Comprehensive Survey of Radio Resource Allocation Schemes for 5G V2X Communications

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ABSTRACT In recent years, intelligent transportation systems, which provide safety and autonomous services on the road using the Internet and cellular technologies, have become increasingly important. Vehicles are equipped with sensors that can transmit data to other vehicles or infrastructure according to different types of services. In order to ensure robust connectivity for safety services, the transmission among vehicles requires low latency, high reliability, and high packet delivery ratio. With the increased number of vehicles, more frequency resources are needed to establish fast and reliable services. In the area of high vehicle density, the demand of frequency resources is increasing to establish stable connectivity in a short time. However, the amount of frequency resources is limited; the resource allocation scheme (RAS) should effectively assign a resource block to each user to ensure the quality of service. In this paper, we present a comprehensive survey of RASs for the 5G-based vehicular networks known as 5G V2X. We also discuss the challenges and opportunities for resource allocation in modern vehicular networks and present numerous promising future research directions.

INDEX TERMS 5G V2X communication, frequency resource, ITS, resource allocation, vehicular network.

I. INTRODUCTION

In recent years, the concept of vehicle-to-everything (V2X) has attracted increasing research attention in both academia and industry. This concept is embodied by the intelligent transportation system (ITS) [1]. As described in [2], the ITS provides different types of vehicular communications, which are called V2X communications, according to the traffic management and transportation requirements of V2X applications. V2X communications connect vehicles to end users and can be categorized as vehicle to vehicle (V2V), vehicle to infrastructure (V2I), vehicle to pedestrian (V2P), vehicle to cloud (V2C), or vehicle to network (V2N) [3]. Hence, V2X communications can significantly improve road safety and reduce traffic congestion, road accidents, and air pollution.

In order to fulfill the vehicle safety applications, the dedicated short range communication (DSRC) was developed to support V2X communications via short range between the devices of onboard units (OBUs) equipped in the vehicles and the roadside units (RSUs) placed in the road [4]. The vehicles exchange safety-awareness data or infotainment data to other vehicles or the road side infrastructure. The transmission range of OBUs is over hundreds of meters which is shorter than the transmission range in the cellular systems. The DSRC standards were proposed by different organizations, which include the IEEE in North America, the Association of Radio Industries and Businesses in Japan, and the European Telecommunications Standard Institute (ETSI) in Europe. Various standards of DSRC have been developed in different frequency spectrum such as the band 902–928 MHz (North America); 5795–5815 MHz (Europe); 5770–5780 MHz (Japan) [5]. In North America, the DSRC communication is allocated 75 MHz of licensed spectrum in the 5.9 GHz band. This spectrum is divided into seven 10 MHz channels with a 5–MHz guard band at the low end [4].

In DSRC, the medium access control (MAC) protocol is developed as the IEEE 802.11p wireless access for vehicular environment (WAVE) based on the IEEE 802.11 standard (Wi-Fi). The vehicles’ transmitter accesses the wireless medium by using the carrier sense multiple access/collision avoidance (CSMA/CA) technique of the IEEE 802.11 standard. The contention-based MAC may cause collision among the vehicles in high-density scenarios. As a consequence,
the network performance degrades in terms of high transmission collision rate, low throughput, low packet reception ratio, and high latency. In addition, DSRC technology limits the quality of service (QoS) requirements such as low data rate, short coverage while the main application of V2X requires high QoS guarantee to prevent the collision. The limitation of DSRC leads to the hybrid solution of DSRC – cellular networking, in which the cellular network can serve as a backup communication, backbone network, or an Internet access to the V2V connection [5].

The cellular V2X can overcome the short-range transmission in DSRC with more reliable communication. The 3rd Generation Partnership Project (3GPP) group has defined the use cases and the architecture to support the V2X communications. The 3GPP and the 5GAA develop the evolution of C-V2X standardization from the LTE-V2X to the 5G-V2X [6].

In [7], the 5G Automotive Association (5GAA) group discussed the fifth-generation V2X (5G V2X) and cellular V2X (C-V2X) for ITS services and applications, considering the technical deployment as well as the practical values. The 5GAA categorized the V2X applications into four main groups of use cases: safety, convenience, advanced driving assistance, and vulnerable road user. The V2X applications require real-time calculations for preventing collisions. For example, the see-through application allows trucks and cars to share images of road hazards or traffic conditions with vehicles behind them; therefore, the drivers know the situation of the road, which helps to prevent traffic jams and collisions.

In the future ITS, each vehicle is embedded with sensors and navigation technologies [8]–[11]. The sensors collect the vehicle state information and include wheel speed sensors, yaw rate and acceleration sensors, and steering and driver input sensors [8]. Depending on the ITS services, the collected data are sent to other vehicles or humans for road safety or autonomous driving. Each vehicle locates its position within the network using global navigation, e.g., the Global Navigation Satellite System or existing infrastructure based such as Wi-Fi access points and a cellular base station (BS) [12], [13].

The 3GPP categorized the V2X communications according to the transport scenarios [1], [7]. The vehicles are connected by wireless transmission to the BS, other vehicles, or network infrastructure [1], [7], [13]–[17]. A vehicle can transmit data to or receive data from the BS, pedestrians, other vehicles, and network infrastructure according to the transmission scenario, as shown in Figure 1.

In parallel to the V2X communications presented in [1] and the V2X application use cases presented in [7], 3GPP Release 16 groups the main services of V2X into four areas according to the critical requirements of scalability, reliability, throughput, and latency [15]. To ensure road safety, V2X communications require high reliability, high throughput, network scalability, and low latency. However, different V2X communications may require different levels of QoS, which depends on the transmitter and receiver for different V2X services. For example, the QoS requirement for latency in V2P differs from that in autonomous driving. Figure 1 shows the full network scenario of V2X communication, which includes different V2X connections and V2X services. The V2X services are described in detail below [15].

- As general aspects, interworking and communication-related requirements are valid for all V2X communications.
- Vehicle platooning refers to a group of vehicles moving together into a platoon with a small inter-vehicle distance. The lead of the platoon forwards messages to other vehicles.
- Extended sensors allow vehicles to exchange data to other vehicles (V2V), pedestrians (V2P), and infrastructure (V2I) to obtain a complete map of the environment.
- Advanced driving allows vehicles to exchange sensor data for achieving autonomous or semi-autonomous driving.
- Remote driving allows humans to remotely drive vehicles.
- Each vehicle enables a V2X application to adapt the QoS needs by estimating the modification of QoS in advance before it actually occurs. The 5G V2X services and QoS requirements are summarized in Table 1.

The radio resource allocation scheme to support V2X communication was introduced in 3GPP Release 14, which describes the technical enablers for V2X services at the physical layer and MAC layer. To satisfy the extensive requirements of V2X services, such as flexible transmission technology, low latency, and high reliability, in the high dynamic environment, 3GPP Release 16 was developed [16], [18]. The 3GPP Release 16 supports the 5G V2X services focusing on more enhancements of V2X scenarios with more stringent requirements for advanced features of automation, which includes physical frame structure and resource management [15], [19]–[21]. The 5G V2X services require the high reliability of about 90 to 99.99 percent in any circumstances and the extremely low latency of about 100 to 10 ms or even down to 3 ms as in Table 1.

The communication messages in V2X contain vehicle state information such as the location and speed [8],

### Table 1. 5G V2X services and QoS requirements.

| V2X Services      | Automation level | Max Latency (ms) | Tx rate (messages/sec) | Reliability (%) | Data rate (Mbps) |
|-------------------|------------------|------------------|------------------------|-----------------|-----------------|
| Vehicles platooning | High             | 10 – 500         | 30 – 50                | 90 – 99.99      | 80 – 350        |
| Advanced driving   | Low              | 3 – 100          | 10                     | 90 – 99.99      | 10 – 50         |
| Extended sensors   | High             | 3 – 50           | 10                     | 95 – 99.99      | 10 – 50         |
| Remote driving     | High             | 5                | 33 – 200               | 99.999          | UL: 25, DL: 1   |

- Vehicles platooning: applications that require communication for maintaining a platoon of vehicles.
- Advanced driving: applications that require communication for autonomous or semi-autonomous driving.
- Extended sensors: applications that require communication for exchanging sensor data.
- Remote driving: applications that require communication for remote driving.

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The communication messages in V2X contain vehicle state information such as the location and speed [8].
These messages are categorized into two types: cooperative awareness messages (CAMs) and decentralized environmental notification messages (DENMs) [1]. According to the messages transmitted among the vehicles, the applications can be considered as “Critical” or “Non-Critical” [12], [14]. V2X services can be categorized into many groups of applications with regard to different criteria of QoS. In [2], the V2X applications were categorized into four groups: (1) information services, which reduce the transmission latency and eliminate errors, providing comfort to drivers; (2) safety services aiming to reduce the risk of hazards by avoiding collisions or blind spots; (3) individual motion control; and (4) group motion control. Among the different categories of V2X services and messages, in this study, we focus on the QoS and the safety requirements in terms of the latency, traffic priority, types of message, or type of V2X service.

The radio communication of V2X-based 5G is classified into two types: Uu radio interface and PC5 radio interface [15], [16]. The Uu interface supports communications between the BS and the vehicle for uplink/downlink transmission [6], [16]. The PC5 interface supports direct communications between vehicles (also known as sidelink communication or the “direct mode”).

In one cell, the eNodeB may serve communications via radio frequency for both cellular users (CUs) and many vehicles, resulting in a high data load at the BS [16]. Another issue is the interference among CUs and vehicles. An effective solution is radio resource management (RRM) at the BS, which allocates the radio resources to devices in the coverage of the cell, allowing them to access the services. RRM is performed at the eNodeB MAC layer to ensure the efficient operation of the available limited radio resources. RRM allocates radio resources to CUs and vehicle users (UEs) in the time domain. The probability of collisions between CUs and UEs (vehicular users) must be minimized, and the spectrum efficiency and network throughput must be improved [22]–[24].

Additionally, V2X communication may cause interference to the CUs or to other V2X communications sharing the same radio resource. The sidelink (SL) transmissions face many challenges, including the physical radio structure, MAC, synchronization, and QoS requirements. Therefore, the 5G V2X ecosystem requires RRM to ensure effective transmission among the vehicles, core network of 5G, gateway, and servers [3].

In this paper, we review the state-of-the-art resource allocation schemes (RASs) of RRM for 5G V2X communications with regard to the QoS for V2X services as well as the latest supporting technologies. The existing RASs are compared according to their V2X services, QoS, and performance in different network scenarios. Additionally, we discuss the current issues and challenges related to the network scenario of 5G V2X and the QoS requirements. To the best of our knowledge, this is the first work to review the RASs in 5G V2X with consideration of the V2X services in different network scenarios.

The remainder of the paper is organized as follows. In Section II, we provide the background of 5G V2X communication. In Section III, we review the existing RASs in detail. A comprehensive comparison is presented in Section IV. In Section V, current issues and challenges are discussed. Section VI concludes the paper.

II. 5G V2X COMMUNICATIONS

A. 5G V2X FRAME STRUCTURE AT THE PHYSICAL LAYER

1) PHYSICAL CHANNEL

In 3GPP Release 16 [6], [15], 5G V2X services and other applications share the same common physical infrastructure for system resource such as spectrum/network bandwidth, storage, and computing. In [19], a SL physical channel carries information generated from higher layer, which includes four categories as follows:

- Physical SL shared channel (PSSCH) for data transmission.
- Physical SL broadcast channel (PSBCH) for supporting synchronization in the SL.
- Physical SL control channel (PSCCH) for sidelink control information (SCI) in time and frequency domain and also scheduling assignment.
- Physical SL feedback channel (PSFCH) for the SL-HARQ feedback and the configured resource pools by the base station.

5G V2X supports the unicast, multicast, and broadcast transmissions. Each UE’s transmission on the PSSCH is associated with a PSCCH transmission.

2) PHYSICAL FRAME STRUCTURE

In 3GPP Release 16 [6], [20], [25], 5G NR uses orthogonal frequency division multiplexing (OFDM). Multiple OFDM
numerologies are defined by a scalable $\mu$ and the cyclic prefix for a downlink or uplink bandwidth. The operating frequency ranges for NR V2X sidelink are listed as follows: The frequency range 1 (FR1) is from 410 MHz to 7.125 GHz. The frequency range 2 (FR2) is from 24.25 GHz to 52.6 GHz. In 5G V2X, the scalable OFDM numerology is used to support different requirements of QoS which called the subcarrier spacing (SCS) configuration factor. The SCS configuration factor $\mu$ defines the flexible frame structure and the subcarrier at the physical layer, in which $\mu = 0, 1, 2,$ or 3. The transmission bandwidth for each channel bandwidth and SCS varies from 5 MHz to 100 MHz for FR1 and from 50 MHz to 400 MHz for FR2.

A bandwidth part is a subset of contiguous common resource blocks, which has the same numerology $\mu$ on a given carrier. The downlink or uplink can be figured with up to four bandwidth parts at a given time. Each channel consists of a set of resource blocks (RBs), and each RB is formed by 12 consecutive subcarriers with the same subcarrier spacing. The resource grid is formed by numerous RBs with the same subcarrier spacing. The radio resource is shown in Figure 2.

In the time domain, the resources are divided into frames with a length of 10 ms per frame; each frame consists of 10 subframes. The slot of the frame depends on the subcarrier spacing, which can be 0.5, 0.25, or 0.125 ms. The physical structure is described in Table 2.

### TABLE 2. Physical Structure in 3GPP Release 16.

| Numerology $\mu$ | 0  | 1  | 2  | 3  | 4  |
|------------------|----|----|----|----|----|
| Cyclic prefix    | Normal | Normal | Normal | Normal | Normal |
| Number of symbols per slot | 14 | 14 | 14 | 14 | 14 |
| Subcarrier spacing $Af + 2\mu \times 15$ (kHz) | 15 | 30 | 60 | 120 | 240 |
| Maximum Carrier Bandwidth | 50 MHz | 100 MHz | 200 MHz | 400 MHz | – |
| Number of slots per frame | 10 | 20 | 40 | 80 | 160 |
| Number of slots per subframe ($2^k$) | 1 | 2 | 4 | 8 | 16 |
| Slot duration (ms) | 1 ms | 0.5 ms | 0.25 ms | 0.125 ms | – |

### B. 5G V2X RADIO COMMUNICATION

In 3GPP Release 14, radio resource allocation is categorized into the overlay mode and the underlay mode [15], [19]. In the overlay mode, the vehicles are assigned dedicated radio resources by the BS. In the underlay mode, the vehicles can share the radio resources with the CUs but must manage the minimum interference to the CUs. In this study, we focus on the RASs of sidelink transmission in 3GPP Release 16, which is categorized into two modes: (1) mode 1, in which the BS schedules the transmission for each sidelink transmission, and (2) mode 2, in which the radio resource of the sidelink transmission is selected autonomously by selecting the radio resource from the resource pool [6]. In [26], the technology and communication of 5G were reviewed with regard to the resource allocation, MAC, networking, and physical layer. Our study differs in that we considered RASs for different V2X network scenarios, levels of QoS, and practical applications.

1) RESOURCE ALLOCATION MODES

As described in [6], 3GPP Release 16 supports two models of resource allocation for sidelink communications, which are called mode 1 and mode 2. The mode 1 UEs and mode 2 UEs transmissions may share the resource pool, which results in more efficient usage even though the collision may occur between mode 1 and mode 2 transmissions [25]. Mode 1 UEs alert mode 2 UEs for their resources to avoid collision in the future transmissions.

In mode 1, the BS schedules the resource for transmission of the UEs over the NR Uu interface. The resource of V2V transmission can be allocation in a slot (in time domain) or sub-channel (in frequency domain) and the UEs are fully in the coverage of the base station. The base station schedules the transmission in two scheduling types, which are a configured scheduling and dynamic grant scheduling [6], [20], [21].

- In the configured scheduling, the base station assigns a set of sidelink resource including several transmission blocks (TBs). The UE sends the information which indicates the expected resources such as the periodicity of TBs, the maximum size of TBs, and QoS information for specific SL traffic.
- In the dynamic grant scheduling, the UEs send a scheduling request to the base station. The base station responds the UEs with a downlink control information (DCI), which consists of the sidelink resources (slots and sub-channels).
In mode 2, the UEs can autonomously measure the reference signals received power (RSRP) during a sensing window and select resources according to the network configuration. The mode 2 sensing procedure can select and reserve resource to be used for blind (re-)transmission or HARQ-feedback-based (re-)transmission of a transport block. The resources are indicated in the SCI scheduling transport block. UE can reserve up to 2 or 3 SL resources within the same resource selection window.

When UE has traffic, the resource selection is triggered with respect to the time of trigger called \( n \). The sensing windows can be 1100 ms or 100 ms for periodic traffic or aperiodic traffic, respectively. In the first stage SCIs during the sensing window, a UE starts sensing procedure by measuring the RSRP of all the subchannels. In the resource selection procedure, the SCI transmissions are used to estimate the resources which have been reserved by other UEs. The UE selects resource for its transmission within a resource selection window. The selection window starts after the trigger \( n \) for selection of resource and cannot be longer than the remaining latency budget as in Figure 3. If the value of RSRP is above the threshold and the traffic priority of the measured resource is higher than its traffic priority, this subchannel is occupied. A higher priority transmission from a sensing UE can occupy resources which are reserved by a transmitting UE with low SL-RSRP and low-priority traffic. If the available resource is less than a certain proportion, a UE selects resource randomly from the remaining resources. The RSRP threshold is relaxed in 3 dB steps until it has at least 20% (or 35, 50% based on traffic priority) of all resources in the selection window for resource selection.

![Figure 3](image)

**FIGURE 3.** Resource selection mode 2 [6].

Figure 3 shows the resource reservation in mode 2 which includes the sensing window, the trigger time \( n \), and reservation window. The processing times \( T_{proc,o} \) before the trigger time indicates to the required time to complete SCIs decoding in the physical layer. The processing \( T1 \) refers to the inter-layer information exchange. The sensing and resource procedure is triggered at time \( n \), and the resource is reversed at time \( m \). Based on the UE sensing, the UE can choose an appropriate amount of resources, which are not used by higher priority traffic UEs.

Comparing to DSRC, the C-V2X resource management has more advantages in terms of supporting high QoS requirements, the number of reuse resource, and the number of UEs. In DSRC, the direct transmission between UEs adapts the CSMA/CA of the IEEE 802.11 standard, which may cause collision and long latency due to the back-off value and contention windows. However, the C-V2X allows the UEs to reserve the resource by using the trigger time \( n \), which minimize the latency. On the other hand, the mode 2 states that the higher priority traffic UEs can reserve the resource block. It results in higher reliability to satisfy the high automation level of V2X use case. In addition, if the low-priority traffic UEs sense the transmitting resource with the high RSRP, a UE relaxes the RSRP threshold until it has at least 20% of all resources in the selection window.

3GPP Release 17 focuses on further enhancements with regard to operation in the dynamic spectrum between new radio (NR) and 4G long-term evolution (LTE). Specifically, the objective is to enhance the scheduling capacity for NR UEs on a shared (LTE+NR) carrier by extending cross-carrier scheduling [16], [27]. As a promising 5G technology, V2V communication allows physically similar devices to communicate directly through a licensed cellular band, bypassing the cellular eNodeB [28].

### III. RESOURCE ALLOCATION SCHEMES IN 5G V2X COMMUNICATION

In this section, the existing RASs are investigated with regard to numerous aspects (e.g., communication mode, requirements, and services). Then, we describe and analyze the RASs and perform a detail comparison. The RASs are categorized into four groups, as shown in Figure 4. The first group is the interference-aware scheme, which focuses on reducing the interference between the vehicles or V2X network and the CU. In the second and third groups, the RAS allocates the communication of the V2X sidelink according to the geographic location and time–frequency selection, respectively. In the fourth group, the clustering algorithm is implemented in V2X to increase the network performance while minimizing the interference.

#### A. INTERFERENCE-AWARE SCHEMES

1) MINIMIZE INTERFERENCE FOR V2X COMMUNICATION UNDERLAYING 5G CELLULAR NETWORKS

In [22], interference among the UEs and CUs may occur, because the UEs and CUs can occupy the same frequency...
band for uplink at the same time. A centralized resource allocation scheme allows a UE to reuse the cellular uplink radio resource. The V2X communication operates on the underlay mode in 5G cellular network, in which the UEs can communicate directly to each other without the 5G base station. The UEs can use the spectrum without affecting the QoS of the CUs. The centralized RAS is considered at the 5G BS (gNB) for reusing the cellular uplink radio resources for both UEs and CUs. The gNB divides the total uplink bandwidth into $Z$ subchannels, each of which is occupied by at most one UE link and one CU uplink. The gNB calculates the objective function, which minimizes the sum of the interference power of the UEs to a certain CU uplink on the total bandwidth, as follows:

$$\min_k \sum_{z=1}^{Z} \rho_{k,z} I_{k,z}^S,$$

where $\rho_{k,z}$ indicates whether a UE $k$ occupies the subchannel $z$ ($1 \leq z \leq Z$), and $I_{k,z}^S$ indicates the interference power of the UE $k$ to one CU uplink on subchannel $z$.

To minimize the interference between the UEs and the CUs, the mixed binary integer nonlinear programming problem is used to solve the UE transmission power and subchannel allocation. The transmission power of the UE on the subchannel is limited by the channel gain and the interfering

![Figure 4. Taxonomy of RASs for 5G V2X communication.](image-url)
link. Each UE is assigned a subchannel in which the transmission power of the UE satisfies the condition of interference.

- MAIN FEATURES: The transmission power of the UE is limited, which reduces the interference to any CUs in the same transmission range, facilitating the communication of both UEs and CUs to the eNodeB.

- LIMITATIONS: The nonlinear programming problem only considers the transmission of UEs, without taking into account the traffic requirements of vehicles (such as safety or non-safety traffic). For example, assume that the UEs and CUs are served by the BS; the autonomous driving service may require a higher QoS than the CUs playing games. Thus, the QoS of traffic should be considered in any network scenario.

2) SHORT-TERM SENSING-BASED RESOURCE SELECTION SCHEME

In [29], the UEs generate different types of traffic and content the resource for transmission. The short-term sensing-based resource selection (STS-RS) scheme aims to reduce the number of packet collisions that occur during resource selection. The time–frequency resource unit is designed as multiple adjacent subchannels within one subframe in the time domain. The resource unit is divided into sensing duration and message transmission. When a vehicle has packet to transmit, a resource selection is triggered. A vehicle performs resource selection in a resource selection window for periodic transmission and message transmission. When a vehicle has packet to transmit, a resource selection is triggered. A vehicle performs resource selection in a resource selection window for periodic transmission. The short-term sensing unit is employed at the beginning of resource selection. If the RSRP is above the threshold, the vehicle excludes the resource. If there is not available resource, the vehicle freezes the timer of sensing on a new sub-frame. If the sensing time is zero, the vehicle selects the available resource and performs the message transmission. Each vehicle configures a sensing timer according to the traffic priority. The higher packet priority has smaller timer or the high CBR has larger timer.

For example, a higher packet priority corresponds to a shorter timer, and a higher channel busy ratio corresponds to a longer timer. If the vehicle detects a busy channel, the vehicle sets a longer timer for the sensing unit to reduce the collision probability. In Figure 5, vehicle A has a higher traffic priority than vehicle B, and the sensing duration of vehicle A is shorter than that of vehicle B. Vehicle B configures a longer sensing duration; if it detects the data transmission of vehicle B, vehicle A restarts the timer when vehicle A stops transmitting.

- MAIN FEATURES: The vehicle can build a map of sensing resource selection; then, the vehicle can reduce the number of overhead packet, which avoids hidden terminal interference. The RAS performs effectively in the 16 m \( \times \) 2000 m highway scenario with multiple lanes (two lanes in each direction, 3.5 m/lane [30]) and a high speed of vehicles. The network reliability is high in dynamic scenarios, which also satisfies the requirement of different types of traffic priority.

- LIMITATIONS: The vehicle may rebuild the map while moving from one BS to another, increasing the computational cost of UE. Additionally, the transmissions of V2X may collide with those of other V2V services such as platooning. This is because platooning consists of many vehicles moving in the same direction, which requires an extremely long transmission duration.

3) ADAPTIVE TRANSMISSION POWER CONTROL ALGORITHM

In [31], the vehicles employ sensing-based semi-persistent scheduling (SPS) for C-V2X; then, UEs select the best time–frequency RAS for transmission of the CAM. In mode 4 communication, the transmission power of the vehicle is varied to achieve the required QoS and to avoid interference with neighbors in large-scale traffic scenarios. The adaptive transmission power control algorithm includes the following four steps. In step 1, the vehicle performs channel sensing to measure the sidelink received signal strength indication (SL-RSSI). In step 2, the vehicle calculates the interference by using the SL-RSSI from its neighbor. In step 3, the vehicle allocates the transmission power according to the calculated interference and the density of vehicles per kilometer. Then, in step 4, the transmission power is determined for each vehicle according to the CAM transmission.

- MAIN FEATURES: UEs are assigned the transmission power according to the channel sensing and the number of neighbors or the density of vehicles; therefore, they can avoid interference with neighbors.

- LIMITATIONS: The safety-related data packets of UEs and pedestrians are not considered. Additionally, the sensing-based scheduling may require a long waiting time, resulting in high latency.

B. GEO-BASED RESOURCE ALLOCATION SCHEMES

1) GEO-BASED SCHEDULING FOR C-V2X NETWORKS

The geo-based scheduling scheme proposed in [32] allows the vehicles to select RBs according to their locations and the information of neighbors. The subchannel is organized into Pools, which include of all the subframes within...
FIGURE 6. (a) Resource pool and (b) geo-based scheduling scheme in 5G V2X [32].

A given time, as shown in Figure 6(a). The resource pool has $N$ sub-channels, which consists of $F$ sub-frames of 1 ms and $C$ sub-channels per sub-frame. The vehicles estimate their ordering according to the beacon message containing the CAMs and basic safety messages.

The vehicles send the beacon containing information regarding the speed and location, as well as $TimeStamp$ data. Then, each vehicle estimates the locations of its neighbors and builds a virtual queue and orders, as shown in Figure 6(b). According to the information of the neighbors, each vehicle selects a $PosIndex$ indicating its position in the queue. The $PosIndex$ takes the value of the number of subchannels in a Pool. Because each vehicle selects one $PosIndex$ value, the geo-based scheduling scheme allows vehicles to share subchannels. However, if two vehicles use the same subchannel, the geo-based scheduling scheme requires them to be separated by the maximum distance for minimizing the interference. For example, in Figure 6(b), vehicle $V3$ can share a subchannel with vehicle $Vi$ because the distance between $V3$ and $Vi$ is longer than the distance between $V3$ to $V1$ and $V2$, and $V3$ is beyond the sensing range of vehicle $Vi$. According to the ordering and the location, the vehicle can avoid the hidden-terminal problem, reducing the probability of packet collisions.

- MAIN FEATURES: The scheduling scheme increases the packet delivery ratio and estimates the locations of neighboring vehicles. Therefore, the number of collision may be reduced, leading to optimal scheduling of UEs in the time–frequency domain.

- LIMITATIONS: The scheduling scheme does not consider the traffic requirements of each vehicle, e.g., safety or non-safety traffic, CAMs, or DENMs. However, vehicles traveling at a high speed may move outside the coverage of a BS in a short duration. Because the transmission range of a vehicle changes according to the vehicle’s speed, the hidden-terminal problem may occur when the vehicle increases or decreases its speed.

2) ZONE-BASED RESOURCE ALLOCATION

In [33], the typical V2X communication is taken as the urban scenario consisting of buildings, four lanes for the vehicle road, and a sidewalk. Interference is more likely to occur at the crossroad than in other areas. The authors investigate the crossroad, where the distance between vehicles is shorter than the transmission range. Owing to the high density at the crossing point of the street, the vehicle may be within the transmission range of another vehicle, which causes a collision in transmitting data to the BS. The urban area can be divided into numerous geographic zones, each of which is assigned a zone ID and a limited resource pool of the sidelink in Mode 2.

The urban scenario is defined in [30], which is shown in Figure 7. The geographic zones are divided into multiple pattern grids, in which each zone is configured with a resource pool. The road can only occupy some grid zones, which is associated with configured resource pool. This is different to C-V2X mode 2, in which the resource pool is not configured according to the grid zones.

The same resource pool can be reused in a different geographic zone without causing interference. Therefore, the UEs can share the same resource pool in the time domain.
with a high latency. In Figure 8, vehicle C is assigned a channel in resource pool 1 according to its direction, while vehicles A, B, and D can take the channels in resource pool 2.

![Resource allocation diagram](image)

**FIGURE 8.** Zone-based resource allocation [33].

- **MAIN FEATURES:** Vehicles dynamically select the channels with regard to the direction and the packet types; therefore, the channel is reused without collision.

- **LIMITATIONS:** The protocol does not consider the highway scenario with high diversity of vehicles and many services, such as platooning services, autonomous driving, or V2P. Each type of V2X service or V2X communication requires a different value of the latency or packet string; therefore, the RAS should consider the QoS requirement as well as the vehicle location.

3) **TWO-STAGE RESOURCE MANAGEMENT SCHEME**

In [34], the V2X network is distinguished between V2V and V2N. The V2V-UE uses the PC5 sidelink to communicate, and the V2N-UE uses the Uu radio interface to communicate to the eNodeB. If there is an obstacle on the road, the communication link between the UE and the eNodeB is disrupted, causing a shadowing effect and packet loss. The two-stage resource management aims to guarantee the connection to the eNodeB; the UE can select another UE with a reliable PC5 connection to establish a cooperative link. The radio resource scheme consists of a two-stage management scheme. The RRM scheme takes the following parameters into account: the channel state information, vehicle density information, and queuing state information. The efficient scheme distributes the radio resources among UEs within the frequency domain and time domain.

The first stage is time-division scheduling. The RBs are assigned for V2N-UEs; all the packets of the V2N-UEs and V2V-UEs are scheduled according to the performance metric in the time domain. For V2N-UEs, the performance metric is calculated according to the throughput of UEs in the past and the number of packets in the buffer. For V2V-UE, the performance metric is calculated according to the packet delay.

The second stage is frequency-division scheduling. The UEs type is scheduled in the frequency domain according to the QoS conditions, which consider the signal-to-interference-noise-ratio (SINR) of every V2N-UE. The resource allocation algorithm aims to maximize the Shannon capacity in the frequency domain according to the SINR of the V2N-UEs.

- **MAIN FEATURES:** Vehicles are grouped according to the channel quality index, and the packet strings are scheduled according to the QoS conditions. The QoS requirements of V2X services are considered in detail; therefore, the network performance is enhanced.

- **LIMITATIONS:** It is necessary to evaluate the channel condition with a short channel sensing duration to satisfy the traffic requirements of V2X services, such as CAMs and DENMs.

4) **POSITION-BASED RESOURCE MANAGEMENT**

In urban areas, there are many vehicles, buildings, crossroads, and pedestrians. With the high density of vehicles, the signal quality of V2X can be adversely affected by high degrees of fading and shadowing caused by the positions and directions of vehicles or obstacles. The RAS presented in [35] assigns radio resources to vehicles with consideration of the vehicle position and direction. The vehicle position is classified into one of two cases (urban or freeway); then, the resource is allocated to the vehicle according to its position.

The resource pool is divided into $N_f$ RBs in the frequency domain; each block has a 10–MHz bandwidth. In the time domain, the total time is divided into subframes with a length of 100 ms. According to the vehicle position, the resource pool is divided into a special sub-resource-pool and a normal sub-resource-pool. If the vehicle position is at the intersection region for the urban case or the high-speed region for the freeway case, the vehicles are allocated to the special sub-resource-pool. If the vehicle position is at a horizontal street for the urban case or the freeway case, the vehicle is assigned the odd time interval or even time interval of the normal sub-resource-pool.

- **MAIN FEATURES:** The RBs are divided into a special sub-resource-pool for the vehicles in the urban case and the normal sub-resource-pool for the vehicles in the freeway case. Thus, the UEs are assigned the resource while moving on the road quickly without interruption.

- **LIMITATIONS:** The vehicles require a pre-assigned resource if they move outside of the cell coverage or move from an urban area to a freeway with a high speed. The QoS of different V2X communications is not considered in the resource management scheme.

5) **GROUP SCHEDULING FOR PLATOONING IN 5G V2X**

The V2X service considered in [36] was vehicular platooning, which consists of multiple vehicles moving in the same direction. In the platooning service, the distance between vehicles is short; thus, accurate transmission is required. The current LTE mobility and resource scheduling scheme for an
individual vehicle cannot solve the problem of multiple vehicles. Owing to the mobility and short distance, interference occurs between platoon members in the same cell or during the handover. Packet loss occurs if the platoon members are at the border of the coverage of the BS or are assigned different frequency resources within the same transmission-time interval.

The platoon is considered as a group with the same scheduling process even when the platoon moves between different BSs. The platoon leader is associated with the BS, while other platoon members communicate only with the platoon leader. The resources are distributed to all the platoon members by the platoon leader, which results in high connectivity of the platoon. The platoon leader sends the group request to the BS and distributes the resources to all the members, as shown in Figure 9. The BS checks for the available resource to communicate with the platoon and then sends a response to the platoon leader. The response can be positive or negative, which indicates the scheduling grant for the platoon or whether the required QoS can be achieved.

FIGURE 9. Group request to the target cell [36].

- MAIN FEATURES: The platoon leader sends the group request to another cell during handover; therefore, all the platoon members are scheduled by the BS. The duration of establishment and resource scheduling is short, which improves the network performance (increasing the reliability and the number of received packets and reducing the latency).
- LIMITATIONS: The scheduling scheme does not consider pedestrians, other UEs, or different types of areas (such as urban areas or freeways). The diversity of vehicles in different locations should be considered to ensure the QoS of V2X communication when vehicles move through different areas.

C. TIME–FREQUENCY SELECTION SCHEMES
1) C-V2X AUTONOMOUS RESOURCE ALLOCATION SCHEME
In [37], the authors investigated the C-V2X autonomous RAS with regard to mode 4 in Release 14 and mode 2 in Release 16. In [1], the DENMs are event-triggered messages that are generated in the case of an abnormal event. If the vehicle detects a road hazard, it generates DENMs to alert other vehicles in its transmission range.

The RAS performs on the autonomous mode in 3GPP Release 14 and Release 16, in which the UEs immediately send any generated packets by using randomly selected resource. Therefore, the generated DENM and CAM at UEs may experience a collision on the resource. Because the DENM has higher priority than the CAM, the random resource selection scheme immediately allows the transmission of the DENM. The DENM is randomly scheduled without considering other parameters such as the resource pool or the number of vehicles. To transmit the CAM or DENM according to the QoS, the sensing-based resource selection scheme assigns the subchannels to the CAM or DENM on the basis of the least interfered resource. The short-term sensing allows UEs to select the subchannel if the sensing window for DENMs is shorter than that for CAMs. The last resource allocation is the short-term sensing with variable selection windows and a variable resource percentage. The duration of the sensing windows for DENMs or CAMs is set as 100 ms. The percentage of resource selection is set as 0.2 and 0.1 for CAMs and DENMs, respectively.

- MAIN FEATURES: The C-V2X autonomous RAS satisfies the latency requirements for DENMs by choosing the sensing duration and the percentage of RB selection.
- LIMITATIONS: The autonomous RAS in 3GPP Release 14 and Release 16 do not consider the high diversity of vehicles or multiple network scenarios with the presence of fading or shadowing.

2) RETRANSMISSION SCHEME IN V2X SIDELINK
In [38], the vehicles share the safety-related messages via the direct sidelink communication. However, the transmitter does not obtain feedback regarding whether the message is successfully received. A loss of data may cause a dangerous situation in some cases, e.g., autonomous driving or road warning.

In 3GPP Release 14 mode 3, the sidelink transmission of UEs can be allocated by the BS in 3GPP. However, the UEs can autonomously select the radio resource from the resource pool in mode 4.

Hybrid automatic repeat request (HARQ) blind retransmission is implemented on the sidelink to ensure the reliability of transmission of UEs. The transmissions of users are scheduled in the time domain by using key performance indicators (KPIs) such as the SNR, packet delivery ratio, and block error rate (BLER). The retransmission is defined by using the Link-to-System (L2S) mapping tables. The L2S mapping tables indicate the performance of the physical link with the SNR and the BLER in two cases: with and without re-transmission. The N users are served by one BS, which is divided into two parts: (1) first transmission and (2) retransmission. The total duration for N users is 100 ms, in which one BS serves N users. The first transmission occupies 50 ms, and the retransmission occupies 50 ms. The SINR for each Rx-UE is calculated using the current SINR and the historical SINR. According to the SINR, the corresponding BLER is used to determine whether the packet is received.
- MAIN FEATURES: The reliability of the data is improved via one blind retransmission in 3GPP Release 14 mode 3 and mode 4. The number of successfully received packets at the UEs is large because the link quality is used to select the transmission link to the BS or to other UEs.

- LIMITATIONS: The sensing algorithm is not described. The vehicle looks up the L2S to estimate the number of successfully received packets, which may result in a long waiting time. The vehicle location and density of vehicles on the road should be considered to evaluate the effectiveness of the RAS scheme.

3) DYNAMIC SCHEDULING ALGORITHM BASED ON PRIORITY ASSIGNMENT FOR V2X
As reported in [39], the dynamic scheduling algorithm based on priority assignment (DSA-PA) is an optimal scheduling algorithm for V2X connections based on the channel conditions of the UEs. In the first step, the UEs are classified into three types of traffic priority: safety traffic, management traffic, and infotainment traffic. The management traffic and infotainment traffic are grouped into non-safety traffic, which has a lower priority than safety traffic. The average blocking rate is used to estimate the number of safety-UEs that are not served by the eNodeB. In the second step, the RBs are divided into three groups sharing three types of traffic. The scheduler ensures that the UEs are assigned to a group of RBs according to their traffic. For each group of RBs, the RBs are assigned to the UEs with the highest SINR. The dynamic scheduling algorithm aims to maximize the throughput at the eNodeB while ensuring the fairness between different UEs by using the SINR of UEs.

- MAIN FEATURES: The scheduling achieves a high throughput while satisfying different types of traffic priority.

- LIMITATIONS: The DSA-PA scheme does not consider the diversity of vehicles or multiple network scenarios. Additionally, the DSA-PA does not consider the mobility of UEs in case the vehicle moves along a highway or in an urban area. The out-of-coverage scenario may cause signal loss during V2X communication, which needs to be investigated.

4) GREEDY CELLULAR-BASED V2X LINK SELECTION ALGORITHM
In the method of [40], the vehicles are scheduled orthogonally according to the overlay scheme for cellular-based V2V communications. First, the vehicle checks the time duration for every generated packet and decides whether to establish a V2V link to the cellular eNodeB by sending a request. If the eNodeB receives the requests from the vehicles, it selects the receiver vehicles to establish V2V links according to the requests for minimizing the latency. The set of vehicles in the range of the cellular eNodeB is denoted as \( \Omega_z \), and the set of vehicles that send requests to the cellular eNodeB is denoted as \( \Omega_i \). Because many vehicles can send requests simultaneously, the eNodeB solves the optimum resource allocation problem to select the suitable channels for V2V links to minimize the total latency. The weighted reduction in latency for vehicle \( v_i \) is given as

\[
 w_v(L) \approx (1/t_{v_i}) \Delta M_v(L), \tag{2}
\]

where \( t_{v_i} \) represents the residual time of the packet of vehicle \( v_i \), \( L \) represents the set of cellular-based V2V links to be established (as determined by the eNodeB), and \( M \) represents the set of possible V2V links from vehicles in \( \Omega_z \) to vehicles in \( \Omega_i \). The data latency is expressed as follows:

\[
 \max_{v_i \in \Omega_i} \sum_{v_i \in \Omega_i} w_v(L). \tag{3}
\]

The eNodeB aims to maximize the weighted sum of the reduction in latency for all the vehicles in set \( \Omega_i \). Therefore, the selected V2V links can work simultaneously with a guaranteed SINR for all the links, and the total network latency is expected to be reduced significantly. When a vehicle switches to a cellular-based V2V link for transmitting its current packet, the contention intensity of its neighbors decreases, and their packet latency is expected to decrease.

- MAIN FEATURES: The scheduling scheme aims to optimize the resources among the vehicles in one cell by considering the transmission requests of the vehicles. The latency of V2V is minimized by considering the number of requests and the optimal resources.

- LIMITATIONS: The out-of-coverage scenario may cause signal loss, leading to a dangerous situation on the road. The QoS, the diversity of V2X communications, and multiple network scenarios should be considered in allocating resources to vehicles.

D. CLUSTER-BASED RESOURCE ALLOCATION SCHEMES
1) CLUSTER-BASED RESOURCE BLOCK SHARING AND POWER ALLOCATION
In [41], the cluster-based RB sharing and power allocation (CROWN) algorithm was implemented to share resources amongst the UEs and CUs. This algorithm aims to maximize the CU sum rate while considering the safety requirements of UEs with regard to latency and reliability. At the BS, the vehicles that do not share RBs can be grouped into a cluster.

- MAIN FEATURES: The CROWN algorithm achieves the stringent latency requirements for vehicles. The throughput of the cellular BS is maximized, while the interference between CUs and UEs is minimized.

- LIMITATIONS: CAMs and DEMNs are not considered. Similar to other RASs, multiple network scenarios should be considered, as well as the traffic priority of V2X communications.

2) CLUSTER-BASED RESOURCE SELECTION SCHEME
As described in [42], the vehicle can elect to become the cluster head according to the residual energy of each vehicle. The time–frequency domain is divided into multiple resource sets, and each cluster occupies one resource set. The cluster head senses the idle channel; then, the cluster head selects
the resource sets with the minimum interference to assign to all its cluster members. The vehicle compares the results of the sensing resource to the resource threshold. The resource threshold is indicated by the number of vehicles and the RSSI for all the resources.

- MAIN FEATURES: Each cluster selects a group of RBs to reduce the resource usage. Consequently, the network performance is enhanced with regard to throughput.
- LIMITATIONS: CAMs and DEMNs are not considered. The platooning service requires the cluster-based RAS, which is not mentioned. Additionally, a variety of V2X communications in different network scenarios may be implemented using the cluster-based RAS.

3) CLUSTER-BASED RESOURCE MANAGEMENT SCHEME
In [43], the cluster head communicates with the cellular link via the V2I links while the cluster members communicate with each other via V2V links. The vehicles can perform V2V or V2I communications depending on their role in the network. The V2I links use the direct cellular communication from vehicles to the BS, while the V2V links use IEEE 802.11p communication. The cluster head forms a cluster with cluster members according to the link communication duration in the highway.

- MAIN FEATURES: Communication with pedestrians is considered, which enhances the safety awareness on the road—particularly in cities. The clustering protocol also considers the channel quality, i.e., large-scale fading, to allocate the RBs and transmission power.
- LIMITATIONS: The platooning service is not considered despite the fact that the vehicles always are grouped as a cluster in the platooning services.

IV. COMPARISON AND DISCUSSION
A. COMPARISON AMONG THE SCHEMES
The V2X services are categorized into several use cases, which have different QoS requirements [15]. The network scenarios of V2X consists of different scenarios such as urban area, freeway, and highway which have different parameters in terms of road width and the number of lanes [30]. The UEs reserve a resource block in frequency-time domain to transmit generated packets to other vehicles or the base station. In the interference-aware RAS, the RAS aims to avoid the collision between vehicles in the same coverage area. The geo-based RAS considers the position of vehicles in the urban area or freeway before allocating a resource block. In the time-frequency RAS, the random resource selection in C-V2X is modified to achieve higher reliability by considering the traffic priority. The cluster-based RAS allows some vehicles to cooperate the communication links, in which some vehicles can share the same resource pool. The above RASs mainly use the random resource selection in different network scenarios. However, the main use cases in 5G V2X have not been investigated in detail. The comparison of four types of RASs is shown in Table 3.

In [15], a DENM massage includes the information of wrong way driving warning, emergency electronic brake lights, and so on. Different use cases or applications can use and share the same V2X messages such as CAMs and DENMs. In a vehicle, there may be more than one V2X applications which are simultaneously running. The requirements to serve the vehicles are defined by the harmonized fashion configuration. The V2X facilities layer serves all V2X applications to optimize the V2X message handling, by considering the overall requirements of different V2X applications. In the comparison, we consider two types of V2X messages which are CAMs and DENMs to consider the QoS requirements.

B. INTERFERENCE-AWARE RESOURCE ALLOCATION
Interference occurs among vehicles and between vehicles and CUs. Interference-aware schemes aim to reduce the number of collisions by limiting the transmission of the UEs. The network scenario is categorized into urban or highway in 3GPP; clustering-based V2X, or platooning. In Table 4, a detailed comparison is presented.

C. GEO-BASED RESOURCE ALLOCATION
In V2X, a vehicle can transmit packets to another vehicle or other receivers depending on the V2X services [2], [20], [36]. On a highway or freeway, the vehicle location changes quickly in the time domain owing to the high speed of the vehicle. In urban areas, the quality of the received signal may be affected by fading or shadowing caused by the building or other obstacles. The resource of the vehicle can be assigned according to its location and the channel quality, as mentioned in Section III. A detailed comparison of these schemes is presented in Table 5.

D. TIME–FREQUENCY RESOURCE ALLOCATION
Because vehicles can communicate with other vehicles by sending CAM or DENM packets, which indicate the priority of the traffic, the RAS should prioritize safety traffic. The density of vehicles per kilometer depends on the network scenario, e.g., highway, urban area, rural area, or freeway. The RAS may be more effective on a highway than in an urban area. Additionally, the vehicles may transmit different types of messages according to the road hazards or traffic that must be taken into account in the RAS. A detailed comparison is presented in Table 6.

E. CLUSTER-BASED RESOURCE ALLOCATION SCHEMES
In the multi-lane highway, many vehicles join the traffic, increasing the amount of resources provided by the cellular BS. Consequently, interferences or collisions may occur. The vehicles grouped into a cluster reuse resources, enhancing the network performance. However, the duration of the link connection is a significant challenge, because the vehicles move at a high speed. A comparison of these schemes is presented in Table 7.
### TABLE 3. Comparison of Four Types of RASs.

| Type of RAS       | Interference-aware                                      | Geo-based                                      | Frequency-time selection                                      | Clustering-based |
|------------------|---------------------------------------------------------|------------------------------------------------|--------------------------------------------------------------|------------------|
| Scenario         | UEs in the same coverage of a base station             | Urban, highway, freeway                       | UEs in the same coverage of a base station                    | Highway          |
| Use case         | General aspect, vehicle quality of support             | Platoon, general aspect, vehicle quality of support | General aspect, vehicle quality of support                    | General aspect   |
| Main features    | - Control congestion, collision in the coverage of a base station  
|                  | - Resource selection scheme: random, packet priority based | - Effective in various network scenarios  
|                  |                                                        | - Sharing the resource pool according to the position and location of UEs  
|                  |                                                        | - Resource selection scheme: random  
| Limitation       | The out-of-coverage may cause signal loss.             | The channel condition and the road condition may vary because the vehicle moves across many roads or streets. The resource blocks must be re-assigned to ensure the connectivity which depends on the SCI and the reservation resource blocks. This procedure may cause high latency and low throughput due to the channel condition.  
| Potential        | - Limit the transmission power of vehicles while estimating the duration of in or out of coverage | - Estimate the duration of network scenarios such as the length of road and the number of RBs reserved for the specific road.  
| Improvement      |                                                        | - Change the duration of sensing window or the selection window to adapt to the geographic area.  
|                  |                                                        | - Predict the channel conditions and the resource pools to adapt the change of the density of vehicles in the coverage.  
|                  |                                                        | - The geo-based RAS can be implemented with the time-frequency RAS to select the RBs more effective.  
|                  |                                                        | - The clustering protocol can be implemented to reserve the group of same speed vehicles.  
|                  |                                                        | - Predict the role of cluster head if the vehicles change the road.  

### TABLE 4. Comparison of Interference-Aware RASs.

| RAS                        | Metrics of resource allocation | Network scenario | QoS          | Approach performance                                |
|----------------------------|-------------------------------|------------------|--------------|-----------------------------------------------------|
| Minimize interference for V2X communication [22] | Interference power of the UEs to the CUs uplink in the same spectrum | Vehicles and CUs in the single cell of gNB | CUs’ traffic | Limit the transmission power of the UEs on the subchannel |
| STS-RS scheme [29]        | Channel condition, traffic priority | Highway          | Packet priority, traffic priority such as channel busy ratio | Reduce the collision during resource selection |
| Adaptive transmit power control algorithm [31] | Varied the transmit power of vehicle | Urban area, highway | RSSI, CAMs | Consider the CAM resource allocation |

V. CHALLENGES AND OPEN ISSUES

A. LATENCY

In the ITS, the delay of packets is the most significant concern when vehicles transmit the safety-related packets with high QoS requirements for V2X services such as remote driving. If the safety traffic does not achieve the required low latency, accidents may occur on the road. In the platooning service, many trucks move in the same direction through many cells, which requires a short delay during the resource allocation. In the same network scenario on a highway, many vehicles may require different latencies according to the services, e.g., platooning or autonomous driving. The RAS should consider the most stringent traffic requirements to prevent accidents on the road.

B. LOCALIZATION

The distance between vehicles also presents a challenge. For example, if there is traffic jam on a highway or in an urban area during rush hour, many vehicles send requests to the cellular BS simultaneously, causing collisions. Thus, congestion...
occurs at the BS, and the packet-loss ratio increases. Because vehicles move at high speeds in urban and rural areas, the connection between a vehicle and other vehicles or the BS may be lost. The navigation should be updated in a short time, which increases the link availability.

The vehicle location may affect the QoS and the RAS. For example, in the highway scenario (where the density of vehicles is higher than that in the rural area), the RAS should ensure the QoS of every vehicle with the specific speed, distance, and acceleration.
C. SAFETY AWARENESS
With the diversity of V2X communications in different network scenarios, a high QoS is needed to ensure traffic safety. The traffic priority of UEs is the most significant concern that should be taken into account in the RAS at the cellular BS and the UEs. The safety messages can be categorized as follows: safety messages or warning messages at the junction of roads and safety messages between vehicles and pedestrians. The RAS should consider the types of vehicles, platooning, and pedestrians to simulate the real scenario in the urban area.

Additionally, the autonomous driving system of vehicles in the ITS should consider the safe distances between other vehicles and pedestrians. Many vehicles and pedestrians may simultaneously exist in the transmission range of an eNodeB, and they both require a high throughput and low latency. The ITS should consider the resource assignment for both vehicles and pedestrians to minimize the interference. Thus, the network throughput is shared among the users, ensuring the safety of humans driving cars and walking on the road.

D. HANDOVER AND STABILITY
While moving at a high speed, a vehicle may change its BS quickly; in this case, a low latency is required during the handover to ensure the transmission stability. For a platooning service with a large number of vehicles on the road, the length of all vehicles may exceed the transmission range of one BS. Thus, the platooning may require the RAS to be served by more than one cell. For example, the platooning leader may be served by one BS while the last platooning vehicle is served by another BS. In another situation, there may be many vehicles at the edge of the transmission range of the BS during a traffic jam; here, the BS should consider the different types of vehicles or services in assigning channels.

E. THROUGHPUT
Another issue is to maximize the throughput of the BS while minimizing the interference among vehicles. With the growth of CUs as well as UEs, the BS aims to ensure a high network throughput for satisfying the data demands of the users. Additionally, the quality of the received signals at the UEs may be affected by other UE transmissions that cause interference. Furthermore, fading and shadowing caused by obstacles in the city area may reduce the network throughput.

F. SECURITY
Security for data transmission is one of the most important challenges, as attackers can intercept data during the transmission. In the worst case, if the attacker takes control the vehicle during autonomous driving, the vehicle may be stolen, or an accident may occur. The data transmission in V2X should be protected to satisfy the requirements of confidentiality, integrity, and availability. Additionally, an authentication mechanism should be developed to authenticate the users and secure the confidential data of the V2X services.

G. MACHINE LEARNING BASED RAS
Machine learning (ML) or artificial intelligent (AI) have been widely applied to wireless networks with regards to the channel access mechanism, routing protocol, power control, and so on. In the 5G V2X, a large number of vehicles may require efficient and reliable resource allocation to reserve the resource pool in frequency-time domain. In addition, the environmental condition also affects the resource pool such as the density of vehicles on the road, the changing of area (from urban area to freeway or vice versa), the speed of vehicles, or the multi-use case of a vehicle. The high speed of vehicles can cause the loss of signals and change the road condition, which require new resource blocks. The learning algorithm can take the vehicle use case, the channel condition, and the environmental condition as the input of the intelligent algorithm which satisfies the QoS in reliability, latency, and throughput of the future communications. The AI can be applied to V2X applications to improve the safety, security, or navigation of vehicles as in [44]. The ML or AI can be applied to predict the available resource or duration that the vehicles are in or out of coverage. The interference can occur even though the vehicles reserve the resource under the 5G cellular network. The ML can predict the channel condition to maximize the number of transmissions while ensuring the QoS requirements.

VI. CONCLUSION
We have reviewed RASs for 5G V2X, which consider the quality of V2X services and the network scenario. In our survey, resource selection schemes for 5G V2X communications have been analyzed with regard to many aspects, such as the network scenario, QoS, network performance, and outstanding features. We have also compared the existing RASs with regard to their outstanding features and limitations, providing readers with a broad view. Then, we have discussed many issues and challenges for V2X networks. In particular, the latency depends on the type of service as well as the type of scenario. Collisions and interference can occur because the cellular BS serves many vehicles and CUs simultaneously with limited channel resources. The geo-based RAS performs effectively in terms of reusing the resource block in a road, in which the resource block is assigned to a specific road grid. In frequency-time RAS, the resource is reserved according to mode 2, which results in high usage of RBs. The clustering-based approach is effective in the highway if several vehicles are moving in the road with the similar speed and keeping the approximate distance. However, the high dynamics of vehicles cause the changing of base station very quickly, which requires the effective prediction of the channel condition, road condition, channel-busy condition, and the available resources. The ML or AI can estimate these conditions, which allow the vehicles to select the resource according to their use cases or services. This survey may give a comprehensive reference to researchers in this area.
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