IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received October 28, 2019, accepted November 14, 2019, date of publication November 19, 2019, date of current version December 23, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2954466

Emerging Technologies for 5G-Enabled Vehicular Networks

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This work was supported in part by the Yueqi Youth Scholar Funding of China University of Mining and Technology, Beijing, in part by the Research Funding for Centrally Affiliated Universities of China under Grant 2014QG01, and in part by the China Logistics Association and China Logistics and Procurement Federation under Grant 2019CSLKT3-117.

ABSTRACT Internet of Vehicles is a specific application of Internet of Things technology in intelligent transportation systems, and has attracted attention of relevant research institutions, automobile manufacturers and communication technology suppliers all over the world. The US government has spent hundreds of millions of dollars on DSRC development, which is a technology that can help achieve V2V and V2I communications, and enable vehicles to communicate with intelligent traffic lights to mitigate traffic congestion and accidents or bad weather on the road. Automakers such as GM and Toyota have well deployed Wi-Fi-based DSRC technology. But with the continuous development of 5G and D2D communications, cellular technology tends to be a strong candidate for V2X communications..Although 5G communication technology does not yet have a unified standard, its related concepts and trends have been recognized by industry area. Automobile manufacturers represented by Ford and BMW expect to achieve a leap in automotive networking through 5G. In the face of the 5G era, the dispute between DSRC and LTE standards has become a hot topic in the field of car networking. DSRC, a dedicated short-range communication developed and tested by automotive technology suppliers is under threat, and the next generation of 5G technology might be the final answer. Based on this point, this paper firstly introduces the development history of the Internet of Vehicles communication standard, and analyzes the advantages and disadvantages of DSRC and cellular network communication technology. Then, the three core elements of the Internet of Vehicles (Node Performance, local Network, and Internet of Things) are discussed for the development trend of vehicle networking communication technology in the context of 5G. Finally, this chapter explains the impact of the development of 5G communication technology on the future development of vehicle networking, and proposes the possible development directions of future vehicle networking technologies.

INDEX TERMS Intelligent transportation systems, vehicular and wireless technologies, Internet of Things, 5G, DSRC, SDN, mobile cloud computing, mobile edge computing.

NOMENCLATURE

Abbreviations	Full name
3G	magnetic flux
4G	3rd Generation
5G	fifth-generation
5G-VANET	5G enabled vehicular ad hoc network
AB	Automotive Brain
AHS	Advanced Highway System
AHS	Automated Highway System
AMTICS	Advanced Mobile Traffic Information CommunicationSystem
AOS	Automotive Operating System
ASV	Advanced Safety Vehicle
BS	Base Station
BSM	Basic Security Module
CACS	Comprehensive Automobile Traffic Control system
CDMA	Code Division Multiple Access
CH	Cluster Head
C-ITS	Cooperative Intelligent Transportation System
Cog-V2V	Cognitive VANETs

The associate editor coordinating the review of this manuscript and approving it for publication was Zhen Ling.

CR	Cognitive Radio
CRAN	Cloud RAN
CSIT	Channel state information known at transmitter
D2D	Device-to-Device Communication
DSRC	Dedicated Short Range Communications
EE	Energy Efficiency
eNB	Evolved Node B
ETC	Electronic Toll Collection
FCC	Federal Communications Commission
FD	Full Duplex
Gbps	Giga Bit Per Second
GSM	Global System for Mobile Communications
HetNet	Heterogeneous Networks
IoT	Internet of Things
ISTEA	Intermodal Surface Transportation Efficiency Act
ITS	Intelligent Transportation System
IVHS	Intelligent Vehicle Highway Systems
IVI	Intelligent Vehicle Initiative
LTE	Long Term Evolution
LTE-A	LTE-Advanced
MCC	Mobile Cloud Computing
MEC	Mobile Edge Computing
MIMO	Multiple-Input Multiple-Output
NB-IoT	Narrow Band Internet of Things
NFV	Virtual Network Functions
NHTSA	National Highway Traffic Safety Administration
NLOS	Non-Line of Sight
OMR	On-Demand Member Center Routing
PaaS	Platform-as-a-Service
QoE	Quality of Experience
QoS	Quality of Service
QZSS	Quasi-Zenith Satellite System
RACS	Road Automotive Communication System
RB	Resource Block
RDS-TMC	Radio Data System-Traffic Message Channel
SDN	Software Defined Network
SDN-V	SDN-VANET
SE	Spectral Efficiency
SSVS	Super Smart Vehicle Systems
TDMA	Time Division Multiple Access
TEA-21	Transportation Equity Act For The 21st Century
USDOT	US Department of Transportation
UTMS	Universal Traffic Management System
V2I	Vehicle to Infrastrctures
V2N	Vehicle to Network
V2P	Vehicle to Pedestrian
V2R	Vehicle to Road
V2V	Vehicle to Vehicle
V2X	Vehicle-to-everything
VANET	Vehicular ad-hoc network
VCC	Vehicular Cloud Computing
VICS	Vehicle Information and Communication System
VIN	Vehicle Identification Number
VNG	Vehicle Neighborhood Group
VRU	Vulnerable Road User
WAVE	Wireless Access in the Vehicular Environment
Wi-Fi	Wireless Fidelity

I. INTRODUCTION

The Cyber-Physical Systems(CPS) is a multi-dimensional, integrated system that integrates information, the physical world, and control processes to provide a variety of information services and real-time monitoring of large engineering systems. The CPS system is a real-time system with high security, high efficiency and reliability. From an application point of view, CPS not only covers real-time monitoring and smart home and other aspects closely related to life, but also has become increasingly widespread in the field of industrial control and large-scale systems such as intelligent management and monitoring. CPS has broad application prospects in various fields such as intelligent sensor control equipment, industrial automation and urban infrastructure construction. Among them, in the field of transportation, vehicular network is a typical applications of CPS.

With the intensive development of 5G, it is foreseen that cities in the future will have a fully connected system in which a large number of smart items and software components are coordinated to achieve different business objectives [13]. Due to the connectivity and the intensive development of autonomous vehicles, the future of transportation is transforming, and the development of the 5G next-generation network technology revolution is expected to meet the various communication needs of the future intelligent transportation systems (ITS) [14]. Wireless technology will make cities smarter and more convenient, and smarter vehicles and networked roadside infrastructure will allow vehicles to communicate with each other and their surroundings [11]. It is predicted that there will be 29 billion Internet of Things devices by 2022 [12]. Since 2016, the pace of 5G testing has been accelerated [8], and 5G not only brings a few Gbps of bandwidth to a single user but also provides a few milliseconds of mission-critical delay and securely connects a large number of devices worldwide, increasing the capabilities of a terminal the wireless ecosystem is planning to start the next technology upgrade cycle [7]. As the processing power and performance improve, LTE and its evolution to 5G will enable end-to-end and terminal-to-local infrastructure connectivity [9]. The importance of wireless communications in transportation is unprecedented [10].

For more than two decades, the automotive industry has been working hard to integrate wireless solutions into automobiles [1]. This technology, as a basic wireless connectivity service in the GSM and CDMA era, has evolved into a growing set of use cases: from voice-based connectivity, such as for emergency calls and concierge services, to on-demand navigation and Wi-Fi hotspot capabilities, wireless software upgrades, remote diagnostics and cloud data analysis, all of which benefit from 4G LTE-advanced technology [2]. However, the automotive industry is currently experiencing an unprecedented change. The following situations occur simultaneously: with the advent of electric vehicles, car manufacturers are moving toward zero carbon emissions targets [3]; car sharing services further reduce congestion and pollution [4]; car manufacturers are committed to improving safety standards; road traffic authorities are facing zero death targets [5]; and the competition to develop autonomous driving technology is becoming increasingly fierce [4]. To support these new vehicular use cases, wireless technology will be specifically developed and optimized as automotive requirements intersect with wireless capabilities. Driven by consumer demand for various ITS applications, bandwidth, high speed and ubiquity, different network architectures and technologies are currently being researched that can be used for the next-generation ITS [15]. In the past few decades, VANET has grown rapidly. VANET is considered to be the key enabling technology for the next generation of ITSs encompassing a wide range of versatile services for ITS consumers from traffic and road safety to infotainment applications such as web browsing and video streaming downloads [17]. By 2020, the number of connected vehicles is expected to reach 250 million [16].

The vehicle ad hoc network (VANET) is an integral part of an ITS. VANET is a special case of a mobile ad hoc network, which can be formed between vehicles with V2V communication or between a vehicle and some infrastructure elements for V2I communication. VANET can provide the basis to improve road safety, as has been recognized in many projects [16]–[18]. These wireless transactions are collectively referred as V2X communication. V2X is an essential element of the new generation of intelligent transportation systems. V2X is equivalent to an NLOS (Non-Line of Sight) sensor [6]. V2X is an enormous improvement over traditional intelligent transportation systems [19], including the vehicle queue, the green wave belt and other previously idealized intelligent transportation systems that can be easily realized. V2X has always provided the road map for intelligent transportation systems reserved by governments, therefore, the research on V2X began as early as the 1980s. In the late 1990s, the European and American governments basically decided to use DSRC technology for the V2X core [20]. By the end of 2017, Japan had essentially completed the deployment of the drive test unit [24], and several states in the United States had already started testing [22], while Europe was just on its initial stage [23]. Beginning with LTE-V2X in 2015, the concept of the NB-IoT began to appear [24]. The strong public relations capability of operators began to make the European and American governments hesitant. The US proposal to force the installation of DSRC in 2023 was put on hold [25].

Exploring the impact of 5G technology on the future development of the Internet of Vehicles network is based on the entire vehicle networking system rather than a single point. Whether it is from the perspective of a single subsystem of the Internet of Vehicles system or from the perspective of the overall vehicle networking system, the Internet of Vehicles is composed of the following three core elements:

(1) Node performance. The vehicle network terminal element refers mainly to all terminal equipment or systems used to sense, collect and transmit data on vehicles, roads, traffic, and vehicle owners, including vehicle terminals, cameras, controllers, sensors, RFID devices, mobile applications. The equipment for car networked applications provides comprehensive, original terminal information services through sensors, RFID, vehicle positioning and other technologies, as well as real-time sensing of the vehicle conditions and control systems, road environment and other information. A vehicle terminal refers mainly to a vehicle's GPS, OBD, in-vehicle infotainment system (IVI), vehicle operating system, etc.

(2) Local network. The communication environment for road traffic is very complicated, and the communication requirements between various entities must be met, such as between vehicles and the outside world, vehicles and vehicles, vehicles and roads, and in-vehicle components. The local network also needs to meet various types of other requirements, such as those for security and information. Communications between services and entertainment information imposes stringent requirements on the performance of the communication network in terms of throughput, delay, bandwidth, and the like. None of existing communication technologies, such as Wi-Fi, WAVE/802.11p, or and 4G technologies, can meet all of these requirements at the same time. Therefore, the best solution currently is to use these communication technologies simultaneously in different vehicle communication systems. Place, set up a heterogeneous vehicle networking system. Heterogeneous car networking can make full use of the advantages of various communication technologies in a complementing manner, and different communication technologies can be adopted for different coverage and service requirements.

(3) Internet of Things (IoT). With the rapid development of the IoT, it is important to build Intelligent transportation systems (ITS). Any device can be connected to the Internet with the rise of the IoT. People, vehicles and roads in the traffic environment can communicate with each other, which will inevitably have an important impact on the transportation system. Therefore, with this motivation, we can explore the impacts of these issues. Find out where you can focus on the combination of traffic and the IoT. ITS effectively integrates a variety of advanced technologies into the entire ground traffic management system, enabling a wide range of functions. These advanced technologies are embodied in five aspects: information, data transmission, electronic sensing, control and computer. Given its development, 5G can enable the application of the Internet of Things from the cloud to the edge or the terminal and accelerate the popularization of intelligent applications, which will make the application prospects of VANET technology more positive.

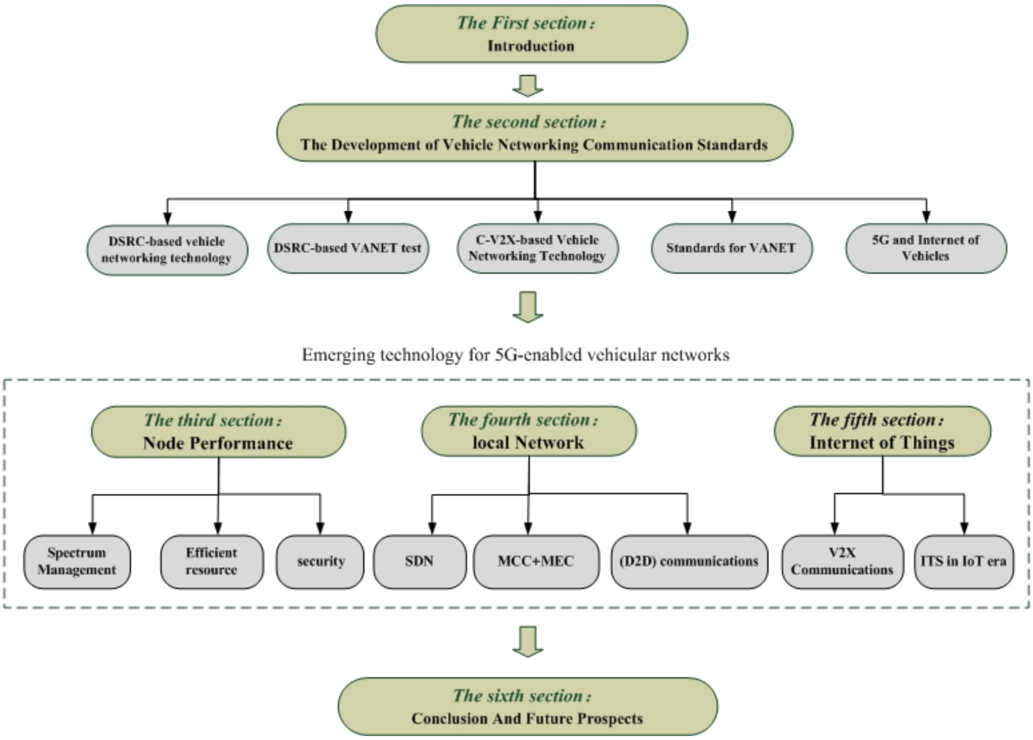

FIGURE 1. A framework of this article.

This article will discuss the possibility of DSRC and cellular parallel hybrid networking implementation from three aspects: the node performance, local networking and IoT. The paper's structure has been shown in Figure 1. In the second part, the development history of the Internet of Vehicles (IoV) communication standard is summarized. In the third part, from the perspective of the node performance, we discuss the spectrum management of VANET, energy efficiency management and the security of VANET in the 5G era. In the fourth part, we analyze the SDN, MCC, MEC and D2D technologies with respect to VANET from the perspective of local networking. In the fifth part, from the perspective of the IoT, we explain the impact of V2X technology on the development of intelligent transportation systems in the context of 5G. Finally, the work of this paper is summarized, and the development direction for VANET technology in the future 5G era is proposed.

II. THE DEVELOPMENT OF VEHICLE NETWORKING COMMUNICATION STANDARDS

A. DSRC-BASED VEHICLE NETWORKING TECHNOLOGY

As is well known, DSRC is a kind of ad hoc network, also known as a vehicle ad hoc network. The IEEE 802.11p-based DSRC is specifically designed for VANET communications, the only proven communication option, to satisfy the delay requirements for collision avoidance based on vehicle communications [35]. The IEEE 802.11p and 1609 standards are under development. They will support wireless access (WAVE) under the in-vehicle environment of VANET and provide secure and non-secure applications for vehicles on the road [26], [27]. In Europe, 802.11p is the foundation of the ITS-G5 standard and supports the Geo Networking protocol for V2X communication [40]. Basically, DSRC can implement QoS management requirements for VANET applications. DSRC is supported by the US National Highway Traffic Safety Administration (NHSTA), which estimates that V2X-enabled security applications can eliminate or mitigate the severity of up to 80% of non-damaged faults, including collisions at intersections and lane changes [36].

The IEEE 802.11p standard is designed for V2X applications and has the most stringent performance specifications. It was first proposed by the Federal Communications Commission (FCC) in 1999 and finalized in 2009 [41] under the supervision of the US Department of Transportation. Extensive field testing has been carried out. However, V2X equipment must be universally installed in automotive and road infrastructure to make V2X effective. NHSTA issued a notice in December 2016 requiring all new light vehicles to use V2V communication [42]. TThe recommendation also points out the requirement for V2V communication performance which can exchange the bidirectional basic safety massage(BSM) by using the onboard DSRC equipment,including the speed,direction,braking state of the vehicle and other relevant information about nearby vehicles [37].

The most powerful argument for supporting DSRC comes from Cisco. Cisco noted that DSRC is the only mature communication option that implements latency requirements for supporting collision avoidance based on vehicle communications [43], and it works reliably (multiple field trials have proven this to the satisfaction of the traffic authorities). The functions provided by DSRC form only a small part of the car service content provided by the car manufacturer. Although there are separate components, the cost is clear; unlike the cellular-based C-V2X, there is a certain network traffic cost. At the same time, product development for DSRC is still growing rapidly.

General Motors (GM) is also a supporter of DSRC. In 2017, General Motors Cadillac launched the first vehicle capable of V2V communication, the 2017CTS. Cadillac claims that the CTS model's V2V communication is based on DSRC technology and can process 1000 messages per second in a 1000-foot range [38]. Cadillac uses Delphi's modules to run NXP's IEEE 802.11p chipset application developed by Cohda Wireless. At present, Cadillac vehicles can only communicate with other Cadillac vehicles equipped with similar equipment. However, this also represents the first large-scale experiment with V2X.

1) DSRC-BASED VANET TEST - USA

Thus far, the US DSRC technology has been extensively tested for more than 10 years, and the technology is relatively mature. From 1950 to 1980, highways and interstate motorways had been extensively built in the states of the United States. A series of problems that did not exist before arose: vehicle jams in the center of city, high-speed collisions have caused numerous casualties, and fuel consumption has increased, while decreasing air quality. In 1986, experts from scientific research institutions, transportation bureaus, etc., discussed future traffic regulations and believed that the future transportation system must simultaneously ensure safety, solve congestion problems and protect the environment [60]. In 1990, the concept of an intelligent vehicle high-speed system (IVHS) was proposed, Later it became ITS by developing it [61]. In 1991, the concept of ITS is already part of the Intermodal Surface Transportation Efficiency Act (ISTEA). In addition, the ISTEA provided an investment of \$6. 6 billion into the research and testing of ITS systems for the next six years [62]. In 1992, the USDOT launched the Automated Highway System project [63] in the ITS study to liberate the driver. The vehicle needs to be driven on a road that has embedded magnets. This is the first time in history that automated vehicles were implemented the interconnection of highways. After the automatic high-speed system test, the USDOT launched the Intelligent Vehicle Initiative in 1997 to speed up the deployment of the anti-collision system. Based on the smart vehicle program, the USDOT proposed new requirements for improving traffic congestion and improving electronic communication technology [64]. At the 10th ITS World Congress in Madrid in December 2003, the USDOT announced the distribution of the 75 MHz spectrum at 5.9 GHz for DSRC research [65] and proposed the VII project, whose goal is to apply V2V and V2I technology for small range applications. In December 2006, the USDOT and the five major automakers jointly tested the role of V2V and V2I in anti-collision systems [66] and established new communication-based safety facilities, consisting mainly of roadside networks and on-board vehicle equipment. In August 2014, the NHTSA and the USDOT proposed the FMVSS No. 150 Act [67], which mandated that new light-duty vehicles support V2V communication, So the number of vehicles supporting V2V communication is guaranteed. On June 25, 2015, the NHTSA and other stakeholders reaffirmed the V2X case [68]. A permanent DSRC pilot project is currently being carried out in New York City, Wyoming and Tampa, Florida [69], with the tests in New York being more comprehensive, including a red light warning. The goal is to improve pedestrian safety, reduce traffic congestion and improve fuel efficiency in urban areas. Relevant authorities will also use information from these projects to improve traffic management and infrastructure planning.

2) THE DSRC-BASED VANET TEST - JAPAN

Japan is one of the most developed countries in the world in terms of intelligent transportation systems. Japan developed the first comprehensive vehicle traffic control system (CACS) [44]. From the mid-1980s to the 1990s, the Road Shop Communication System (RACS) [44], the Advanced Vehicle Traffic Information and Communication System (AMTICS) [45], the Super Intelligent Vehicle System (SSVS) [46], and related safety projects were completed. Research on vehicle systems (ASV) [47] and new traffic management systems (UTMS) [48] was also conducted. In 1994, the Ministry of Construction of Japan invited a number of Japanese companies and groups to jointly conduct field trials of ETC [49], which provided the basis for the selection of Japanese frequencies for DSRC.

Japan's ITS research and application development work mainly focuses on three aspects: the Vehicle Information and Communication System (VICS) [50], Electronic Toll Collection (ETC) [52] and the Advanced Highway System (AHS) [51]. VICS uses different methods wireless beacons, optical beacons and FM stereo channels at the same time, so it can provide the driver with the required information at any time and in any place. Since the beginning of VICS, a beacon of 2.4 GHz radio waves has been used to provide road traffic information to vehicles within approximately 200 km. Optical beacons are mainly placed on the main trunk roads of general roads. When the vehicle passes through the coverage area of the optical beacon, it can automatically provide road traffic information approximately 30 kilometers ahead and 1 km behind the vehicle. Moreover, VICS information is provided through an FM stereo channel [53]. This is the radio wave from the Japan Public Broadcasting NHK's FM stereo channel base station in each prefecture. The vehicle traveling in the receiving area of the FM stereo channel can receive road traffic information from each prefecture and surrounding area. In 2011, the RSU that Japan began to deploy was a 5.8 GHz DSRC system, which was essentially completed by the end of 2017 [54]. At present, Japan uses dual frequencies of 2.4 GHz and 5.8 GHz [55]. In early February 2018, the Japanese Ministry of Land and Resources announced that it would stop the old 2.4 GHz VICS system at the end of March 2022 and that all of them will be transferred to the VICS system with 5.8 GHz DSRC technology. 56]. Japan launched three quasi-zenith satellites in 2017 and completed the QZSS system [57], which can achieve absolute line-level positioning [58]. Japan has already begun to integrate the QZSS system into the intelligent transportation system. It is expected that by 2022, Japan will be able to accurately transmit V2I, especially traffic signal information [59].

3) DSRC-BASED VANET TEST IN EUROPE

European and US DSRC implementations use the 802.11p standard at the physical and MAC layers, but they differ in the way to handle the networking, transport, and application layers. Although different methods are used for message routing and different channel assignments are utilized, the European ITS G5 standard and the US WAVE standard provide stable security and privacy measures and are based on security-related and non-security related types of information. In other words, the European equivalent for DSRC is called ITS-G5.

In Europe, DSRC technology has been used for charging and is planned for V2X communication. The European Telecommunications Standards Institute (ETSI) plans to adopt a phased approach, with the implementation of the ''Day One'' deployment of ITS G5 in 2014 [70]. The application does not rely on the widespread adoption of DSRC, such as road engineering, emergency vehicles, and traffic congestion warnings. The ''Day One'' ITS G5 deployment is now taking place from Rotterdam, the Netherlands, through the C-ITS pathway from Frankfurt, Germany to Vienna, Austria. This pathway will provide drivers with compatible OBU information about upcoming roadworks, traffic conditions and road hazards.

B. C-V2X-BASED VEHICLE NETWORKING TECHNOLOGY

With the development of cellular communication technology, the role played by cellular communication is becoming increasingly important. Currently, cellular communication technology has been changed from simply transmitting sound to transmitting audio and data from person-to-person to machine-to-machine communication. V2X technology is an application of machine to machine (M2M) transformation. C-V2X is a cellular communication based V2X technology defined by 3rd Generation Partnership Project (3GPP) [71], which includes V2X systems based on LTE and future 5G. The end-to-end delay, channel access delay and network throughput performance of VANET applications will be significantly reduced when the density and network traffic of VANET based on DSRC technology is large [39], while DSRC has a short coverage distance and the disadvantage of high infrastructure costs, and thus, C-V2X is a powerful complement to DSRC technology. C-V2X realizes the information exchange of V2V, V2N and V2I with the existing LTE network facilities. The most attractive feature of this technology is that it can keep up with changes and adapt to more complex security application scenarios to meet low latency and high reliability as well as meet bandwidth requirements.

At the beginning of 2015, the 3GPP officially launched the technical requirements and standardization research based on C-V2X. In early 2015, the 3GPP Requirements Working Group carried out the C-V2X requirements research [73], which was completed in March 2016. The 3GPP Architecture Working Group started the C-V2X architecture study in early 2016 and completed standardization at the end of 2016. In the C-V2X research, the 3GPP Wireless Technology Working Group launched the SI project in July 2015 [74], which was completed in June 2016. In December 2015, the V2X standard project, named ''V2V based on LTE PC5 interface'' was launched, which was the project of [72], and standardization was completed in September 2016. In June 2016, the V2X standard project ''V2X service based on LTE'' was launched, and the project research was successfully completed in March 2017. In September 2016, the V2V standard of C-V2X was officially frozen at Release 14 [68], which indicated that the 3GPP had completed the first phase of LTE-V, namely, Device-to-Device (D2D)-based. At the 49th plenary session of the ISO TC 204 held in Paris, France, in April 2017, China's C-V2X standard project application was approved [75] which meant that C-V2X became a candidate for the ISO ITS system. The second phase of the C-V2X standard was released in September 2017, including V2V, V2I and V2P communication based on cellular networks.

C. STANDARDS FOR VANET

In November 2017, NXP and Autotalks jointly published an article clarifying that IEEE 802.11p would be used in LTE-V2V for security applications [28]. In December 2017, the 5GAA Alliance released a white paper about fully connected vehicles in Toronto: Edge computing for advanced automotive communications [29]. On February, 2018, the 5GAA announced the deployment of LTE-V2X [30] in 2020. The decline of DSRC has been obvious.

The LTE-V2X camp claims that LTE-V2X has superior capabilities beyond those of DSRC [77], [30]. According to the 5GAA white paper, ''5G high reliability, low latency features can be fully applied to V2X and will significantly enhance the role of ADAS and CAD'' [71]. The specific content includes the following [71]. First, when LTE-V2X supports high-speed mobile scenes, the relative speed reaches 500 km/hr, and reliable communication, reliable information transmission, and reliable warning can be realized. In dense and fast-moving usage scenarios, the effective communication distance can reach more than twice that of DSRC. Second, LTE-V2X will use the same frequency band for direct communication in traffic as DSRC, and LTE-V2X has a superior security performance. More consistently, this is due to the communication industry doing a good job in standardization and the industry's scale. Third, LTE-V2X synchronization technology enables inertial navigation devices to maintain a part of the positioning accuracy, so that navigation can still work even if the GPS signal is lost. The LTE-V2X network is accurately synchronized, while DSRC is asynchronous. Fourth, the LTE-V2X has a very clear technological evolution path. Automated driving has put forward many new requirements for the entire communication system, such as the need for greater bandwidth and lower latency, while 5G has evolved toward compatibility with LTE-V2X. Fifth, there is a cost advantage in network deployment, and the system must work stably in network deployment. This infrastructure is developed on cellular technology, so it has a unique advantage because it can be integrated into current cellular base stations. Base stations may be renovated by adding LTE-V2X infrastructure. Without having to build separate stations, the deployment cost is optimal.

The DSRC camp said that, first, the LTE-V2X maintains many similarities with the current LTE system, which is derived from the cellular uplink technology but inherits the frame structure, subcarrier spacing, and clock accuracy of the existing peak-slot technology. Attributes such as requirements and resource block concepts are not well suited for automotive applications [68]. The resource allocation mechanism used by it does not correctly handle messages with different lengths, and the multiuser access mechanism does not handle broadcast messages or message conflicts well. LTE-V2X does not have an equivalent mechanism, and a conflict will not be detected if it occurs. Two users may send messages using the same resource block. The resource is kept for multiple transfers by semi-permanent allocation techniques before the resource is reselected. Therefore, the multiple transmissions of these two users will be lost. LTE-V2X mitigates this problem by adding a certain degree of randomness to reselect the event time between users but does not completely resolve the risk of a conflict, for example, if two cars are approaching an intersection. Once in the effective communication range, IEEE 802.11p will ensure collision-free operation and will issue a warning if necessary. The LTE-V2X cannot do this; it will give priority to the warning signal of a vehicle. Second, LTE-V2X will have problems if there is no network coverage. LTE-V2X is inseparable from GPS access. The IEEE 1609.4 standard also needs GNSS signals, but only for switching from one channel to another, that is, it needs a much lower clock and frequency accuracy. It has strict synchronization requirements, otherwise, it will not be able to correctly receive messages from adjacent and nearby transmitters, and the communication distance will be limited. Third, the heavy-duty design of LTE-V2X also leads to a higher overhead. On the commercial side, the LTE-V2X cannot take advantage of the standard LTE modems already in vehicles. Strict synchronization requirements can also significantly increase the cost of LTE-V2X hardware. Fourth, the current cellular version can only solve the basic V2X use case, but it does not address safe driving, and safe driving requires an extremely low latency. Fifth, although V2X communication can greatly improve transportation security if it is deployed on a large scale, because there is no universal agreement on the communication protocols, it is still unrealized.

After the LTE or cellular camp realized that the European and American governments would not give up DSRC, in the second half of 2017, the idea of DSRC and a cellular parallel hybrid networking [20], [34] system emerged. This idea combines DSRC with the advantages of cellular networks. As early as 2015, Nokia also supported cellular and DSRC hybrid networks [31]. Cisco also clearly expressed support for DSRC and LTE hybrid networks [32]. Huawei also proposed the idea of combining cellular and ad hoc networks [33].

D. 5G AND INTERNET OF VEHICLES

Cellular technology tends to be a strong candidate for V2X communication. In response to new complexities and demands, projects and industries have introduced 5G technology for the in-vehicle network, especially to improve performance [81]. 5G PPP proposes how 5G will enable the vision of next-generation connectivity and autonomous driving as well as new mobile services [76]. 5G networks provides a range of access and connectivity solutions that meet the needs and requirements of mobile communications in the future. 5G networks provides wireless connectivity for all new applications and use cases, including vehicle and traffic safety/control, smart homes, critical infrastructure, industry processes, ultrahigh-speed media transmission, and the Internet of Things [82], [83]. The overall goal of 5G is that it can provide ubiquitous connectivity for any type of device and application which may benefit from connectivity [84], [85].

5G communication technology incorporates a range of emerging technologies, including CR [86], MIMO [87] and FD [88]. Some scholars believe that VANET will further enhance connectivity performance in the 5G era, primarily because of the main problems in communications based on IEEE 802.11p, which include a lack of spectrum, low latency and highly reliable periodic communication transmission [86]. However, some scholars believe that 5G is a business concept that focuses on a wider range of IoT communication applications, such as mobile phones and other mobile terminals, not just vehicle nodes. A win-win solution will focus on the strongest point of each technology, thereby jointly providing the best car-to-vehicle communication solution, continue to deploy IEEE 802.11p for safety-critical applications, and ensure that the upcoming LTE-V2X technology can co-exist [28].

For the application of 5G technology in VANET, first, due to the high mobility of vehicles and their irregular distribution, vehicles can quickly join or leave the network, and the links between vehicles are often connected and disconnected; thus, updating the network topology in a timely manner is critical to the operation of 5G-VANET. Second, the more stringent latency requirements of 5G-VANET further exacerbate these challenges and therefore require a more consistent link quality. When high-density vehicles communicate directly with the BS or RSU during peak hours, a large amount of concurrent V2I communication can result

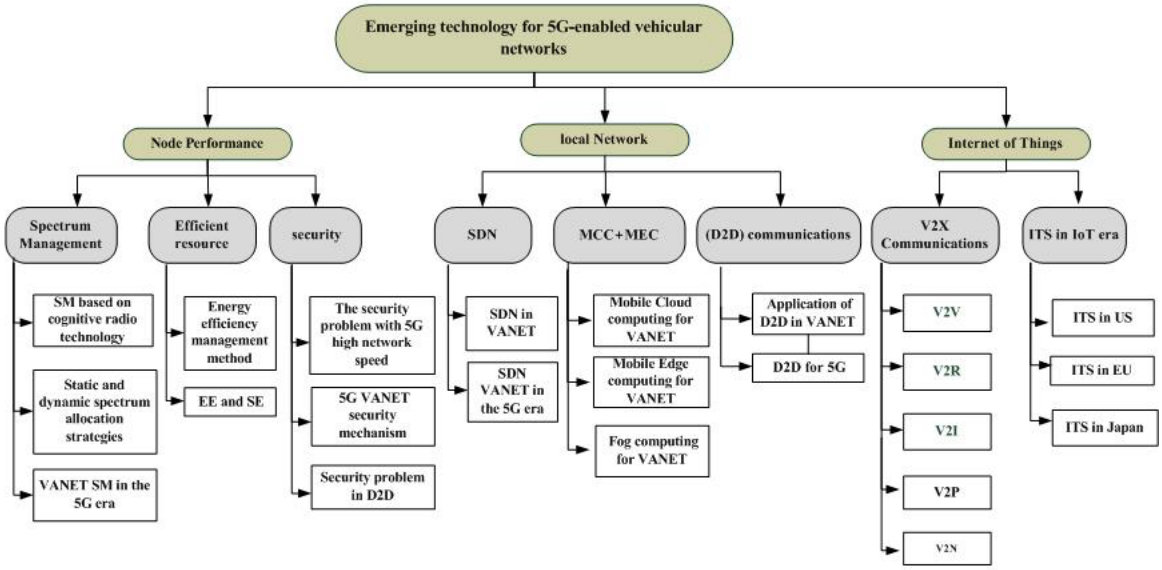

FIGURE 2. Emerging technologies for 5G-enabled vehicular networks.

in extremely high signaling overhead and an increase the probability of an outage. Third, various access networks and vendor-specific devices have also challenged 5G-VANET because of its heterogeneous and rigid cellular network architecture. 5G is envisioned to have a heterogeneous network (HetNet) architecture [12] due to the inevitable network densification caused by high data rates and mixed use of different wireless technologies. Fourth, 5G technology is based on a "large capacity, large bandwidth, large links, low latency, and low power consumption" [9], as future 5G networks become more complex, vendor-specific hardware and protocols make it difficult and costly for operators to dynamically adjust their network operations. Perhaps the next generation of 5G technology is worth looking forward to; however, given that the specifications of 5G have not yet been formulated, it leaves substantial room for imagination in the development of future vehicle networking-related technologies.The following paragraphs's structure has been shown in Figure 2.

III. NODE PERFORMANCE

A. SPECTRUM MANAGEMENT

Scarce spectrum resources and valuable energy resources are the biggest reasons behind the evolution of each generation of wireless communications. Spectrum planning and distribution have become the focus of attention in the industry in the 5G era. In 2016, the US FCC passed the "New Spectrum Domain" proposal, which aims to define the meaning of 5G network applications and open the high-frequency spectrum above 24 GHz to 5G. As a result, the United States became the first country in the world to plan the frequency of 5G communication technology. The frequency bands opened by the FCC totaled 10.85 GHz. Among them, the number of licensed frequency bands is four times that of the current FCC licensed frequency bands, and the number of unlicensed frequency band resources is 15 times that of the frequency resources used by WiFi [21].

The difficulty with spectrum resource management in VANET is that when traffic jams or emergencies occur, a large number of vehicles will quickly aggregate in a short period of time, and the demand for specific spectrum and routing resources will explode, leading to more complex communication requirements. The competition for local resources with limited road traffic support is increasingly prominent, and frequent competition for limited resources can lead to serious transmission delays or network paralysis [147]. The FCC allocates a 75 MHz bandwidth in the 5.850 GHz to 5.925 GHz band for DSRC [148]. The high-speed mobility of a vehicle makes the road traffic environment more complex and changeable. The contradiction between the complex traffic environment and the explosive growth of communication requirements is also increasingly prominent. Some scholars optimize VANET spectrum management based on the TV band. Fawaz *et al.* proposed a system for sensing the TV spectrum by extending the DSRC control channel based on the cognitive network principle [149]. Di Felice *et al.* proposed a new spectrum management framework based on Cog-V2V and described a distributed sensing method based on intervehicle cooperative communication [150]. However, the feasibility of using an idle TV band for vehicle communication in a VANET system based on the TV band is limited. This method is suitable for the suburban environment. The average vehicle density in urban areas is higher than that in remote areas, so it is difficult to ensure QoS support for some important applications [152].

1) SPECTRUM MANAGEMENT BASED ON COGNITIVE RADIO TECHNOLOGY

Some scholars have proposed introducing cognitive radio technology to utilize additional idle licensed spectrum resources to improve spectrum utilization anddeal with the shortage of spectrum resources in vehicle self-organizing networks [153]–[156]. The introduction of cognitive radio in the vehicle self-organizing network enables the vehicle node to determine the optimal transmission parameters based on the collected spectrum information, alleviating the pressure of insufficient spectrum resources and increasing the transmission capacity.

VANET mitigates the problem of spectrum scarcity by detecting and utilizing spectrum holes in the authorized primary network through the opportunistic spectrum access mechanism. Cognitive car networking is a possible basic cognitive cycle architecture consisting of four phases: monitoring, analysis, reasoning and action [167]. The monitoring phase includes the perception of information such as node location, cognitive policies, and service application QoS requirements. The analysis phase and the inference phase include analyzing the system performance, wireless communication environment, and optimizing the spectrum strategy. Reconfiguring parameters and optimizing adjustments occurs during the action phase [151]. In the cognitive architecture of the cognitive car network, the spectrum sensing in the monitoring phase and the spectrum management in the inference phase are the foundation of the whole cycle process, providing available spectrum information and coordinating the spectrum access processes.

2) STATIC AND DYNAMIC SPECTRUM ALLOCATION STRATEGIES

Static configuration is also possible when designing and optimizing the spectrum allocation strategy. This is where the evolved Node B can statically deploy spectrum to the vehicle. It should be noted that vehicles of 5G scenarios in the future constitute an indispensable part of the IoT environment [158], and in addition to security, vehicles will also participate in auxiliary communications. In terms of dynamic spectrum management, the FCC has also made attempts to address the issues involved. For example, a related database has been established for the TV white spectrum, and a spectrum access system has been established for the 3.5 GHz band. However, access to these systems is limited, and only users who are trusted by the third parties and registered in the database can access it, which requires a large amount of synchronization overhead, resulting in less flexible and dynamic use. In March 2017, blockchain technology was discussed for the first time at the IEEE Dynamic Spectrum Access Network Group meeting. The basic point of discussion was that dynamic distributed spectrum management requires dynamic distributed database support. Experts in the IEEE spectrum have begun to study the application of blockchain technology in spectrum management and are currently developing management software for small operators who operate microcells [159]. Blockchain technology is also changing the way people think. For example, mobile operators need a large amount of money to purchase spectrum usage rights. If blockchain technology enables different users to share the spectrum, this will greatly save on the cost for spectrum users. Recently, the French Spectrum Management Agencybegan to study blockchain technology to improve the content of spectrum management [160]. However, the application of blockchain technology is still under research and development, and there are still many problems to be solved. For example, is a blockchain-based database more efficient than a centrally managed database? Can real-time spectrum dynamic sharing or transactions be achieved through blockchain technology? Can blockchains be used in automatic spectrum sharing? These issues are subject to further research and argumentation.

3) VANET SPECTRUM MANAGEMENT IN THE 5G ERA

With the development of 5G technology, there will be a large number of communication base stations and cells, which require more flexible and dynamic spectrum management methods. Therefore, a dynamic, distributed approach is needed to monitor spectrum resources. Most IoT computing and storage capabilities are very limited and require cloud computing to provide services. Therefore, connecting these devices through a 5G system requires a large amount of spectrum resources in addition to capabilities for handling large-scale connections and improvements in security. Network densification refers to the ultradense deployment of wireless infrastructure [161]. 5G will require D2D communication with a larger coverage area to provide innovative proximity-based services and access to data. In addition, the 5G program uses the spectrum more efficiently by sharing between users (primary, secondary, and tertiary) [162].

Intensive radio coverage is achieved for vehicles in the vehicle network. Due to the increased system capacity of 5G networks, many collocated vehicles can access the network at the same time, but the number of these connected vehicles is limited due to limited spectrum resources and low spectral efficiency, as discussed in previous work. Huang *et al.* proposed that vehicle neighbor groups (VNGs) could be formed for vehicle neighbors to enrich vehicle services in a 5G-enabled in-vehicle network [163] Many connected vehicles' information can be delivered simultaneously while in a common location. Vehicles that are collocated may continue to be vehicle neighbors, especially when the near-end vehicles have the same destination or a similar route. These vehicles can form a VNGs that can serve the request sharing experience. Then, various services such as data sharing, mobile interaction, and resource cooperation can be conveniently provided in a VNG [163]. In 2017, China had the world premiere of frequency band planning for 5G systems [164].

B. ENERGY EFFICIENCY MANAGEMENT

The ultradense networking technology in 5G can effectively address the need to greatly improve the spectrum efficiency of cellular networks, but the ultradense deployment of the network also brings unprecedented energy costs. Due to the increase in in-vehicle mobile data traffic and the ubiquitous mobile access requirements of passengers, resource sharing between potentially densely distributed vehicles significantly increases the energy and resource consumption of V2X communications. Therefore, energy efficiency and spectral efficiency will be the main goals of VANET-5G system design. The measured data obtained by tracking a real network for one week shows that densely deployed base stations with different functions are in a low load state for most of the time, and the traffic load of the network changes in space and time [131]. Specifically, within a day, the time-to-wait ratio of the load below 10% of the peak is as high as 30% and 45% on weekdays and weekends, respectively [131]. Therefore, in ultradense networks, a large number of base stations are not fully utilized most of the time. However, even in a low or empty load state, the base station will consume more than 90% of the overall energy consumption. For example, a typical UMTS base station consumes 800 to 1500W, but the RF output power is only 20 to 40W [132]. The economic cost caused by this immense energy expenditure has already constituted one of the biggest obstacles for the development of operators [133]. In the 2G and 3G era, profit-sharing methods such as increasing the coverage area and increasing the data rate are unsustainable. Communication operators are facing a severe situation in which they cannot make ends meet. Energy conservation has become the main determinant of profitability in the future. Therefore, how to achieve the energy-efficient deployment of ultraintensive heterogeneous wireless networks is a major scientific issue worthy of in-depth study [134]. To ensure the relay link capacity between the gateway and the base station, some scholars have proposed a nonorthogonal multiplexing modulation (NOMM) scheme to effectively aggregate V2I traffic and further improve energy efficiency [135].

The so-called ''worst case'' network design concept widely used in the field refers to a design that will meet the needs of users all of the time, even during peak business hours. As mentioned above, in an actual wireless network, the traffic load varies in time and space, and thus, this traditional design concept will inevitably lead to a large waste of network energy and a significant reduction in network energy efficiency. Actual data shows that in the traditional low-density deployment of cellular networks, almost 60% to 80% of the total energy consumption is at the base station [131], [132]. Undoubtedly, this situation will become extremely serious in the future with ultradense wireless heterogeneous networks. Preliminary results have shown that the base station density per unit area increases by a factor of 10, resulting in a 35.6% increase in spectral efficiency and a 59.2% reduction in energy efficiency. Therefore, in an ultradense wireless heterogeneous network in which small base stations are densely deployed, if all the base stations are still turned on during a light traffic load period (such as around midnight), as in conventional network management, a large amount of energy is undoubtedly wasted. To this end, the existing research focuses mainly on load-adaptive base station switch control, active buffering and interference-aware inter-network resource allocation to improve the flexibility of network control and the efficiency of joint resource allocation.

1) ENERGY EFFICIENCY MANAGEMENT METHODS

First, it is completely unnecessary to keep a base station in operation to meet the highest network service requirements at any time, as this will cause great energy waste. Through big data analysis, the spatial and temporal distributions and change rules of network services can be known, and then the adaptive base station switching mode with load sensing capability can be adopted. The main purpose of this mode is to turn on the appropriate number of base stations to support the current network traffic load and turn off the remaining base stations to reduce the energy overhead. This model enables network planning to match the time-to-space network traffic load and reduces the static power of the base stations, thereby achieving energy savings at a large scale. However, frequent base station switching operations will introduce additional signaling overhead in the system and may cause network oscillations. The issues are how to ensure that shutting down base stations for energy saving will not significantly reduce a user's quality of service, for instance by lowering the data transmission rate for network users. The energy trade-off problem is strictly mathematically modeled and flexibly regulated. Some studies have attempted to solve base station control problems from different perspectives. Niu *et al.* proposed a cellular scaling technique that adjusts the coverage of a cell according to the change of the traffic load to achieve the purpose of controlling energy consumption [135]. Liu *et al.* presented a new throughput-maximal framework and delay-minimal framework in drastically varying fading channel environments with high velocities of moving nodes [197]. Oh *et al.* introduced the concept of a ''network factor'' from the perspective of dynamic base station state switching. To study the problem of network energy conservation [136], some scholars further studied the joint optimization scheme of base station regulation and user association and analyzed the trade-offs of ''energy-delay'' and ''energy-return'', respectively [132], [137]. The nonuniformity of the business distribution in the spatial dimension was considered, but these studies did not analyze the variability of the business distribution in the time dimension, although this feature will also significantly affect the network energy consumption [132], [135]–[137]. Hua *et al.* investigated the throughput and transmission delay performances for real-time and delay sensitive services through a repeated game theoretic solution [199].

Second, with the development of semiconductor processes, it has become easier to configure large-capacity memories in user terminal devices or network devices. The energy efficiency of an ultradense heterogeneous network can be improved by pushing and precaching in advance based on information such as the content popularity, user behavior characteristics, user influence, and user social relationships in the network. For example, if the popularity of the content has been predicted, the system can precache highly popular content in the smart device of the influential user. When the social relationships between users are known and the users are close to each other, the shared content can be directly obtained by D2D [138], [139]. Through device direct communication and precached content, the transmission distance can be effectively reduced, and network congestion can be avoided so that the transmission power of the network and the user can be significantly reduced. In this way the traffic load of the base station can also be alleviated, and a user can quickly obtain the required content, which improves the quality of service for users. Of course, you also need to carefully consider the trade-offs between the benefits it brings and the costs that can result. For base station-level or user-level caching, questions arise about: how many base stations or user terminal devices need to be selected for content precaching; how prepushing and prestorage of data start from when a user makes a formal request; how to address the randomness and time variations of the wireless network; how to design a reliable active caching mechanism to reduce network overhead as much as possible; and how to strictly model the revenue-overhead tradeoff problem under active caching and flexibly control both. The current research on these issues is still in an exploratory stage.

Third, although the transmit power is much smaller than the overall power consumption of the base station, the transmit power of the transmitter determined during resource allocation can have a significant impact on the energy consumed by network components such as amplifiers and cooling systems. To realize the vision of green ultradense wireless heterogeneous networks, in addition to reducing static power consumption on a large scale through base station switch control, it is also indispensable to reduce the transmit power at a small scale through resource allocation. Fehske *et al.* found that by reducing the transmit power from 20W to 10W, the total power consumption of a macro base station can be reduced from 766W to 532W (that is, 234W of power is saved) [140].

Fourth, the user association is considered or not considered. If considered, the corresponding association scheme will significantly affect the load distribution and the energy and spectrum efficiency of the network. In an ultradense wireless heterogeneous network, multi-network systems coexist (such as 5G, 4G, UMTS, and Wi-Fi.), and for the same network standard, the behavior of service users may be covered by different deployments and different commitments. The function of a large / small base station is completed. This unique feature of ultradense wireless heterogeneous networks provides network diversity for user associations. Terminals with multimode interfaces do not have to be able to send and receive data over the same standard network as traditional single-mode terminals. Therefore, different user association policies may result in different bearers and distributions of the service load between different types of networks and between different base stations of the same type of network, thus affecting the working status of each network and in turn affecting network interference levels and internetwork resources. Joint optimization ultimately affects the energy efficiency of the network. Base station switching and user association determine the macro working state of the network and are further needed to optimize the heterogeneous resources between the networks to achieve efficient spectrum data transmission.

2) EE AND SE

Heliot *et al.* derived approximate spectral efficiency-energy efficiency relationships for MIMO systems by using heuristic curve fitting [141], and Chih-Lin *et al.* derived simple closed expressions for large-scale MIMO systems [142]. Xiong *et al.* established a framework for spectral efficiency-EE relationships for downlink orthogonal frequency division multiple access (OFDMA) systems [143], which imposes a minimum instantaneous rate requirement for each user and between multiple users and ensures the fairness of QoS constraints. In addition to spectrum efficiency-energy efficiency trade-offs, there are other trade-efficiency-related trade-offs, such as trade-offs between energy efficiency and delays or deployment costs, which were investigated in [144]. The proposed new network architecture for caching provides new opportunities to improve the efficiency of spectrum and energy utilization [145].

C. 5G SECURITY

In recent years, with the rapid development of the Internet of Vehicles industry, the accompanying network security risks have also intensified, and network security threats have become increasingly severe. In 2016, the Nissan LEAF car application was found to have system vulnerabilities, allowing hackers to remotely control vehicles, access driving history tracks, disrupt vehicle heating and air conditioning systems, etc. In 2017, Tencent's Cohen Lab once again cracked the Tesla Model X system. The car's web browser looks for computer vulnerabilities, sends malware, and ultimately manipulates the brakes, trunks, lights, and broadcasts. The speed of progress in mobile networks is not synchronized with the development of network security, and the extent and scope of threats to intelligent transportation systems in the context of the Internet of Things will be even worse. In 2018, Avast, a world-renowned cybersecurity company, said that although the direct impact cannot be predicted at present, the advent of the 5G network era will pose a further threat to autonomous vehicles [79].

The 5G network can provide VANET with ultrareliable, ultralow latency connections that promote road safety, traffic management, information dissemination and driver and passenger autopilot. 5G-VANET also causes very large security and privacy problems. Intelligent networked cars, people, roads, clouds, and apps constitute a complex network of vehicles, and as part of the Internet, car networking will inevitably face a variety of complex information security threats and risks. VANET is characterized by highly mobile network nodes, uncertainty in terms of the network scale, time-sensitive data exchange, and a wide range of safe driving information transmissions. Therefore, a VANET security system should provide authentication, availability, nonrepudiation, privacy, protection, data verification, information integrity, confidentiality of information, network scalability, reliability of broadcast messages, etc. [104]. While V2X technology realizes more services for car networking, it also exposes the car's control system to the network virtual environment, which is vulnerable to external malicious attacks and brings new security problems.

1) THE SECURITY PROBLEM OF 5G HIGH NETWORK SPEED

The ultrahigh speed and ultralow delay features of 5G bring many conveniences to people, but they also bring many opportunities for hackers. Due to the unique characteristics of fast movement and high dynamics of VANET, the time to key establishment between vehicle pairs is quite limited. Huang *et al.* proposed a reaction protocol called on-demand member center routing (OMR), which is suitable for the scenario in a VANET highway environment [116]. OMR is triggered when a member sends a request for additional 3G / 3.5G bandwidth to other members of the queue. Hussein *et al.* proposed a three-way integration among SDN, a VANET and 5G network to implement a flexible VANET security design method, which achieves a good balance among network, mobility, performance and security functions [117].

2) 5G-VANET SECURITY MECHANISMS

Another obvious change in the 5G network is the change in security mechanisms. Previous generations of networks have used "protection walls" at the network entrance to prevent malicious attacks on the network, but 5G networks have completely changed this feature because 5G networks need to be open, which is reduced to some extent. This protection wall relies partly on the internal security mechanisms of the network to block network attacks, which requires that the internals of the 5G-VANET be sufficiently flexible. 5G-VANET is the key point between cyberspace and real space. Attacks in cyberspace can cause substantial damage to real space through VANET, for instance, privacy leakage, traffic congestion and even more serious traffic accidents [118]–[120]. Therefore, it is important to mitigate any attacks in 5G-VANET.

3) SECURITY PROBLEMS IN D2D COMMUNICATION

D2D communication has significant advantages, but new application scenarios expose D2D services to unique security threats. The academic and industrial standardization circles have not seriously studied the security of D2D communication. Because the number of nodes is very large (millions of cars/smart phones), internal attackers can easily broadcast security messages, and thus, in-depth research is required to define privacy metrics and quantify the strength of anonymity. In privacy protection design, special consideration needs to be given to the impact on the network performance. The impact of security/privacy on the network performance should be kept to a minimum. Dynamic PKI design and management in a large-scale environment is a challenge that requires enhanced research into reporting and shutting down malicious ITS node technologies. 5G networks will be able to connect multiple devices at the same time, which means that new network forms and devices are introduced into 5G networks, which increases the complexity and the security threats to network devices and also constitutes a big challenge for 5G network security. In addition, the privacy of customers may also be threatened by leaks, so we must do a good job in the area of defense, such as reliably mapping a customer's real space and cyberspace identity.

IV. LOCAL NETWORKS

A. SDNs

Due to the continuous development of Internet of Things technology, the traditional underlying network architecture has been unable to meet the needs of human beings. The equipment is complicated, the configuration is troublesome, the iteration is slow, and all kinds of problems keep coming up. In this context, in 2006, the Clean State project of the Stanford University Lab first proposed the software defined network (SDN), and the idea of control and forwarding separation was quickly recognized by scholars from numerous fields [165]. An SDN is a new innovative network architecture based on the Emulex network. An SDN has flexible software programming capabilities and powerful network control capabilities, which can quickly and effectively solve the problem of limited resource scale expansion and low networking flexibility faced by current network systems [166]. At present, many scholars are trying to integrate SDNs into VANET, but due to the characteristics of a vehicle itself, high-speed mobility and rapid changes in the network topology, the application of SDNs in the Internet of Vehicles has great challenges.

Some SDN-based car networking communication architectures have emerged since 2014. Correia *et al.* proposed a layered SDN-V architecture that improved the communication performance and efficiency of VANET [167]. Ku *et al.* described the different modes of operation of the SDN-V architecture [168], and Truong *et al.* proposed a method based on SDN-V and fog calculation to solve the delay problem in the Internet of Vehicles [169]. Jerbi *et al.* proposed an adaptive edge computing solution based on regression admission control and fuzzy weighted queuing to monito and respond to QoS changes in in-vehicle network scenarios [170]. Salahuddin *et al.* designed the SDN-based RSU car cloud [171]. Based on an SDN, Shafiee *et al.* developed a collaborative data scheduling algorithm integrated into an RSU to enhance the data propagation performance by utilizing the synergy between V2I and V2V communication [172]. Riggio *et al.* designed the abstract programming part of the SDN wireless network [173].

1) SDNs IN VANET

The SDN-centralized control management feature can solve the problems of network node multichange, high node mobility, network topology dynamics and noncentrality caused by network node cooperative communications. The specific technical advantages are as follows. 1) The SDN controller optimizes routing decisions. During the movement of the vehicle, the data traffic in some places may become overcrowded. The SDN controller can obtain the information of the relevant nodes and find the routing policy in time to improve the network utilization and reduce congestion. 2) SDN controllers optimize spectrum management. To reserve channels for the emergency traffic that VANET services, the SDN controller can coordinate the use of better channels according to actual needs and can dynamically optimize the use of wireless excuses and channel isolation. 3) SDN controllers can optimize network resource management. When the density of neighboring nodes is too low, all nodes are instructed to increase power to achieve more reasonable packet delivery and reduce interference. The SDN controller can decide whether to change the power of the wireless interface to adjust its transmission range. However, the application of SDN technology in VANET has certain problems: VANET has a high node mobility, and RSU coverage has limitations, resulting in a short communication between the vehicle and RSU when the vehicle enters overlapping RSU coverage areas. If the best RSU is not established in time to make a connection, it will affect not only the timeliness of information processing and satisfactory service, but also the operation status of the RSU in the entire region, including the throughput and bandwidth utilization, rate, and load balance. For example, delay-sensitive security information is not delivered in time, while entertainment information for nonsecure applications occupies most of the bandwidth; some RSUs have network congestion, while others have wasted bandwidth. The load imbalance of RSUs will directly lead to a decline in the network performance. Therefore, in a variety of overlapping RSU coverage areas, a more scientific algorithm is needed to obtain the best solution for vehicles to access RSUs so that the performance of all aspects of the network are stably maintained and the unreasonable connection of a vehicle is avoided when the vehicle transmits a large amount of data and needs to switch RSUs frequently.

SDN technology is limited by RSU: when many vehicles are connected to the same RSU, frequent switching problems can degrade the SDN performance [174]. Therefore, many scholars are working to solve the low SDN performance problem caused by frequent handovers. Duan *et al.* proposed 5G-VANET to support an SDN; this scheme uses SDN's global information collection and network control to adaptively aggregate adjacent vehicle capabilities according to real-time road conditions [175]. Li *et al.* proposed an optimization strategy to balance latency requirements with the cost of cellular networks [176]. We support that vehicles send SDN control requests over cellular networks by discounting network bandwidth.

2) SDNs AND VANET IN THE 5G ERA

In next-generation VANET and 5G networks, SDN technology will play a very important role in network management. Duan *et al.* proposed a new layered 5G next-generation VANET architecture to integrate the centralization and flexibility of SDN and CRAN with 5G to flexible manage and control the network and efficiently utilize resources in large-scale VANET [175]. This combination of technologies effectively allocates resources with a global view. For future 5G mobile communication technology, the research results of Ge *et al.* show that regardless of the vehicle density, 5G SDN-V systems can provide the minimum transmission delay compared with traditional architectures and that the throughput is significantly improved [177]. Wan *et al.* proposed a low integration by integrating IEEE 802.11p and 5G radio access technologies, which achieves an in-vehicle network architecture with a high latency and reliable communication [178]. An actual example demonstrated that this proposed architecture can meet the specific requirements of application while maintaining network scalability. Hussein *et al.* proposed a three-way integration among VANET, 5G and SDNs and to implement a flexible VANET security design method that provides a good balance between network mobility, performance and securityfunctions [117].

B. MOBILE CLOUD COMPUTING AND MOBILE EDGE COMPUTING

The vehicle itself is limited by its resources, such as the computing power, storage and wireless bandwidth. The characteristics of the vehicle itself have become the bottleneck for the rapid development of the Internet of Vehicles technology. To improve their price competitiveness, vehicle manufacturers are equipped with small-sized and low-cost hardware systems. A vehicle has limited computing and storage resources, making its data processing capabilities weak. At the same time, most of the current applications, such as vehicle multimedia entertainment and location-based services, require a high level of computing power and a large storage capacity, all of which make it impossible for a single vehicle to effectively support these diversified new applications. The introduction of mobile cloud computing allows us to see the possibility of solving the above problems.

1) MOBILE CLOUD COMPUTING FOR VANET

The 5G network will be a heterogeneous network based on cloud computing. Since the introduction of wireless new technologies must meet the access control of existing standards, it is necessary to establish a new control mechanism to coordinate wireless resources between various standards, between frequency bands and between cells to significantly improve a users' experience and data access capabilities in various scenarios. By clouding the management and scheduling functions of wireless resources, resource partitioning and management as needed, the development of cloud computing makes it possible to provide infrastructure, platforms and software as a service to any user accessing the Internet. With the rapid development of mobile Internet and cloud computing technologies, mobile cloud computing, as a new technology, has recently attracted widespread attention in academia and industry [179].

We can apply mobile cloud computing technology, such as clouds deployed near access points and traditional centralized remote clouds, to the Internet of Vehicles to enable resources between vehicles to be shared [180], [181]. If a vehicle has sufficient computing resources, cloud computing can also be provided to mobile in-vehicle devices (such as mobile terminals) for use, thereby improving the performance and saving the energy of the mobile in-vehicle device. Liu *et al.* proposed a novel communication system to integrate vehicular network and Cloud to provide shareable multimedia services, i.e., local news, weather forecast, popular game videos etc. A relay-selective multi-hop scheme is designed in this system where Road Side Units (RSU) will be allocated by Cloud assistance to provide multimedia services [198]. Abolfazli *et al.* proposed a new paradigm for Mobile Cloud Computing (MCC) to be used by vehicle drivers by using services as a utility in a pay-as-you-go model and processing large amounts of data anytime and anywhere [182]. However, uploading real-time information to the cloud (such as traffic jams or accidents) by using the Internet is expensive and time consuming [183]. The concept of vehicular cloud computing (VCC) was first proposed by Weigle *et al.* [187]. The purpose of VCC is to enable vehicle communications during a journey, thus addressing the convergence of ITS and the enormous computing and storage capabilities of MCC. Underutilized vehicle resources, including computing power, network connectivity, and storage facilities, can be combined or leased to customers with those resources on the road, similar to the way resources are provided for current traditional clouds. In addition, VCC provides a ubiquitous wireless sensor network, and the ITS's and MCC's technical feasibility improve road safety and safety in smart urban transportation systems [185], [186]. The goal of VCC is to provide drivers using vehicle computing with a number of computing services at a low cost, accidents, travel time and ensuring low-energy and real-time service to drivers by using QoS software, platforms and infrastructure [184]. VCC storage and computing resources are fully utilized, and meaningful integration of these resources will have a major impact on society.

2) MOBILE EDGE COMPUTING FOR VANET

According to Intel CEO Brian Krzanichde, a vehicle will generate and consume approximately 40 terabytes of data every 8 hours [194]. A large amount of data is coming soon, and it will far exceed the amount of data generated by ordinary people today. An average driving car will produce 4,000 GB of data per hour per day. This amount can be compared to the current video, chat and other Internet usage of ordinary people. In other words, approximately 650 MB of data [194] is generated every day, and this amount is expected to increase to 1.5 GB per day by 2020 [194], and thus, a large amount of data needs to be transfered over the network. During the driving process, it is difficult to obtain a strong network connection and maintain the connection during the transmission of large amounts of data. Even if the network environment is idedl, traffic data transmission time is still consumed due to the too long distance between vehicles and the remote data center. Therefore, for practical reasons, most of the processing must occur at the edge, and the Internet of Vehicles can use edge computing to quickly make decisions on the control of the car.

In 2014, scholars proposed MEC (Mobile Edge Computing) [188]–[192], [200]. In MEC, storage space and cloud computing resources are set in the edge of the vehicle access network as well as very close to the moving vehicles, which greatly reduces the round trip time of the data packets. The MEC cloud server can support latency-constrained responses to client requests and help deploy new latency-sensitive services to service providers. Another advantage of MEC is that it can offload traffic loads from the backbone. A fog calculation framework is proposed at the edge of the network to avoid frequent switching between the vehicle and the RSU [188]. Edge computing is a relatively new term that has become increasingly important since the IoT era began [189]–[191]. A technical challenge encountered with edge computing is the need to have sufficient localized computing processing power and memory capacity to ensure that the vehicle is capable of performing its required application service tasks. If you place a large number of processors and a large amount of memory in a car, this will add a large burden to the car, which will increase the chance of machine failure and use more power, add more weight to the car and so on. Therefore, it is necessary to carefully mix localized processing and cloud computing processing.

It is necessary to understand the relationship between mobile edge computing and cloud computing: cloud computing encompasses the big pictures, focusing on the big data analysis of non-real-time and long-cycle data, and cloud computing can play a special role in areas such as periodic maintenance and business decision support. Edge computing primarily processes local real-time data. The analysis of short-cycle data can better support the real-time intelligent processing and execution of local services [191]. For the timeliness of data processing, if you rely entirely on cloud computing, the transmission time and feedback time will greatly reduce the data processing efficiency. Using mobile edge calculations to perform simple preliminary processing and then uploading the complex data to the cloud to be solved by cloud computing can solve the problem of the timeliness of data processing, reduce the transmission cost, and reduce the pressure of cloud computing. Therefore, the operation mode of cloud computing combined with mobile edge computing is as follows: the edge end preprocesses the data, extracts the feature transmission to the cloud, and performs computational analysis. Compared with the cloud, edge computing has the advantages of low latency, high throughput, simplified data, and high security [189], [190].

3) FOG COMPUTING FOR VANET

Fog calculation is the middle ground between edge computing and cloud computing. It is an intermediate calculation acting as an intermediary between the edge and the cloud [191], [192]. In many fog computing applications, sensor data from an endpoint device or a device directly attached to a simple class server computer can be triggered by the gateway to perform certain actions or certain types of tasks. The data are then transferred to a more powerful server on the chain. These servers typically perform more advanced data analysis in the cloud. Fog calculation means installing computer servers on the road, which do not have the same type of delays and problems as real clouds but provide near-cloud functional services that can be faster and more reliable on the highway. Imagine a self-driving car that can speed by and is able to communicate without connecting with the cloud. However, this requires a large amount of infrastructure to be added, and both the initial setup and the maintenance require significant cost increases.

C. DEVICE-TO-DEVICE (D2D) COMMUNICATIONS

In the next few years, large-scale device access will bring enormous challenges to network management and spectrum resources. As a reliable short-range communication technology, D2D (device-to-device) communications can effectively alleviate the load of the core network. Data diversion is implemented for short-distance traffic communication in the Internet of Vehicles. The traffic volume in a city is large, and the traffic lines and road conditions are complex. D2D can realize direct communication between communication terminals without using a base station and expand the network connections and access modes. A high channel quality enables the efficient use of spectrum resources while improving the link flexibility and network reliability. D2D enables the Internet of Vehicles to have the following two characteristics: first, people's demand for services for various Internet of Vehicles applications, such as real-time traffic broadcasts, violations, news and entertainment, has increased; second, frequent lane changes and overtaking in low-speed scenarios pose a large threat to driving safety. Especially when traffic events occur, traffic status messages are broadcast repeatedly in a short form over short distances, which tends to cause limited link congestion.

D2D communication is a device-to-device terminal direct communication technology. Such devices are not limited to mobile phones of human-to-human communication or machines of machine-to-machine communication. Under the control of cellular communication systems, End users communicate directly with each and share cell resources within a certain range by D2D resources. D2D technology is also one of the most important technologies of 5G [78], [80], [90]. The combination of 5G cellular networks and D2D communication in the in-vehicle network can not only improve the performance of the in-vehicle network but also increase the revenue of network operators and service providers. D2D communication has been conceived as a joint technology for 5G wireless systems for providing services, including real-time data and video sharing.

In 2009, Doppler *et al.* proposed the concept of D2D communication [193]. In April 2013, the 3GPP organization focused on D2D technology and endorsed it. D2D technology began to be promoted and researched [157], and D2D standardization was in the early stages. D2D (also known as sidelink [163]) supports direct communication between the different devices that are not connecting without going through an eNodeB or key network. In traditional cellular communication, when there is a data transmission or an information interaction between user A and user B, the two-hop network must be indirectly connected through the base station as a relay. D2D communication technology breaks this limitation. When two close-range users have communication requirements, if the distance between the two is close enough and the communication link is good enough, the two users can directly establish a communication link for data transmission [146]. D2D technology allows devices to transmit data with a higher speed and lower latency, power consumption and better spectrum utilization. This technology an support D2D communication spread on the same spectrum (i.e., in-brand) or on an unlicensed spectrum (i.e., out-of-brand) [110]. The underlying D2D communication can produce the interference between D2D and cellular users, requiring an appropriate resource allocation algorithm [138]. D2D communication can be enlarged to support inter-channel links [196] and has recently been researched as a technology to support the cooperative exchange of beacons and safety critical data [129], [130]. The algorithm which is different from the traditional LTE sheduling can make spatial reuse and fully mitigate interference [195], which allows different transmissions to allocate in the same RB by increasing the spectrum utilization.

1) APPLICATION OF D2D IN VANET

In the Internet of Vehicles, mobile access points are dense, vehicle communication distance is relatively small, and the number of communication nodes is extremely large; hence, D2D communication will be able to exert great advantages. However, the biggest difference between vehicle-centric D2D communication and human-centered D2D communication is mobility. Due to the limited range of D2D communication and the faster movement of vehicles, vehicles that are undergoing D2D communication are easily disconnected due to an out-of-communication range. However, a vehicle can only travel on an existing road. Unlike other mobile devices which can move in any direction, its movement state is limited. At present, the vehicle network DSRC technology achieves workshop and road communication. However, the RSU / OBU communication distance is short, which easily leads to the scalability problem of the traffic message network. It is necessary to improve the traffic message transmission network to improve the reliability and real-time performance of traffic message transmission. Therefore, based on the strong mobility of the vehicle, the D2D connection pair selection method is explored to establish a link with a long survival time and high reliability. This can reduce the probability of D2D communication interruption and improve the traffic message propagation performance.

The key of the issue of D2D resource allocation is when we think properly allocate spectrum resources and transmission opportunities for D2D users, and improve network performance without causing too much interference to cellular users meantime [121]. The framework in [122] allows mobile users to decide on the operation mode for establishing a cellular link or a D2D link for transmission. Spectrum sharing between cellular users and D2D users is studied in [123], where bidirectional D2D communication is utilized to aid cellular transmission. A reverse iterative combinatorial auction mechanism is proposed in [124], in which spectrum resources serve as bidders to compete for packets of D2D transmission pairs, and the system sum will be optimized using an auction-based scheme. In [125], the Stackelber game model was developed, in which the cellular user is the leader and the D2D user is the follower of the purchase of spectrum resources. A similar resource allocation game is proposed in [126], in which the D2D user acts as a player in the auction system, and its goal is to focus on the life cycle of the network. In [127], the social connection between D2D users and its relationship with the link quality are studied. On this basis, the optimization of social-aware resource allocation is proposed. A column generation-based approach was introduced in [128] for resource allocation to optimize spectrum utilization, where QoS for D2D links can be guaranteed without affecting cellular users with harmful interference.

In VANET, the transmission delay is an important performance indicator. There are two mathods to allocate radio resources in a D2D-based network. One of the method is allocating the orthogonal resources (static allocation) to the D2D and other cellular devices. The second method is to allocate concurrent resources (dynamic allocation) between D2D and other cellular devices [103]. Obviously, the second method makes the allocating of the radio resources more available and effcient, but it also products new interference problems [99]. By using D2D, you can reduce latency and design solutions that do not require cellular network coverage. In D2D mode, the immediately adjacent vehicles communicate directly, which ultimately reduces latency and offloads traffic from the Evolved Node B. D2D will be an attractive solution for local data exchange between vehicles [100]. Zhang *et al.* addressed the issue of cyber-physical scheduling of UAV resources in order to achieve an efficient delivery service [201], and the method is also applied to D2D.

2) D2D IN 5G NETWORKS

D2D of 5G networks provides a safe infrastructure that will protect the spread and the variety of secure and nonsecure applications. D2D improve the speed of the communication between vehicles, and enhance the system's spectral efficiency, system capacity and throughput, on the whole. In [102], Hashim *et al.* develop an example for extending the D2D of in-vehicle infrastructure which has the ability to facilitate in-vehicle services and use the LTE band. In 2016, Cao et al. proposed a new method based on 5G-D2D technology to improve the delay performance of VANET. In VANET, due to the random access nature of multiple access and carrier-aware collision avoidance (CSMA/CA) mechanisms for multiple access, the end-to-end delay may be high due to two stores when the network is temporarily disconnected and the channel access to contention delays catch up with the (SAC) delays. In this study, a hybrid system based on D2D and IEEE 802.11p communication has become possible [101]. Li *et al.* [98] proposed a routing method of 5G-D2D for in-vehicle networks, which can decrease the ability of connection and scalable of the in-vehicle network and reduce the traffic load of the 5G base station at the same time.

V. INTERNET OF THINGS (IOT)

The Internet connects the objects to the other objects, so that the world can form a unique network of related items, but all these connections are still based on the premise of Internet Technology. At present, the IoT is widely used in agriculture, industry, telemedicine manufacturing, smart home, intelligent transportation, urban management, environmental monitoring, public safety and other fields. And various fields have undergone great changes with the involvement of IoT technology, which has fundamentally changed the lives of consumers. According to the current development of social Internet technology and informatization, the development space of the IoT and the Internet of Vehicles (IoV)is relatively large in the future. With the rapid development and wide application of IoT technology, the IoV technology is gradually established and developed under the condition of the theory of Internet of Things technology.

A. V2X COMMUNICATIONS

Vehicle to Everything (V2X) is a new generation of information and communication technology that enables all-round connectivity and communication between vehicles and vehicles, people, transportation infrastructure and networks. V2X means the exchange of information between the car and the outside world. Vehicle networking communication includes Vehicle to Vehicle (V2V) [111], vehicle to road equipment (V2R) [107], Vehicle to Infrastructure (V2I) [108], Vehicle to Pedestrian (V2P) [109], Vehicle to Network (Vehicle -to-Network, V2N) [71] and several other categories. At present, the development of V2V is the most mature.

1) V2V

V2V is the most mature V2X development. V2V communication prevents accidents and sends the information of the vehicle's position and the other vehicle's speed through a dedicated network [111]. The V2V communication service has been included in the 3GPP Rel-13 release. V2V is a

TABLE 1. Five communication modes of V2X.

Application scenario	Applications	Way of communication
V2V	Vehicle and car lane change notification, brake notification, automatic driving, traffic information sharing, safety collision avoidance, etc.	DSRC/Cellular communication
V2R	Vehicle identification highway, vehicle driving, highway entrance and exit identification, etc.	DSRC/Cellular communication
V2P	Car entertainment, navigation, payment applications between cars and drivers, passengers, and safety collisions between vehicles and pedestrians	DSRC/Cellular communication
V2I	Information interaction between vehicles and roads, signal lights, obstacles, surrounding buildings and other pavement facilities	DSRC/Cellular communication
V2N	Communication between the car and the Internet, using the car seat mobile communication terminal for web browsing, entertainment navigation, search, uploading and downloading, etc.	Cellular communication

network as the mess in which nodes (cars, intelligent traffic lights, etc.) can capture,transmit and forward signals. The traffic condition of one mile away can be collected by a jump of 5-10 nodes on the network. the vehicle can send 10 locations, speeds, directions and other information within each second with V2V communication. A vehicle can detect the running trajectory of another vehicle, such as whether another vehicle wants to grab a red light, or whether it will suddenly turn, etc., thereby avoiding a collision accident. V2V communication increases the safety of car consumers using vehicles and saves travel time. The main use environment of V2V communication is in the highway environment, and its vehicles have various driving states: anchor parking, traffic jam ahead, vehicle formation, follow-up, and lane change. Highway anchor parking is a very dangerous scene. The speed of the rear vehicle is very fast. The braking distance is about 60-80 meters. The braking distance of the large truck is longer. It is also very dangerous to place the ''tripod'' in the reverse direction along the road. At this time, the V2V will come in handy, telling the rear of the vehicle how many meters from the front of the vehicle by multicast, and how many meters need to be decelerated. In the scenes of heavy fog, blizzard, and freezing, dozens or even hundreds of vehicles are colliding with each other. V2V communication can broadcast the accident point and relative distance through V2V 500-800 meters ahead to remind the rear vehicle to decelerate and brake according to the distance.

From the perspective of reducing the probability of accidents, reducing social insurance costs, reducing vehicle maintenance costs, reducing economic losses, and improving traffic management efficiency, investment is relatively economical, and V2V communication is also the cornerstone of unmanned technology development.

2) V2R

V2R needs to be divided into two scenarios: the first is the highway, and the second is the urban road. The expressway is the first step, and the urban road needs to be based on the increased identification and classification of the urban road to achieve more complex data judgment and data communication.

V2R on a highway is relatively easy. First, there is a possibility for clear identification, there are no sidewalks, traffic lights, pedestrians and other complex road conditions, and thus, only the highway, vehicle driving conditions and highway entrance and exit signs need to be identified. Second, high-precision maps have already laid out the highway in advance. A high-precision map can be accurate to the centimeter level, which is very helpful for the route planning and automatic driving of a vehicle. Finally, the realization of V2V as soon as possible can also help the rapid development of V2R. Each car can share the collected road information and pass this information to the cloud to promote the rationalization and perfection of road information.

3) V2I

The I in V2I refers to all the infrastructure encountered during the vehicle's travel [108]. This I include utility poles, buildings, overpasses, bus stops, tunnels, traffic lights and much more. Because highways are divided into highways, urban roads, ordinary country roads, etc., the road conditions of different roads vary greatly, the environment is different, the speed is different, and the traffic volume is different. Therefore, the demand for V2I is also very different. In the context of highways, the emphasis is on safety services in fast driving. Urban roads focus on the protection of vulnerable groups, especially pedestrians. There are many scenes on ordinary country roads, including plain roads, mountainous mountain roads, next-door roads, and rural roads. Ordinary roads have a need for the safety of pedestrians and the safety of pedestrians. The congestion cost of urban roads is very high, and the annual global congestion cost has reached trillions of dollars. Therefore, if the city can be interconnected with vehicles through roadside unit facilities, vehicle violation detection systems, traffic signal control systems, etc., it can greatly enhance the ability of the traffic efficiency of reducing the vehicle the cost of congestion. When the visibility of the intersection is poor, the V2I can get the information of the traffic light and vehicle information, and submit the massage to the Automotive Brain system (AB), which analyzes the Automotive Operating System (AOS) and decide whether to continue driving or to wait.

4) V2P

V2P (Vehicle-to-pedestrian) communication can facilitate Vulnerable Road User (VRU) security by allowing vehicles and pedestrians to exchange information [109]. Through a cooperative intelligent transportation system, the security of VRU can be enhanced in various ways, and the sensing system protects VRU based on the embedded sensor. Traffic accidents are the result of a combination of people, cars and roads. The responsibility of being the driver of the driver of the vehicle cannot be ignored. After seeing the pedestrian, the driver can take appropriate avoidance measures to prevent the accident from being closely related to the speed of the vehicle at that time. Therefore, it is of great significance to study the safe driving speed of the vehicle to effectively avoid pedestrians and prevent traffic accidents.

Whether or not it is a mobile phone, especially a wearable device, interactive communication with the V module in the vehicle can be realized. That is, the P module is an effective tool for realizing V2I in LTE-V because all P (active people, people only move for a purpose) are equipped with a long distance device at any time. Modules that can be interconnected ensure that the vehicle is ready to receive. The vehicle can be effectively supplemented with a camera, radar sensor and other identification technologies to effectively implement V2P.

5) V2N

V2V without network assistance has many problems with congestion, interference management and coverage. These defects have been verified many times in the system analysis of IEEE 802.11p. The more feasible solution is to provide V2V direct communication capability, while the cellular network provides assistance. Then, V2N communication greatly relieves the communication pressure in the hotspot area and ensures the stability of the vehicle network communication [110].

V2N can also be used for map updates, traffic management, and providing the roadside environment beyond a certain distance. In addition, car manufacturers also hope to collect vehicle driving and sensor information through V2N and carry out big data analysis in the network, which is closer to the 5G mMTC scenario. With the arrival of 5G, the capability of V2N will be further strengthened and more helpful in the acquisition and transmission of automatic driving information. Around the car driving and safety-related "net", V2N acts as an extension of the traditional sensor, and with V2V, combined with V2N's assistance, security and stability will be greatly enhanced by the 5G network. For wireless networks, after a car is connected to the Internet, no matter which technology is used in the vehicle communication, the large amount of data generated by the vehicle needs to be shunted by V2N. The sensor senses various types of information and that more precise information needs to be carried by V2N.

B. INTELLIGENT TRANSPORTATION SYSTEMS IN THE IOT ERA

As early as the popularity of 3G/4G, we tried to combine mobile communication technology with travel services to explore the possibility of intelligent transportation systems. However, the upper limit of 3G/4G data transmission rate and the existence of delay limit the further development of intelligent transportation. 5G communication technology has a data transmission rate greater than 10Gbps and a delay of less than 1ms. With the development of 5G technology, the problems encountered in the 3G/4G era will be solved. These provide unlimited imagination for the development of the next urban smart transportation system.

The two major themes of intelligent transportation development in the future are road safety and the mitigation of traffic congestion. Future traffic will be smart to provide safe, efficient and comfortable mobility. As an important carrier of traffic, cars are also the core link in the transportation system. The intelligentization and networking of automobiles have become an important direction for future development. The intelligentization of automobiles will help to improve driving control and safety performance. The networking of automobiles is the basis for realizing traffic management and information services and for realizing smart automobiles. Intelligence provides important support. It is important to actively deploy innovative technologies and applications for car networking and autonomous driving and promote the development of intelligent and networked vehicles, which are of great significance in accelerating industrial transformation and upgrading, building industrial agglomeration and effectively solving energy consumption, environmental pollution and traffic congestion. Countries and regions such as the United States, Europe and Japan have introduced relevant strategic plans to present car networking and autonomous driving development goals. With an increasing number of vehicles and traffic jams, urban traffic management is becoming a serious problem. In [97], Liu *et al.* proposed a new four-tier urban traffic management architecture that combines VANET, 5G, SDNs, and MEC. This novel architecture shows significant potential for mitigating traffic congestion.

Developed countries and regions such as the United States, Europe, and Japan began to develop V2X technology research in the late 20th century or early 21st century and established a relatively complete technical standard system. Currently, the V2X system is based on IEEE 802.11p. In addition, the United States, Europe and Japan have identified a dedicated wireless frequency band for intelligent transportation systems. The United States uses the 5850 MHz-5925 MHz frequency band, the European Union uses the 5855 MHz-5925 MHz frequency band, and Japan uses the 755.5 MHz-764.5 MHz frequency band. In early 2015, 3GPP officially launched the technical requirements and standardization studies based on LTE-V2X. At the beginning of 2015, 3GPP SA1 (Demand Working Group) carried out LTE-V2X demand research, which was completed in March 2016. At the beginning of 2016, 3GPP SA2 (Architecture Working Group) started WI, and it is expected to complete standardization by the end of 2016. In terms of LTE-V2X research, the 3GPP RAN (Wireless Technology Working Group) launched the SI project in July 2015, which was completed in June 2016. The WI project for V2V communication was started in early 2016, and then the V2I project was launched in June 2016. The WI project is expected to complete the standardization of V2V and V2I in September 2016 and March 2017, respectively. China supports LTE-V2X technology research, development and industrialization. LTE-V2X is a V2X-specific short-range communication technology based on LTE. In China, many relevant research institutions, enterprises and organizations actively cooperated to jointly promote the development of the V2X standard system and standard specification as well as research on dedicated wireless frequency bands. Because the automotive industry is using 5G connectivity technology, 5G networks will achieve commercial operations faster. Networked self-driving trucks have obvious appeal, and vehicle queues will soon become a common sight on highways and roads. With these networks, manufacturers will be able to implement V2X connectivity, and trucks will be able to be connected to other vehicles, infrastructure, and even pedestrians, which is key to changing transportation modes, enabling coordinated driving, and ultimately enabling automated driving safety applications. In 2017, the European Union proposed the ITS Development Action Plan and the EU Future Transportation Research and Innovation Program to develop vehicle road coordination, active safety, road safety systems and traffic informationization in the field of traffic safety [91]. In 2015, the Chinese government's ''China Manufacturing 2025'' and ''Internet Plus'' development strategies were successively put forward, and the transformation and upgrading of the automobile industry and structural optimization adjustment were vigorously promoted [93]. The smart transportation strategies of various countries are as follows:

1) ITSs IN THE UNITED STATES

The United States is in the front-runner status in the world with its research level, and experiments on large-scale in-vehicle interconnections have achieved certain results. In recent years, a series of studies have been carried out in the United States [89], including the study of safety between vehicles, vehicle environment application research, and vehicle environment data research. In 2011, the United States launched the connected vehicle safety pilot program [114]. In 2013, its subproject, Safety Pilot Model Deployment, was carried out, which tested mainly a real-life scenario [115]. The purpose of the project is to obtain user data in a real driving environment, study whether the in-vehicle network can effectively assist participants in a state of high concentration, and study the role of the vehicle unit in the in-vehicle network. Through these three aspects of research, we provide empirical support for the decision of the US transportation sector in 2014. The project built a test environment in Ann Arbor, Michigan, with roadside units on both sides of a 73-mile road using more than 2,800 vehicles with onboard communication units. In this project, vehicle and roadside units from different manufacturers were used to test different V2V and V2I applications and observe the user's response.

The technology of Vehicle networking will provide drivers with the tools they need to predict potential collisions and significantly reduce the annual loss of life. The technology of V2V Communication can make the performance of the vehicle systems improved, which helps to save lives. Therefore, as of 2017, the NHTSA is committed to improving the life-saving potential of automotive technology. To seriously reduce the possibility of road accidents in the United States, the Department of Transportation issued a report which concern about the Common Rule of the customized Rule, which prepare to offer the new light vehicles V2V communication technology, and a communications platform for vehicles that need to transmit and receive standardized messages and remain open to testable technologies.

2) ITSs IN EUROPE

Due to the particularity of Europe, the EU recognizes that the successful implementation of a European ITS must rely on coordination and cooperation at all levels of the European Union. In July 1996, the EU officially adopted the ''Trans-European Transport Network (TEN-T) Development Guide'', which marked the beginning of a series of measures to promote the development of the information society through traffic information and to develop cross-border services. As an important part of the EU's transport policy, the guide specifically refers to information and communication infrastructure and traffic information services for traffic management, further affirming the role of ITSs in improving road traffic efficiency, improving safety and achieving sustainability [113].

In 2001, the European Union incorporated an ITS program into the ''Europe 2010 Transport Policy: Time for Decisions''. To create an integrated market for ITS products and services across Europe, the proposal for realizing an ITS integrated market was put forward, emphasizing ''ITSs in many aspects''. A Lieutenant General will become an integral part of European transport, especially as the Galileo plan is currently a key requirement in Europe [105].

Synergistic intelligent transportation in the European Union refers to the communication between road vehicles and other vehicles, traffic signals, roadside infrastructure and other road users through technology. With the accumulated information available, collaborative intelligent transportation systems have a great potential for improving road traffic safety and reducing traffic congestion. At the same time, considering the expected good returns and the low overall configuration cost, there is great interest in speeding up the promotion and application of the system within the EU. According to the report, a social benefit of 3 euros can be obtained for every 1 euro invested in the development of a collaborative intelligent transportation system. The European Commissioner in charge of transportation said that the digitization of traffic will help create new economic growth points and make traffic smarter. This report shows that the EU has taken an important step in the development of a collaborative intelligent transportation system. It is expected that more results will be achieved this year. It is hoped that by 2019, connected vehicles will be seen on the roads in the EU.

C-ITS is a major component of the future smart city ecosystem. C-ITS improves the environmental awareness and environmental adaptability of vehicles, and is a reliable guarantee for vehicles to achieve safe and rapid autonomous navigation, which helps vehicles to provide safer and more convenient travel modes. Considering the significant challenges of increased mobility and the important contribution of intelligent traffic to smart cities in the future, the orchestration-based service portfolio provides a promising approach to mobility and intelligent traffic [94]. C-ITS provides high-precision positioning of large-scale vehicles on the road in real time, which helps to fine-tune the characteristics of traffic flow and precise control, which is conducive to real-time monitoring of urban traffic and traffic guidance control. C-ITS enables the vehicle to realize the automatic identification of abnormal behavior and collision warning based on the current position information and micro-motion recognition such as lane change, overtaking, and motion direction correction. By accessing massive amounts of cloud data, vehicles will benefit from cloud-based decision making and smarter decision making by coordinating a large number of services. Due to the strong influence of vehicle connectivity and traffic safety cooperation, stakeholders, including government, industry and academia, have been encouraging and promoting the development and standardization of cooperative intelligent transportation systems (C-ITS) [96]. The C-ITS vehicle is equipped with a device for two-way communication, and the sensor is capable of capturing and reporting vehicles in the surrounding traffic and environment. More specifically, they relate to vehicle integration systems [95] designed to provide drivers with more comfortable and safer driving.

3) ITSs IN JAPAN

Japan is one of the first countries in the world to launch ITS research. In 1973, when the Ministry of International Trade and Industry began to develop the CACS (Comprehensive Automobile Control System), it initiated research and development activities for ITSs. In the mid-1990s, various provincial departments in Japan moved from R&D projects that promoted joint cooperation for the development of ITSs. After the mid-1990s, the development of ITSs began to be promoted at the highest level of national policy. The Basic Policy for the Advancement of a Highly Information and Communication Society was officially adopted by the Cabinet of Ministers in Japan in June 1995. In the ''public sector informatization'' section, one of the five research areas of ''Basic Policy'', road traffic informationization is listed as the first priority [106]. On the basis of the above basic guidelines, in the same year, the four provinces and one hall (a postal province, construction province, transportation province, province of general production, and police department) related to ITS research jointly developed and published information on roads, transportation and vehicles. The implementation of the policy has demonstrated the positive attitude of the Japanese government to the promotion of ITS development at home and abroad and proposed nine areas of Japanese ITS research and development [106]. In July 1996, the four provinces and one hall jointly formulated the ''Promoting ITS Overall Conception'' proposal, which has enormous significance for the promotion of Japanese ITSs. It proposes the basic concepts of Japan's long-term vision of ITSs, an ITS development and implementation plan, and ITS functional goals for the next 20 years. It also defines 20 services for ITSs in nine areas and clarifies the cooperative development of production, learning, government, and business mechanisms. It paved the way for the development of ITSs as a basic national policy, and Japan plans to gradually implement these 20 services by 2015 [160].

In recent years, ITS development has been an increasing priority in Japan's basic national policy. ITS development is reflected in all of the important policies of the Japanese government recently released through the IT society, such as the 2000 Basic Law on the Formation of an IT Society, the E-JAPAN Strategy in 2001, and the E-JAPAN Priority Policy Plan in 2001. The locations of key elements in the IT community [112], especially in the E-JAPAN Priority Policy Plan, suggest that ITSs and VICSs are among the most important components of their third-generation information communication system and propose policies to strengthen ITS R&D. In 2013, the Cabinet Office of Japan led the ''Declaration on the Creation of the World's Most Advanced IT Countries'' [92] and promoted the development of an automated driving system. In 2017, the Japanese government will jointly launch the testing of automated vehicles with automakers in remote areas with highways and low traffic, thus launching an intelligent transportation system.

The Japanese government plans to commercialize this service by 2020. In 2020, Tokyo, Japan, will host the 32nd Summer Olympic Games, so this year is very important for Japan. Japan wants to show the world the power of next-generation technologies such as autonomous vehicles and green energy-efficient powertrains. The Japanese government and automakers hope to popularize autonomous driving technology nationwide around 2025. Japan hopes to significantly reduce the occurrence of traffic accidents through the promotion and popularization of self-driving cars and strives to achieve a goal of nearly zero traffic accidents by 2030.

VI. CONCLUSION AND FUTURE PROSPECTS

Globally, the significant impact of V2X on road transport systems has been recognized by participants such as different car manufacturers and telecommunications companies. At the same time, a series of more mature research proposals and proposals have been given in the industry. In the future, high-speed, low-latency, and large-bandwidth information networks will enable the rapid development of industries such as cart networking and autopilot. To date, most countries have allocated dedicated radio spectrum to support V2X communications and to facilitate the development of corresponding V2X security technologies and ITS applications. Based on V2X communication, vehicles can quickly detect potentially dangerous and uncomfortable road conditions and communicate them to other vehicles, prdestrians on the roadside, and wayside nodes to further disseminate massage primarily to improve road safety. In addition, V2X communication responds quickly to sudden traffic conditions, reducing the time spent in crowded traffic and providing additional benefits such as reduced energy consumption and vehicle emissions. As a key technology in 4G and 5G communication systems, device-to-device (D2D) and vehicle-to-everything (V2X) communication can make our system performance improved, user experience enhanced and cellular communication applications extended. The future is receiving widespread attention. 5G high / ultra-high density networking, low device energy consumption greatly reduces signaling overhead, solves bandwidth and delay related problems, and 5G delay reaches millisecond level, meeting low latency and high reliability Sexual demand has solved many problems and challenges faced by the current car network, enabling OBU to achieve better performance under high-speed mobile, becoming the biggest breakthrough in the development of car networking.

This paper analyzes and organizes the literatures of DSRC and cellular parallel hybrid networking technologies for 5G communication technology development from three aspects: Node Performance, local Network and Internet of Things (IoT). At present, in the development of D2D and V2X, there are difficulties in which multiple interests are not easy to coordinate, making them less suitable for scale. This also leads to the phenomenon that the existing D2D/V2X research is out of touch with the actual application, which becomes the bottleneck for their further development. How to break through this bottleneck has not seen relevant research. In the future, research on the deployment and application of D2D/V2X architecture in real cellular networks requires further practical research.

ACKNOWLEDGMENT

This article was written during the period that the first author worked as a visiting scholar in the United States. Thanks to the professors and students of Lawrence Technological University in the United States for their supports and advice for the work.

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