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A Novel Scheme for Large-Size Data Block Transmission in Vehicular Ad Hoc Networks: Architecture, Challenges and Discussions

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ABSTRACT Limited by the bandwidth of IEEE 802.11p protocol, a large-size data block commonly cannot be transmitted within one communication link in a vehicular ad hoc network (VANET). When transmitting large-size data block in VANETs, the traditional routing-layer-based solutions usually employed a large number of routing paths to extend the data link duration through continuously changing routing path, which commonly leads to frequent communication link disconnection and re-connection. Another shortcoming of the routing-layer solutions in transmitting large-size data block is that dense relay node is required to obtain sufficient stable routing paths for maintaining the long data transmission duration. In this paper, we present a new scheme for efficiently transmitting large-size data block in VANETs, which dedicate to improve the data transmission efficiency through shortening the total duration of the data transmission process at the network architecture and physical connection levels. Based on the assistance of the dual-communication mode and edge computing technique, a heterogeneous network architecture is proposed to introduce multiband orthogonal frequency division multiplexing (MB-OFDM) based ultra-wideband (UWB) technique into the VANETs for transmitting large-size data block. The key challenges of the scheme and alternative solutions for the challenges are analyzed, in which several mechanisms for quick parameter pre-configuration, the quick MB-OFDM UWB link establishment and highly efficient multi-user access to the OFDM-UWB network are presented. The key obstacles that limit the effectiveness of the scheme are also evaluated, of which the results show the presented scheme is feasible.

INDEX TERMS VANET, vehicle-to-vehicle, large-block data transmission, MB-OFDM UWB, Internet of Vehicles.

I. INTRODUCTION

As the number of vehicles on the road is still rapidly rising, traffic issues such as traffic congestion and accidents are worsening in recent years. These problems usually cannot be entirely resolved through the traditional methods of increasing transportation infrastructure due to the strict space restriction and the great cost of upgrading infrastructures in urban areas. The intelligent transportation system (ITS) provides a new direction with much lower cost and more flexibility for improving the vehicle traffic. So far, it has been proved by many processes that the ITS is effective in reducing traffic accidents and traffic congestions [1]. For example, by equipping vehicles with DSRC communication equipment for collision warning, the vehicle traffic accident rate can be significantly reduced [2]. Many statistics also show that

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road sections equipped with VICS (Vehicle Information and Communication System) [3] in Japan can obviously reduce the vehicle travel time.

The vehicular ad hoc network (VANET) is a core element of the ITS, which supports the vehicle-to-vehicle (V2V) communication between vehicles and the vehicle-to-infrastructure (V2I) communication between vehicles and road side units (RSUs) [4], [5]. While it has some similarities with other ad hoc networks, such as self-organization and short signal transmission distance, the VANET has some special characteristics, such as high dynamic network topology, fast time-varying channel, and restricted vehicle moving path, which brings new challenges to the network organization and data transmission. One major challenge arising from these characteristics is that the communication in VANETs usually encounter link disconnect more frequently than in other wireless networks, which will greatly reduce the efficiency of data transmission, especially the transmission of large-size data block.

Many works have been done to improve the data transmission efficiency of the VANET, of which the most popular research direction is to explore effective routing algorithms at the routing layer. Up to now, there have been many routing algorithms proposed for VANET environments. Among them, one major category is the geography-based (position-based) routing protocols [6]–[13]. Early geography-based routings are designed mainly based on the greedy packet forwarding mechanism, such as the Greedy Perimeter Stateless Routing (GPSR) [6] and the Greedy Perimeter Coordinator Routing (GPCR) [7], which are usually unsuitable for complex traffic environments due to the corresponding complex routing process. To simplify the routing process, street maps are used in the routing path building process in the Directional Greedy Routing (DGR) [8]. Three other important categories are topology-based routing [14]–[19], broadcast-based routing [20]–[23], and cluster-based routing [24]–[30]. Topology-based routing protocols such as Ad hoc On-Demand Distance Vector (AODV) [14], Destination Sequenced Distance Vector (DSDV) [17], and Dynamic Source Routing (DSR) [18] are famous topology-based routing protocols for mobile ad-hoc networks (MANETs), although they are not suitable for urban VANET environments. In [16] and [19], the routing protocols based on improved AODV were designed for VANETs. Broadcast-based routing protocols improve the reliability of the packet forwarding and simplify the process of relay node choice by broadcasting the packet in a multipath way. In [22], an improved distance-based VANET routing protocol dedicating to multi-hop broadcasting was presented for reliable packet dissemination, which has reliable packet dissemination with an acceptable network overhead under complex environment factors. Cluster-based routing protocols transform the big network into small grouped networks to minimize the control overhead and the collision among vehicles. In [24], a Cluster-Based Life-Time Routing (CBLTR) protocol was proposed, which aims to increase the route stability and average throughput in the two-direction segment scenario. Some routing protocols based on multi-technology combination were shown in [13], [31]–[33], such as the clustering scheme based on vehicle positions [32], [33].

Based on techniques such as position forecast, clustering, and multi-path routing, the routing-layer approaches have certain effect on improving the efficiency of data transmission in VANETs. However, there are strict constraints for popularizing them in VANET applications with large-size data block transmission.

- *Frequent link disconnection and reconnection*. The process of transmitting a large-size data block in IEEE 802.11p networks needs to be maintained for a long time as the data rate supported by the IEEE 802.11p protocol in actual VANETs is usually not high. However, the duration of a stable routing path in VANETs is commonly short due to the highly dynamic network topology, which means multiple routing paths and frequent routing path changing are usually required to maintain the long data transmission duration. Therefore, frequent link disconnection and reconnection occurring within a data transmission process is common to the routing-layer approaches.
- *Inefficient large-size data block transmission.* When transmitting a large-size data block, the frequent routing path switching caused by the highly dynamic network topology of VANET will lead to a lot of time wasted on communication link establishment as well as unstable data link, both of which will seriously reduce the efficiency of data transmission.
- *Dense relay nodes.* Dense relay nodes are usually required to obtain sufficient stable routing paths to maintain a long data transmission duration, which means the routing-layer approaches for transmitting large-size data block in the VANET is usually not suitable for the VANET environment with scarce vehicles, such as the urban road at night.

Some 5G-based vehicle communication schemes have been designed in recent years to avoid the above-mentioned defects [34]–[40]. A popular direction for the design of 5G-based VANET scheme is employing Software Defined Networking (SDN) technique for network management by exploiting the network control capabilities of SDN [34], [37], [38]. In [34], a cluster-based 5G-VANET was proposed, where neighboring vehicles are clustered adaptively according to real-time road conditions by exploiting SDN's global information gathering and network control capabilities while dynamic beamforming coverage is adopted to enhance the link communication quality and network robustness. However, these 5G-based schemes also have insuperable defects:

A. INCREASING THE NETWORK LOAD OF 5G

5G systems will serve an unprecedented number of devices in the future. It is forecasted that there will be more than 50 billion connected devices by 2020, which means the network access resource of 5G is not quite enough in the future [41]. If the VANET data is also transmitted through the 5G network, it is doubtless that the network load will be greatly increased. This is not conducive to the balance utilization of the wireless spectrum resources.

B. LIMITED SERVICE COVERAGE

Due to the large population of cities, the urban area is the main coverage area of the 5G service. However, the road of the suburban area and the motorway are the other two major application scenarios of VANETs, except for the urban area. The limited coverage area of the 5G service greatly decreases the efficiency of 5G-based VANET in practical applications.

C. COST OF DATA TRAFFIC

Like other mobile communication techniques, such as 3G and 4G, 5G communications also generate data traffic cost. However, as the maintenance cost of the infrastructures in VANETs, such as RSUs, are very low, the VANET can operate with much lower cost. The data transmission service supported by the VANET-based ITS can be provided to vehicles with very lower cost and even as a public service with free of charge, considering the effectiveness of the ITS on improving the traffic security and transportation efficiency [42]–[44]. Therefore, the data transmission charge is also one insuperable defect of the 5G-VANET scheme.

With the increasing popularity of transmitting large-size data block in VANETs, a solution with high data transmission efficiency is essential to the popularization of VANETs. In this paper, a scheme based on network convergence is proposed for improving the efficiency of transmitting large-size data block in VANETs. Compared with the traditional routing-layer-based works, our work mainly focuses on the network architecture and data link layers. A heterogeneous network architecture based on dual wireless networks is designed, in which the IEEE 802.11p network is employed for accelerating the link establishment of the Multiband Orthogonal Frequency Division Multiplexing (MB-OFDM) ultra-wideband (UWB) network while the MB-OFDM UWB network is used to quickly transmit larger-size data block. With the help of the IEEE 802.11p network and edge computing technique, the network structure and some link parameters of the MB-OFDM UWB network are preconfigured to shorten the network establishment delay, and then the large-size data block is transmitted at a rate up to Gbps level to ensure the data transmission process is completed within a very short time interval. In this way, the large-size data block is transmitted within a very short period, which can greatly reduce the number of link disconnection during the data transmission process. In addition, when transmitting large-size data block, the proposed scheme has better environmental compatibility than traditional VANETs as it is no long needed to maintain the long data transmission duration through dense relay nodes, which is essential for popularizing the scheme in actual VANETs due to the wide range of application environments of VANETs.

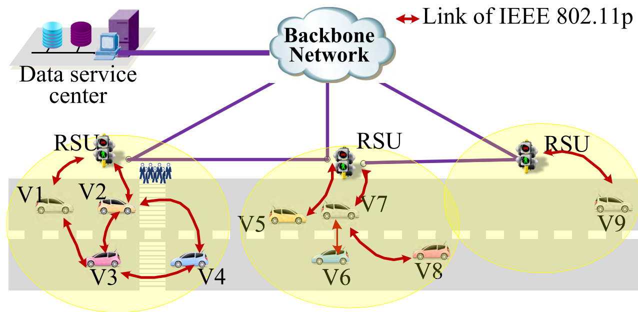

FIGURE 1. A typical network architecture for Internet of Vehicle.

The rest of the paper is organized as follows: The background and motivations are presented in Section II. The presented network architecture and ahead key challenges are shown in Section III. In Section IV, the key obstacles to the effectiveness of the scheme are evaluated and discussed. A conclusion is drawn in Section V.

II. MOTIVATIONS

A. BACKGROUNDS

Fig.1 presents a typical network architecture for VANET (Internet of Vehicle), which is composed of three major components: The On-Board Unit (OBU), RSU, and Data Service Center (DSC).

The OBU is the electronic device equipped on vehicles to obtain the vehicle information and communicate with RSUs and OBUs of other vehicles. The RSU is an infrastructure with fixed position, which is usually used to forward data in the vehicle-DSC and V2V communication. In the above network architecture, the vehicle-DSC communication process can be divided into two parts: V2I communication and RSU-DSC communication, of which the RSU-DSC communication can be implemented in a highly efficient way through employing wire communication while the V2I (and V2V) communication must depend on wireless communication due to the high mobility of the vehicle. Therefore, the V2V and V2I communications are the bottleneck for restricting the efficiency of the vehicle-DSC data transmission.

IEEE 802.11p has been defined as the physical and MAC specification for vehicle communications in VANETs by the IEEE802 LAN/MAN Standards Committee, for which a total of 75MHz spectrums from 5.85-5.925GHz are allocated. Seven channels with 10MHz bandwidth each, in which four service channels are included, are employed for safety and non-safety communication. Based on Quadrature Amplitude Modulation (QAM) mapping and OFDM modulation, the maximum data rate of IEEE 802.11p is up to 27 Mbps with the maximum communication distance of 300 meters. However, due to limitation factors, such as inter-car interferences and fast fading, included in the practical VANET channel environment, the average data rate of the communication is much lower (usually lower than 3Mbps, some test results are shown in Section IV) in practical VANET systems. Therefore, in VANETs based on traditional routing-layer schemes, a large number of link connections are required to transmit

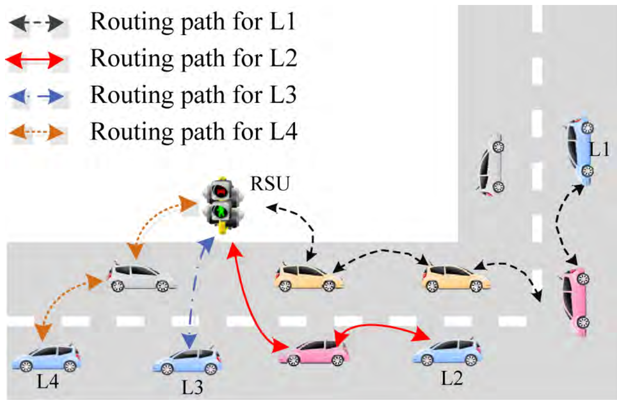

FIGURE 2. A typical process of transmitting large-size data block in traditional VANETs.

a large-size data block, which is the main reason for the low efficiency of transmitting large-size data block in VANETs. In traditional routing-based VANETs, a typical process of transmitting large-size data block through V2I communication is presented in Fig.2.

Due to the highly dynamic network topology and the limited data rate of the IEEE 802.11p network, multiple routing paths should be employed to transmit a large-size data block. As shown in Fig.2, the routing path should be changed frequently during the period that the vehicle runs from position L1 to L4. There are two shortcomings in this data transmission mechanism: one is the frequent link connection establishment and disconnection, which greatly reduces the efficiency and reliability of the data transmission; another is that the large-size data block cannot be transmitted in the VANET environment with rare relay vehicles as there is commonly not enough relay vehicles to ensure that sufficient routing paths can be found for the long-term data transmission.

With the rapid expansion of the VANET application range, more and more VANET applications require transmitting large-size data blocks such as pictures, short video, and geographic information, which can further enhance the effectiveness of the VANET in improving vehicle traffic. For example, the on-site picture of the traffic accident can not only help drivers to judge the congestion degree, but also help rescue workers to understand the situation of injuries. In the future, the limitation to the VANET caused by the low efficiency of large-size data block transmission will become increasingly obvious.

B. MOTIVATIONS

From the above analysis, we know that the large-size data block usually cannot be transmitted within the duration of one link connection due to the short connection duration of VANET caused by the high mobility of vehicles. To transmit large-size data block in VANETs, the traditional routing-layer schemes extend the data link duration through finding multiple routing paths with the help of relay nodes, which causes frequent link disconnection as well as unstable data link.

Analyzing this issue from another perspective, it is obvious that if the data transmission process can be quickly completed within a much shorter time period, during which the network topology of the VANET can even remain unchanged, the large-size data block can be transmitted with very few(or even no) link disconnection and reconnection. In addition, as the data block is transmitted through establishing a few even one link connections, the method requires much less relay nodes, which means the method is commonly less affected by the external application environment.

However, there are two prerequisites for quickly transmitting large-size data block in VANETs. One is that the communication link can be quickly established, and the other is that the data transmission rate is very high. The MB-OFDM-UWB technique [45], [46] supports a maximum data rate of Gbps level owing to the characteristics of ultra-wide bandwidth, although its existing protocol is not suitable for the VANET environment due to the long-time delay of the link establishment and other constraints such as the multi-user access mechanism. If the MB-OFDM UWB technique can be introduced into the V2V and V2I communication without the constraints mentioned above, the large-size data block can be transmitted in VANETs with very high data rate.

With the rapid development of distributed computing and cloud computing technology in recent years, the current DSCs in VANET systems usually have strong computing power [47]. At the same time, the IEEE 802.11p signal has a much longer transmission distance than the MB-OFDM UWB signal, which means that there must have been an IEEE 802.11p network for a period of time when the MB-OFDM UWB network is forming, if the RSU and vehicles support both the IEEE 802.11p network and the MB-OFDM UWB network. Based on above assumptions, a heterogeneous network can be formed based on the IEEE 802.11p and the MB-OFDM UWB network, in which the MB-OFDM UWB network is employed for transmitting large-size data block and the IEEE 802.11p network is used to pre-configure link parameters for the MB-OFDM UWB network. Based on the preconfigured parameters, both the link establishment and multi-user access in the MB-OFDM UWB network are completed with a short time delay. For example, based on the preconfigured Time Frequency Code (TFC) type, the TFC identification process at the OFDM-UWB receiver can be omitted, which can obviously shorten the time delay of the link establishment process (shown in Section III.C). In this way, it is much possible to significantly shorten the time delay of the OFDM-UWB link establishment.

III. THE PROPOSED SCHEME

A. NETWORK ARCHITECTURE

The IEEE 802.11p protocol does not have the ability of transmitting data with a very high data rate due to its narrow channel bandwidth. To transmit a large-size data block with a very high data rate, another wireless communication technique with wide bandwidth should be introduced into VANETs. The UWB technique, a short-range wireless communication technique targeted at transmitting data in Wireless Personal Area Networks (WPANs), has great advantage in high-speed data transmission owing to the wide bandwidth resources allocated to it [48], [49]. The initial solution for UWB directly employs the Impulse Radio (IR) [50], [51] for data transmission, in which the carrier is not used. However, due to the multipath interference and the very short duration of the signal pulse, it is still a challenge to correctly obtaining the transmitted data at the IR-UWB receiver in the high-data-rate scenario. Compared with the IR-UWB solution, the MB-OFDM UWB solution has much better potential for high-rate data transmission [52]–[55]. First, the MB-OFDM UWB technique divides the entire bandwidth into several band groups with much narrower bandwidth, which can greatly reduce the implementation difficulty of the analog front-end of the receiver. Secondly, the MB-OFDM UWB solution inherits the good features of the OFDM technique, such as good anti-multipath capability and high spectral efficiency. The Inter-Symbol Interference (ISI) caused by the multipath signal is one of the major hurdles to high speed data transmission in wireless systems. Thirdly, the receiver of the MB-OFDM UWB solution has low complexity. Compared with the RAKE based receiver employed in the IR-UWB technique, of which the complexity increases linearly with the RAKE fingers, the OFDM demodulation module in the MB-OFDM UWB receiver has much lower complexity in the scenario with high data rate and high dispersive [52].

Based on the above analysis, the MB-OFDM UWB technique is introduced into VANET for transmitting large-size data block in this paper. As shown in Fig.3, a heterogeneous network architecture based on two short-range wireless networks is designed, in which the MB-OFDM UWB and IEEE 802.11p network are employed for transmitting large-size data block and small-size data, such as control signals of network management, respectively. In addition to the two wireless networks, the DSC is another major component in the network architecture, which is responsible for managing the heterogeneous network under the help of SDN techniques. Of the two wireless networks in the heterogeneous network structure, signal coverage of the IEEE 802.11p network is much wider than the MB-OFDM UWB network (about 20 meters), which can ensure that the vehicle has been connected to the IEEE 802.11p network for a period of time when it starts to access the MB-OFDM UWB network. The IEEE 802.11p network employs traditional self-organization mode for network organization, of which the network structure is organized without the participation of the DSC. To ensure the status information of vehicles can be continuously obtained, the IEEE 802.11p network is always active. For example, the vehicle will directly communicate with the RSU once it enters the signal range of the RSU.

However, an active MB-OFDM UWB network is only established when there are large-size data block to be transmitted. There are two models for establishing the MB-OFDM UWB network. When the vehicle wants to communicate with

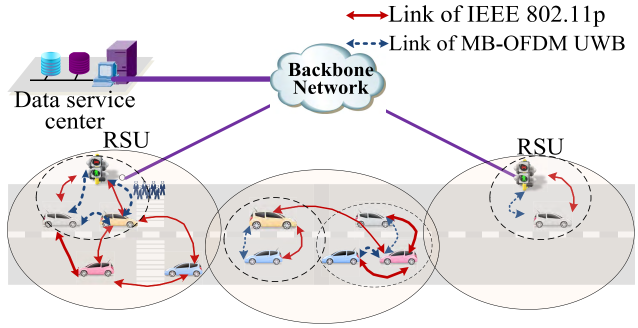

FIGURE 3. The proposed heterogeneous network architecture, in which OFDM-UWB technique is introduced for transmitting large-size data block.

the RSU through the MB-OFDM UWB network, it first sends a request to the DSC through the IEEE 802.11p network. Then, the DSC pre-configures communication parameters to assist the establishment of the MB-OFDM UWB network among the RSU and vehicles.

When the scenario is V2V communication, the self-organization model is employed, in which the DSC does not participate in the network establishment. As multiple parallel V2V communications coexisting within the coverage of the MB-OFDM UWB signal are allowed (the analysis results are presented in the following Subsection B), the V2V communications are divided into multiple groups, of which each group is a network with smaller size. By assigning orthonormal TFC types to these grouped networks, mutual interference between networks can be avoided. When the vehicle wants to establish a grouped network to transmit a large-size data block, it first detects the existing MB-OFDM UWB networks, and then selects the TFC type which is orthonormal to the TFC types of the existing MB-OFDM UWB networks.

One major function of the network-management task of the DSC is pre-configuring parameters for the MB-OFDM UWB network. First, the parameters such as the TFC type and the multi-user access mode, for which the signal detection process has long time delay, are pre-configured. Then, the pre-configured parameters are sent to the RSU/vehicles through the IEEE 802.11p network. Based on the preconfigured parameters, both the mutual conflict between users during the multi-user access process and the time cost on the establishment of the communication link between the vehicle and the RSU can be greatly reduced.

B. MAJOR CHALLENGES

The fundamental goal of our scheme is to transmit the large-size data block within one link connection as far as possible to avoid employing relay nodes to prolong the data transmission duration as much as possible. Two prerequisites are required to achieve this goal under the VANET environment. One is that data is transmitted with very high rate, and the other is that the link connection can be established quickly. The defined maximum data rate in the MB-OFDM UWB specification [45] is 1Gpbs, which means that the MB-OFDM UWB has the ability of transmitting most of the large-size data packets that appear in VANET applications such as pictures and short videos, within the duration of one vehicle-RSU connection in theory. However, the link establishment process in MB-OFDM UWB systems usually has a long time delay due to the characteristics such as low power spectral density of the signal and the complex process of the physical-layer connection. In addition, the data rate in practical MB-OFDM UWB systems is also interfered by some external factors such as signal interference and multi-user accessing mode. Including economic concerns, the major challenges for the presented scheme are as follows:

- Quick parameter pre-configuration. As mentioned above, the organization of the MB-OFDM UWB network in our scheme depends on the pre-configured parameters. If the parameters cannot be pre-configured and sent back to the RSU and vehicles within the valid time interval, the time delay of the link establishment will be prolonged, which has great impact on the data transmission efficiency due to the very short duration of the vehicle-RSU connection. To quickly preconfigure parameters for the RSU and vehicles, two prerequisites need to be met. One is that high computing power is required for the DSC due to the existence of complex algorithms in the parameter pre-configuration process. As distributed computing and cloud computing techniques are developing rapidly in recent years, the computing power of the DSC is not a major hinder to the quick parameter pre-configuration. Another is that the DSC receiving requests from vehicles and sending back parameters to the RSU and vehicles in time, which is the key challenge to the parameter pre-configuration as the time delay of the data transmission between the DSC and RSU through the public network is uncontrollable due to the multiple routing processes.
- Efficiency decline caused by link establishment. The establishment of physical layer connection between the receiver and the sender in MB-OFDM UWB systems usually has a long time delay. For example, as the received preamble symbols are spread among multiple sub-bands, a long time delay is commonly required for the TFC identification process at the OFDM-UWB receiver. The physical-layer connection delay increases not only the time consumption on the physical layer connection process but also the inter-frame interval. Another issue related to the OFDM-UWB link establishment is that the data transmission capacity assigned to the individual user is much lower than the maximum value of the system capacity due to multi-user access, which is contrary to the scheme's goal of completing the transmission of a large-size packet as soon as possible.
- *Economic concerns.* Compared with the traditional VANET schemes, the proposed scheme has higher economic cost, of which the most important additional cost is that the OBU on vehicles and the RSU need to support both the IEEE 802.11p network and the MB-OFDM UWB protocol.

C. OPTIONAL SOLUTIONS TO THE CHALLENGES

Since the IEEE 802.11p network and the MB-OFDM UWB network can work on different frequency ranges, there is no interference between their signals, which means simply adding the additional MB-OFDM UWB transceiver system is the major requirement needed for the traditional OBU and RSU devices to support both MB-OFDM UWB and IEEE 802.11p communications. As the cost increase of the OBU and RSU devices is not a key issue restricting the scheme effectiveness, we mainly discuss the optional solutions for the parameter pre-configuration and link establishment.

1) PARAMETER PRE-CONFIGURATION APPROACHES

The high computation performance requirement for the DSC hardly becomes the key restriction for the quick parameter pre-configuration in the future due to the rapid development of the DSC computing power and distributed computing techniques [56], [57]. The biggest hurdle to the quick configuration of parameters for the MB-OFDM UWB network is the uncontrollable time delay of the DSC-vehicle/RSU data transmission process due to the multi-layer routing process. Based on these understanding, two optional solutions are presented as follows:

One approach is dividing the parameter configuration process into multiple steps and introducing edge computing capability to the RSU. First, the DSC extracts the mathematical model for computing the target parameter and sends the mathematic model to the RSU. Second, when the vehicle, which wants to transmit a large-size data block, enters the IEEE 802.11p signal coverage of the target RSU, the RSU with edge computing capability directly configuring parameters for the vehicle. Third, the RSU returns the actual parameters obtained during the communication to the DSC to update the extracted mathematical model. As the pre-configured parameters are designed not for assisting data transmission but for optimizing the process of OFDM-UWB link establishment, the mathematic models can be simplified, such as linearizing, which can greatly reduce the position related calculations executed at the RSU. For example, the pre-estimated channel impulse response is employed not for channel equalization but for evaluating user priority.

Another approach is updating the network architecture, in which a mobile edge computing server (MECS) is inserted between the DSC and RSU, as shown in Fig.4. The MECS is connected to the RSU through a dedicated line while the DSC still communicates with the MECS through the backbone network. The MECS is dedicated to pre-configure parameters for the MB-OFDM UWB network, each of which provides services for several RSUs. A mathematic model is extracted at the DSC or directly at MECS according to the computation complexity of the model extraction process. When the vehicle enters the IEEE 802.11p signal coverage of the RSU, the parameters to be pre-configured are calculated at the MECS according to the vehicle information such as position and the size of the data to be transmitted.

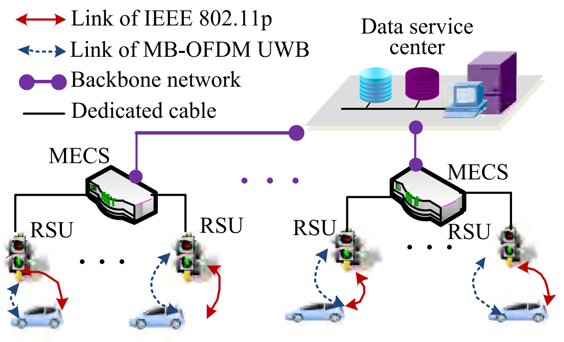

FIGURE 4. The updated network architecture with MECS inserted between the DSC and RSU.

TABLE 1. Time frequenccy codes for band group 1.

TFC No.	Band ID for TFC					
1	1	2	3	1	2	3
2	1	3	2	1	3	2
3	1	1	2	2	3	3
4	1	1	3	3	2	2
5	1	1	1	1	1	1
6	2	2	2	2	2	2
7	3	3	3	3	3	3
8	1	2	1	2	1	2
9	1	3	1	3	1	3
10	2	3	2	3	2	3

2) HIGH-EFFICIENT LINK ESTABLISHMENT

In MB-OFDM UWB protocol, the total spectrum of 7500MHz is divided into fourteen 528MHz bands while the OFDM modulated symbol is adopted for information transmission, which brings good features such as robustness in dispersive channels, high spectrum efficiency and wide bandwidth. Compared to other short-range communication techniques such as impulse radio UWB, the MB-OFDM UWB technique has better potential to be employed in high-speed data transmission applications.

However, MB-OFDM UWB technique is not suitable for transmitting large-size block data in VANET environments. There are two major hurdles: one is that traditional multi-user access methods commonly deteriorate the data rate of the individual user seriously, and the other is that the establishment of physical-layer connection between the receiver and transmitter has long time delay.

a: PHYSICAL LAYER CONNECTION.

In the MB-OFDM UWB protocol, multiple sub-bands are adopted to broaden the communication bandwidth. The data to be transmitted are spread over sub-bands according to TFC code (the TFC codes of band Group 1 are shown in Table 1). To connect with the sender, the receiver must first identify the TFC type used by the sender. However, the TFC identification process in MB-OFDM UWB systems usually has long time delay due to the low power spectral density of signal and the extended inter-symbol interval on a sub-band.

Based on the aforementioned heterogeneous network, the TFC identification within the physical-layer connection process can be omitted. The TFC type can be pre-allocated by the MECS according to the position topology of vehicles, and be sent back to the vehicle and the RSU through the 802.11p network. The TFC type allocation process is shown in Fig.5.

When the transmitter has detected the receiver in the IEEE 802.11p network, it sends the request of block-data transmission to the MECS through the IEEE 802.11p network. The MECS then allocates the TFC type for all the requests according to the position topology of vehicles. In specification [45], ten TFC types have been defined for each band group, of which some TFC types are orthogonal to each other,

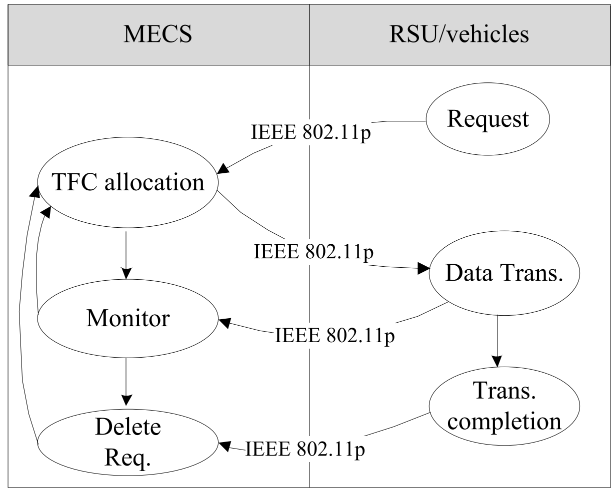

FIGURE 5. Under the assistance of IEEE 802.11p network, the designed TFC type pre-allocation process.

such as TFC 5 with TFCs 6 and 7, which means that multiple communications can coexist in a VANET without mutual interference. In addition, the MB-OFDM UWB signal decays quickly with the increase of communication distance. According to the S-V channel model of OFDM-UWB communication [58], the amplitude of the channel response decays exponentially with communication distance, which means that the OFDM-UWB signal from the sender with long distance (about 25 meters) can be ignored. Therefore, if the allocated TFC types meet these two requirements, parallel OFDM-UWB communications in a VANET is permissible. According to these prerequisites, the MECS builds the position topology of the network nodes based on the predicted vehicle position, and allocates the TFC types for all requests based on the position topology. The allocated TFCs are also sent to the RSUs/vehicles through the IEEE 802.11p network. A simplified example of TFC allocation is shown in Fig.6. In the figure, TFC 5 is assigned for communications C1, C3 and C5, as the distances of V5 to V1, V2 to V6, and V3 to V10 are larger than 25 meters, while TFC 6 being orthogonal with TFC 5, is employed for communications C2 and C4 to avoid mutual signal interference by exploiting the factor that the distance between V3 and V7 is larger than 25 meters.

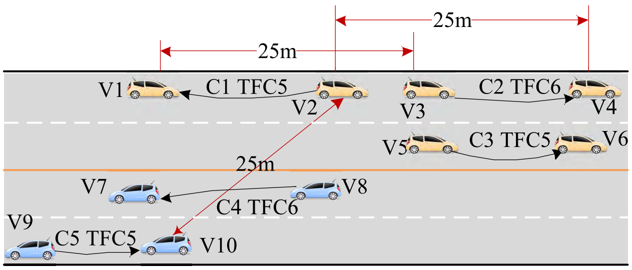

FIGURE 6. A TFC allocation scheme for eliminating interference between OFDM-UWB signals.

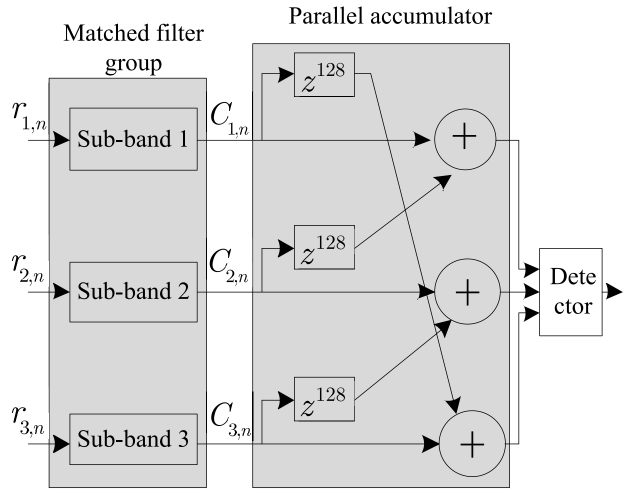

FIGURE 7. The designed parallel accumulator for detecting TFC 1 under the premise that the receiver knows the used TFC type.

During the process of data transmission, the allocated TFC types can be adjusted according to the updated position topology to avoid the occurring of signal mutual interference caused by the changed network topology.

Based on the pre-configured TFC type, the OFDM-UWB receiver knows the TFC type before the link establishment. Therefore, parallel accumulator can be employed at the receiver to shorten the time delay of the physical layer connection, as shown in Fig.7. The received signals $r_{i,n}(i = 1, 2, 3)$ on the three bands are detected at the same time in a parallel way, and then the two consecutive symbols received on different bands are accumulated to improve the correct probability of the signal detection. The accumulated results, which are finally used for symbol detection, can be given by $C_{i,n}+C_{j,n}z^{128}$, where sub-bands i and j are selected according to the TFC type used at the sender.

In this way, the 21 standard preamble symbols for frame synchronization defined in specification [45], of which the time duration is 7.5us, can be reduced to six symbols at most, which means the time delay of the physical layer connection can be obviously shortened. In this way, the time delay of both the handclasps in link establishment and the inter-frame interval can be obviously shortened.

b: MULTI-USER ACCESS

Traditional TDMA and OFDMA are the two major multi-user access technologies for MB-OFDM UWB systems.

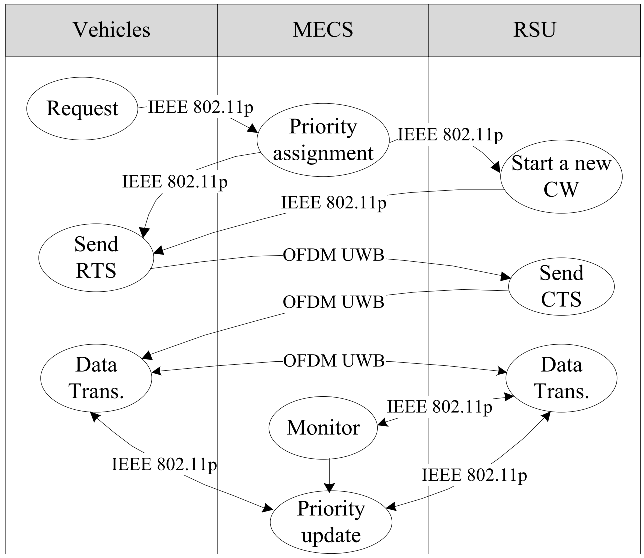

FIGURE 8. The designed network access process for the OFDM-UWB based V2I communication under the assistance of the IEEE 802.11p network.

However, both are not ideal for transmitting large-size data block in VANETs as either the time or the spectrum resource of the system is divided into small pieces by them, which would cause the data rate of the individual user to be much lower than the supported maximum data rate of the system. Non-Orthogonal Multiple Access (NOMA) technique has the ability of allocating almost the total time and frequency resource of the system to an individual user [59]–[61]. However, it cannot be used in MB-OFDM UWB systems due to the low power spectral density of the MB-OFDM UWB signal. In fact, it is difficult to achieve high multi-user access efficiency while maintaining high data rate of the individual user in MB-OFDM UWB systems by only using multi-user access method.

In this paper, a comprehensive solution of system level is adopted by taking advantages of the IEEE 802.11p network and edge computing in the heterogeneous network structure. As parallel V2V communications in the MB-OFDM UWB network is allowed under VANET environments, the V2I communication is the main obstacle to ensure high data transmission efficiency for individual users in the network when there is multi-user access. With the help of the IEEE 802.11p network, a new network access mechanism is designed for the OFDM-UWB-based V2I communication, as shown in Fig.8.

The MECS assigns priority to the requests according to factors such as data transmission efficiency and data priority, when it has gathered the requests through the IEEE 802.11p network. Then, the list of the priorities of the requests is sent to the RSU, while the priority of each request is sent back to the corresponding vehicle through the IEEE 802.11p network. To reduce the time delay of the network access caused by the excessive number of priorities as well as the complexity of the priority assignment at MECS, MECS only assign a small number of priorities, in which the requisites with high priorities occupy one priority each, while the others

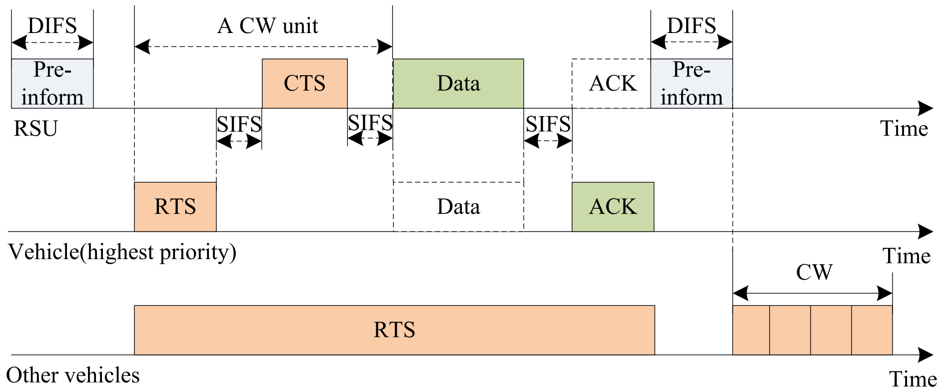

FIGURE 9. **The designed network-access competition mechanism for the OFDM-UWB-based V2I communication.**

share one priority. For example, in a case with a total of four priorities, the vehicles with highest, the second highest, and the third highest priority occupy the first, the second, and the third priority, respectively, and the others share the fourth priority.

The RSU starts a new Contention Window (CW) when the previous MB-OFDM UWB data transmission is completed or aborted under the prerequisite that at least one priority list has been received. The protocol for network-access competition among vehicles in the V2I communication is shown in Fig.9, where a limited-competition mechanism is employed to avoid the access conflict between users, which is one of the major factors contributing to the long-time delay of multi-user access in wireless communication systems.

When the current data transmission is about to be completed or terminated, the RSU broadcasts the information of the beginning of a new CW to vehicles through the IEEE 802.11p network. Assuming the CW in Fig.9 includes a total of four CW units, the vehicle with highest priority directly sends the Request-To-Send (RTS) signal to the RSU within the first CW unit. If the RSU has received the RTS, it sends a Clear-To-Send (CTS) signal also within the first CW unit. Once the CTS signal is received, the vehicle with the highest priority then occupies the channel for data transmission while the other vehicles skip the current CW to wait for the next CW. In addition to the RTS and CTS, two Short Inter Frame Space (SIFS) are included in one CW unit to give enough response time to the receiver. The vehicles with the 2^{nd} and 3^{rd} highest priority send the RTS signal within the 2^{nd} and 3^{rd} CW unit, respectively, if they have not received the CTS within the previous CW units. If the RSU does not receive RTS during the first three CW units, then it chooses the vehicle with best channel condition from the vehicles with the lowest priority. The channel response changes quickly in the VANET environment due to the rapid changing of vehicle position, which may cause the vehicles to temporarily miss the CTS signal. To avoid that vehicles with lower priority send an RTS signal during the first three CW units, which will interfere with the ongoing data transmission, the RSU informs other vehicles to wait for the next CW through the IEEE 802.11p network as well as sends the CTS signal when it has received the RTS during the first three CW units. After the acknowledgement (ACK), a Distributed Inter-Frame Spacing (DIFS) is inserted before the next CW.

To avoid the inefficient transmission occupying channel resources, the data transmission processes are monitored and can be terminated according to real-time conditions, such as the actual data transmission efficiency and vehicle position changes during the data transmission period. When the priority of the current data transmission process is drastically turned down and there are other requests with much higher priority, the current data transmission process should be terminated.

IV. EVALUATION AND DISCUSSIONS

Due to the much less link disconnection and the very high data transmission rate, the proposed heterogeneous network scheme definitely has much higher efficiency in transmitting large-size data block assuming it is achievable. The main uncertain factor for the effectiveness of the scheme is whether it is achievable under the strict constraints. Therefore, the key constraints on the feasibility of the scheme are the main concern of this section. First, the data transmission capacity of one vehicle-RSU connection has a significant impact on the efficiency of the scheme. A small capacity usually means a large number of link connections are required to transmit a large-size data block, which will greatly reduce the efficiency of the scheme. Second, a short vehicle-MECS delay is required to ensure the parameter pre-configuration can be completed in time. Lastly, the system scalability in the future and the additional economic cost, which are important to the application value of the scheme, are also discussed in this section.

A. CAPACITY

1) SINGLE-USER ACCESS MODE

The supported data transmission capacity of one vehicle-RSU connection in the VANET is variable with the vehicle speed

TABLE 2. The supported V2I data transmission capacity of the single-user access mode under good environment.

Parameters	40km/h	60km/h	120km/h
Maximum link duration	≈ 3.6s	≈ 2.4s	≈ 1.2s
Number of PLCP preamble	$\approx 1016 \times 3.6$	$\approx 1016 \times 2.4$	$\approx 1016 \times 1.2$
Time for PLCP preamble	$\approx 3657 \times 2 \times 3.75$us	$\approx 2438 \times 2 \times 3.75$us	$\approx 1219 \times 2 \times 3.75$us
CW unit and ACK	1+1	1+1	1+1
Time for CW unit and ACK	$\approx 18 \times 3.75$us	$\approx 18 \times 3.75$us	$\approx 18 \times 3.75$us
Data transmission capacity	$\approx 3657 \times 1$Mb ≈ 457MB	$\approx 2438 \times 1$Mb ≈ 304MB	$\approx 1219 \times 1$Mb ≈ 152MB

as the connection duration changes with the vehicle speed. By ignoring the effect of the unimportant interfering factors of actual environments, such as Doppler shift, the connection duration is roughly linearly related with the vehicle speed, which also means that there is an approximately linear relationship between the data transmission capacity of one vehicle-RSU connection and the vehicle speed. Therefore, if the vehicle with speed $\mathcal{S}$ has a connection duration $\mathcal{D}$, it can be deduced that a vehicle with speed $\alpha\mathcal{D}$ has a connection duration $\mathcal{D}/\alpha$. By assuming only band group 1 and band group 2 are employed, the maximum of the valid communication distance in OFDM-UWB systems is about 20 meters. Therefore, for the V2I communication, in which the vehicle speed is $\mathcal{X}$m/s, the vehicle-RSU connection duration can be roughly simplified as $40/\mathcal{X}$.

In specification [45], two Physical Layer Convergence Protocol (PLCP) preambles, the standard PLCP preamble with 30 preamble symbols and the burst PLCP preamble with 18 symbols, are respectively defined for normal and burst data transmission, of which the duration of these two symbol sequences are 9.375us and 5.625us, respectively. In the burst PLCP preamble, 12 preamble symbols are used for packet/frame synchronization and the other 6 symbols are employed for channel estimation. As parallel accumulator can be employed at the receiver in our solution, the packet synchronization needs at most six preamble symbols, which means that the duration of the preamble symbol sequence is 3.75us. According to the user access mechanism presented in Section III, one OFDM symbol is enough for designing the CTS and RTS signal. As both the RTS and CTS signal are transmitted between the sender and receiver directly in a broadcasting mode, a data frame structure without Media Access Control (MAC) head and routing information can be employed for the RTS and CTS transmission, as shown in Fig.10.

The frame format in Fig.10 is composed of three components: the PLCP preamble, the PLCP head, and the PLCP Service Data Unit (PSDU) with one data symbol. The length of the defined PHY head in specification [45] is 46bit. Therefore, the duration of the frame structure for the RTS (or CTS) signal depends mainly on the PLCP preamble. Due to there is frequency synchronization deviations at the receiver, the time and frequency offset between the receiver and sender will accumulated with time. Therefore, a data block with large

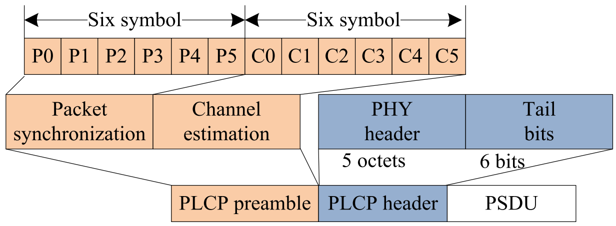

FIGURE 10. The shortened frame format for transmitting RTS and CTS, in which the MAC head and routing information is not used.

size should be divided into multiple data frames, as shown in Fig.11.

As pilot subcarriers are employed in each symbol for channel estimation and fine frequency synchronization, the PSDU payload (the maximum is 16,383 octets) can be extended to more than one megabit by modifying the data format of burst transmission model in the scenario that the data rate is 1Gbps. In this way, the number of the data frames transmitted within one second can be decreased to about 1016.

The data transmission capacities of one vehicle-RSU connection of the single-user access mode under good environment and bad environment are analyzed, respectively. Under good environment, the vehicle has highest priority, which means there are only one CW unit employed in the CW and the frame size is the upper bound (one megabit). To the bad case, we assume that four CW units are used and the frame size is 16,383 octets. Under the condition that there is only one vehicle connects with the RSU in the VANET, the supported V2I data transmission capacity of one vehicle-RSU connection are shown in Tables 2 and 3.

2) MULTI-USER ACCESS MODE

As aforementioned, if the TFC types are orthogonal or the inter-signal distance meets related requirements, multiple V2V communications coexisting within the OFDM UWB signal coverage is allowed. Assuming two band groups are employed in the OFDM-UWB system, there are at least six orthogonal TFC types. Due to the limitation of safe driving rules, there are normally less than ten vehicles on a 25-meter-long four-lane road by assuming that the vehicle speed higher than 20km/h, which means that the MB-OFDM UWB-based VANET has the capability to support almost all vehicles participating in V2V communication at the same time. However,

TABLE 3. The supported V2I data transmission capacity of the single-user access mode under bad environment.

Parameters	40km/h	60km/h	120km/h
Maximum link duration	$\approx 3.6s$	$\approx 2.4s$	$\approx 1.2s$
Number of PLCP preamble	$\approx 7722\times3.6$	$\approx 7722\times2.4$	$\approx 7722\times1.2$
Time for PLCP preamble	$\approx 27799\times2\times3.75us$	$\approx 18532\times2\times3.85us$	$\approx 9266\times2\times3.85us$
Number of CW and ACK	4+1	4+1	4+1
Time for CW and ACK	$\approx 54\times3.75us$	$\approx 54\times3.75us$	$\approx 54\times3.75us$
Data transmission capacity	$\approx 27797\times16KB=434MB$	$\approx 18530\times16KB=289MB$	$\approx 9264\times16KB=144MB$

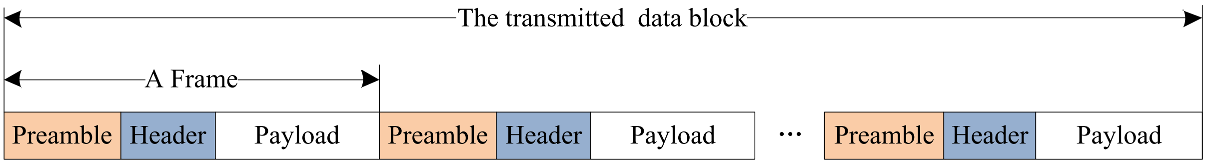

FIGURE 11. The structure of the transmitted data block, in which multiple frames are included.

TABLE 4. The supported V2I data transmission capaccity for each vehicle under multi-user access mode on a three-lane road.

Speed, Safe distance	Environment	Number of vehicles	Maximum inter vehicle distance	Data transmission capacity
40km/h, 30m	Worst case	6	30m	$\approx (7722\times6.3\times16KB)\div6\approx126MB$
	Normal case	3	40m	$\approx (1016\times7.2\times1Mb)\div3\approx304MB$
60km/h, 60m	Worst case	3	0m	$\approx (7722\times2.4\times16KB)\div3\approx96MB$
	Normal case	3	40m	$\approx (1016\times4.8\times1Mb)\div3\approx203MB$
120km,120m	Worst case	3	0m	$\approx (7722\times1.2\times16KB)\div3\approx48MB$
	Normal case	3	40m	$\approx (1016\times2.4\times1Mb)\div3\approx101MB$

in the V2I scenario, parallel communications are not allowed, in which the RSU can only communicate with one vehicle at a time. When there is multi-user access in the MB-OFDM UWB network, the V2I communications in serial model is the main obstacle to effectively transmitting the data of all users. Therefore, the data transmission capacity of the multi-user access mode under the serial V2I communication scenario is the main focus in this subsection.

Due to the constraint of safe-driving distance and the width of the road, there is a limit to the number of vehicles that can be accommodated on a road section. For example, there are at most six vehicles on the 30-meter-long three-lane road section by assuming the vehicle travels with a speed of 40km/h and a safe-driving distance of 30 meters. Assuming the vehicle status is 40km/h speed with a 40-meter safe distance, 60km/h speed with a 60-meter safe distance, and 120km/h with a 120-meter safe distance, respectively, the supported V2I data transmission capability for each vehicle under the multi-user access mode is shown in Table 4, in which the road condition is that there are three lanes on the one-direction road. In the table, the number of vehicles is the number of vehicles which want V2I communication with the same RSU. The maximum inter-vehicle distance is the distance between the first vehicle and the last one on the one-direction road, which is positively correlated with the total V2I data transmission duration of the whole grouped vehicles. Based on these concepts, we define the "worst case" is the environment that the number of vehicles in the group is the upper bound of the vehicle numbers on the road section with a minimum value for the maximum inter-vehicle distance. Therefore, in the case that vehicles travel with 40km/h speed and a safe distance of 30 meters on the three-lane road, the "worst case" is that there are two rows of vehicles with 30-meter-long inter-row distance and three vehicles per row, which means that the number of vehicles and the maximum inter-vehicle distance are 6 and 30 meters, respectively.

From Table 4, we can see that the "worst case" under the 60km/h-speed condition can support a data transmission capacity of 96MB for each vehicle during the duration of one vehicle-RSU connection. As the size of most data blocks appeared in practical VANETs such as pictures and short video is smaller than 96MB, the data transmission capacity of this case has almost no constraint on the data transmission efficiency of the network. To the 120km/h-speed scenario, which corresponds to the motorway environment, the "normal case" can support a data transmission capacity of 101MB, which is also large enough for efficiently

TABLE 5. The data transmission capacity of V2V communication between vehicles traving in opposite directions under single-user access mode.

Parameters	40km/h	60km/h	120km/h
Maximum link duration	$\approx 1.8s$	$\approx 1.2s$	$\approx 0.6s$
Number of PLCP preamble	$\approx 7722 \times 1.8$	$\approx 7722 \times 1.2$	$\approx 7722 \times 0.6$
Time for PLCP preamble	$\approx 13899 \times 2 \times 3.75us$	$\approx 9266 \times 2 \times 3.75us$	$\approx 4633 \times 2 \times 3.75us$
Number of CW and ACK	1+1	1+1	1+1
Time for CW and ACK	$\approx 18 \times 3.75us$	$\approx 54 \times 3.75us$	$\approx 18 \times 3.75us$
Data transmission capacity	$\approx 13898 \times 16KB=217MB$	$\approx 9265 \times 16KB=144MB$	$\approx 4632 \times 16KB=72MB$

transmitting large-size data block in VANETs. To the ''worst case'' of this scenario, the supported capacity is about 48MB, which is not so satisfactory as many short videos appeared in VANETs have a data size larger than 48MB. However, on practical motorways, the vehicle traveling at a speed of 120km/h commonly appears on the road section with sparse traffic, which means the ''worst case'' is less common. In fact, the ''worst case'' under the 120km/h-speed condition has almost no impact on the data transmission efficiency of the OFDM-UWB network in practical VANETs. One reason is that it is impossible to keep high speed as 120km/h with dense vehicles on the road for a long time in practical traffic environment, which means that the ''worst case'' under the 120km/h-speed condition occurs occasionally with very short duration. The other reason is the occasional data-transmission congestion can be solved through adjusting resource allocation such as delaying some data transmission task, as real-time transmission is not required for most large-size data block transmissions.

3) V2V COMMUNICATION SCENARIO

When the V2V communication occurs between the two vehicles traveling in opposite directions, the connection duration of the communication will be much shorter than the V2I communication scenario. The data transmission capacity of this scenario should also be evaluated. However, as analyzed in Subsection A.b), the MB-OFDM UWB-based VANET has the capability to support almost all vehicles participating in V2V communication at the same time due to the limited vehicle number on the road. Therefore, the common application environment of this scenario is the point-to-point communication, which is the same as the single-user access mode of the V2I communication in terms of user access. From the results in Table 2 and Table 3, it can be seen that the data block with larger frame size has less CW units, which means it wastes less time in transmitting invalid preamble symbols. By setting the low bound, 16,383 octets, for the frame size, the evaluated data transmission capacities of the single-user access mode under the V2V scenario that the two vehicles traveling in opposite directions are shown in Table 5.

B. VEHICLE-MECS DELAY

In Fig.3, the pre-configured OFDM-UWB parameters are configured at the DSC and transmitted back to vehicles through the IEEE 802.11p network, which has strict requirements for the vehicle-DSC delay. Based on the heterogeneous network structure, two potential approaches for reducing the vehicle-DSC delay have been presented in section III, of which one is inserting MECS between the DSC and RSUs and the other is directly employing edge computing technique at the RSU by dividing the parameter-configuration process into multiple steps. Based on these two approaches, the process of evaluating DSC-vehicle delay can be converted to evaluating the MECS-vehicle delay.

Due to the constraint of road space and safe-driving rules, there is an upper bound to the number of vehicles on a road section. For example, when vehicles running at a speed of 60km/h, the upper bound of the vehicle number on a 300-meter-long three-lane road section is approximately fifteen by assuming the safe-driving distance is sixty meters. By randomly placing nodes within the distance range of 20 to 300 meters from the RSU, we test the data transmission rate of IEEE 802.11p network. One test case is that 35 nodes communicate with the RSU simultaneously, which corresponds the upper bound of the vehicle number in the scenario that vehicles travel on the five-lane one-direction road with 40km/h speed and 40-meter safe distance, and the other case is that 10 nodes communicate with the RSU, which correspond to the upper bound of the scenario that vehicles run on the five-lane road with 120km/h speed and 120-meter safe distance. The data rates of the nodes, which are placed 50, 100, 150, 200, 250 and 300 meters away from the RSU, are tested, respectively, as shown in Fig.12.

Based on the analysis results in section IV.A, it can be drawn that the vehicle-RSU communication duration are about 25 second if the vehicle passes a 280-meter-long road section at a speed of 40km/h, and about 8.4 second if the vehicle speed is 120km/h. As most of the pre-configured parameters are used to select an item from the list, such as the TFC type and the user priority, the transmitted parameters can be designed with a size much smaller than 1Kb. Assuming the size of the OFDM-UWB parameters transmitted in the IEEE 802.11p network is 1Kb, the total thirty-five 1Kb-size packets in the 35-node scenario can be transmitted within the limited time if the average data rate higher than 1.39Kpbs, and the average data rate higher than 0.96Kpbs is required for the 10-node scenario. From Fig.12, it can be seen that the supported data rate of the IEEE 802.11p network in both the

TABLE 6. The comparison on the facilitie cost.

Facility	ITS based on the traditional VANET	ITS based on the proposed heterogeneous network
DSC	● Needed ● Supporting complex algorithms ● High computational power	● Needed ● Supporting complex algorithms ● High computational power
MECS	● Not needed	● Needed ● Real-time network management
RSU	● Needed ● Supporting IEEE 802.11p protocol	● Needed ● Supporting IEEE 802.11p protocol ● Supporting OFDM-UWB protocol
OBU	● Needed ● Supporting IEEE 802.11p protocol	● Needed ● Supporting IEEE 802.11p protocol ● Supporting OFDM-UWB protocol

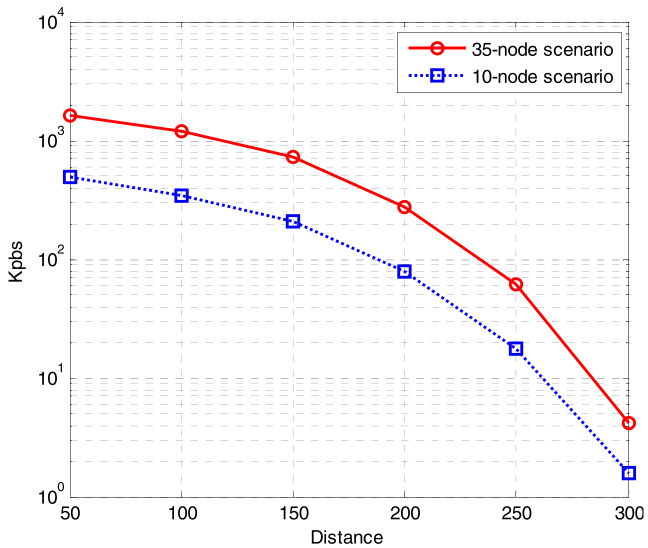

FIGURE 12. The simulated Data rate of nodes with different distances from the RSU, under the assuming that there are 35 nodes and the10 nodes communicate with the RSU at the same time, respectively.

35-node scenario and the 10-node scenario are much higher than the low bound of the required data rate. As the number of lanes of most one-direction road is less than six, the results in Fig.12 show that the parameters can be transmitted back to the vehicle through the IEEE 802.11p network with a large time redundant, which means the vehicle-MECS delay does not constrain the data transmission efficiency of the OFDM-UWB network.

C. ADDITIONAL ECONOMIC COST

The comparison on the facility cost between the ITS based on traditional VANET and the ITS based on the heterogeneous network of this paper is shown in Table 6. As the practical ITS commonly have the capability of network management and big data analysis [62], [63], a DSC with high computation power is also required in the ITS based on traditional VANETs. From the table, we can see that two additional costs will be added in the ITS based on our VANET scheme. One is that the MECS should be employed to realize real-time network management. Another is that the RSU and the OBU should support both IEEE 802.11p protocol and OFDM-UWB communication.

According to the aforementioned approach in section III, the MECS function can be directly loaded in the RSU to avoid inserting a specialized MECS device in the network, in which the computation complexity of the RSU is controllable by extracting the mathematical model of parameter configuration at DSC. The additional support for OFDM-UWB communication in the RSU and OBU will increase the cost of these devices. However, as there is no interference between the OFDM-UWB signal and the IEEE 802.11p signal, simply adding a MB-OFDM UWB communication interface in the RSU (or OBU) will not increase the device cost significantly.

D. SYSTEM SCALABILITY

With the increasing demand for transmitting large-size data block through VANETs in the future, the probability of multiuser-access congestion in the VANET, especially at RSU side, will also increase continuously. Some methods and techniques can be introduced into the heterogeneous VANET scheme presented in this paper to future improve the data transmission efficiency.

1) CACHE-AIDED DATA TRANSMISSION.

The driving path and the driver's demand for information in the vehicle driving process have certain regularity. For example, due to the constraint of road structure, the driving path of vehicles in the short coming period has great determinacy, while the driver are commonly concerned about some specific information, such as the graphic of the congestion scene on the ahead road. Therefore, if the data can be pre-transmitted and cached at the receiver during the period when the status of the RSU is idle, data transmission congestion at the RSU can be obviously reduced.

In traditional VANETs, the pre-transmission mechanism may cause a rapid increase in the amount of the transmitted data due to the unavoidable redundant transmission, which will greatly increase the data transmission load of relay nodes and the amount of the total transmission as the count of data transmission is linearly related with the relay numbers of the multiple-relay process. However, to the heterogeneous VANET in this paper, most large-size data blocks is directly transmitted between the transmitter and the receiver, which means the transmitted redundant data will not be linearly amplified by the relay nodes in the transmission process.

2) LOAD BALANCING FOR RSU.

In the VANET scheme of this paper, VANET nodes do not participate in data relay, which means the data transmission load of the RSU is mainly derived from the direct RSU-vehicle communication. Therefore, load balancing techniques can be employed at the DSC to avoid excessive RSU-vehicle data transmission being centralized on several RSUs.

V. CONCLUSIONS

In this paper, a heterogeneous network scheme composed of an IEEE 802.11p network and a MB-OFDM UWB network is designed to introduce the MB-OFDMUWB technique into the VANET for large-size data block transmission. The key challenges of the scheme and available solutions for the challenges are analyzed, of which the mechanism of quick parameter pre-configuration, quick OFDM-UWB link establishment and highly efficient multi-user access to the OFDM-UWB network are designed. The key factors to the effectiveness of the scheme, such as the data transmission capacity of one link connection and the MECS-vehicle delay, are evaluated and discussed. The evaluation results show the scheme is feasible.

ABBREVIATIONS

ACK:	acknowledgement
AODV:	ad-hoc on-demand distance vector
CBLTR:	cluster-based life-time routing
CTS:	clear-to-send
CW:	contention window
DIFS:	distributed inter-frame spacing
DGR:	directional greedy routing
DSC:	data service center
DSDV:	destination sequenced distance vector
DSR:	dynamic source routing
GPCR:	greedy perimeter coordinator routing
GPSR:	greedy perimeter stateless routing
IR:	impulse radio
ISI:	inter-symbol interference
ITS:	intelligent transportation system
MANET:	mobile ad-hoc network
MAC:	media access control
MECS:	mobile edge computing sever
MB-OFDM:	multiband orthogonal frequency division multiplexing
NOMA:	non-orthogonal multiple access
OBU:	on board unit
QAM:	quadrature amplitude modulation
PSDU:	PLCP service data unit
PLCP:	physical layer convergence protocol
RSU:	road side unit
RTS:	request-to-send
SDN:	software-defined networking
SIFS:	short inter frame space
TFC:	time frequency code
UWB:	ultra-wideband
VANET:	vehicular ad hoc network
V2I:	vehicle-to-infrastructure
V2V:	vehicle-to-vehicle
WPAN:	wireless personal area network

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