Survey on the Internet of Vehicles: Network Architectures and Applications

Baofeng Ji, Xueru Zhang, Shahid Mumtaz, Congzheng Han, Chunguo Li, Hong Wen, and Dan Wang

Abstract

The vehicular ad hoc network (VANET) has been widely used as an application of mobile ad hoc networking in the automotive industry. However, in the 5G/B5G era, the Internet of Things as a cutting-edge technology is gradually transforming the current Internet into a fully integrated future Internet. At the same time, it will promote the existing research fields to develop in new directions, such as smart home, smart community, smart health, and intelligent transportation. The VANET needs to accelerate the pace of technological transformation when it has to meet the application requirements of intelligent transportation systems, vehicle automatic control, and intelligent road information service. Based on this context, the Internet of Vehicles (IoV) has come into being, which aims to realize the information exchange between the vehicle and all entities that may be related to it. IoV's goals are to reduce accidents, ease traffic congestion, and provide other information services. At present, IoV has attracted much attention from academia and industry. In order to provide assistance to relevant research, this article designs a new network architecture for the future network with greater data throughput, lower latency, higher security, and massive connectivity. Furthermore, this article explores a comprehensive literature review of the basic information of IoV, including basic VANET technology, several network architectures, and typical application of IoV.

Introduction

With the development of communication technology, mobile networks and the automotive industry and cars are no longer just simple transportation tools. Vehicles equipped with smart devices such as wireless sensors, onboard computers, GPS antennas, radar, and so on can collect and process large amounts of data while enabling information interaction between vehicles. The development of automobiles is transforming from an era of providing traditional transportation services to an intelligent era [1].

The concept of the vehicular ad hoc network (VANET) was first proposed at the International Telecommunication Union — Telecommunication Standardization Sector (ITU-T) Automotive Communications Standardization Conference in 2003. VANET, using vehicles as mobile nodes or routers, is the application of the mobile ad hoc network (MANET) in the transportation field. The main purpose is to achieve direct communication between vehicles (V2V) and communication between vehicles and roadside fixed infrastructure (V2I) [2, 3]. A VANET relies on the transportation department to manage the roadside unit (RSU) and the onboard unit (OBU). Each car is equipped with an OBU as a transmitter to communicate with other vehicles on the road. The RSU is installed on the street to enable communication between the vehicle and the infrastructure.

However, VANET has not been widely used and has not brought great commercial value for a long time. The main reasons are unstable network service quality, incompatibility with personal communication devices, and lack of the the ability to process big data. Vehicles and other communication devices are often randomly connected to the network. The mobile network it constructs is a temporary network with limited coverage [4]. It cannot meet the demand for stable communication between a large number of high-speed mobile vehicles, so it can only be applied to small-scale short-term applications and services. Especially in the urban traffic environment, road congestion, buildings blocking signals, and complex urban road networks further affect the practical application of VANET.

In the fifth generation (5G)/beyond 5G (B5G) era, the number of communicable things is growing, and the concept of a common network framework including all existing heterogeneous networks is being reshaped. A large number of communicable devices in our daily life are gradually being interconnected, and the era of the Internet of Things is coming [5]. It is predicted that by 2020, there will be 25 billion communicable devices connected to the network.

At the same time, the Internet of Things is introducing intelligent concepts into a variety of existing research areas, such as smart healthcare services, smart homes, smart industries, smart communities, and intelligent transportation systems (ITS). In this era, traditional VANET

Baofeng Ji (corresponding author) is with Henan University of Science and Technology, the LAGEO of Institute of Atmospheric Physics, Chinese Academy of Sciences, and the University of Electronic Science and Technology of China; Xueru Zhang and Dan Wang are with Henan University of Science and Technology; Shahid Mumtaz is with the Institute of Telecomunications, Aveiro, Portugal; Congzheng Han is with the LAGEO of Institute of Atmospheric Physics of Chinese Academy of Sciences; Chunguo Li (corresponding author) is with Henan University of Science and Technology and Xizang Minzu University; Hong Wen is with the University of Electronic Science and Technology of China.

Digital Object Identifier:
10.1109/MCOMSTD.001.1900053

2471-2825/20/$25.00 © 2020 IEEE

Authorized licensed use limited to: University of Science & Technology of China. Downloaded on December 03,2020 at 04:16:33 UTC from IEEE Xplore. Restrictions apply.

technology has also accelerated the pace of transformation. With the vehicle as the carrier, the concept of the Internet of Vehicles (IoV) connected via wireless networks has emerged. The IoV application environments can fuse the vehicle-to-everything (V2X) and big data or artificial intelligence (AI) to enhance the future 6G network. A general IoV system can be seen in Fig. 1.

IoV, also known as V2X, as its name suggests, hopes to realize information interaction between the vehicle and all entities that may affect the vehicle, with the aim of reducing accidents, alleviating traffic congestion, and providing other information services. V2X mainly includes vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-roadside (V2R), vehicle-to-sensors (V2S), and vehicle-to-pedestrian (V2P). In addition, unlike VANET, the implementation of IoV relies mainly on two technologies, namely vehicle networking and vehicle intelligence. The vehicle networking consists of three parts: VANET, onboard information service, and mobile network. VANET represents short-range communication between vehicles. Onboard information service refers to the ability of information exchange between vehicles to provide remote positioning, remote diagnosis, navigation and other information services. Mobile networks mean that every car can be used as a powerful mobile terminal. Vehicle intelligence refers to using advanced technologies, such as deep learning, big data analysis, cognitive computing, and artificial intelligence, to achieve information sharing between vehicles and people, and vehicles with each other, the environment, or infrastructure. This provides a guarantee for a wider range of communications.

In this context, this article gives a comprehensive overview of the related research and technology development status of IoV. The main features and contributions of this article are as follows:
- To provide the basic technical background of IoV to help researchers understand the concept, models, and applications of IoV
- To summarize the development status of network architectures in IoV and propose a new network architecture

The structure of this article is organized as follows. At first, we briefly introduce the development background of IoV, VANET technology, and the technical advantages of the current IoV. Next, we summarize the network architecture of IoV and propose a car-road-cloud collaborative network architecture. Then typical applications of IoV are discussed. Finally, we conclude the whole article.

The Background and Advantages of the Internet of Vehicles

The development of IoV is derived from VANET technology. In order to better understand the concept of IoV, this section outlines the VANET and analyzes the advantages of IoV.

Overview of VANET

With the development of wireless communication technology, the realization of communication between vehicles has gradually become the research focus in intelligent transportation systems. Therefore, the concept of V2V and V2R communication has emerged gradually, which is known as the vehicle self-organizing network. Its presence allows vehicles to communicate with the help of pre-established infrastructure, as well as independent communication between vehicles. This section introduces the main communication components, communication types, and drawbacks of VANET.

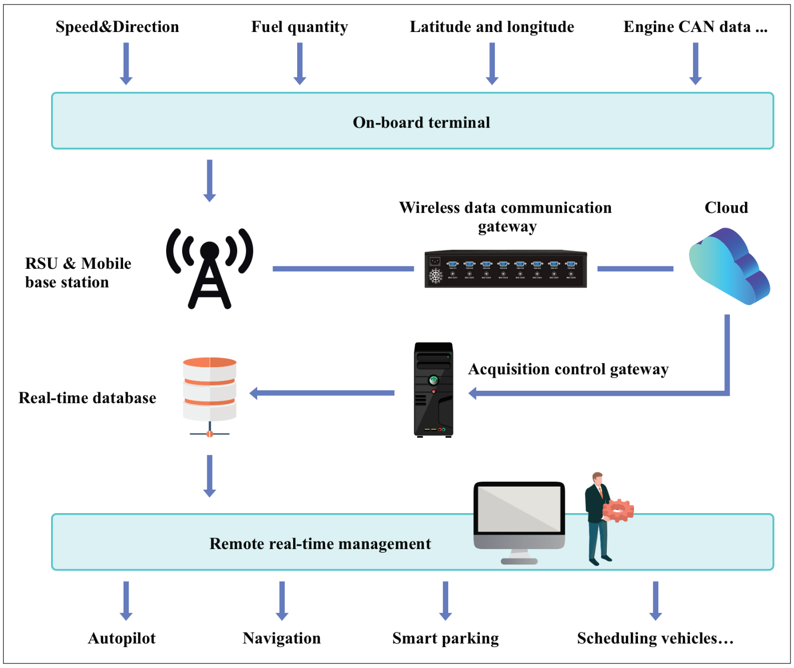

Figure 1. System structure of IoV.

The VANET basic communication system consists of three main components: the onboard unit (OBU), the application unit (AU), and the roadside unit (RSU):
- The OBU consists of a number of electronic components, including read/write memory for storing and retrieving information, user interface, a dedicated interface connected to other OBUs, and network devices for dedicated short-range communication (DSRC). Its main functions are to achieve radio access, geographic routing, network congestion control, reliable transmission of messages, and data security. Each vehicle is equipped with an OBU and a set of sensors for collecting and processing useful information including speed, acceleration, fuel quantity, and more. The information is then sent to a nearby RSU or other vehicle over a wireless network based on the IEEE 802.11p standard. In addition, it can provide communication services for AU.
- The AU is a device inside the vehicle that can run certain applications. It can be either a dedicated device for a secure application or a regular device (e.g., a personal digital assistant, PDA). The AU can only communicate with the network through the OBU.
- The RSU is a communication device installed beside the road or at a designated location. For example, a pre-established infrastructure or a bus that can travel regularly according

Authorized licensed use limited to: University of Science & Technology of China. Downloaded on December 03,2020 at 04:16:33 UTC from IEEE Xplore. Restrictions apply.

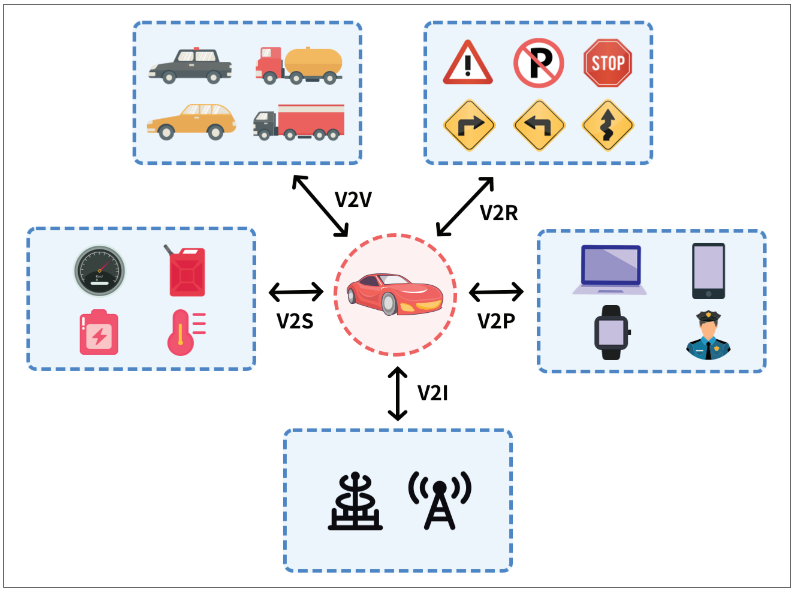

Figure 2. The five types of communication models in IoV.

to a designated route can be used as an RSU to assist communication between cars on a road [6]. An RSU uses DSRC technology to communicate with the OBU. Its main function is to extend the communication range by forwarding information to other RSUs or OBUs, to provide local communication for passing vehicles, to serve as a source of information in V2I communication, and to provide information such as current road safety for vehicles. The OBU can access the Internet through the RSU.

The communication model of VANET can be divided into three categories, which are closely related to the three main components of VANET. They are onboard communication, V2V, and V2I:

- The onboard communication is realized by the OBU and the AU, where the OBU provides a communication link for the AU, thereby ensuring the operation of various onboard applications.
- Communication between vehicles is an important part of the ITS. Vehicles can use the OBU to form a MANET to communicate with each other. Vehicles can broadcast useful information to each other, such as emergency braking, collision detection, and traffic status information, thereby improving user travel efficiency. In addition, the mobile vehicle can also act as a relay node to assist the source vehicle in forwarding data to the destination vehicle, which will further expand the communication range.
- In general, V2I communication is realized by wireless access technology (WAVE). The vehicle establishes a connection with the RSU to enable information exchange between the vehicle and other networks such as the Internet. This not only expands the communication range but also provides drivers with more comprehensive information on transportation and environment. It ensures the safety of pedestrians and drivers and improves the efficiency of the traffic management system.

Advantages of the Internet of Vehicles

Safeguarding traffic safety, improving travel efficiency, and reducing pollutant emissions are the original intentions of researching VANET technology. However, due to the emergence of many problems in the commercialization process, even the developed countries have only used the most basic VANET technology in the past 20 years. The practical application of VANET technology has been ineffective for the following main reasons:

- Failure to work with other networks causes the vehicles in the ad hoc network to lose network services once they are disconnected. Therefore, VANET cannot guarantee continuous and stable communication.
- Incompatible network architectures have prevented many current communication devices from communicating with VANET.
- The limitations of computing ability and storage space, as well as the lack of cloud computing capabilities, have made many intelligent applications impossible to implement.
- The accuracy of each application service is low, because VANET only calculates and processes localized traffic data information.

On this basis, we need to develop more reliable and market-oriented vehicle communication technology. The emergence of IoV technology makes up for the shortcomings of VANET and will bring bright prospects for the development of smart transportation systems in the future. We analyzed the advantages of IoV from multiple perspectives:

- The heterogeneous network architecture of the IoV realizes the cooperation between the vehicle communication network and other communication networks.
- Most communication devices in daily life are compatible with IoV.

The mutual cooperation of different types of networks and the emergence of multiple communication models (V2S, V2V, V2P, V2R, V2I) have realized the sharing of big data and the reliability of various communication services, and at the same time expanded the application range of automotive communication. This is one of the most important advantages of IoV. Specifically, V2S represents onboard sensor communication via Ethernet and Wi-Fi. V2V and V2R indicate that vehicles and the vehicle or RSU can communicate via WAVE. V2P represents communication between a vehicle and a person's handheld terminal devices using Apple's CarPlay, the OAA Android system, or NFC. V2I represents communication between vehicles and infrastructure via Wi-Fi or LTE/4G/5G/B5G/(as can be seen in Fig. 2).

- The improvement of information processing capabilities and the development of cloud computing and AI technology enable vehicles to autonomously choose to access better-performing networks to ensure stable network connectivity.

Network Architectures of IoV

Overview of Existing Network Architectures

In the past few years, many researchers have proposed the design scheme of the IoV network architecture. Table 1 summarizes the existing IoV architectures.

Authorized licensed use limited to: University of Science & Technology of China. Downloaded on December 03,2020 at 04:16:33 UTC from IEEE Xplore. Restrictions apply.

Existing architectures	Features
(2017) Zhisheng Niu *et al.*	[1] Three-dimensional (ground communication network, adjacent space platform, aerial satellite network)
(2018) National Vehicle Network Industry Standard System Construction Guide	Three layers (perceptual layer, network layer, application layer)
(2015) Kazi Masudul *et al.*	[7] Six elements (tNote message, OBU , RSU , home base unit , tNote cloud, and user interface)
(2016) Abdullah *et al.*	[2] Three elements (cloud, connection, clients)
(2018) LI-MINN *et al.*	[8] Seven elements (identification layer, physical objects layer, inter-intra devices layer, communication layer, cloud services layer, multimedia and big data computation layer, and application layer)
(2017) Tao Lei *et al.*	[9] Four layers (vehicle network environment sensing and control layer, network access and transport layer, coordination computing control layer, application layer)
(2019) Kai Liu *et al.*	[10] Four layers (data layer, virtualization layer, control layer, application layer)
(2016) Kaiwartya *et al.*	[11] Five layers (perception layer, coordination layer, AI layer, application layer, business layer)
(2018) Min Chen *et al.*	[12] Five layers (sensing layer, communication layer, cognition layer, control layer, application layer)
(2017) Ashish Nanda *et al.*	[13] Seven layers (user interface layer, data acquisition layer, filtering and pre-processing layer, communication layer, control and management layer, processing layer, security layer)
(2018) Chaker *et al.*	[14] Connecting SIoV and online social networks

Table 1. The existing IoV network architectures.

For the application requirements of intelligent traffic management, combined with the outstanding advantages of a spatial information network in terms of coverage, space-time reference, situational awareness, and so on, Zhisheng Niu *et al.* proposed an air-ground integrated vehicular network architecture [1]. The architecture is based on the cooperation between the terrestrial communication network and the adjacent space platform, supplemented by the air satellite network. This extends the traditional two-dimensional road network into three-dimensional space. The air-ground integrated vehicle network will be able to support future diverse automotive applications.

In 2018, the National Vehicle Network Industry Standard System Construction Guide pointed out that from a technical point of view, the network architecture of IoV can be divided into three parts: the terminal (sensing layer), management (network layer), and cloud (application layer). The terminal in IoV refers to various terminal devices, including onboard wireless communication terminals, roadside communication facilities, and personal portable communication terminals. Its main function is to collect data, realize the transmission and reception of information between vehicles and other vehicles, and the sharing of traffic information. Management refers to using V2X, DSRC, and other communication technologies to achieve a variety of heterogeneous network connections between vehicles and vehicles, vehicles and roads, and vehicles and platforms. Cloud refers to a comprehensive information and service platform, mainly including business platforms, data platforms, and support platforms. It provides a variety of vehicle networking industry public services and industrial applications.

Designing the network architecture of IoV based on the main elements in the network can more effectively show the meaning and function of IoV as a comprehensive heterogeneous network.

Kazi Masudul *et al.* divided the elements in IoV into six categories [7]: tNote message, OBU, RSU, home base unit (HBU), tNote cloud, and user interface. Based on this, the Social IoV (SIoV) network architecture is proposed. A tNote message is a wrapper for user information, vehicle status, and different types of sensory messages. The OBU plays a key role in the perception and construction of vehicle interaction information. In SIoV, whenever the OBU appears within the communication range of the RSU, the RSU will ask the OBU if it wants to share the social graph of the OBU-OBU. Based on the data sent by the HBU, a home/remote social network can be constructed. The HBU plays an important role in the static network construction of SIoV. tNote cloud is the core infrastructure that preserves all vehicle interaction data and its timestamps. The user interface is further divided into profiles, routes, friends, groups, and subscriptions.

Abdullah *et al.* believe that the three major elements of IoV [2] are cloud, connection, and clients. The cloud is the brain of IoV, which handles a series of services related to intelligent computing. These services in the cloud platform use a reliable connection to access each other. According to the different wireless access technologies, the connections are divided into different types, which are the second largest element of IoV. With the help of network connections, clients can use cloud-based services.

In 2018, Li-Minn *et al.* introduced seven main elements in the Universal IoV (UIoV) architecture [8]and seven corresponding core layers. The Identification Layer is responsible for identifying vehicles and non-vehicle devices in IoV. The physical objects layer collects all the data in the UIoV system and sends the data to the intra-inter devices layer for further processing. In the traditional architecture, there is no intra-inter devices layer. The intra-inter devices layer and the communication layer in UIoV are combined to realize the connection of different heterogeneous objects and networks. Cloud computing and cloud virtualization technologies in the cloud service layer provide hardware computing platforms, infrastruc-

Authorized licensed use limited to: University of Science & Technology of China. Downloaded on December 03,2020 at 04:16:33 UTC from IEEE Xplore. Restrictions apply.

Network architecture design with heterogeneous networks is a challenging problem. Its network features include interoperability, scalability, reliability, and modularity. The design focus is to optimize the number of layers in the network architecture and to enhance the distinction between layers.

ture, and software services for IoV systems. The multimedia and big data layer is responsible for data preprocessing, big data computing, and intelligent transmission. The application layer in UIoV is responsible for providing services and determining the protocols used for messaging.

Tao Lei and co-author also proposed a four-layer network architecture in 2017 [9]. The first layer is the vehicle network environment sensing and control layer; environment sensing is the cognitive basis of the services in IoV. The control of the vehicle and the traffic environment is the basis for the implementation of various services. The second layer is the network access and transport layer, which is mainly responsible for network access, data analysis, and transmission. The third layer is the coordination computing control layer, which has the group intelligence collaborative computing capability and cognitive computing capability; it is mainly responsible for resource scheduling. The fourth layer is the application layer, which provides various services.

Kai Liu *et al.* proposed a new IoV network architecture [10] designed to improve the scalability and reliability of information services while increasing the flexibility of application management. The architecture also contains four layers; the data layer of the architecture includes various nodes with heterogeneous wireless communication interfaces. Due to frequent changes in the topology of IoV, a large amount of information is continuously generated and shared at the data layer. In order to maintain the accurate logic of the underlying resources, the virtualization layer abstracts some nodes into fog nodes and abstracts the network, computing, communication, and storage resources in IoV. The SDN controller of the control layer is responsible for scheduling the abstraction resources of the virtualization layer and communicating with the application layer to implement applications such as data sensing and road safety management.

Network architecture design with heterogeneous networks is a challenging problem. Its network features include interoperability, scalability, reliability, and modularity. The design focus is to optimize the number of layers in the network architecture and to enhance the distinction between layers. The IoV architecture should enable the interconnection of vehicles with heterogeneous networks and other communication devices, and it should also be a service-oriented architecture.

Kaiwartya *et al.* proposed a five-layer architecture [11]. The first layer is the perception layer. The main function of this layer is to collect various information related to vehicles, equipment, environment, and so on by means of low energy consumption and low cost. The second layer is the coordination layer, which is mainly responsible for interoperability and coordination between different networks (WAVE, LTE, and WiFi) and unified information of different structures. The third layer is the AI layer, which is the brain of IoV. Its function is to process, store, analyze, and make decisions on information. The main technologies used in this layer are vehicle cloud computing and big data analysis. The fourth layer is the application layer, which is responsible for providing intelligent services to users. The fifth layer is the business layer, which helps the business development and investment by analyzing the effects of the application.

The network architecture proposed by Min Chen also includes five layers [12]. The sensing layer is responsible for the acquisition and preprocessing of multi-source heterogeneous big data. Different from the previous communication layer, the communication layer in the architecture adopts a cloud/edge hybrid structure to adapt different timelines of different applications. The data cognition engine in the cognition layer processes and analyzes heterogeneous data streams through a variety of cognitive analysis methods (machine learning, deep learning, data mining, etc.). With the support of technologies such as network function virtualization (NFV), software defined networking (SDN), self-organized networking (SON), and network slicing, the resource awareness engine in the control layer is responsible for managing and scheduling network resources. In the application layer, there are mainly two types of services: custom application services and intelligent transportation applications.

Ashish Nanda *et al.* proposed a seven-layer network architecture [13]. The first layer is the user interface layer, which is responsible for information interaction between the user and the vehicle. The data acquisition layer collects data using onboard sensors and RSUs. The filtering and pre-processing layer rejects the useless data in the collected data and then transmits the remaining data to the communication layer for transmission. Control and management are responsible for managing network service providers and making decisions. The processing layer is responsible for processing large amounts of data, making it relevant information required for a variety of applications. All of the above layers are directly managed by the security layer to prevent attacks.

In heterogeneous networks such as IoV, in addition to ensuring communication between vehicles, driver/passenger credit factors must also be taken into account, as they are likely to tamper with the system and prevent normal communication. Therefore, Chaker *et al.* proposed a network architecture that combines IoV with an online social network to assess the honesty of drivers and passengers based on online social network profiles, thus ensuring that the networked users do not have the risk of tampering with the network system [14].

New Architecture for Collaboration of Vehicle-Road-Cloud

The existing network architecture provides a solid foundation for further research. In the context of the rapid development of C-V2X and 5G/B5G technology, this article designs a new network architecture for the future network with greater data throughput, lower latency, higher security and massive connectivity (as can be seen as Fig. 3).

The purpose is to build a vehicle-road-cloud collaborative integrated network. On one hand, it promotes the rapid development of intelligent networked vehicles and provides users with safer and more efficient modes of travel. On the other

Authorized licensed use limited to: University of Science & Technology of China. Downloaded on December 03,2020 at 04:16:33 UTC from IEEE Xplore. Restrictions apply.

hand, it can improve the comprehensive sensing capability of road conditions and dynamic traffic management and control capabilities, laying the foundation for the development of intelligent transportation. The network architecture proposed in this article consists of four layers: the security authentication layer, data acquisition layer, edge layer, and cloud platform layer. The function of each layer is described in detail below, while the main elements of the architecture are given in Fig. 4.

Security Authentication Layer: In IoV, security issues mainly occur during V2V communication and V2I communication [15]. The main function of the security authentication layer is to identify whether the identity of the vehicle and the RSU requesting to connect to the network is legal, in case an illegal vehicle or an illegally set RSU steals or falsifies the information of a legitimate vehicle. A legal car has a unique factory serial number. When the user uses the vehicle communication function, the vehicle serial number and the user login password are required to verify their identity. The security authentication layer first ensures the legitimacy of the vehicle by querying the manufacturer's vehicle serial number database and then verifies the login password to ensure that the communication request comes from the owner. Similarly, the legal RSU also has a unique identity number. After the security authentication layer queries the road traffic management database, the legal RSU can communicate with the vehicle.

Data Acquisition Layer: In order to realize the car-road-cloud collaborative network, it is necessary to realize smart cars and smart roads. Vehicles can obtain surrounding vehicle and environmental data through various OBUs integrated with C-V2X modules. The RSUs on the road can monitor traffic environment data in real time after configuring various sensors, cameras, and radar. The main function of the data acquisition layer is to collect and classify different types of data from different networks and digitize the data to ensure that the data can be transmitted to the edge layer safely and accurately.

Edge Layer: In the future, the analysis and storage of massive data poses a huge challenge to the real-time data processing capabilities of IoV. A large amount of data streams are generated by edge devices; hence, processing and analyzing data through a single cloud computing event will cause serious delays. Therefore, we need to process data closer to the data source. The edge layer uses the edge node, which is a physical device closest to the data source, to perform preliminary filtering and analysis on the collected local data. It publishes data analysis results for local traffic events and real-time conditions of the road in real time, then formulates a local decision making scheme, thereby undertaking some of the tasks of cloud computing and enhancing the computing ability of the cloud data center.

Cloud Platform Layer: The cloud platform is the "smart brain" of IoV. In the cloud platform layer, the cloud data center analyzes the collected global traffic data, then formulates a global strategy and dispatches traffic resources rationally. Specifically, the cloud platform layer can implement the following functions: connection management, data management, assisted automatic driving, path planning, intelligent navigation, and information security. In addition, the cloud platform also has network development capabilities. By counting and evaluating the historical data of various services in the cloud platform, not only can the existing service quality be improved, but also new business channels can be expanded.

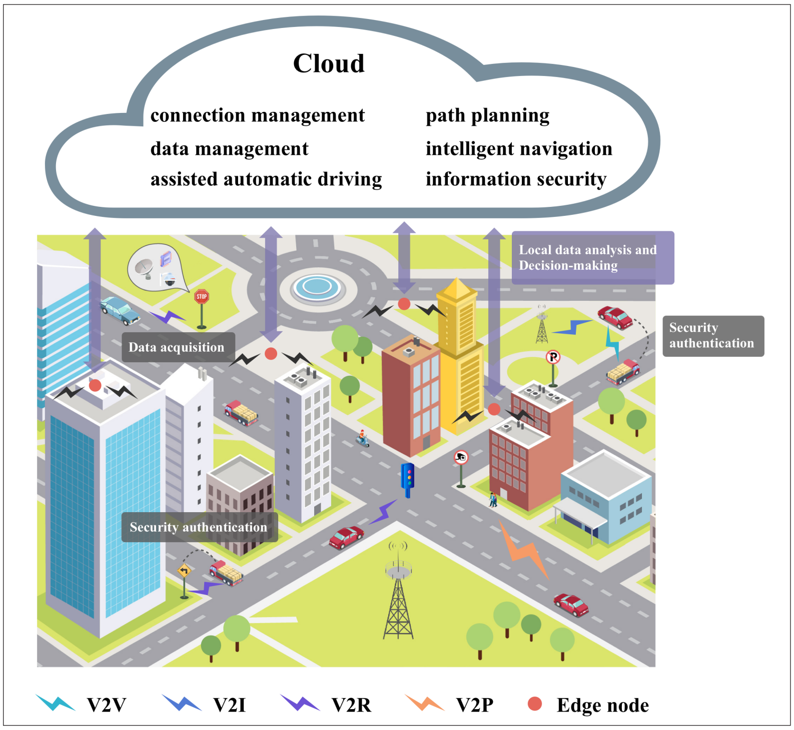

FIGURE 3. Application scenarios of the new architecture.

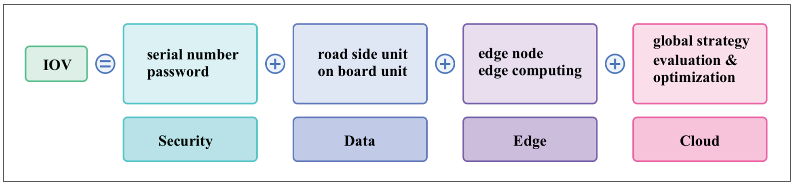

FIGURE 4. The main elements of the proposed architecture.

Typical Application

The field of IoV application is extensive, and the research focus in each country is different. The countries in North America attach importance to safety applications. Europe and Japan have complex road conditions, so there is more research on navigation applications. China is focusing on improving the driver experience. In the future, for the prominent problems in China's urban transportation, the application scope of IoV will be further expanded. V2V and V2I communication technologies provide the basis for the development of various applications. The exchange of information in V2V and V2I communication improves the driving experience and ensures traffic safety. At present, IoV applications can be divided into two categories, namely service applications and safety applications, as shown in Fig. 5.

The most basic IoV application is the onboard service application. The goal of the service application is to improve the experience of the driver and passengers. Service applications can be divided into three categories:

Authorized licensed use limited to: University of Science & Technology of China. Downloaded on December 03,2020 at 04:16:33 UTC from IEEE Xplore. Restrictions apply.

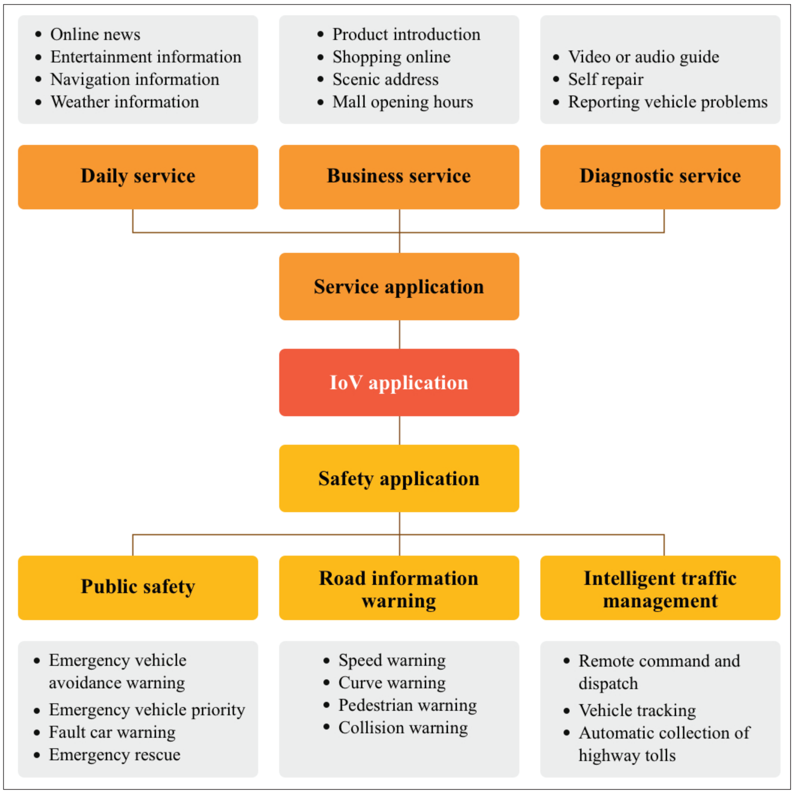

FIGURE 5. Typical application in IoV.

- In the first type of application, the vehicle and the user can obtain various life service information by accessing a network, such as real-time updated weather information, navigation information, entertainment information, and online news.
- In the second type of application, local merchants, scenic spots, and shopping malls can broadcast their addresses, business hours, and product information to the vehicle through the surrounding RSUs.
- The third type of application is mainly to provide diagnostic services for vehicles. Cloud-based maintenance systems can help diagnose driver-reported vehicle problems and provide video or audio solutions.

Safety applications are designed to enhance the safety of drivers, passengers, and passers-by. In these applications, V2S/V2V/V2I/V2P/V2R communication enables information exchange between vehicles and other communicable devices, which will greatly ensure traffic safety, achieve emergency warnings, and avoid accidents. We can specifically classify safety applications into the following categories.

Public safety

Emergency vehicle avoidance warning: The application is used to guide ordinary vehicles to avoid emergency vehicles such as ambulances and fire engines in order to prevent road traffic from affecting emergency vehicles. Using V2V communication, the application broadcasts the speed, direction, and route information of the emergency vehicle to ordinary vehicles, thereby evacuating congestion in advance and ensuring the smooth passage of the emergency vehicle.

Emergency vehicle priority: The infrastructure at the intersection automatically sets traffic lights on the emergency vehicle's driving route to green after receiving the broadcast information of the emergency vehicle, shortening the time for emergency vehicles to reach their destinations.

Faulty car warning: After an accident, a faulty vehicle broadcasts accident-related information to surrounding vehicles and infrastructure to prevent the occurrence of secondary accidents and guide vehicles to adjust their driving routes in time.

Emergency rescue: The vehicle is equipped with an emergency rescue system. When a major traffic accident occurs or a major safety hazard occurs in the vehicle, the emergency button on the vehicle can be triggered manually or automatically to send a distress signal to the control center. After the control center accurately locates the accident vehicle according to GPS technology, the rescue vehicle is dispatched in time. In addition, the rescue system also combines GSM onboard communication and a vehicle backup antenna. During the rescue process, the control center can communicate with the driver in real time and dispatch rescue resources in real time.

Road information warning

The purpose of this type of application is to prompt the driver to pay attention to the road signs and the driving status of the preceding vehicle to prevent accidents. When the vehicle travels to a school, hospital, or corner, the RSU at a roadside sign will send a warning message to the vehicle in advance to remind the vehicle to slow down. When the vehicle travels to an overpass or parking space, the RSU will send a message to alert the driver to the bridge limit height or parking space width. In addition, road information warning applications include collision warning, pedestrian warning, and signal light prompts.

Collision warning has been receiving much attention. The application uses vehicle and roadside infrastructure sensing systems to collect road condition information and operating parameters of various communication devices. Car spacing information, road information, and basic information on the front vehicle are fed back to the driver, guiding the driver to adjust driving behavior in time to ensure safe driving. In recent years, people's research on this kind of application has mainly focused on intelligent intersections. At intersections in the future, no signal indicators will be set. The vehicle will use the positioning system, wireless communication, vehicle sensing, and computing system to realize real-time decision making functions. The vehicles coordinate independently and then pass through the intersections in turn.

Intelligent traffic management

This effectively integrates advanced information technology, data communication transmission technology, electronic sensing technology, electronic control technology, and computer processing technology into the entire transportation management system to establish a real-time, accurate, and efficient integrated transportation management system. The traffic management center can realize remote command and dispatch, vehi-

Authorized licensed use limited to: University of Science & Technology of China. Downloaded on December 03,2020 at 04:16:33 UTC from IEEE Xplore. Restrictions apply.

cle tracking, automatic toll collection, and other functions through the system. It can comprehensively reduce the probability of traffic accidents, alleviate road congestion, and improve road transportation efficiency.

Conclusion

The Internet of Vehicles is a technology with great potential in the 5G/B5G era. This article provides a comprehensive survey on IoV. First of all, we outline the development of IoV. Then VANET technology is introduced in detail, and the advantages of IoV are analyzed thoroughly. Next, we summarize the existing network architectures from the perspective of the number of layers and network elements, and propose a new four-layer network architecture. In addition, we discuss many emerging applications in IoV and divide them into safety applications and service applications. This survey can lay the groundwork for researchers to further understand and investigate the Internet of Vehicles.

Acknowledgment

This work was supported by National Natural Science Foundation of China (61801170,61801435, 61671144); the National Thirteen Five Equipment Research Fund (6140311030207); the National Natural Science Foundation of China (61801170,61801435,61671144); the Project of Education Department Cooperation Cultivation (201602011005,201702135098); the China Postdoctoral Science Foundation (2018M633351); LAGEO of the Chinese Academy of Sciences (LAGEO-2019-2); the Program for S&T Innovation Talents in University of Henan Province (20HASTIT022, 17HASTIT025); the Henan Youth Talent Project; and Young Backbone Teachers.

References

[1] Z. Niu *et al.*," Space-Air-Ground Integrated Vehicular Network for Immersive Driving Experience," *Chinese J. Internet of Things*, 2017.

[2] A. Dua, N. Kumar, and S. Bawa, "A Systematic Review on Routing Protocols for Vehicular Ad Hoc Networks," *Vehic. Commun.*, vol. 1, no. 1, 2014, pp. 33–52.

[3] S. Li *et al.*, "SINR Balancing Technique for Robust Beamforming in V2X-SWIPT System Based on a Non-Linear EH Model," *Physical Commun.*, vol. 29, 2018, pp. 95–102.

[4] K. Song *et al.* "Performance Analysis of Antenna Selection in Two-Way Relay Networks," *IEEE Trans. Signal Processing*, vol. 63, no. 10, 2015, pp. 2520–32.

[5] B. Ji *et al.*, "Joint Optimization for Ambient Backscatter Communication System with Energy Harvesting for IoT," *Mechanical Systems and Signal Processing*, vol. 135, 2019.

[6] D. Kwak *et al.*, "Seeing Is Believing: Sharing Real-Time Visual Traffic Information via Vehicular Clouds," *IEEE Access*, vol. 4, 2017, pp. 3617–31.

[7] K. M. Alam, M. Saini, and A. E. Saddik, "Toward Social Internet of Vehicles: Concept, Architecture, and Applications," *IEEE Access*, vol. 37, 2015, pp. 343–35.

[8] L. Minn *et al.*, "Deployment of IoV for Smart Cities: Applications, Architecture, and Challenges," *IEEE Access*, 2018 .

[9] F. Yang *et al.* "Architecture and Key Technologies for Internet of Vehicles: A Survey," *J. Commun. and Info. Networks*, vol. 2, no. 2, 2017, pp. 1–17.

[10] K. Liu *et al.*, "A Hierarchical Architecture for the Future Internet of Vehicles," *IEEE Commun. Mag.*, vol. 57, no. 7, July 2019, pp. 41–47.

[11] O. Kaiwartya *et al.*, "Internet of Vehicles:Motivation, Layered Architecture Network Model Challenges and Future Aspects," *IEEE Access*, vol. 9, 2016, pp. 5356–73.

[12] C. Min *et al.*, "Cognitive Internet of Vehicles," *Computer Commun.*, vol. 120, 2018, pp. 58–70.

[13] J. Contreras-Castillo *et al.*, "Internet of Vehicles:Architecture, Protocols, and Security," *IEEE Internet of Things J.*, vol. 5, no. 5, 2018, pp. 3701–09.

[14] C. A. Kerrache *et al.*, "TACASHI: Trust-Aware Communication Architecture for Social Internet of Vehicles," *IEEE Internet of Things J.*, vol. 6, no. 4, 2019, pp. 5870–77.

[15] N. Zhao *et al.*, "Artificial Noise Assisted Secure Interference Networks with Wireless Power Transfer," *IEEE Trans. Vehic. Tech.*, vol. 67, no. 2, 2018, pp. 1087–98.

Biographies

Baofeng Ji (fengbaoji@126.com) received his Ph.D. degree in information and communication engineering from Southeast University, China, in 2014. Since 2014 he has been a postdoctorial fellow in the School of Information Science and Engineering, Southeast University. He is also an associate professor at Henan University of Science and Technology. His current research interests include MIMO wireless communications, cooperative wireless communications, and millimeter-wave wireless communications. He has published over 40 peer-reviewed papers, published three scholarly books, holds six invention patents, and has submitted six technical contributions to IEEE standards.

Xueru Zhang (1035044503@qq.com) is a Master's student at Henan University of Science and Technology.Her current research interests include relay coordination, the Internet of Vehicles, and cognitive wireless networks.

Shahid Mumtaz (dr.shahid.mumtaz@ieee.org) received his Master's and Ph.D. degrees in electrical and electronic engineering from the Blekinge Institute of Technology, Karlskrona, Sweden, and the University of Aveiro, Portugal, in 2006 and 2011, respectively. He has over seven years of wireless industry experience and is currently a senior research scientist and technical manager at the Instituto de Telecomunicações Aveiro, 4TELL Group. He is currently a visiting researcher with Nokia Bell Labs, Murray Hill, New Jersey. He is the author of 4 technical books, 12 book chapters, and more than 150 technical papers in the area of mobile communications.

Congzheng Han [SM] (c.han@mail.iap.ac.cn) received her Ph.D. degree in electrical and electronic engineering from the University of Bristol, United Kingdom, in 2008. She worked at the University of Bristol, Toshiba European communication technology research laboratory (project cooperation), U.K. mobile communication virtual research center, and U.K. telecom regulatory authority. Her main research fields include wireless LAN, multi-carrier transmission technology, MIMO, multi-user transmission, wireless resource optimization, opportunistic scheduling algorithms, location information aided communication, green energy saving communication, British and European communication standards, electromagnetic wave energy acquisition and storage technology, and atmospheric observation technology.

Chunguo Li (chunguoli@seu.edu.cn) received his B.S. degree in wireless communications from Shandong University in 2005, and his Ph.D. degree in wireless communications from Southeast University, Nanjing, in 2010. From 2012 to 2013, he did postdoctoral research at Concordia University, Montreal, Canada. Since 2013, he has been with DSL Laboratory supervised by Prof. J. M. Cioffi. His current research interests include 5G cellular transmission, underwater communications, green communications, and next-generation Wi-Fi. He is a Senior Member of the Chinese Institute of Electronics.

Hong Wen (sunlike@uestc.edu.cn) received her Bachelor's degree in wireless communications from Sichuan University in 1997 and her Ph.D. degree in wireless communications from Southwest Jiaotong University, Chengdu, in 2004. She is currently a professor at the University of Electronic Science and Technology of China. She has published more than 70 papers in internationally renowned journals and important international academic conferences. She is a reviewer for *IEEE Network*, *IEEE Journal on Selected Areas in Communications*, *IEEE Wireless Communications Letters*, and more than 10 other authoritative international academic journals. Her research interests include communication network security technology, wireless communication physical-layer security technology, and world-integrated network security technology.

Dan Wang received her Ph.D. degree in communication and information systems from Shanghai Jiaotong University in March 2009. In April 2009, she served as an associate professor in the School of Information Engineering, Henan University of Science and Technology. As first author, she won two first prizes and one second prize in the Henan Province's Tenth Natural Science Excellent Academic Paper competition. She is mainly engaged in the new generation of wireless communication system theory and key technology, and theory of ultra-wideband wireless communication systems.

In recent years, people's research on this kind of application is mainly on intelligent intersections. At the intersections in the future, no signal indicators will be set. The vehicle uses the positioning system, wireless communication, vehicle sensing and computing system to realize real-time decision-making functions. The vehicles coordinate independently and then pass through the intersections in turn.

Authorized licensed use limited to: University of Science & Technology of China. Downloaded on December 03,2020 at 04:16:33 UTC from IEEE Xplore. Restrictions apply.