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D2D-V2X-SDN: Taxonomy and Architecture Towards 5G Mobile Communication System

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ABSTRACT In the era of information society and 5G networks, cars are extremely important mobile information carriers. In order to meet the needs of multi-scenario business requirements such as vehicle assisted driving and in-vehicle entertainment, cars need to interact with the outside world. This interconnection and data transmission process is usually called vehicular communication (V2X, Vehicle-to-Everything). Device-to-device (D2D) communication not only has partial nature of communication, but also alleviate the current problem of spectrum scarcity of resources. The application of D2D communication in V2X can meet the requirements of high reliability and low latency, but resource reuse also brings interference. Software-defined networking (SDN) provides an optimal solution for interoperability and flexibility between the V2X and D2D communication. This paper reviews the integration of D2D and V2X communication from the perspective of SDN. The state-of-the-art and architectures of D2D-V2X were discussed. The similarity, characteristics, routing control, location management, patch scheduling and recovery is described. The integrated architecture reviewed in this paper can solve the problems of routing management, interference management and mobile management. It also overcome the disconnection problem between the D2D-V2X in terms of SDN and provides some effective solutions.

INDEX TERMS 5G wireless networks, D2D communication, V2X, SDN, interference management.

I. INTRODUCTION

Since the introduction of 1G mobile communication system in the 1980s, mobile communication technology has developed rapidly at a rate of 10 years and has penetrated into all aspects of society and had a profound impact on all walks of life. With the popularization of smart terminals and the continuous emergence of new wireless services such as the Internet of Things (IoT), Internet of Vehicles (IoV), and virtual reality (VR), higher requirements are put forward for the performance indicators of future mobile communication systems, which promotes the global academic and industrial circles to invest in 5G mobile communication system standardization research. Nowadays, the standardization research of 5G has been underway with release 18 around the corner. Massive multiple-input multiple-output (MIMO) technology, ultra-dense heterogeneous small cell network and millimeter wave (mmWave) communication are considered to be the three core key technologies of 5G [1]. With the advent of the 5G commercial era, the research and development of the 6G

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mobile communication system has also officially started [2]. The 6G mobile communication system will have full coverage, full application, full spectrum, and strong security. As a potential enabling technology for 6G, massive MIMO still has a lot of room for development. As a key technology in 4G and 5G communication systems, D2D and V2X communication has the prospect of improving the system performance, enhancing user experience, expanding the cellular communication applications, and has attracted widespread attention. D2D communication means that user data can be directly transmitted between terminals without going through the network. V2X refers to vehicles using proximity services to achieve communication with any other network and between any individuals, including vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), vehicle-to-roadside infrastructure (V2I) and other forms of communication [1]. It can provide support for many new application scenarios, such as vehicle automatic driving, highway safety systems, traffic information management, etc. D2D and V2X technology have a great correlation. Since 3GPP proposed the D2D-based V2V concept in LTE Rel.12 and Rel.13, V2X technology has developed rapidly and has attracted increasing attention from the industry. With the completion of the 3GPP LTE-V2X Rel.14 version, the promotion of the V2X industry has officially started. Many communication companies around the world have released chips or modules that support V2X, and V2X test bed trials have also been carried out in different regions. V2X can be implemented based on D2D communication technology, but the requirements for reliability and delay characteristics are more stringent, and the allocation of D2D wireless resources is a key factor affecting reliability and delay. Therefore, most of the principles and application scenarios of D2D communication can be transformed into suitable V2X communication. Only a few technologies related to V2V characteristics need to be re-planned and considered (for example, vehicle movement will cause instantaneous channel state changes, resulting in resources re-allocation in D2D communication) [2]. V2V and V2P can either use the dedicated short-range communication technology based on IEEE 802.11p, or the D2D technology of the authorized communication frequency band of the cellular network. Similarly, V2I can use either IEEE 802.11p technology or cellular network technology. In comparison, the use of cellular network/D2D technology for V2X can save the energy of transmitting polling signals and has better communication continuity. However, IEEE 802.11p has low synchronization requirements and more stable standards [3], so people think IEEE 802.11p is a D2D of a non-cellular network authorized frequency band. They will coexist for a long time, and the unified control of software will fully utilize their respective advantages. Both D2D and V2X are regarded as important components of 5G communications, which can provide backup network and multiple application services for cellular mobile communications. Since the establishment of D2D and V2X communication can be carried out without relying on the control of the base station, it reduces the communication delay and expands the coverage. At the same time, there is in-band spectrum management in D2D or V2X and due to the lack of unified coordination, interference management, mobility management, and routing management issues are faced by cellular users. The SDN data/control separation design concept makes a good balance between the network flexibility and centralized control capabilities. Applying SDN concepts and technologies to the D2D/V2X network architecture can enhance the D2D/V2X network intelligence and overall control capabilities. It provides strong support for solving the above problems. For this reason, in recent years, the academic community has put forward the two concepts of software-defined D2D communication (SD-D2D) and software-defined V2X communication (SD-V2X), and has conducted extensive research and achieved some results, which strongly promote the development of D2D and V2X technology. Based on the commonalities and characteristics of SD-D2D and SD-V2X, this paper sorts out the technical characteristics of SD-D2D and SD-V2X. It also analyzes their development status, communication architecture, location and discovery management of D2D nodes. Finally, the key technologies such as routing control, D2D flow table management, V2V path planning are also discussed. The V2V path restoration were analyzed in detail, and the future development trend was also prospected.

The integration of V2X, D2D and SDN is the focus of most scholars and industry due to their similar OpenFlow (OF) protocol characteristics and inter-operability. This makes them flexible and adaptive to various deployment scenarios.

The abbreviations in this paper is shown in Table 1. The remaining of the paper is organized as follows. In Section II, the research review of SDN-D2D communication is discussed. In Section III, the SDN-D2N communication is reviewed. In Section IV, the SDN-V2X communication is reviewed. Section V provides the review of key technologies in management of SDN in D2D and V2X. Finally, Section VI concludes the paper.

II. D2D-SDN COMMUNICATION REVIEW

At present, the academia has carried out detailed research on the SD-D2D system in order to solve the problems of in-band spectrum management and interference management among cellular users, mobility management, routing management, and mode switching. How to communicate in an ultra-dense heterogeneous network with limited spectrum resources is an important issue that must be solved in the future 5G network to realize the D2D technology. An efficient network architecture will help D2D technology to better integrate in 5G communication systems [4]. Based on the above reasons, the operators urgently need a new technology. On the one hand, it can use the transmission resources constructed by D2D communication to reduce the traffic congestion of the cellular network and improve the quality of user experience

TABLE 1. Abbreviations.

SDN	Software-defined network
D2D	Device-to-Device
V2V	Vehicle-to-Vehicle
ITS	Intelligent transportation system
QoE	Quality of experience
5G	Fifth-generation
VANET	Vehicular Ad Hoc Network
WDN	Wireless distribution network
WLAN	Wireless local area network
NAS	Network assisted system
API	Application programming interface
UE	User equipment
BS	Base station
SINR	Signal-to-interference plus noise ratio
RSS	Receive signal strength
OBU	On-board unit
RSU	Road-side unit
IoV	Internet-of-vehicle
IP	Internet protocol
NA	Network authorization
3GPP	Third-generation partnership project

(QoE). On the other hand, the flexibility, manageability and convenience of D2D communication can be enhanced through methods such as virtualization. SDN was originally designed for wired communication, but the flexibility of the OpenFlow protocol provides the ability to reconfigure the network, paving the way for the application prospects of SDN in wireless communication. The design concept of SDN data/control separation makes the network highly flexible and can centrally control the network equipment. At present, the research and application of SDN in wireless communication in academia and industry are mainly concentrated on the core network, base station (eNode B) and access network level. In response to different application scenarios and actual needs, researchers have proposed a variety of mature and effective typical application scenarios [4]–[7]. In recent years, SDN technology has been integrated into D2D communication architecture, based on inter-node assistance, providing mobile small cloud and edge computing. The introduction of SDN into the access network has gradually become the research focus of the academic community. Based on the design concept of SDN, the industry applies it to the D2D architecture of mobile communications, and proposes the SD-D2D architecture to improve the flexibility and efficiency of D2D networking in a heterogeneous network environment. Its basic architecture is shown in Figure 1. Among them, the eNodeB and the mobile terminal constitute the data plane, and the SDN controller and the top end resource allocation, route management and other functional modules constitute the control plane.

The authors in [8] proposed a D2D communication architecture that uses the SDN under full network control. Five components are integrated in the network and mobile terminals: D2D server, SDN global controller, SDN local controller, Open vSwitch and wireless resource mapper. The advantage of this architecture is to solve the shortcomings of traditional technology, allowing two mobile devices to communicate with each other without a manager. It enables the network topology scalable and avoiding management nodes in harsh conditions such as energy depletion and single point of failure. In addition, the hierarchical control system does not require the LTE interface of the mobile device to remain active, which saves the terminal's transmission energy consumption and improves the effectiveness of resource utilization. Different from the above-mentioned SDN solution, based on the concepts of SDN and NFV, reference [9] proposed a new method based on the combination of centralized radio access network (C-RAN), hierarchical D2D and distributed SDN controller architecture, through the cooperation of micro-cell base stations and D2D. It effectively shunts the main base station traffic while reducing the network signaling overhead and energy consumption. The authors in [10] proposed a SDN-based portable communication method in a heterogeneous network environment, virtualizing mobile terminal devices into virtual devices in a cloud environment. It uses SDN and NFV technologies to convert the data the and multimedia streams and opportunistically re-routed to nearby devices to realize the transfer of processing traffic in the access cloud framework. Therefore, it reduces the potential impact on the physical entities. This method moves all mobility management and calculations in the physical network to the cloud. Although the power of cloud computing is increased, the physical network can reduce the transmission of control signaling. The authors in [11] unified the mobile ad hoc networks (MANETs), wireless sensor networks (WSN), D2D networks, and vehicle networking into wireless distributed networks (WDN), and then proposed a WDN-based hybrid SDN framework. The framework uses two different frequency bands for data transmission and network control respectively, and adopts the idea of hybrid control, combining the advantages of centralized processing and distributed processing. That is, the controller performs centralized preprocessing, and the forwarding node makes distributed routing decisions to improve the scale and reliability of the wireless network. The authors in [12] combined the D2D technology with SDN and proposed a file distribution system. In this system, the network nodes and devices communicate through D2D, with a cache and forwarding capabilities to improve the network throughput and reduces the energy consumption. According to the different placement of cache content, the system is subdivided into two models in this article. In model A, the CDN server and SDN controller are deployed in the data center. In model B, the CDN server is deployed in the data center, but the base station has the control function and caching function of SDN. This model moves the control and caching function down to the access network, which greatly improves the response speed of content distribution. The authors in [13] proposed a new SD hybrid D2D framework in the mobile cloud environment, which centrally deploys the SDN controllers and divides the terminal equipment group into several mobile clouds. Each mobile cloud is managed by a cluster head (CH) which controls and manages the terminals under its jurisdiction through D2D communication, and the SDN controller communicates with the CH through an LTE link. This framework reduces the energy consumption of the original terminal's LTE wireless link and network, and at the same time, the management of the mobile cloud also enhances the scalability of the wireless network. Based on [13], the authors in [14] further proposed a SD mobile cloud D2D communication framework for public safety applications in 5G networks, using a layered architecture to place the SDN controllers. That is, the global control is adopted for the core network, and the local control is adopted for the mobile and small cloud. The advantage of this layered architecture is that it provides the scalability of the mobile and small cloud, saves the network energy and ensures the robustness of the network. The authors in [15] combined wireless network virtualization with SDN and self-learning D2D communication. At the edge of the mobile network, they proposed a knowledge-centric and D2D communication assisted cellular network architecture. First, a D2D assisted virtualized edge cellular network architecture is designed, which is composed of a physical layer, a knowledge layer, and a virtual management layer. The architecture dynamically detects the network structure by making full use of the knowledge information obtained in D2D communication between mobile users and manages the communication resources. Then, it describes the problems and potential solutions in the system, including knowledge extraction, social perception, incentive schemes, trust management mechanisms and optimized resource allocation.

Generally speaking, at present, the research on SD-D2D is relatively extensive, but there are still shortcomings. From the perspective of the research field, the SD-D2D research mainly focuses on the improvement of the network communication performance (such as bandwidth, delay, throughput), and related research is still not in depth and detailed. Some specific and potential scenarios, such as concert multicast, IoT D2D, etc., but few authors have studied it. From the perspective of the research content, it is necessary to expand the core applications of 5G networks. For example, the research on traffic offloading currently focuses on the local offloading of small ordinary files, and there is a lack of research work on multimedia offloading with high bandwidth requirements. From the perspective of D2D deployment and application, existing research has combined D2D communication with social networks for resource allocation, interference control, routing, and data distribution to effectively improve the network performance. However, it lacks in the actual cellular network SD-D2D to deploy and apply research in the architecture. At the same time, it should also be noted that, although D2D technology has long become a communication hotspot technology, there are few large-scale applications. This is a bottleneck problem in its development. A good business application model is needed to solve trust problems, friend matching, and incentives/charges, malicious fraud and other issues. In future research, we need to consider how to load social network functions and social attributes of application terminals in the controller, and how to maintain social network information in the controller. Relying on the SDN to build a good ecological chain, these problems are expected to be resolved reasonably, and related fields may be research hotspots in the future.

From the standpoint of SDN, this article examines the integration of D2D and V2X communication, D2D-V2X architectures and state-of-the-art were reviewed. It also explained the similarities, characteristics, routing control, location management, patch scheduling, and recovery. The suggested integrated architecture is capable of resolving routing, interference, and mobility management issues. It also solves the D2D-V2X disconnection problem in terms of SDN and offers some practical solutions. The summary of the related research works is mentioned in Table 2.

III. V2X-SDN COMMUNICATION REVIEW

V2X communication is one of the supporting technologies for smart transportation and smart cars. It enables a new generation of vehicles equipped with multiple networking access and sensing technologies (such as cameras, sensors, radars, and positioning devices) between them and the surrounding environment for enhanced interaction [16], [17]. V2X communication is widely regarded as a key technology to improve the road safety and traffic efficiency, and can greatly promote the development of intelligent transportation systems (ITS). Based on V2X communication, vehicles can quickly detect potentially dangerous and uncomfortable road conditions and communicate them to other vehicles, nearby pedestrians, and roadside nodes to further disseminate information. In addition, the rapid response to sudden traffic conditions through V2X communication can reduce the time spent in congested traffic and bring additional benefits such as reduced energy consumption and vehicle emissions. At present, on a global scale, the obvious impact of V2X on the road transportation system has been recognized by participants such as different car manufacturers and telecommunications companies. At the same time, a series of more mature research programs and proposals have been given in the industry. So far, most countries have allocated dedicated radio frequency spectrum to support V2X communication, and promote the development of corresponding V2X security technology and ITS applications. Major automakers and telecommunications company participants have joined the Fifth Generation Automobile Association (5GAA), based on LTE enhancements and 5G systems, to provide solutions that interoperate with cellular V2X (C-V2X) technology [18]. In the technical development of 5G vehicle-connected networks, SDN technology decouples and separates the network management functions from network transmission functions, making network management more effective. It will become an important method of network architecture. In addition to the advantages it brings

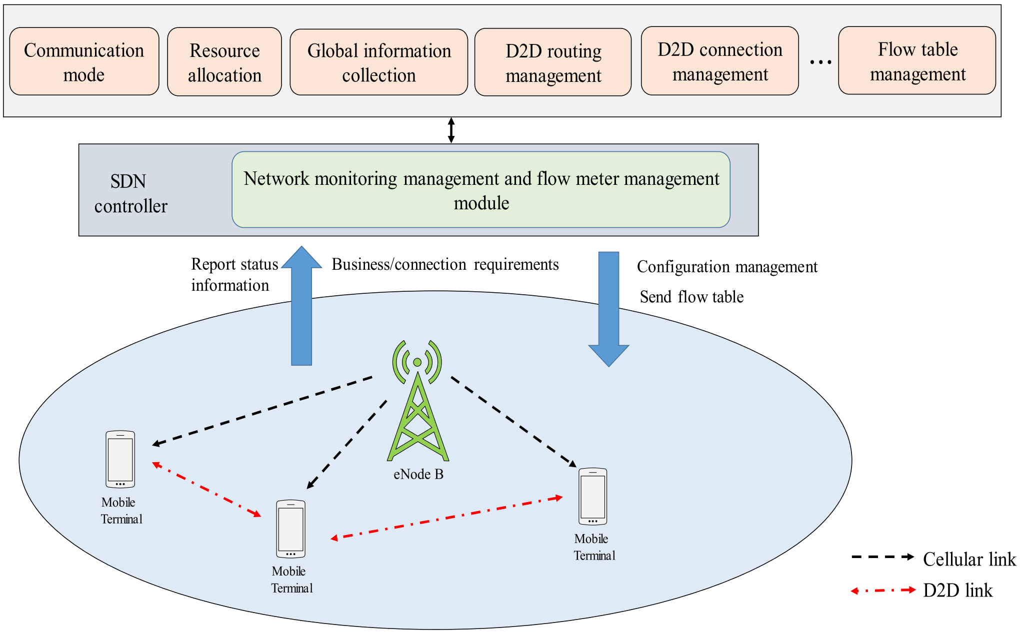

FIGURE 1. Proposed system model of D2D-SDN.

TABLE 2. Summary of literature review and scope.

Scope & contributions	Ref [8]	Ref [9]	Ref [10]	Ref [11]	Ref [12]	Ref [13]	Ref [14]	Ref [15]
QoS requirements of 5G	×	×	×	✓	✓	×	×	✓
RAN slicing architecture and implementations	×	✓	✓	✓	✓	✓	✓	✓
Standardization efforts	×	×	×	×	×	×	×	×
Network slicing management in Fog and MEC	×	×	×	×	×	×	×	×
Placement of Virtual resources and VNFs	×	✓	×	✓	✓	×	✓	✓
Market drivers and Key vertical segments	×	×	✓	×	×	✓	×	✓
Connectivity loss between SDN controller and vehicles	✓	✓	✓	✓	✓	✓	✓	✓
Dynamic resource management	✓	✓	×	✓	✓	×	✓	✓
Efficient resource utilization	✓	✓	✓	✓	✓	✓	✓	✓

to wired and wireless networks, the SDN also has unique advantages that are particularly suitable for vehicular networks. The logical centralized control function based on SDN provides a global understanding of the network topology and can efficiently allocate all types of network resources (such as bandwidth, spectrum, power transmission, etc.). On the one

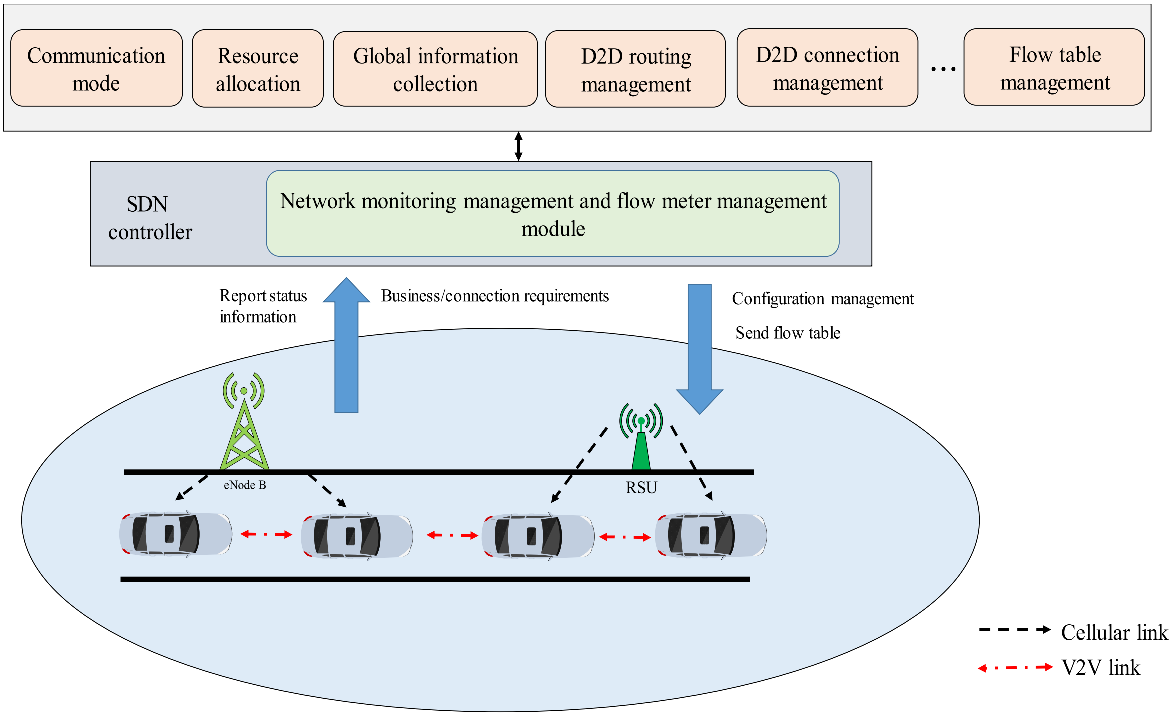

FIGURE 2. **Proposed system model of V2X-SDN.**

hand, the SDN controller selects the most suitable solution for each specific road condition and adjusts the system parameters according to the actual situation, which can enhance the performance of the existing vehicle architecture. On the other hand, with the virtualization and abstraction brought by SDN, the heterogeneous network technology integration in the network becomes simple and transparent. Therefore, the industry has proposed the SD-V2X network, and its basic architecture is shown in Figure 2. It is very similar to the SD-D2D structure introduced in Section 2. In Figure 2, the eNodeB, RSU, and vehicle-mounted terminal constitute the data plane, and the SDN controller and the top end resource allocation and path management functional modules constitute the control plane.

A. RESOURCE ALLOCATION AND OPTIMIZATION UNDER SDN CONTROL

The V2X network expands the forwarding function of SDN. In order to prevent network congestion, reduce packet loss, and save spectrum resources, scholars have studied wireless resource management technology based on SDN in a heterogeneous access environment [19]–[23]. For example, in the literature [19]–[21], scholars combined cluster-based vehicle ad hoc network (VANET) with 5G cellular network. Using the SDN controller, similar access behavior to vehicles (such as vehicle driving route, vehicle speed, the distance to the RSU, etc.) are clustered, and the commonality is explored to form a vehicle cluster. The cluster heads are managed through the SDN controller to achieve a hierarchical architecture and improve the stability of the vehicle network performance. The authors in [22] proposed a resource allocation mechanism under multiple heterogeneous access environments in the SD-IoV and the correlation is jointly determined for the resource allocation strategy. When the V2I communication cannot meet the user's QoE requirements and in order to further improve performance, it deploys V2V communication. The simulation results show that the solution can effectively utilize the available bandwidth of LTE and Wi-Fi networks, thereby better meeting the needs of users for QoE. The authors in [23] solved the resource management problem of the cognitive radio access network in V2I using an adaptive controller, optimizing energy management, and dealing with sudden network changes caused by reliability.

B. SDN-BASED ROUTING AND FORWARDING FUNCTIONS

Build a global dynamic information database based on SDN and make routing decisions. In the traditional vehicle-connected network, they cooperate with each other and exchange different information collected by their respective sensors. Thereby constructing a local dynamic information database. The local dynamic information database contains static information such as road signs, traffic and weather conditions. Integrating the SDN into the vehicular network allows the controller to centrally manage and maintain the global dynamic information. By collecting and filtering the local dynamic information provided by the vehicle, the controller obtains and builds a global dynamic view of the entire (or part) network state. It can make more sensible and finer decisions on the routing request of the vehicle. For example, the authors in [24] proposed an SDN-based on-demand routing protocol for VANETs, which separates the data forwarding layer and the network control layer to improve the data trans-mission efficiency. The RSU functions as a local controller and is responsible for selecting suitable vehicles to forward the packets within the area under the jurisdiction of the road section. The plan adopts a two-level design architecture of the global and the local layer. The global layer uses the ''ranking query plan'' to collect the vehicle information and determine the range along the road section. The local layer is responsible for selecting suitable vehicles to forward the packets in the range determined by the global layer.

C. SDN-BASED IOV TRAFFIC OFFLOADING

In the traditional vehicular network, the offloading decision can only be made partially based on the limited information of the network. For example, based on the historical network parameters, it cannot reflect the current real-time state of the network and may even lead to unprofitable decisions. In addition, in the SDN based vehicle network, the centralized global view of the SDN controller can be used to dynamically make more beneficial offloading decisions based on the real-time network status, which is more suitable for the needs of users and adapts to the current network conditions [25], [26]. The authors in [22] proposed a scheme for offloading the cellular communication traffic through V2V communication in VANET. This scheme effectively offloads the cellular network traffic by measuring the V2V path existing in VANET. At the same time, the solution also designed an SDN based mobile edge computing server (SDNi-MEC), which solved the complex problem of V2V traffic offloading in VANET. Each vehicle reports its status information to the database of the SDNi-MEC server, and the SDN controller on the server measures whether there is a V2V path between the two vehicles based on the status information, so as to offload the existing cellular traffic between the two. The performance analysis of this scheme shows that, when the vehicle density reaches medium, this kind of traffic offloading scheme has better throughput on both the cellular network link and the V2V path. The authors in [27] proposed a centralized IoV traffic offloading framework similar to SDN, in which the data stream generated at the source end of the data center is opportunistically transmitted to the destination. Among them, the SDN controller acts as a central service broker (SB), configures the forwarding path of the IoV data flow in the control plane, and sets a number of offload hotspots on the road. It acts as a local service agent (SA). The plane implements the data flow forwarding. Integrating the SDN method into the distribution of floating content (FC). It realizes distributed and opportunistic sharing of the content in a given geographic area—anchor zone (AZ) which can effectively improve the distribution performance of FC [24], [28]. The authors in [24] proposed a VANET content distribution mechanism supported by SDN as a content centric network and FC. According to the node mobility, the SDN controller selects the best cache utility node, decides the distribution path, and forwards the activated content by AZ etc. The simulation results show that the mechanism can adapt to the highly dynamic and volatile network environment, and effectively improve the performance of content storage, dissemination and forwarding in VANET. The authors in [28] proposed an SDN based VANET FC distribution architecture. The RSU is used as the SDN controller. By collecting the speed and position of the vehicle within its coverage, the size of the AZ can be optimized and greatly improve the FC performance.

D. SDN-BASED VEHICLE CLOUD RESOURCE MANAGEMENT

The application of the IoV requires shorter waiting time to achieve low latency and highly reliable response. Therefore, scholars have proposed a SDN based vehicle cloud server to solve such real-time requirements. In addition to the network management, the SDN controller also provides management of vehicle cloud resources (such as computing and storage resources), and manages the OBU of each terminal. The authors in [29] proposed an architecture for updating the vehicle embedded software based on SDN and cloud computing. The SDN controller is located in the data center or edge device, and forms a mobile vehicle cloud with RSU, base station subsystems and other data centers. Therefore, the decision of the control plane is not determined by a centralized element, but by the cooperation of elements in the cloud. In the above case, the vehicles can cooperate with each other based on the instructions of the SDN controller to obtain the complete update content. This SDN based software update distribution method improves the network performance by reducing the utilized cellular bandwidth and the corresponding usage costs (such as the dedicated short-distance communication band-width) and software update delivery delay. The authors in [30] integrated the 5G fog computing technology into the architecture to process faster, efficiently switch and track management, and can implement different levels of real-time user defined security while maintaining low overhead and minimal configuration of the system.

E. SDN-BASED VEHICLE NETWORKING SECURITY

The security of in-vehicle communication also puts forward higher requirements for the use of SDN, which is also crucial to the security and privacy of vehicle applications [30]–[32]. Because the SDN controller has an intelligent, centralized network view, it can identify potential attacks through the traffic analysis on the data plane, perform anomaly detection, and isolate malicious or infected nodes accordingly. The authors in [10] suggested that the SDN controller can coordinate a trust based authorization scheme and select the intermediate nodes to act as relays based on reputation. The authors in [17] also adopted a similar trust mechanism to disseminate safety emergency data. The authors in [30] proposed a VANET/5G security architecture that supports SDN. This architecture is based on the SDN controller, has a global view and management capabilities, implements various types

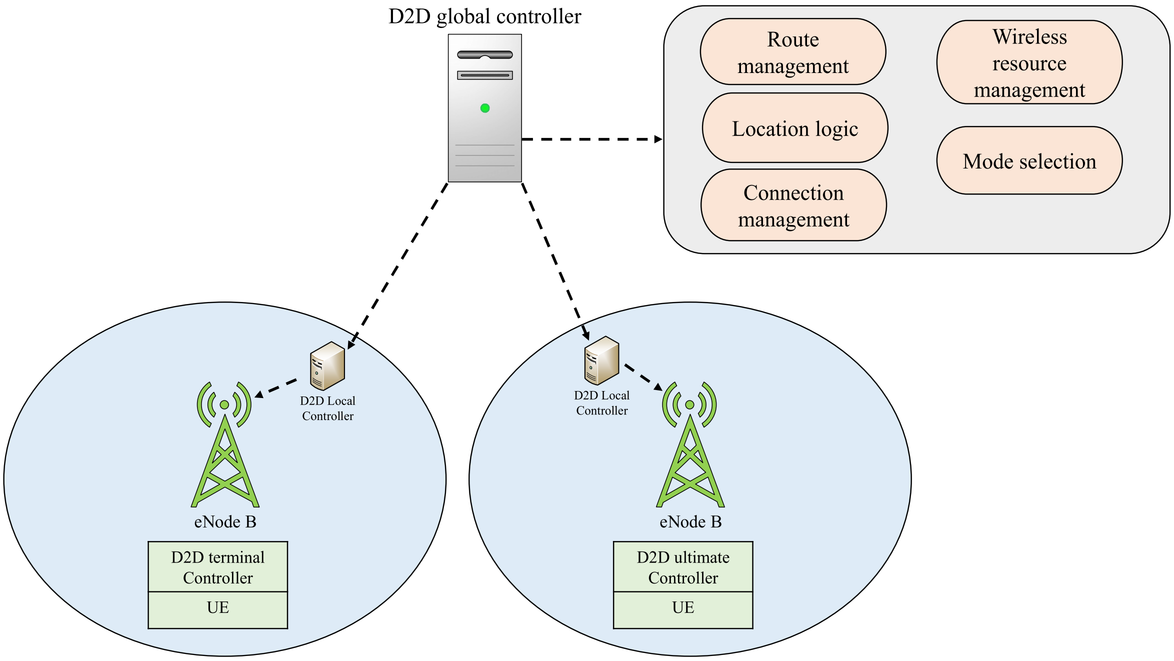

FIGURE 3. Layered architecture for D2D-SDN communication.

of attacks (such as controllers or vehicles), distributed denial of service (DDoS). It has other security technologies such as prediction and traceability, and reduce their impact. In summary, the existing SD-V2X research covers the issues such as interference management, routing management, resource allocation, and security. Although, the vehicle is different from other mobile devices in that it can only run on existing highways, and its motion state has certain constraints. However, the existing studies have not considered too many constraints on the operation of vehicles. In view of the rapidity and constraint of vehicle movement, combined with the map overlay, the controller needs to enhance the ability to predict and perceive the trajectory of a single vehicle, plan the V2V path in advance. It uses the vehicle clusters for cooperative V2X to improve the reliability and throughput of communication. In future, for V2X to be widely used, it is necessary to build a good industrial ecological environment and solve the coordination problems of various parties such as operators and auto manufacturers. With the gradual deepening and maturity of SDN and V2X related technologies in 5G networks, how to solve cross industry and cross vendor coordination issues based on the open architecture of SD-V2X, and to conduct more in-depth applied research on feasible business models, will become the basis of research hotspots in the field.

IV. COMMUNICATION ARCHITECTURE OF SDN IN D2D AND V2X

A. D2D-SDN ARCHITECTURE

The SDN concept is introduced into cellular network D2D communication, and the information collected by the SDN controller from multiple sources is used to dynamically adjust the forwarding decisions. The data plane is composed of multiple base stations. The control plane is responsible for centralized control of network equipment and resource allocation, query network status information such as the resource usage and load of the base station. 5G technology adopts the network assisted system (NAS) in which the base station can simultaneously manage the cellular and D2D connection of the mobile node [31]–[33]. By loading the application module of the SDN controller in the base station, it can obtain the global information such as node movement information and resource information [34], [35]. The base station i can directly obtain the movement information and resource information of the terminal nodes in its coverage area and provide it to the SDN controller. The neighbor base station j then obtains the information of the terminal nodes covered by the base station through the SDN controller. The layered architecture for SD-D2D communication is shown in Figure 3. In the SD-D2D architecture, the performance of the control plane has a great impact on the entire network. At present, regarding the placement of SDN controllers in 5G mobile communication networks, the academic community is divided into three viewpoints: centralized, distributed and hierarchical.

Since a single controller cannot adapt to the challenge of huge network pressure, a hierarchical deployment of the controller can be considered to reduce a large number of signaling interactions generated by D2D communication management. Also, to meet the application of low-latency requirements, while facing the expansion requirements of mobile small cloud and fog computing, and improve the scalability of cellular networks. Based on the hybrid D2D communication framework proposed in [9], [13], [14], this paper adopts a hierarchical control method. A global control for the core network and local control for the access network. In an autonomous domain, all base stations are centrally controlled by the global D2D controller, which maintains the control plane of the entire autonomous domain. The D2D local controller module on each base station is responsible for routing and forwarding between nodes in the area. The benefits of this layered architecture are that, it can give full play to the scalability of centralized control, so that the underlying forwarding equipment can be uniformly controlled and managed. Thereby, making it transparent, realizing device virtualization, and promoting network capability opening, to improve the network flexibility and efficiency of mobile communication. At the same time, the mobility of the node is also considered to reduce the signaling interaction of D2D communication management in the core network. The data packets of mobile communication are first accessed to the base station closest to the user, and then the D2D local controller decides whether it is the node communication within the base station or the local D2D communication can be constructed. If so, the local D2D communication is constructed. If not, the D2D global controller determines the forwarding path of the data packet, optimizes the path for storage and forwarding, and finally reaches the target base station and sends it to the target user. The global controller masters the network topology and load conditions provided by all base stations in its autonomous domain, and forms a network status information database to manage the entire network. The information that can be processed by the status information database includes D2D device identification, service identification, IP address allocation information, user identification number, user security information, user location information, etc. At the same time, the global controller is also responsible for coordinating the mobility management entity (MME) to perform the radio resource management, location management, connection management, and route management for each D2D pair. The local controller is at the intermediate execution layer. For the upper control plane, the main function is to receive the control instructions and report local network information. The specific function is to send the status information collected in the base station to the global controller and receive the control instructions from the global controller, through the OpenFlow protocol to issue instructions to the underlying data plane for execution. For the lower data plane, the main function is to assist the base station in the local D2D communication management of the terminal, such as location information management, determining the distance between nodes, flow table management, etc. [36]. The terminal controller acts as a background service on the mobile terminal side, which is responsible for selecting an appropriate interface for each application, monitoring the status, controlling the Open vSwitch and radio resource mapper.

B. D2D-SDN OPPORTUNISTIC AND AD HOC NETWORK

In 5G communication, the introduction of D2D technology has made it possible for cellular communication terminals to establish wireless opportunistic networks and WANETs, and the application scenarios of wireless communication have been further expanded. For example, the cellular networks can form ad hoc networks through D2D technology, such as MANET or VANET to offload the local traffic, expand the communication area, build emergency disaster recovery communication network, etc. At the same time, with the help of SDN technology, the resource utilization rate of the cellular network is higher and the performance is more stable.

1) Ad hoc network using D2D-SDN technology traditional: The wireless communication networks have high requirements for communication infrastructure, and damage to the core network facilities or access network equipment may cause the communication system to be paralyzed. When the wireless communication infrastructure is damaged, or in the blind area of the wireless network, the terminal can use D2D to realize the end-to-end communication and even access the cellular network. Therefore, the authors in [37] deployed a real terminal equipment to design and implement a disaster-tolerant network based on SDN that combines DTN and MANET—NDN. When a natural disaster such as earthquake occur, the NDN assumes the role of communication as part of the basic communication network facilities. In NDN, each SDN switch is responsible for monitoring the network performance. Once the network performance drops, the NDN controller will switch to other networks. Through multi-hop terminal equipment as a relay, data is transmitted from the source to the destination, or a gateway to the Internet. The experimental data shows that the network is independent of the basic communication network and can meet the needs of disaster recovery and communication needs of the shared network. At the same time, by reducing the unnecessary communication connections, the energy of the terminal battery can be greatly saved. The authors in [38] proposed a D2D-SDN self-organizing network form under a specific network application which is an information-centric network virtualization solution based on D2D communication. The solution provides the system's global view controller through SDN, dynamic virtual resource allocation and internal cache. In the proposed architecture, the physical resources can be abstracted and shared by multiple mobile virtual network operators (MVNOS) at the same time. For example, according to the requirements of information-centric network virtualization, three virtual networks can be formed on the data plane to perform conventional, information-centric, and information-centric D2D communication transmission. Then, construct three virtual SDN controllers on the control plane, responsible for managing the corresponding virtual network. At the same time, by integrating the D2D communication in an information-centric wireless network, the content caching function is not only enabled in wireless operation and maintenance equipment, but mobile devices also have content caching capabilities. The virtual resource allocation problem can be used as a large-scale combinatorial optimization problem, through discrete random approximation method is used to solve the problem. The simulation results show that the MVNOS cannot only benefit from sharing of the

physical infrastructure, but also benefit from the caching function of different network elements. 2) Opportunity network using SDN/D2D technology: The authors in [39] proposed and implemented a multi-hop MANET with SDN capability in actual equipment. The SDN controller adopts an open network operating system (ONOS), and the SDN switch adopts the Open vSwitch protocol. MANET has the advantages of D2D data transmission and the flexibility of centralized network management. The simulation results show that, compared with distributed self-organizing networks, the proposed scheme has better performance. The results prove the feasibility of future deployment of this kind of network. In addition, the article also provides a repository containing all the development components. A test platform can be designed and developed by deploying this repository with SDN capabilities. The authors in [40] used the SDN and cyber-physical systems (CPS) to propose and simulate a flexible, configurable, and opportunistic network based mobile collaborative community. The idea is to use the local high-bandwidth communication connections, such as IEEE802.11 (Wi-Fi) and other technologies, under the dynamic scheduling of the SDN controller, to achieve bandwidth aggregation for multiple terminals. Thereby, effectively improving the original low-bandwidth environment speed at which the users upload files. The authors in [41] proposed an opportunistic network traffic offloading mechanism based on the SDN control. This mechanism runs a SDN based application programming interface (API) on all terminals, so that under the deployment of the SDN controller, through Wi-Fi interfaces between terminals wireless access points (AP), an opportunistic wireless mesh network can be independently constructed. At the mobile access network level, the traffic can be effectively offloaded to the wireless local area network (WLAN), thereby increasing the bandwidth of the cell.

C. V2X-SDN NETWORKING ARCHITECTURE

The existing IoV architecture has some functional defects in the network management and integration. For example, it is very difficult to deploy services on the large-scale, highly dense and dynamically changing IoV network topology, and lacks scalability. The heterogeneity and non-programmability of vehicle equipment and the dependence on suppliers make the IoV system structure rigid and difficult to manage, and lacking intelligence. Due to the diversity of deployment environments and the heterogeneity of communication technologies, it is difficult to select appropriate technologies based on actual conditions and rapid changes in the network parameters, which lacks flexibility and adaptability. These deficiencies limit the function of the system and often lead to an insufficient utilization of network resources. Therefore, the adoption of the IoV architecture based on SD-V2X technology can improve the flexibility, programmability and scalability of the current IoV architecture. Compared with the SD-D2D-based cellular and opportunistic/self-organizing network architectures introduced in Section 4.2 and Section 4.3, the SD-V2X has the common point that both are integrated with 5G cellular networks and SDN technologies. Also, the network capacity is increased through short-range communication. The difference is that, because the vehicular communication has mobility which requires higher real-time performance, and cellular networks to provide vehicles with high-capacity and low-latency communications. Therefore, in view of the high-speed mobility, each vehicle is equipped with a cellular and an IEEE 802.11p network interface to increase the communication reliability. According to the scheduling of the controller, the corresponding interface and the communication mode are optimized. Secondly, in the IoV, both RSU and OBU are loaded with wireless OpenFlow protocols. Like other OpenFlow switches, they have SDN functions and can be programmed and controlled. Various heterogeneous access technologies enable the vehicles to access the basic network in a variety of ways, such as V2I access through base stations, roadside units, WLANs or through V2V multi-hop access. In the original IoV architecture, the SDN controller is generally located on the side of the data center and base station. In order to improve the scale, flexibility and reliability of the IoV, the original controller needs to be redeployed. The control function is moved down to the roadside end to realize the localized control, clear layered functions, and reduce the management delay. From the perspective of the deployment location and level of the controller, the existing V2X-SDN technology's IoV architecture is mainly divided into centralized [22], [38], [42]–[44] and hybrid [19]–[21], [45]–[47]. The centralized architecture uses only one global controller. Because the controller needs to exchange a large amount of state information with network elements, it cannot meet the low latency requirements of future vehicular networks applications. The hybrid architecture uses a hierarchical management architecture to exchange the control information hierarchically to provide a low-latency guarantees for vehicle applications. The hybrid architecture balances the network management delay and the cost of the cellular network, and encourages the vehicles to send the SDN control requests through the cellular network and uses the V2V network for data transmission. The hybrid architecture based on SD-V2X technology is shown in Figure 4. Vehicles send their contextual information to the central controller via the eNodeB or RSU, including the geographic location, vehicle speed, direction, and perceived neighbors acquired using GPS. The global SDN controller constructs a global status information according to the central controller. The control plane places the controller between the base station and the roadside unit. The control plane consists of a global SDN controller, base station and RSU. The global SDN controller cooperates with the base station and RSU to complete the control task. The global SDN controller determines according to the global status information general abstract policy rules, base stations. The RSUs execute these rules based on the local state information. At the same time, the control range of the SDN controller extends to the OBU. The OBU is triggered by the controller to generate the corresponding forwarding actions at the data level. For example, the inter-vehicle V2V technology is used to distribute real-time traffic information between multiple vehicles through multiple hops to provide timely traffic warning information sharing function. Through the introduction and analysis of the above-mentioned various SD-D2D/V2X communication architectures, it can be seen that the centralized SDN controller is introduced in D2D and V2X, and the leading decision-making or assisting decision is made based on the global information. It can flexibly solve the problems of multi-layer interference between D2D and cellular users, resource allocation conflicts, routing decision limitations, terminal mobility management. Therefore, improve the utilization of wireless network resources, network topology flexibility, and reducing the cost of terminal energy consumption. However, while solving the D2D/V2X problem, it also introduces new shortcomings. For example, the wireless signaling overhead on the control channel will increase. When the network topology changes, it will cause inter-domain and intra-domain routing switching, resulting in frequent flow table updates. The corresponding signaling overhead, node processing overhead, and communication delay will further increase. This will affect the V2X when the vehicle is moving at high speed and the performance impact is greater. In addition, the centralized control also puts forward new requirements on the terminal, requiring the terminal chip to integrate the Open vSwitch flow table processing capabilities and wireless resource mapping manager, etc. It also increases the cost of chip development and production accordingly.

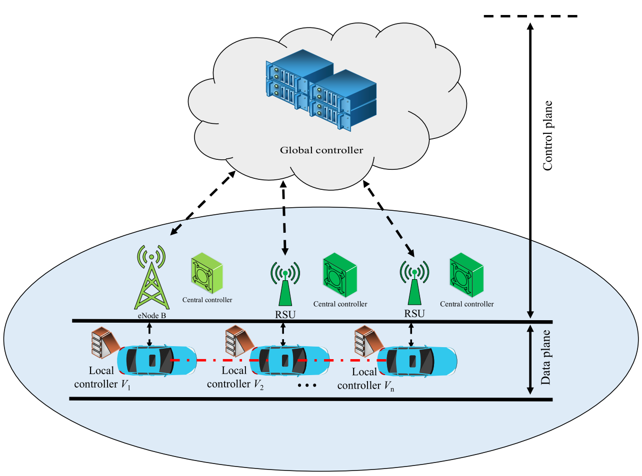

FIGURE 4. Hybrid architecture based on SD-V2X technology.

V. KEY MANAGEMENT TECHNOLOGIES OF SDN IN D2D AND V2X COMMUNICATION

In the analysis of key technologies in this section, the SD-D2D is mainly used as an example. The key technology of SD-V2X has many similarities with SD-D2D. It is not the focus, but only the characteristics of SD-V2X are explained. The discussion on the integration of D2D and SDN includes the following four key technologies:

1) D2D architecture based on SDN hierarchical control;
2) Location management;
3) Discovery management;
4) Routing management.

Because the key technology 1) has been introduced in detail in Section 4.1, the last three key technologies will be introduced here.

A. LOCATION MANAGEMENT IN D2D-SDN

The important feature of D2D communication is the use of geographical proximity between the nodes, but the distance between the nodes determines the size of the transmission power. At the same time, the path loss of wireless signals makes the distance affect the strength of the received signal. Therefore, the distance between the nodes is the key to the construction of D2D communication.

The introduction of SD-D2D communication makes the global management of node locations feasible. The D2D controllers can obtain the global status information such as node location and link information through a dedicated signaling channel. This information is also used for the discovery and establishment of D2D communication. A series of technologies such as routing provides the basis for decision-making. The controller performs global scheduling such as routing, traffic offloading, communication mode selection and switching based on the global status information. References [34]–[36] proposed a location management solution for D2D communication, which is specifically introduced as follows.

In each control cycle, first interact with the base station through the signaling channel node to report the current node location and other status information. From which the D2D local controller obtains the real-time information of each node. Then the local controller summarizes it to the global controller status information of the nodes in the controlled base station. For example, the positions of node i and j can be expressed as (x_1, y_1) and (x_2, y_2). The location information can be expressed as $I = \{(x_1, y_1), (x_2, y_2), \ldots (x_n, y_n)\}$.

According to the node location information, the Euclid distance D_{ij} is deployed to measure the direct distance between the nodes i and j, namely

$$D_{ij} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{1}$$

Therefore, in the global controller, an adjacency matrix $\boldsymbol{M}$ is used to record and manage the distance information between all the nodes to form the global position information of the network nodes, namely

$$\boldsymbol{M}_{n\times n} = \begin{bmatrix} 0 & D_{12} & \cdots & D_{1n} \\ D_{21} & 0 & \cdots & D_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ D_{n1} & D_{n2} & \cdots & 0 \end{bmatrix} \tag{2}$$

Then, deploy the Dijkstra shortest distance algorithm on the adjacency matrix $\boldsymbol{M}$ to calculate the shortest distance D'_{ij}= Dijkstra($\boldsymbol{M}, i, j$) for D2D communication between any two points, and then select the path through the control channel and global scheduling of communication resource allocation.

According to the position information of the nodes, the controller can measure the position between the nodes and optimize the transmission path. According to the number of intermediate nodes transmitted through, it can be divided into two kinds of distance measurement methods: single-hop and multi-hop D2D communication inter-node position measurement.

1) INTER-NODE POSITION MEASUREMENT OF SINGLE-HOP D2D COMMUNICATION

The position measurement between the nodes for single-hop D2D communication is shown in Figure 5. Suppose that in this scenario, nodes *i* and *j* belong to the same eNodeB. After receiving the location information of nodes *i* and *j*, the local controller obtains the distance D_{ij} between the two according to equation (1). Then, it judges whether the distance can satisfy the construction the needs of the D2D communication. If yes, then the D2D discovery notification information is sent to both parties.

2) INTER-NODE POSITION MEASUREMENT OF MULTI-HOP D2D COMMUNICATION

The position measurement between the nodes for multi-hop D2D communication is shown in Figure 6. Assuming that in this scenario, nodes *i* and *j* belong to different eNodeB. If the D_{ij} value exceeds the distance range of D2D communication, although a direct D2D connection cannot be established, the global controller determines that a multi-hop D2D communication can be constructed. Therefore, based on the shortest path transmission planning, the global controller plans the multi-hop D2D communication connection.

B. DISCOVERY MANAGEMENT IN D2D-SDN

The network authorization (NA) D2D communication requires the assistance of the cellular network to authorize the connection. Since the base station does not include the D2D communication function, it is necessary to establish a D2D neighbor discovery mechanism. According to the level of D2D discovery, the discovery modes can be divided into two types: direct neighbor and global neighbor discovery.

1) DIRECT NEIGHBOR DISCOVERY

Many researchers have proposed a D2D discovery mechanism based on the same base station [48]–[50]. When the two communication nodes are managed by the same local controller, the evolved UMTS terrestrial radio access network (E -UTRAN) dedicated signaling of user terminal to user terminal (UE-UE) for direct neighbor discovery between the nodes. Referring to the D2D direct neighbor discovery defined by 3GPP, the following two direct D2D neighbor discovery models are proposed.

Model 1 "Announcement UE" (such as UE1) periodically broadcasts an announcement request to the neighboring UEs,

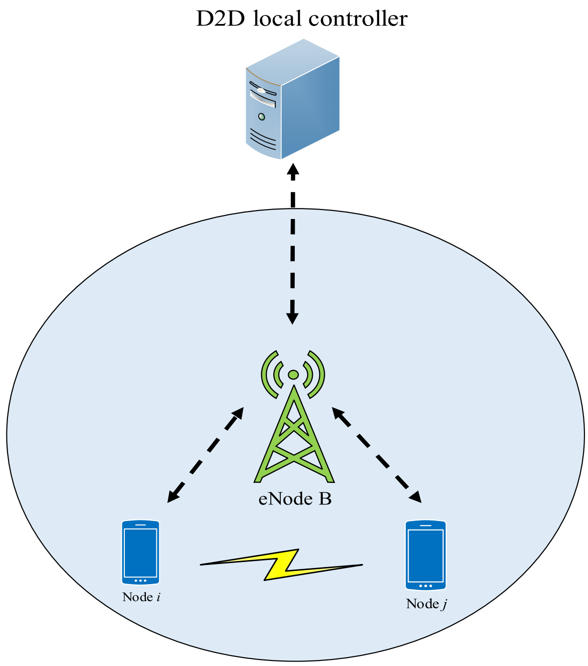

FIGURE 5. Position measurement between nodes for single-hop D2D communication.

including the node identification, status and other information, allowing itself to be discovered by neighboring UEs. After receiving the broadcast, the "monitoring UE" (such as UE2) matches its target node list. Only when UE1 is in the target list of UE2, it will respond to the announcement request. After receiving the confirmation, UE1 will apply for radio resources to the D2D local controller to establish the D2D communication.

Model 2 "Discoverer UE" (such as UE3) periodically broadcasts announcements to neighboring UEs, including node identification, status, target node list and other information. Only the nodes in the target node list ("discovered UE", such as UE4) will respond to the discovery request. After UE3 receives the confirmation, the subsequent process is the same as model 1.

Although the two direct neighbor discovery models have different signaling designs between the UEs, they can effectively and timely discover the D2D devices. However, these two mechanisms send polling signals periodically to the node, which will cause a large energy consumption and shorten the standby time of the at the same time. Due to the limitation of transmission power, the direct neighbor discovery range at the UE level is relatively small.

2) GLOBAL NEIGHBOR DISCOVERY

In order to save the energy consumption of the D2D node discovery, the network level can be centrally controlled to realize and optimize the neighbor discovery. It cannot only save the node energy consumption, but also expand the scope of discovery and discover more neighboring nodes.

When two communication nodes belong to different base stations and are managed by different local controllers, the

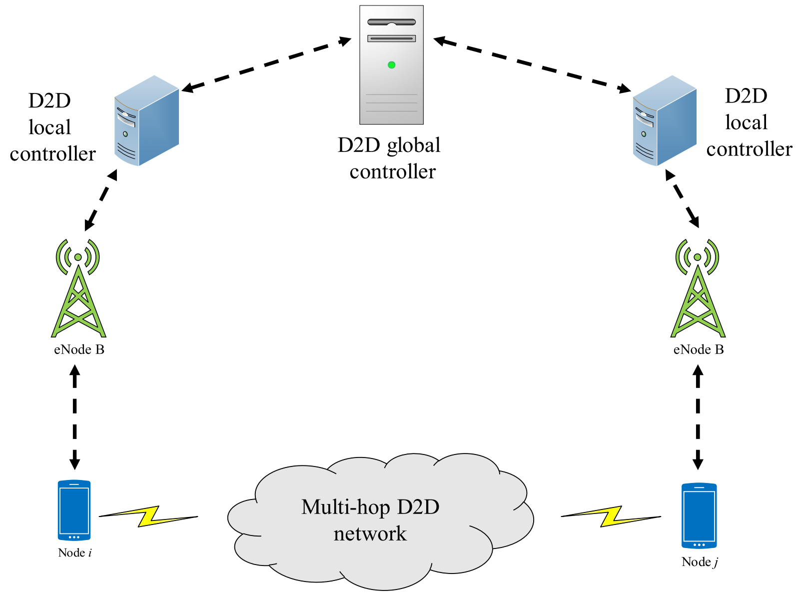

FIGURE 6. Inter-node position measurement for multi-hop D2D communication.

upper-level global controller uniformly manages the global neighbor discovery. Then, the controller determines the quality of the D2D communication link (such as signal-to-noise ratio, transmission distance) to make a judgment. After the communication conditions are met, the two parties are notified through the signaling channel to perform the D2D neighbor node discovery. At the same time, with the help of node location information and direct connection technology (such as WLAN direct or LTE direct technology), the direction connection of D2D communication is established.

References [48]–[50] can get the D2D global neighbor discovery signaling process, as shown in Figure 7, and the specific introduction is as follows.

1) UE1 and UE2 register their node information with the global controller through the local controllers 1 and 2 to which they belong, respectively. It includes the information such as user identification and node status.

2) UE1 sends UE2's proximity request to the local controller 1. That is, when UE2 is in the vicinity, the local controller 1 will send a neighbor reminder about UE2 to the node. Because UE2 is not managed by the current controller, the local controller 1 cannot perform direct neighbor transmission. Then, it sends UE2's proximity request to the global controller. After receiving the request, the global controller sends a proximity request preparation to the home controller of UE2.

3) UE1 and UE2 periodically report the current location update information to the global controller through the local controller.

4) The global controller calculates the relative distance between UE1 and UE2 based on their location information. If the distance meets the allowable threshold for D2D communication, the global controller sends a proximity notification to both parties.

5) The global controller sends the UE2 proximity notification response to the D2D local controller 1, and sends the UE1 proximity notification to the D2D local controller 2.

6) UE1 discovers UE2, applies for radio resources from the global controller, and uses the WLAN direct or LTE Direct technology to establish a D2D connection.

C. ROUTING MANAGEMENT IN D2D-SDN

1) DESIGN

The SD-D2D inherits the concept of separation of SDN control from the underlying transmission network. It realizes the virtualization of the D2D network through the flow table, and provides an overlay network independent of the transmission link. Using the SD-D2D's flow forwarding and control mode based on the flow table matching, the network control function is concentrated on the controller. The central controller can achieve the flexible control and monitoring of routing, flow, network behavior, terminal resources, etc. Through the controller formulate corresponding execution strategies and forwarding rules for rapid deployment and distribution, shielding the details of routing decisions from the terminal nodes. Therefore, providing support for functions such as network view, virtualization, and dynamic routing. At the same time, the controller plans the D2D communication path based on the real-time global network node information database. Then, carry out dynamic and continuous optimization, modify or delete the forwarding path by updating or deleting the flow table entries. Thereby, realizing the global path optimization.

According to the division of the base stations to which the two communication parties belong, the D2D-SDN route management can be divided into two types of scenarios: route management within the same and different base stations,

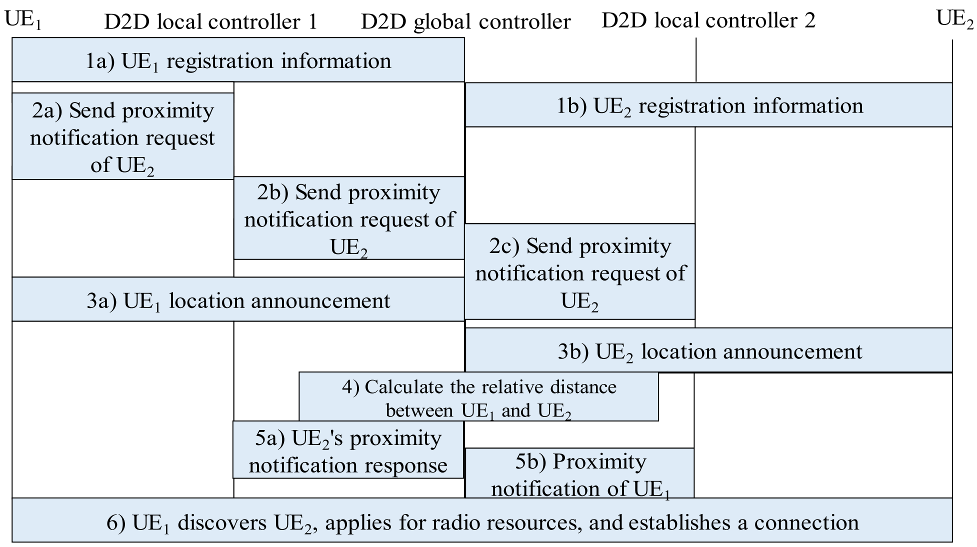

FIGURE 7. D2D global neighbor discovery signaling process.

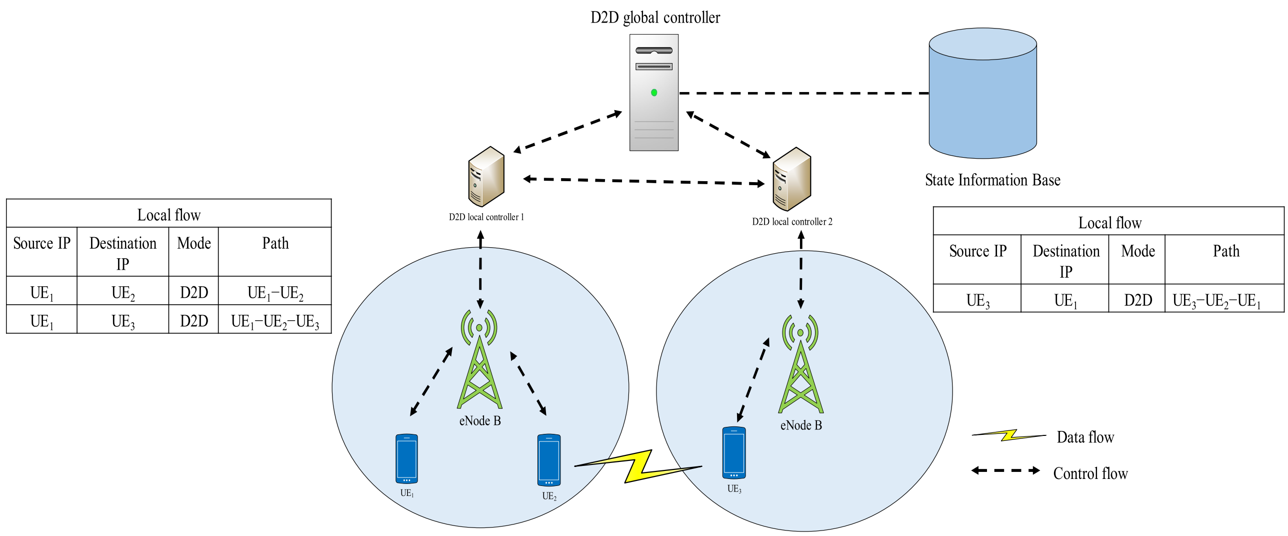

FIGURE 8. Route management within/between base stations.

as shown in Figure 8. Take the single-hop D2D communication under the same base station as an example. During the transmission of the control flow, a wireless network signaling is always maintained on the control flow between UE1 and the local controller. It is established at the beginning of the call establishment and released. Then, maintain it during the period for wireless resource allocation, link status reporting, power control, connection and routing management. When the link signal to interference plus noise ratio (SINR) does not meet the requirements, it will recalculate the forwarding path and update the flow table entry. When the communication ends, it is responsible for releasing the connection and recycling the radio resource block. The data flow represents the path of data transmission between the nodes. The forwarding rules are obtained through the control flow, and D2D communication is used to send data on the planned path [51]–[53].

1) Route management within the same base station

When the two nodes belong to the same base station, regardless of a single-hop or multi-hop communication between the nodes, the local controller uses the local flow table for routing management.

2) Routing management between different base stations

When the two nodes belong to different base stations, the communication between the nodes needs to be negotiated by the respective local controllers, and then the respective local flow tables are used for routing management.

2) FLOW TABLE

1) Establishment of flow table deploy a corresponding flow table on each local controller. When a new traffic arrives, it establishes an end-to-end route for the flow, and control the transmission of the data flow at the data level according

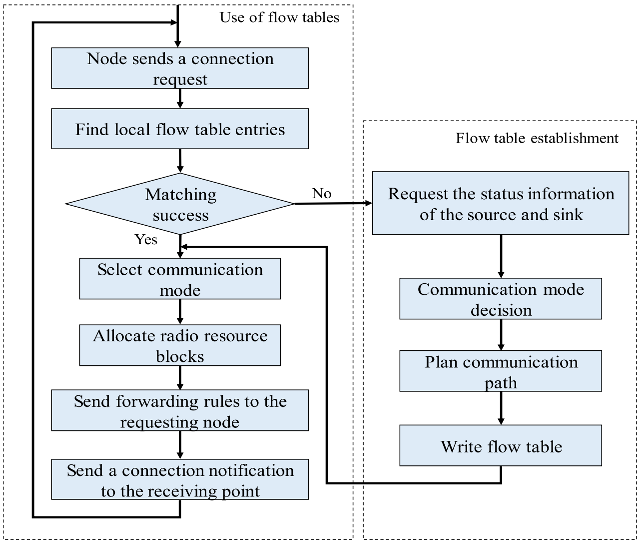

FIGURE 9. Flowchart for management of flow table.

to the flow table. The flow table structure of data packet forwarding is shown in Figure 9. The flow table field contains the following fields: source IP address, sink IP address, communication mode, and forwarding path. The controller selects the corresponding communication mode according to the routing decision. For example, a field value of "D2D" indicates that data is transferred from the source and sink through a D2D connection, and a field value of "B2D" indicates that data is transferred from the source and sink through a cellular network connection.

In the initial state, the forwarding entry in the local flow table is empty. With the connection requests between the nodes, the controller will gradually establish and continuously improve the entries in the flow table.

For a newly arrived connection request (such as UE1 to UE2), first, the local controller 1 to which the UE1 belongs requests the status information database for the respective locations and home base station IDs of UE1 and UE2. Then, judge according to the base station ID to which the UE2 belongs. When UE1 and UE2 belong to the same base station, the local controller directly performs communication mode selection and path planning. That is, by calculating the shortest distance between the nodes, it is judged whether the D2D communication can be constructed. Make communication mode decisions and plan single-hop/multi-hop D2D communication path. Then, write forwarding rules into flow table entries. When UE1 and UE2 belong to different base stations, the local controllers 1 and 2 negotiate to calculate the shortest distance between the nodes. Then, take the communication mode decisions, and plan the order between the base stations for single-hop/multi-hop D2D communication path, and write the forwarding rules into flow table entries. Finally, the local controller sends the forwarding rule to the requesting node UE1.

2) Update of flow table when the node position changes. It will trigger the flow table update operation. The global controller obtains the latest position of the node, recalculates the shortest distance between the nodes, and is responsible for notifying the local controller to update the corresponding flow table entry. At the same time, the timing of the entry reset the device to zero. In order to solve the problem of invalid flow tables, the local controller sets a timer for each flow table. If the local controller finds that a flow table has not received an update letter related to it within T time slots information. Then, set the entry as invalid and delete the entry after waiting for a period of time.

3) Use of flow table when the connection request from UE1 to UE2 is sent to the D2D local controller. The D2D local controller first searches the local flow table for the entry where the source IP is UE1 and the destination IP is UE2.

When an entry is found, the process of establishing a flow table is executed. If the match is successful, the corresponding communication mode (D2D and cellular mode) is selected according to the communication mode in the flow table entry. The local controller allocates D2D radio resource blocks to UE1 and UE2 respectively, and sends the forwarding rules in the flow table to UE1. At the same time, the UE2 is notified to prepare for the upcoming D2D connection. UE1 sends a polling signal to the next hop node UE2 according to the forwarding path. After UE2 receives the polling signal, it measures the state of the communication link with UE1 and sends the channel state information to the D2D local controller. The local controller performs the link SINR measurement. When the SINR meets a certain threshold, both parties are notified to establish a D2D connection, and data packets are transmitted on this link.

D. V2X-SDN KEY TECHNOLOGY

SD-D2D communication equipment is usually static or low-speed mobile, and V2X-SDN, as a comprehensive communication solution for vehicle and road. The network collaboration can provide low latency and high reliability in a high-speed mobile environment. The secure communication capability meets the needs of multiple applications for the IoV. Based on the TD-LTE communication technology, it can maximize the use of resources such as the TD-LTE deployed network and terminal chip platform to save the network investment and reduce the chip costs. In the V2X-SDN key technology, it is mainly explained from the perspective of path management, including V2V connection establishment, path planning and restoration. Among them, the V2V connection establishment process is included in path planning and restoration, so it will not be described separately.

1) PATH PLANNING

Using SD-V2V technology, the cellular-based vehicular communications can be offloaded to IEEE 802.11p or D2D-based V2V. The path discovery based on V2V VANET can be performed by a third-party controller. The controller keeps track and calculates the status of the vehicle. If there is a V2V path between the vehicles, it will notify the vehicles of both parties to reduce the calculation cost of the vehicle OBU. The

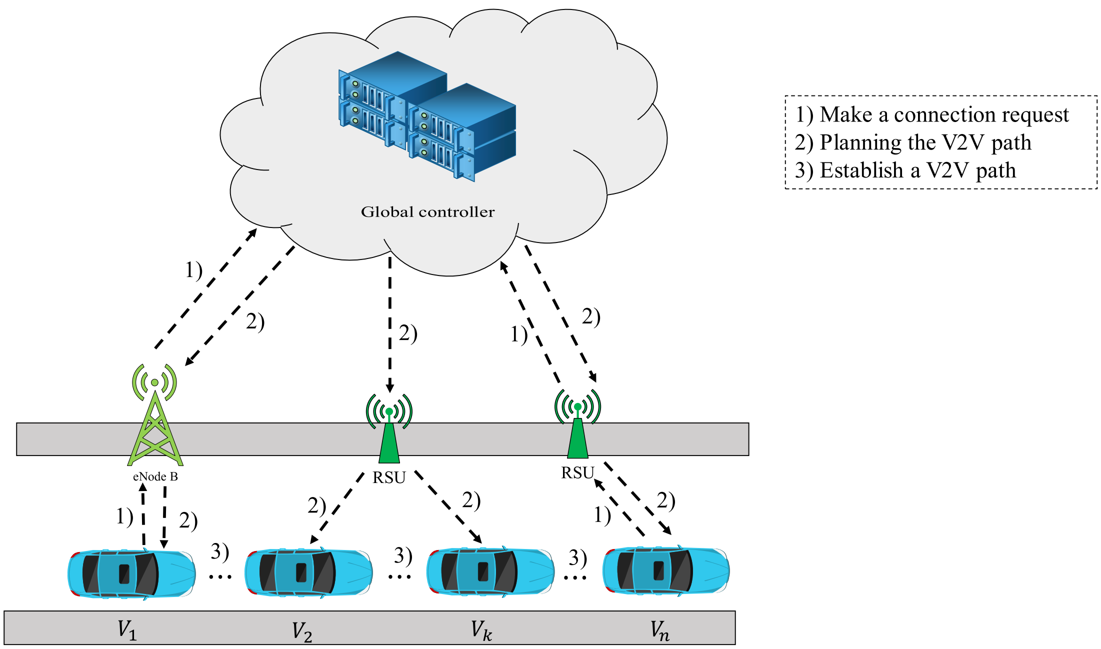

FIGURE 10. **Path planning of V2V networks.**

vehicle is maintaining the cellular connection. At the same time, it realizes fast switching to the V2V path and realizes the offloading of cellular network traffic.

The V2V path planning is shown in Figure 10. The specific steps are as follows.

1) In the initialization state, all vehicles in the network send real-time vehicle environmental information, such as geographic location, vehicle speed, direction, and neighboring vehicle IDs to the global controller from their respective central controllers through the cellular network.

2) The controller receives the vehicle information, saves it in the global status information database. It continuously checks the condition of the vehicle to provide a basis for decision-making for possible V2V connections.

3) At time t_0, V_1 sends a connection request to V_n to the base station.

4) The global controller searches for a feasible multi-hop V2V path between V_1 and V_n according to the trajectory of the vehicle. Taking the path between V_1 and V_2 as an example, considering the high-speed mobility of vehicles, the connection duration between the vehicles can be used as a measure of the stability of the V2V path [24]. According to the communication coverage of OBU, by calculating the vehicle driving direction, relative position and speed between the vehicles are used to predict the connection time. The path with the longest connection time is regarded as the best multi-hop V2V path.

5) If there is a feasible path $P = \{V_1, V_2, \ldots, V_n\}$, the SDN controller notifies all relay nodes on the path P to insert forwarding rules into the flow tables of all nodes.

6) If there is no V2V path, arrange for V_1 to establish a connection to V_n through the cellular network.

2) PATH DISCOVERY

In a high-speed vehicular environment, due to the uncertainty of vehicle driving, the original route planning will often be broken, which will affect the entire V2V multi-hop path. In order to prevent the single-point path failure, the SDN controller is required to provide a dynamic fast path repair mechanism which responds to a sudden path changes. It makes path re-planning and restoration in a timely manner. An example of V2V path restoration is shown in Figure 11. On the road, when a bifurcated road occurs, the vehicle will suddenly change its direction, or it will suddenly change its speed, which will break the original V2V path. The controller activates the V2V path repair mechanism to guide the vehicle's OBU to handle the abnormalities and carry out the path recovery operation.

Assuming that the original V2V path is $P = \{V_1, .., V_{k-1}, V_k, V_{k+1}, \ldots, V_n\}$, when a node V_k in the path concentration deviates from the original driving direction, the controller will trigger a "driving direction change" notification. After the controller receives the notification of the change, it immediately calculates and searches for a backup path P' to repair the path between V_{k-1} and V_{k+1}. Suppose that the vehicle V_{k-1} is the previous hop node of V_k in the original path P, and the vehicle V_{k+1} is the node in the original path P for the next hop node. The controller tries to find the backup node V_k between the two, so that it is adjacent to both and can communicate with each other.

Assuming that the controller can find the backup path, the new backup path $P' = \{V_1, .., V_{k-1}, V_k, V_{k+1}, \ldots, V_n\}$ is used instead of the original path $P = \{V_1, .., V_{k-1}, V_k, V_{k+1}, \ldots, V_n\}$, and perform the corresponding flow table operation at the node. In V_{k-1}, add the flow table entries

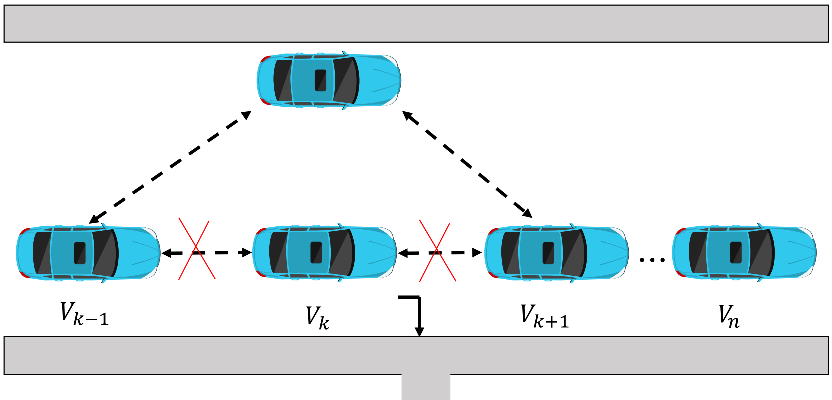

FIGURE 11. V2V path restoration example.

from V_1 to V_n. The next hop node is updated to $V_{k'}$. Add a flow table entry from V_1 to $V_n \sim V_k$, and V_{k+1} is the next hop node. Delete the existing flow table entries from V_1 to V_n in V_k, and finally send a ''path update announcement'' to all relevant nodes. Assuming that the backup path is not found, the relevant flow table entries in the path set are deleted, and the ''path update announcement'' is sent to all the relevant nodes which send the remaining data of V_1 to V_n through the cellular network. It is worth noting that, the replacement node $V_{k'}$ may be a multi-hop V2V path formed by a single node or multiple nodes, so the path delay after repair may become longer. But from the point of view of the single-point repair function, it is more effective than the original path and the impact is minimal.

VI. CONCLUSION

SDN has gradually expanded its coverage from single domain, wired management networks (such as intranets, data centers) to wireless dynamic environments (such as cellular networks, VANET). D2D and V2X are very technically related. In the future, they will develop collaboratively with the support of SDN. Therefore, this article studies and summarizes the SDN-based D2D and V2X communications, and also discusses the key technologies.

Based on the existing research works, it can be seen that the cellular network SD-D2D architecture is close to maturity, and the IoV SD-V2X framework has been initially determined. By taking the advantages of the centralized decision-making of SDN technology, it can indeed effectively improve the existing users in D2D/V2X communications. There will be more models and concepts emerging based on SD-D2D and SD-V2X architectures for issues such as interference management, mobility management, and routing management between D2D and cellular users.

At present, in the development of D2D and V2X, there are difficulties in coordinating the interests of multiple parties, which makes them less widely used.

This has also led to the fact that the existing SDN-D2D/V2X research is out of touch with actual applications, which has become a bottleneck for their further development. However, there is no relevant research on how the advantages of SDN-based architecture can break through this bottleneck. Therefore, in the future, it is necessary to conduct research on the deployment and application of SDN-D2D/V2X architecture in actual cellular networks to enhance the scalability of the SDN architecture. The collaborative deployment and work of network servers such as multicast servers, cloud computing servers, security authentication servers, and trust servers require further practical research. In addition, it is also necessary to consider how to load social network functions and social attributes of the application terminal in the controller, and how to maintain social network information in the controller.

With the advent of 5G networks and the continuous deepening of the SDN technology it contains, SDN-based D2D and V2X communications will gradually be applied.

Especially with the development of 5G-based V2X-based vehicle safety/autonomous driving and intelligent transportation systems from all walks of life, the application research of SDN-based V2X will be rapidly strengthened.

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