain conditions, the car can drive automatically, and the driver only needs to intervene in specific situations. Specifically, $L4$–$L5$ automatic driving can be regarded as one "exclusive driver." People can do more things in the car without paying too much attention to the situation of the car. The vehicle intellectualization generally includes two fields: the autonomous driving assistance (ADA) and autonomous automatic driving (AAD) [11]. The ADA belongs to the SAE $L0$–$L2$, which is characterized by the on-board sensor equipment and electronic control unit to sense the vehicle environment. With the corresponding calculation and analysis, it enables the driver to detect possible danger in advance, and provide an early warning. For the AAD, it belongs to SAE $L3$–$L5$. The characteristics of this system lie in that the vehicle sensing equipment and the vehicle computing platform perceive the vehicle environment. In addition, with the high-precision map, the driving path planning and driving decision-making are formed through the analysis and processing of the vehicle computing platform and artificial intelligence software. By combining the electronic control unit of the vehicle, the automatic driving of the vehicle can be realized independently. The main functions of automatic driving include path planning, environment perception, environment recognition, vehicle positioning, map modeling and driving decision. Generally, the key technologies to realize the above functions are the vehicle electronization and intelligence, as well as the information sharing.

5G-V2X Communications

Considering the application requirements of IoV and focusing on the communication performance indicators of the automatic driving applications, in this section, D2D communication, network slicing, and 5G-NR technologies are introduced to the 5G-IoV networks, providing a theoretical basis and technical support for the development of 5G-IoV technical standards. Moreover, the corresponding open issues faced by these technologies are also described.

Device-to-Device Communications

For a large vehicle density, the security information exchanged for the vehicles will exceed the load of BS, which results in network congestion. In traditional networks, communications normally go through the BS suiting the conventional low data rate mobile services. However, with the rapid development of high data rate, direct communications are widely considered. As one key technology of LTE and 5G communications, D2D communication allows data transmission independently of the BS and core network, which can significantly improve the spectral efficiency, throughput, energy efficiency, delay, and fairness of the network [12]. However, due to the complicated IoV, and the frequent changes of the network structure, topology, environments and demands, conventional D2D communication technology is hard to satisfy the requirements mentioned above. The remaining open problems can be summarized as: the D2D communications in multi-cellular network, impact of vehicle mobility on D2D communications, dynamic QoS requirements and large-scale D2D communications in IoV.

Network Slicing

The technology of network slicing divides the physical networks into several independent logical networks to provide customized services for the differentiated services [13]. According to the QoS requirements of different services, network slicing is allocated with the corresponding network functions and resources to realize the instantiation of 5G architecture. However, due to the characteristics, heterogeneity and complex functions of V2X services, it is difficult to directly use network slicing to support the services of eMBB, URLLC and mMTC. Therefore, the network slicing suitable for the 5G-V2X communication according to the key performance indicators and functional requirements of V2X applications should be designed. To sum up, with the continuous prosperity of 5G-IoV application scenarios, one will be facing the following tasks: (1) determine the granularity of slicing and improve the flexibility of the system; (2) combine artificial intelligence with 5G, adjust the allocations of network resources to realize automatic operation, maintain the network, and meanwhile reduce the complexity and difficulty of the slice management; (3) design the security protocol of the IoV considering the impact of other slices and total network system.

5G New Radio

Based on the frame structure, multi-antenna, waveform and coding, and so on, the highly flexible 5G-NR is configured via parameters to optimize the corresponding technical schemes according to the specific business requirements [14]. It is considered that the NR based V2X supplements LTE-V2X, which is used for the enhanced V2X (eV2X) services and supports the interoperability with LTE-V2X. In general, the service requirements of eV2X contain the strict reliability, low latency, high data rate and large communication range in the high-density scenarios. Consequently, to achieve these requirements, it is necessary to propose appropriate enhancements for the uplink, downlink and sidelink services of the 5G-NR, that is, the ultra reliable, low latency and enhanced mobile broadband sidelink. The higher level solutions for the 5G-NR V2X include the following aspects: the cluster management, congestion control, mobile management, QoS management and flexible switching between the interfaces of C-V2X PC5 and Uu. In particular, with many kinds of radio access technologies (RATs), it is also necessary to realize the efficient cooperation and coexistence for different RATs mechanisms. Moreover, in order to meet the challenges of eV2X, it is imperative to develop new kinds of technologies to support the extremely low latency, high reliability and high efficient PC5 and Uu communications, which dynamically adapts to the user distribution and business types, and improves the driving experience of the users.

With the above observations, it is clear that effectively introducing these technologies to V2X systems can support the development of 5G-IoV. In general, the low latency and high reliability requirements of V2X can be satisfied by D2D communications, providing enhanced spectrum efficiency and throughput; for network slicing, it is necessary to allow the coexistence of different verticals over the same physical infrastructure, which is a flexible softwarized network approach; for NR, its deployment scenarios are diverse, such as the indoor hotspot and dense urban, offering deployment flexibility.

Software Defined Vehicle Network Technology

The core idea of SDN is to separate network control (control plane) and forwarding function (data plane), as well as to simplify network management. Figure 2 illustrates the vehicle network architecture based on SDN including the applications, communications/networks (protocols and technologies) and perceptions (sensors and actuators), where the issues of security, cost and legitimate use are involved. In Fig. 2, the application program adopts the application control plane interface (A-CPI) to communicate with the control plane, while the control plane and data plane communicate with each other via the data control plane interface (D-CPI), where the A-CPI is a programming interface that provides high logic abstraction and business model for the developers, and realizes the information exchange between the top application and network. Moreover, the D-CPI is responsible for forwarding the logic control strategy issued by the SDN controller and collecting network status from the network devices, which has a unified communication standard and adopts the OpenFlow protocol. For a simple OpenFlow applicable to the vehicle network, each flow consists of three parts: the matching field, counter and instruction set. When the flow processes packets, the packets first match the flow entries. In what follows, if the corresponding matching flow entry is found, the instruction set in the flow entry is executed. Otherwise, the packets will be discarded and transferred to another flow, and then returned to the controller and/or modified packet header data.

The heterogeneous vehicle network (HetVANET), which integrates the different network access technologies, namely the DSRC, LTE and millimeter wave communication, is a potential solution to meet intelligent transport system (ITS) communication requirements. In order to provide better service in the vehicle network with the changing network topology and service quality requirements, it is necessary to understand the global information of the HetVANET. Since the SDN can support the dynamic characteristics of VANET and ITS applications, it can be integrated into the vehicle network to realize the virtualization of wireless resources to promote large-scale network management and optimization. In order to meet the strict requirements of ITS, SDN, cloud computing and MEC are considered as the candidate technologies of 5G vehicle networking in the future. However, when the number of vehicles connected to the BS increases, a large volume of data traffic may cause congestion at the SDN controller. In the meanwhile, the frequent switching between high-speed mobile vehicles and BS will seriously affect the quality of network service. Therefore, it is necessary to deploy the distributed SDN controller to relieve the pressure of the centralized SDN controller and adopt the cluster and partition technologies to improve the stability

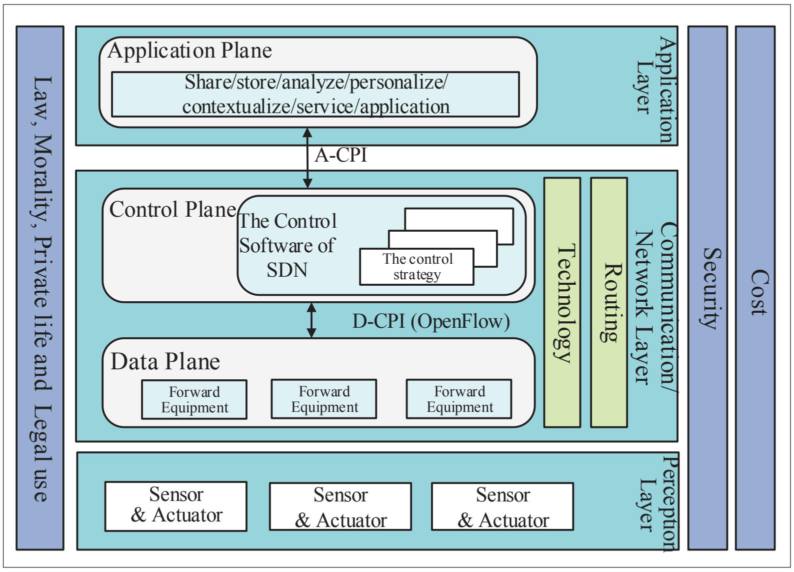

FIGURE 2. The SDN based IoV architecture.

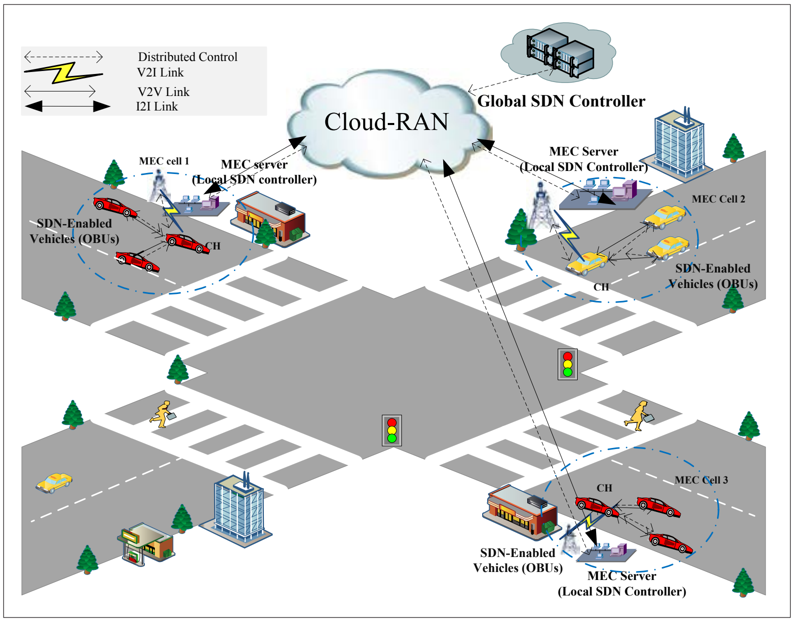

FIGURE 3. The SDN for HetVANET with cluster.

of the vehicle network. In Fig. 3, a cluster based SND-HetVANET is proposed, where the users (cars) in a MEC cell complete the information exchange via the cluster head, and then adopt the MEC server to update and download messages from cloud-RAN, with the MEC server as a local SDN controller. The details of the processing strategies are summarized as follows:

- Extend the traditional vehicular network by integrating large-scale deployment of cellular networks and rich cloud computing resources.
- Realize network partition by clustering technology to reduce interference and overhead, while enhancing the scalability and mobility of the network.
- Deploy the MEC server on the edge of the network to provide low latency service for vehicles.
- Adopt a clustering algorithm to build network topology and deploy the local SDN controller on the cluster head vehicle.

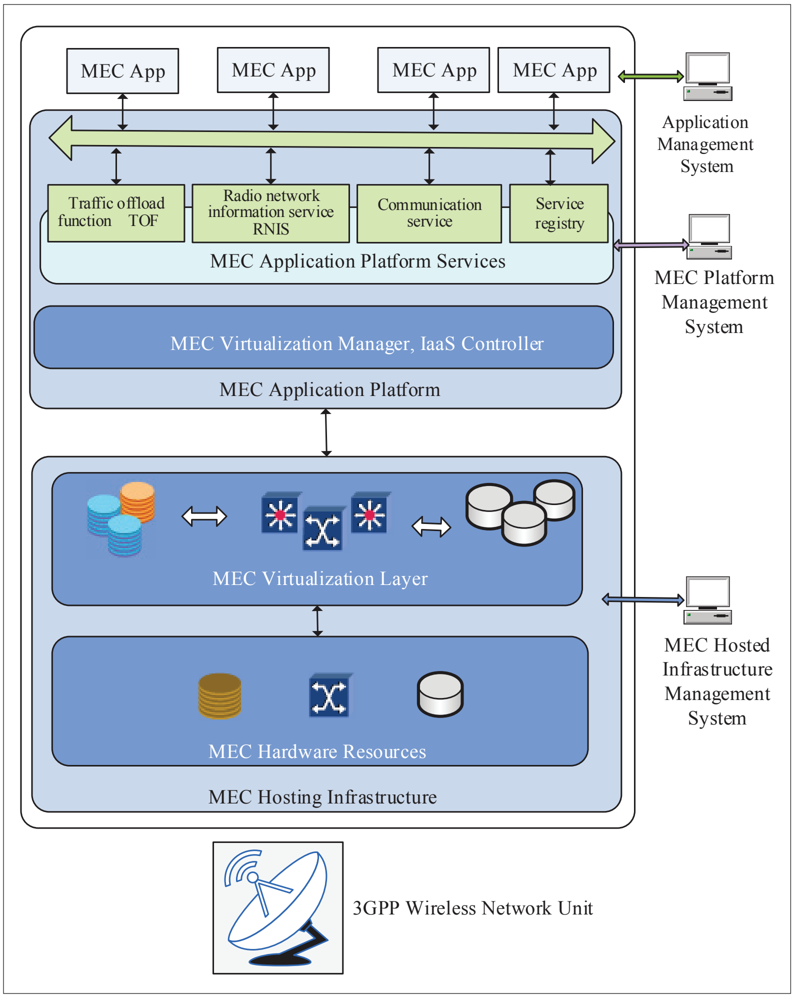

FIGURE 4. The basic framework of MEC platform.

- Deploy a MEC server including a regional SDN controller on the cellular BS and global SDN controller on C-RAN to realize hierarchical and distributed deployment of network control.

The remaining open problems include the following: when the SDN controller breaks down, how to manage the network; how to ensure the security of the open interface; how to communicate between the SDN controller and distributed MEC server; how to design a fast propagation mechanism of the control information.

Multi Access Edge Computing Technology for IoV

The Industry Specification Group of MEC within the European Telecommunications Standards Institute (ESTI MEC ISG) defines a reference frame for a MEC server (also known as a MEC platform), which consists of the managed infrastructures and application platforms, as shown in Fig. 4. The managed infrastructure includes the MEC hardware components (the computing, memory, and network resources), and MEC virtualization (abstracting hardware implementation details to the MEC application platform), where the MEC application platform includes a virtualization manager and infrastructure as a service (IAAs) controller, and provides a variety of MEC application platform services. Moreover, the MEC virtualization manager supports managed environments providing IAAs devices, while the IAAs controllers provide the security and resource sandbox (virtual environment) and MEC platforms. The MEC application platform mainly provides four services: the traffic unloading function, wireless network information service, communication service and service registration. The operators manage and configure the MEC applications and control their life cycle through the MEC application platform management interface.

By adding distributed computing and storage services to the roadside BS, the MEC has become a key technology to promote the progress of IoV. In addition, receiving and analyzing messages from the neighboring vehicles and roadside sensors, the interconnected vehicle cloud transmits hazard warning and time delay sensitive messages within a 20ms end-to-end delay, while the driver can react immediately according to the received messages (as shown in Fig. 5), making automatic driving possible. Moreover, collecting real-time data from the roadside camera and sensor equipments at the edge of IoV can realize traffic control automation. The sensor equipment detects the distance and speed of the nearby objects (pedestrians and vehicles), and the traffic control system sends the signals to the intelligent traffic lights to indicate vehicle behavior according to the collected data.

In order to allocate appropriate communication and computing resources, as well as to guarantee the uninterruption between the vehicle and server during the unloading period, a collaborative vehicular edge computing (CVEC) framework [15] is proposed in Fig. 6. This system can support more scalable vehicle services and applications through horizontal and vertical collaboration, and basically solve the problems in managing and controlling heterogeneous network resources. However, it is still hard to satisfy the requirements from the real-time and high bandwidth of a vehicle network. Generally, the open issues in applying MEC to 5G-V2X to enrich and expand the application scenarios of IoV are:

- Deploying the MEC server on the edge of the network, and designing a MEC assisted data communication protocol according to the computing power requirements.
- Making full use of the characteristics of MEC regional coverage to develop and deploy vehicle networking services with geographic and regional characteristics.

Security and Privacy Protection Technology for IoV

5G-IoV is an extremely complex communication process with unavoidable multi-party security authentications, which involves security authentication between the mobile terminal and 5G-OBU, vehicle and vehicle, vehicle and pedestrian, vehicle and relay, and vehicle and 5G BS. In the process of ensuring communication security, the security of privacy is more concerned, which determines whether IoV is acceptable and widely used by users. Recently, in addition to the dynamic anonymity algorithm, the OBU should change the anonymity at a certain time interval or when the vehicle enters different areas, and eliminate the attack of capturing the real identity of the vehicle through anonymous collection and analysis. Considering various heterogeneous networks in 5G-IoV, it is necessary to design a novel secure communication and privacy protection protocol. For example, in 5G communications, the SDN technology is used to select multiple transmission paths for the data flow according to the corresponding sensitivity level. On the other hand, to avoid privacy leakage at the wireless access point, only the receiver can decrypt and reorganize the data flow and private key. With the development of the research on physical layer security (PLS), the strong ability of resisting eavesdropping becomes an effective supplement to high-level encryption security, further enhancing the security of the communication system. In a 5G-IoV communication system, the PLS guarantees the confidentiality and reliability of the data by integrating the advanced technology of 5G. Given the ubiquitousness of wireless connections, an enormous amount of sensitive and confidential information, for example, financial data, electronic cryptography, and private video, have been transmitted via wireless channels. Moreover, since the heterogeneous networks, massive MIMO and mmWave technology have great potential to provide seamless wireless coverage, high network throughput and tremendous data traffic increase, which are the highlights of envisioned beyond 5G and 6G communication systems. Therefore, applying these technologies in PLS is an important priority, which is hopeful to provide a theoretical basis for the evolution of 5G-IoV systems.

In order to ensure the communication security and information privacy in MEC, more advanced security and confidentiality measures should be proposed. Because of that, the current security and authentication mechanisms applied in cloud computing is hard to satisfy the security standards of MEC, leading to the edge devices and user information in an unsafe position. Moreover, the different levels of the entity authentication and the security problems of the authentication and authentication should also be solved in MEC based 5G-IoV systems.

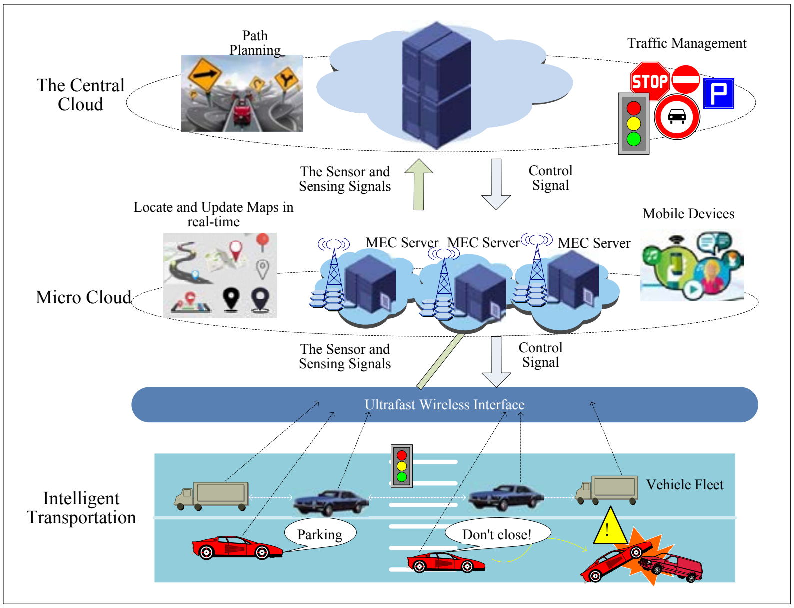

FIGURE 5. The MEC based intelligent transportation system.

Concluding Remarks

By seamlessly converging 5G and IoV technologies, 5G-IoV holds great promise to support the demands of future and emerging IoV services and applications. In this article, we first characterized 5G-V2X network architectures with the 5G NR, network slicing, and D2D technologies, which enable new opportunities to satisfy the requirements of ultra-low delay, ultra-high reliability and ultra-large bandwidth. Based on SND and MEC, we have observed the research and development

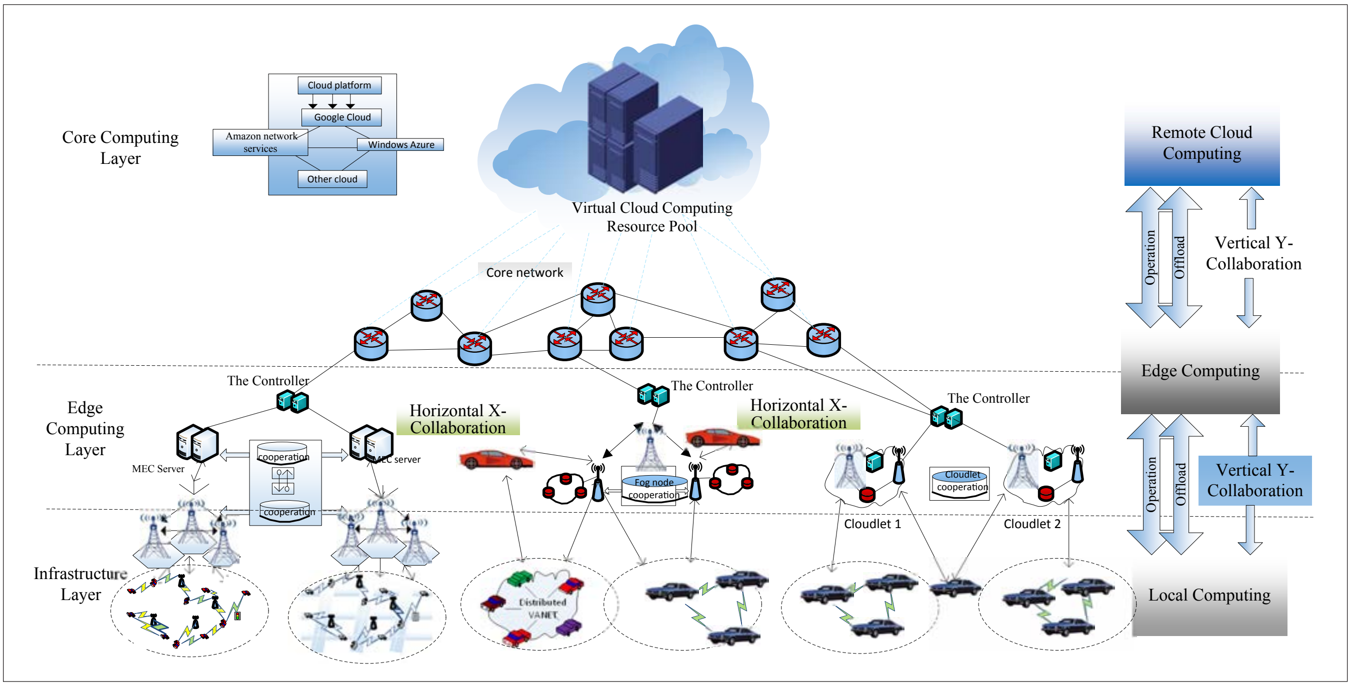

FIGURE 6. The collaborative vehicular edge computing (CVEC) framework.

of 5G-V2X networks, and provided the challenges, opportunities, and future research trends, as well as the open issues for the related technologies. Finally, we identified the security and privacy protection technology for 5G-IoV networks. The interesting future research avenues would be: introducing the trusted platform module and other privacy protection entities into the MEC network to provide different degrees of security protection for 5G-V2X communications in the form of modularization; proposing the information security, identity authentication and privacy protection policy for automatic driving; structuring a comprehensive security defense system with the chain of "End-Management-Cloud" for 5G-IoV.

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