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Research Article

MVR Delay: A Queueing Based Routing Model for C-V2X Mode 4 in VANET's

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During the last few years, the demand for vehicular ad-hoc networks (VANET) has gained great attraction in the intelligent transport system. The VANET architecture includes several critical features, such as distributed networking and the rapidly changing network topology. Due to the significant characteristics of road safety, it has gained a great deal of interest in industry and academia to enhance the safety of the road transport system. Efficient message exchange between vehicles and roadside units is a tedious task in VANET. Several techniques have been introduced to improve communication, but efficient packet delivery and delay reduction are challenging issues. Currently, the VANET technique has evolved as a "vehicle-to-everything (V2X)" communication standard. In addition, the 3GPP standards have introduced a new communication standard as an alternative to the IEEE 802.11p system. In this new release of 3GPP, two new communication modes are introduced, mode 3 and mode 4. Mode 3 requires a cellular infrastructure, whereas mode 4 can operate without cellular coverage. In this work, we focus on C-V2X mode 4 communications and present a novel routing scheme to deal with hidden terminal problems. The proposed approach generates a virtual queueing model in which efficient channel selection is performed so that packet collision and interference can be reduced by maximizing the distance in the virtual queue model. The experimental results demonstrate that the average performance of the proposed approach is obtained as 0.9383, 0.09 s, and 0.0617 in terms of packet delivery, end-to-end delay, and packet drop rate, respectively.

1. Introduction

In the current living situation, transport and mobility play an important role in daily life. Currently, the automotive industry has noticed a huge demand for vehicles. Significant expansion has resulted in the emergence of extensive highways and road networks that exert a profound impact on the country's economic progress. However, we face several social and economic issues due to the increased number of accidents resulting in injuries and death among drivers and pedestrians. Recently, the World Health Organization (WHO) reported that every year more than 1.25 million people die from road accidents [1]. Road accident death is the ninth leading cause of death. Furthermore, 20–50 million more people were injured worldwide. Recent studies [2] have reported that if the driver obtains critical information about road conditions or information about accidents, around 60% of road accidents can be prevented. Due to these issues, intelligent transportation systems (ITS) are gaining a lot of attention that can help prevent road accidents and traffic jams by sharing crucial information between vehicles [3].

The main aim of ITS is to improve the efficiency of traffic management by reducing traffic problems and controlling mishaps. In addition, intelligent transportation systems provide a robust communication service to offer communication among vehicles and pedestrians. Due to these significant advantages of ITS, automotive industries realize the need for connectivity between vehicles [4] because this communication setup provides crucial information such as traffic flow parameters and driving conditions and shares this information with other neighboring vehicles. To share this information and improve communication between vehicles, the research community has introduced a new type of ad-hoc network that is especially devoted to vehicular systems, and this communication strategy is called VANETs [5]. In VANETs, vehicles communicate with the road infrastructure with the help of wireless communication while moving. Generally, VANETs have two main components: an attached unit (an onboard unit) and a roadside unit (RSU). OBUs are the types of radio that are installed in each vehicle to communicate with nearby vehicles or devices, whereas RSUs are the roadside units that are installed along with the streets or roads. These RSU units are used to communicate with the infrastructure with the help of a dedicated short-range communication (DSRC) setup [6]. Vehicle-to-vehicle (V2V) communications [7] and vehicle-to-infrastructure (V2I) communications are the two main types of VANET communication [8]. In the V2V scenario, vehicles exchange information with other neighboring vehicles where packets are transmitted as multicast or unicast manner. In the V2I scenario, vehicles communicate with roadside units with the help of a high-bandwidth connection.

Currently, VANETs have evolved as vehicle-to-everything (V2X) communication, which is a promising technique for establishing communication with other devices, such as vehicle-to-everything, offering vehicles the ability to communicate with other entities, such as vehicles, application infrastructure, and cellular networks [9]. Figure 1 shows the general architecture of the V2X network. The V2X communication standards are based on the cellular infrastructure; hence, it is referred to as cellular V2X (C-V2X). This communication standard is defined by the 3GPP group [10]. The C-2VX standard is also adopted as a substitute for the IEEE 802.11p standard because it uses a PC5 interface to establish direct communication between vehicles. This communication scheme is also known as V2X sidelink communication. Existing V2V communication systems are supported by DSRC standards; however, these systems have limitations, such that these systems only work for short-range communication, do not provide highly compact networks, and are unreliable broadcast services [11]. Moreover, conventional short-range communication methods based on DSRC do not support the variety of incoming traffic for diverse applications. To overcome these issues, the 3GPP standard presented Release 14 which is an evolution of LTE to support V2X communication. The existing 3G model contains two modes, Mode 1 and Mode 2 for in- and out-of-coverage operation. In this new release (Release 14), two new communication modes are also introduced, Mode 3 and Mode 4 which are specially designed for vehicular communication. According to the mode 3 standard, a cellular network is used to manage the resources used in direct V2V communication, while mode 4 selects and manages the resources without utilizing any cellular infrastructure. Mode 4 has reported a significant improvement in V2V safety applications because it does not depend on the infrastructure based on cellular networks. Figure 2 shows a general structure of the mode 3 and mode 4 strategies.

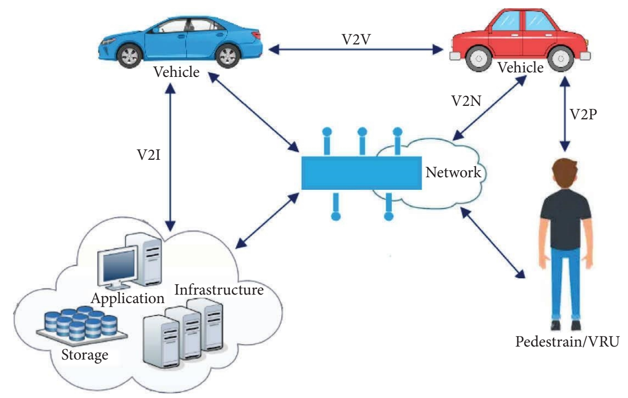

Figure 1: General architecture of the V2X network.

C-2VX has several advantages over DSRC-based communication, such as offering long-range communication, reliable communication, and improved safety and congestion handling [12]. Moreover, it supports LTE and 5G techniques that can be used for the functioning of the RSU [13]. This helps to eliminate the issue of installing and maintaining RSUs, resulting in a low-cost deployment of vehicular communication [14, 15].

1.1. Contribution. In this study, we introduce a novel approach to improve communication in CV2X mode 4. Generally, the conventional semipersistent scheduling (SPS) approach suffers from the issue of hidden terminal problems. To overcome this issue, we present a novel scheduling approach in which subchannel selection is performed by maximizing the distance between vehicles that are using the same channel. This helps reduce collisions and interference between users. The main contributions of this work are as follows. Generally, the SPS approach makes the C-V2X scheme more prone to hidden terminal problems; therefore, we introduce a scheduling approach.

(i) The proposed model `introduces a scheduling mechanism based on the maximum distance between vehicles.

(ii) According to the proposed scheduling, the vehicle estimates the location of neighboring vehicles and performs the subchannel selection task to reduce packet collision.

(iii) This approach generates a virtual queueing model to improve channel selection and reduce packet collisions.

1.2. Article Organization. The remainder of this article is structured as follows. Section 2 provides a concise literature review on the existing techniques of the C-V2X scheme, Section 3 presents the analytical solution and proposed approach to improve the efficiency, Section 4 presents the experimental analysis where we compare the performance of the proposed model with state-of-the-art techniques, and lastly, Section 5 provides the concluding remarks and highlights future work in this regard.

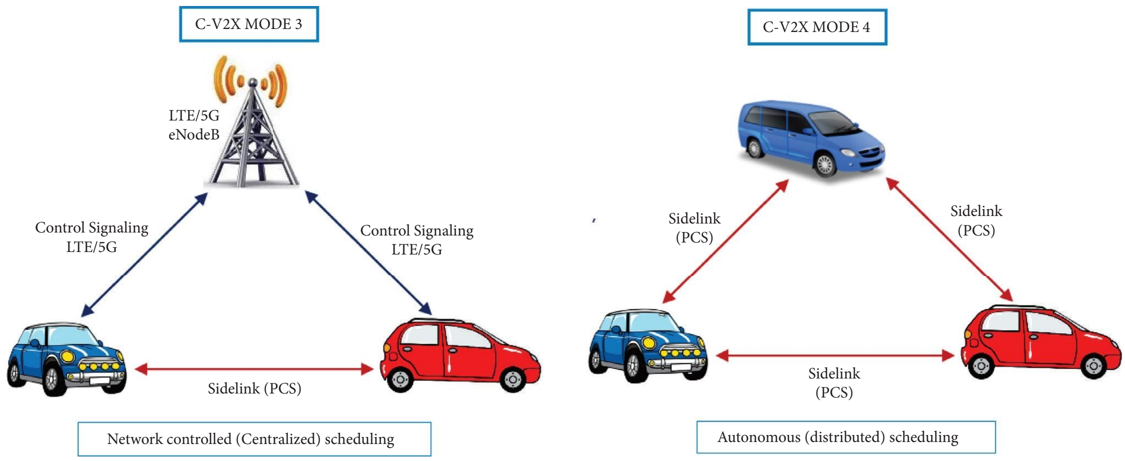

Figure 2: General structure of C-V2X mode 3 and mode 4 communications.

2. Literature Survey

In this section, we study existing VANET schemes based on the C-2VX communication strategy. Mannoni et al. [16] presented that IEEE 802.11p and C-V2X (3GPP Release 14) are currently promising techniques to enhance VANET communication. Here, the authors compared the performance of these two standards for the physical and medium access control (MAC) layers. First of all, the performance of the physical layer of the single link is evaluated and expanded to derive the performance of the MAC layer where users are scheduled to their corresponding MAC layers. This study shows that C-V2X outperforms for low-level density and, as congestion increases, ITS-G5. Emara et al. [17] discussed that cellular C-V2X has gained a great deal of attraction in the automotive industries due to its applications for road safety, infotainment, and automated driving. However, end-to-end message transmission latency is a challenging issue in these applications. For example, vulnerable road users (VRUs) send messages to vehicles about their location, activity, and status using the cellular network. In this work, the authors considered the VRU scenario based on the highway scenario and argued that conventional cellular architectures can be replaced with multiaccess edge computing (MEC). This helps mitigate latency issues. According to Abanto-Leon et al. [18], the C-V2X mode 4 operates in a decentralized manner, where vehicles independently monitor the power received in subchannels before choosing the appropriate channel for their use. This is useful for vehicles to discover and select the optimal subchannel with low interference. However, VANETs are highly dynamic in nature, and hence, the selected subchannels fluctuate rapidly. Due to this scenario, channel selection is also performed frequently. According to the 3GPP standard, the selection of the subchannel depends on the linear average of the perceived power intensity on each subchannel. In this article, the authors introduced a nonlinear power averaging phase scheme in which an exponential weighting scheme is used to assign high priority to channels. Ghafoor et al. [19] reviewed DSRC and C-V2X technologies for VANETs and presented a QoS-aware relaying algorithm that considers the multimetric model to assign priorities to dual interference vehicles and helps to achieve robust communication, which is equipped with different radio access techniques. This scheme enables the combined use of DSRC and C-V2X in VANETs.

Qi et al. [20] reported that conventional VANETs are based on DSRC for communication. However, multihop data communication in DSRC-based VANETs suffers from data rate and delay-related issues, which affect the quality of service of the communication system. Thus, the combined DSRC and cellular VANET models are adopted. However, cellular networks increase the cost of network bandwidth. The problem of reducing bandwidth consumption and end-to-end delay is considered an NP-hard problem, which is solved by using a two-stage heuristic algorithm.

Hua et al. [21] reported that C-V2X communication models use macrocell or femtocell for communication. Today, the macro-femtocell network model is used in the C-V2X models. These networks have mainly two problems (a) due to the high-speed mobility of vehicles; it requires a faster connection switching from one base station to another base station. (b) Poor selection of base stations leads to network congestion and network load imbalance. To overcome these issues, the authors introduced a base station selection scheme using the Markov decision policy.

Chen et al. [22] presented a novel C-V2X architecture based on the network slicing and spatial reuse technique that supports both low latency and broadband services; that is, it can perform communication for ultra-reliable low latency communications (URLLC) and enhanced mobile broadband services. Abbas and Fan [23] presented a hybrid scheme for the C-2VX technology to increase the reliability of VANET. The main idea of this scheme is to establish direct device-to-device communication between vehicles with lower latency and to offer long-range communication. Mainly, this approach uses a combination of C-V2X and IEEE 802.11p, where cellular eNodeB is used to control device-to-device (D2D) links. Optimal resource allocation is the important paradigm that selects optimal channels and allocates the appropriate channel to minimize the latency of the system. D2D links are selected on the basis of the greedy mechanism.

Sattiraju et al. [24] discussed the channel estimation technique, which is widely adopted in orthogonal frequency division multiplexing (OFDM) systems to mitigate intersymbol interference with the help of channel state information. In this field, the least squares and the minimum mean squared error are the most efficient techniques in the physical layer. In this work, the authors incorporated a deep neural network-based scheme that uses CNN (convolution neural network) for channel estimation. The comparative study shows a significant improvement in performance by using deep learning for high-mobility scenarios.

Aslani et al. [25] focused on the C-V2X mode 3 models, where two groups of users are considered cellular and vehicular users. In the communication phase, cellular users establish communication with the help of base stations, whereas vehicular users use direct vehicular links to establish communication. Vehicular users use the spectrum-sharing mechanism of an OFDM system. Here, the main objective is to enable transmission for the vehicular user at the same time as the cellular user is transmitting on a subcarrier. In various scenarios, the subcarriers are limited and vehicular links are also limited due to the QoS requirement of cellular users where interference between cellular and vehicular users is considered. Thus, the main objective here is to increase the number of vehicular links to satisfy the QoS requirement. In this work, the author considered a resource allocation problem for the C-V2X mode 3 network, and the authors considered a high-mobility scenario that causes the Doppler effect. Furthermore, it is also assumed that channel state information is not present for the base station. For this approach, a novel scheme is introduced to allocate resources and minimize unattended vehicular links. In resource allocation, the availability of power and the availability of subchannel are determined and assigned accordingly to cellular and vehicular users.

Zhang and Zhang [26] presented an optimized cluster-based hybrid routing by combining DSRC and C-V2X for vehicular networks. The main aim of this work is to maintain the QoS of VANETs. Therefore, this article introduced hierarchal clustering-based routing to handle frequent handovers to maintain the communication link that is interrupted due to the high mobility of vehicles. Moreover, the problem is formulated as a nonlinear integer programming problem; therefore, a heuristic approach is also introduced to elucidate the optimization problem.

In the study by Alghamdi [27], the focus was on exploring the potential benefits of 5G technology in the context of C-V2X scenarios. The authors highlighted advantages such as increased throughput, higher data rates, and the minimal delay offered by 5G. However, ensuring QoS while sending emergency messages remained a challenging task. To address this, the authors proposed a novel approach that used stable matching-based routing to guarantee QoS. This approach involved identifying the best forwarding node that minimized communication delay. Furthermore, the model used enhanced sphere decoder like (ESDL) to identify the most suitable device for efficient D2D communication in VANET environments.

In the work of Wu et al. [28], the authors highlighted the limitations of the current C-V2X communication models, particularly the standard SB-SPS protocol, which exhibited poor performance due to issues such as hidden terminals and half-duplex problems. To overcome these challenges, the authors proposed a self-adaptive MAC protocol specifically designed for C-V2X mode 4 communication standards. This new communication protocol incorporated frame information and received signal strength indicator (RSSI) for resource scheduling. It also dynamically adjusted frame length on the basis of the network environment to improve performance and address identified problems.

In another study by Wu et al. [29], the focus was on developing a time division multiple access (TDMA)-based MAC protocol. This protocol was designed to enhance the scheduling of time slots in VANETs. The proposed scheme used two-hop neighbor information to detect packet collisions and adjust time slots accordingly. Additionally, an adaptive frame length model was incorporated to address density-related issues in VANETs. This model dynamically adjusted the frame length based on vehicle density, further optimizing the performance of the MAC protocol.

Kezia and Anusuya [30] also focused on QoS-related issues faced by VANETs to deliver emergency messages due to frequent changes in network topology. Therefore, the authors introduced an emergency packet routing algorithm that uses trajectory data to deliver the packets. Emergency packets used in this approach consist of information to predict collisions, including propagation distance, traffic density, and candidate number.

Abbas et al. [31] not only discussed the importance of delivering the emergency message in VANETs but also reported the challenges faced by these networks. Therefore, the authors suggested position-based routing because these methods do not require any routing table to be maintained. However, position-based routing also faces challenges due to variations in the positions of vehicular nodes, and these nodes follow the greedy mechanism due to which the node can go out of communication range. These issues lead to degraded network performance, and also selection of relay nodes becomes a challenging issue. Therefore, the authors introduced a position-based reliable emergency message routing (REMR) technique that uses vehicle behavior to produce the mobility matrix to improve packet delivery. Moreover, this approach uses location information and Euclidean distance to identify the neighboring node. The mobility matrix includes speed, angle of movement, and position to minimize link interruption.

Bute et al. [32] discussed that with the help of the C-V2X schemes, the applications can be transferred to another node to perform specific tasks. However, the offloading of these tasks becomes a challenging issue. Therefore, the authors developed a cooperative task-offloading scheme for these networks. This approach explores vehicular edge computing, where the vehicle directly uses the V2V direct sidelink to offload to the server and the MEC server. This scheme uses a clustering mechanism in which vehicles are grouped together to form the cluster. This clustering helps to improve the reliability of the link. Moreover, this work presents an NP-hard optimization problem to decrease energy consumption.

Sun et al. [33] introduced a joint approach for the selection of communication modes and the adaptation of using a game theory-based approach. The main objective of the game theory model is to improve the overall performance. This approach uses priority-based packet transmission, where packets with high priority will have inflexible latency limitations. Do et al. [34] presented a detailed study on maximum throughput scheduling (MTS) for cellular and ad-hoc networks.

Rahmani et al. [35] developed a hybrid routing approach using *Q* learning and fuzzy logic for VANET. This approach has three phases, such as analyzing traffic conditions, applying the routing at the intersection level, and applying the routing at the road level. Each roadside unit (RSU) in the first phase has a traffic table at hand that details the flow of traffic on the four road segments that link to the appropriate intersection. The RSUs then determine the optimum route between various junctions using a Q-learning-based routing technique. Finally, the cars in each segment of the system choose the primary relay node using a fuzzy logic-based routing strategy.

Shah et al. [36] reported the importance of reliable and secure transmission of warning messages for road safety in VANETs. Therefore, the authors adopted the clustering-based mechanism to overcome these challenges, where rebroadcasting to nearby clusters is allowed. In this context, reliable cluster head selection is considered a challenging issue. The authors introduced the optimal path routing scheme, which focuses on vehicle mobility to overcome overhead and maintain the authenticity of the message in a high-mobility environment. Later, the selection of the head of the cluster is made based on the median number of odd or even numbers of vehicles to prolong the life of the network.

Khan et al. [37] used the concept of reinforcement learning to overcome routing issues in VANETs and reported that existing schemes are unable to handle high dynamic scenarios and prevent network congestion. Therefore, the authors presented an intersection-based routing approach using the Q-learning method. This scheme uses global and local views, which helps to design the *Q*-learning model to obtain the best route between intersections.

Lou et al. [38] introduced intersection-based V2X routing through Q-learning (IV2XQ) for VANETs. This method uses a hierarchical routing approach to improve QoS, while at the intersection level, a Q-learning-based routing method is developed. This approach finds the network environment and chooses the most efficient paths between crossings using past traffic data. Road junctions are considered the state space in this learning process, whereas road segments are considered the action space. As a result, the Q-learning method has fewer states and converges more quickly.

Habelalmateen et al. [39] introduced the traffic-aware clustering routing protocol (TACRP), which focuses mainly on traffic management and minimizing energy consumption. Therefore, the implementation of a traffic management unit is crucial to regulate the flow of traffic. In addition, vehicles with similar speeds and directions are considered in a group to formulate the clusters. The process of selecting a cluster head takes into account factors such as centralization, distance, energy, and weight parameters, ensuring an efficient choice of cluster heads. Javed et al. [40] focused on the efficient traffic messages in VANET systems where the authors have introduced the concept of a fog-assisted roadside unit (RSU). This model divides the roads into groups and performs the cluster head selection process to facilitate data transmission between vehicles and the RSU. Furthermore, it uses a combined model of IEEE 802.11p and C-V2X to reduce the time to re-enter the information. In [41], Renda et al. presented a detailed experimental analysis of 802.11p in the VANET scenario and evaluated its performance for packet inter-reception time.

3. Proposed Model

The 3GPP specifies that vehicular networks have the freedom to choose their radio resources using semipersistent scheduling (SPS), a well-known method. However, this scheduling scheme introduces a challenge in the C-V2X scheme, as it becomes more susceptible to the hidden terminal problem, which adversely affects QoS in the network. Therefore, in this section, we propose a scheduling approach to address this issue specifically in the C-V2X scenario.

3.1. C-V2X Mode 4 Communication. Following the 3GPP standard, vehicles operating in C-V2X mode 4 independently determine their resources to transmit data and control information. These channels are subdivided into various subframes, resource blocks, and subchannels for effective organization. Each subframe has a duration of 1 ms and a resource block (RB) that can be allocated to a given LTE user. The RB is 180 kHz wide in terms of frequency. Each RB contains 12 subcarriers with a frequency of 15 kHz for each subcarrier. These subchannels are considered as a group of resource blocks in the same subframe. However, the number of RBs can vary in each subchannel, as shown in Figure 3(a). These subchannels are utilized to transmit data and control information with the help of transport blocks (TBs). This transport block contains the full packet, which consists of information such as the beacon message, the basic safety message, or the cooperative awareness message.

To ensure the right channel selection, vehicles must continuously monitor transmissions across all subchannels, avoiding those already used by other vehicles. Before selecting its subchannels, the vehicle must determine the selection window (SW) within which it can explore suitable contender subchannels. SW, shown in Figure 3(b), is defined as the time period that starts from the desired reservation time (T) and extends to the maximum transmission latency limit. According to the 3GPP standard [22], this latency value varies depending on the transmission rate, with values of 100 ms, 50 ms, and 20 ms assigned to vehicles transmitting at 10 pps, 20 pps, and 50 pps, respectively. As discussed above, the vehicles sense the information of all subchannels, which helps avoid the selection of subchannels. To select the

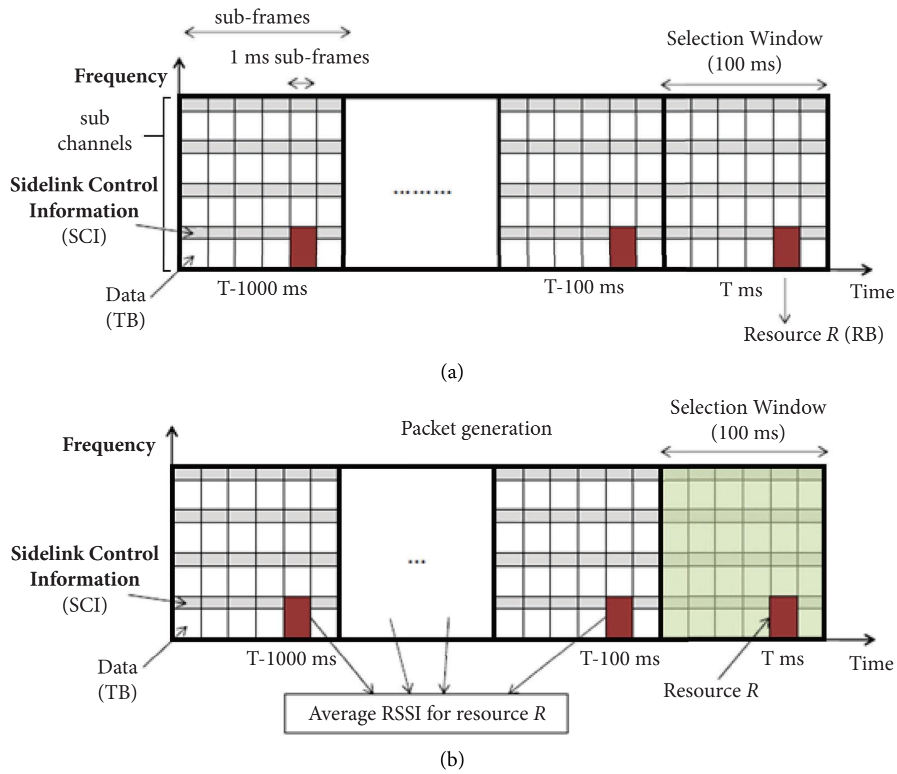

FIGURE 3: (a) C-V2X mode 4 channel and scheduling without selection window. (b) Candidate subchannel of C-V2X mode 4 with selection window.

subchannel vehicles, we identify the selection window to search for the candidate subchannel. We schedule the selection window (SW) with frequency, sidelink control information (SCI), and time attributes defined in the group structure as shown in Figure 4.

3.2. Scheduling Scheme. The primary objective of this approach is to devise an efficient resource selection method that minimizes packet collisions. This scheme primarily emphasizes exploiting the distance between two vehicles using the same subchannel, thereby reducing the occurrence of packet collisions. To achieve this objective, we organize the subchannel in the form of a group denoted as G. This G contains the subchannels. In general, a group refers to a collection of subchannels that encompass all subframes within a designated time interval. Let us consider that a group G has total N number of subchannels, given as follows:

$$N = S_F.S_C = \frac{1000}{\lambda}.S_C, \quad (1)$$

S_F denotes the total number of 1 ms subframes in the group and S_C denotes the total count of subchannel in each frame. Here, $S_F = 1000/\lambda$ where λ represents the frequency of packet transmission in packets per second (PPS). This scheduling scheme is distributed scheduling and is operated by each vehicle in two phases as follows.

3.2.1. First Phase. In the first phase of the scheduling operation, all vehicles assess the location of neighboring vehicles at the end of the G. The group architecture is depicted in Figure 4, and the scheduling process can be described as follows.

(i) At this stage, this approach uses location, speed, and time stamp data that the neighboring vehicle transmits in the last beacon message. Once the location is obtained from each vehicle, the system organizes the nearby vehicles into a virtual queue based on their respective positions. The vehicle position of the vehicle is denoted as *PosIndex* which is also attached to other beacon messages.

(ii) The queue data and *PosIndex* information, which are transmitted by neighboring vehicles, are used to compute the *PosIndex* of other vehicles. If the previous vehicle overhears the information that the preceding vehicle has a similar *PosIndex* to the current vehicle, then the *PosIndex* of the current vehicle is updated to *PosIndex* + 1. In contrast, if the vehicle does not detect any similar position value, then it maintains the last obtained *PosIndex* value.

(iii) Finally, the vehicle selects the suitable subchannel for data transmission based on their *PosIndex*. The channel is selected in such a way that each vehicle that is using the same channel is placed at a far

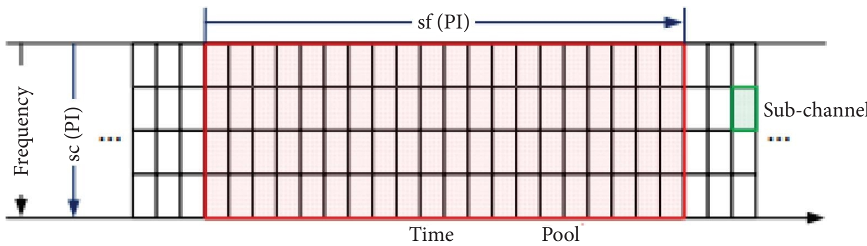

Figure 4: Group structure for subchannels.

distance so that packet collision can be avoided. This process is carried out on the basis of its virtual locations obtained through the beacon messages.

Let us consider that the current vehicle V has the U number of earlier vehicles which range from 1 to U where v_1 vehicle is closest to the vehicle v_t which is estimating the position index of neighboring vehicles and v_U is the vehicle whose location is far from the vehicle v_t. In our simulation scenario, if the *PosIndex* of vehicle u is PI_u, then the position of $u-1$ will be as $\mathrm{PI}_u + 1$, it can be realized the concept as mentioned in step (c). The maximum value of *PosIndex* is $N-1$. However, there can be an error in this process in estimating the position; thus, the vehicle v_t checks the position of all preceding vehicles and computes *PosIndex* corresponding to its own *PosIndex*. This can be expressed as follows:

$$\mathrm{PI}_t = \arg\max_{\mathrm{PI}} \sum_{u=1}^{U} \Phi(\mathrm{PI}, \mathrm{PI}_u + u), \tag{2}$$

where $\Phi(X, Y) = f(x) = \begin{cases} 1, & \text{if } X = Y, \\ 0, & \text{if } X \neq Y. \end{cases}$

3.2.2. Second Phase. Furthermore, subchannel selection is an important process in which vehicles pick their suitable subchannel from the group G. This subchannel selection process is performed on the basis of their position index. The group architecture is depicted in Figure 2. This group contains total subframes as 0 to $S_F - 1$ and subchannel in frame as 0 to $S_C - 1$. In this work, if a vehicle has the position value as PI, then it selects the subchannel in the subframe using module operation, given as follows:

$$\mathrm{sf}(\mathrm{PI}) = \mathrm{PI} \bmod S_F. \tag{3}$$

The vehicle with position index PI chooses the subchannel in subframe $sf(\mathrm{PI})$ which is expressed as $sc(\mathrm{PI})$ with

$$\mathrm{sf}(\mathrm{PI}) = 2.R(\mathrm{PI}).\,N_p.\mathrm{mod}S_c + \left\lfloor \frac{2.R(\mathrm{PI}).N_p}{S_c} \right\rfloor .N_p, \tag{4}$$

where N_p denotes the subchannels occupied by the vehicle and $R(\mathrm{PI}) = \lfloor \mathrm{PI}/S_F \rfloor .\mathrm{mod} \lfloor S_C/N_p \rfloor$

As discussed above, the proposed scheme mainly focuses on reducing collisions in data packets by placing the vehicle position virtually in such a way that vehicles that use the same subchannel should be far from each other. To achieve this, we develop a randomization scheme. At this stage, each vehicle is asked to transmit one packet in subchannels. This packet contains position information. We consider the vehicle to have total packets. According to 3GPP standards to allow communication in C-V2X mode 4, the parameters are randomly selected in a range as given in Table 1.

Here, we assume that the C-V2X scheme allows one to use the same subchannel between 0.5 s, i.e., $w_{\min}/\lambda$ and 1.5 s, i.e., $w_{\max}/\lambda$. With the help of this, we compute the probability that the vehicle transmits the data using the randomly selected subchannel as follows:

$$\mathbb{P}_{\text{random}} = \left(\frac{w_{\min} + w_{\max}}{2} \right)^{-1}. \tag{5}$$

Randomly selected subchannels exclude those corresponding to the position index based on the virtual queue. This exclusion ensures that the selected subchannel maximizes the distance between collision vehicles, creating what is known as the random transmission window. To maximize the distance, the vehicle selects the transmission window corresponding to the position index. The center of the transmission window can be computed as follows:

$$C_{\mathrm{tw}} = f(x) = \begin{cases} \mathrm{PI} + \left\lceil \dfrac{N}{2} \right\rceil - \dfrac{S_F}{2}, & \text{if } S_C \bmod 2 = 0, \\[2ex] \mathrm{PI} + \left\lceil \dfrac{N}{2} \right\rceil, & \text{if } S_C \bmod 2 = 1. \end{cases} \tag{6}$$

On the basis of this equation, the vehicle randomly selects the subchannel according to its position index, and the packet collision can be minimized.

4. Results and Discussion

This segment describes the experimental analysis of the proposed method and measures the performance by varying several parameters. The performance obtained is compared to existing schemes in terms of packet delivery rate. This approach is simulated using the NS2 simulation tool. Table 2 shows the complete simulation parameters used in this work.

In this experiment, we have considered a varied vehicle density, and the average number of vehicles varies from 2000 to 6000 in each simulation scenario. Simulation scenarios consider a 5-km highway with four lanes. The maximum speed of the vehicle is set at 70 km/h. During communication, the channel bandwidth is fixed at 10 MHz where data packets of size 190 bytes are transmitted over 2 and 4 subchannels. This data transmission scheme uses the quadrature phase shift keying (QPSK) modulation scheme.

Table 1: Selected parameters for 3GPP communications.

Parameters	Values considered
w_{min}	5, 10, 25
w_{max}	15, 30, 75
λ	10, 20, 50

Table 2: Simulation parameters.

Parameter	Considered value
Traffic density	0.1, 0.2, 0.3 veh/m
Average vehicle count	2000, 4000, 6000
Maximum speed of vehicles	70 km/h
Length of highway	5 km
Lanes	4
Channel bandwidth	10 MHz
Packet size	190 byte
Subchannel per subframe	2, 4
Modulation and coding scheme	QPSK
Number of simulation rounds	500

The performance obtained is compared with existing protocols which are as follows:

(i) IEEE 802.11p multihop [40, 41]: this scheme uses the IEEE 802.11p standard, where a probabilistic multihop protocol is used to transmit traffic messages

(ii) C-V2X MTS [34, 40]: this technique uses the MTS algorithm in C-V2X communication to transmit the safety message

(iii) Fog-assisted cooperative crotocol (FACP) [40]: this technique is based on cooperative data transmission assisted by fog in VANET

The performance obtained is compared in terms of the packet reception ratio, which is a measure to identify the successful packet delivery, and the end-to-end delay is the measurement to deliver the packet to the next vehicle.

4.1. Packet Delivery Ratio. First, we measured the performance in terms of packet delivery ratio for various vehicular densities and compared it with the existing FACP scheme [40]. Figure 5 shows that the proposed approach achieves better performance and illustrates the comparative analysis of these techniques.

In this experiment, as the number of vehicles increases or the density of vehicles increases, the packet delivery rate decreases due to packet collision, whereas the proposed approach solves this problem with the help of a virtual queuing model. This experiment shows that the average performance is obtained as 0.8483, 0.8917, 0.9133, and 0.9383 using FACP without cooperation, FACP with random relay nodes, fog-assisted FACP, and the proposed approach, respectively. This study shows that the result of the proposed model is improved by 10.60% compared to FACP without cooperation, improved by 5.22% compared to FACP with random relays, and improved by 2.73% compared to fog-assisted FACP.

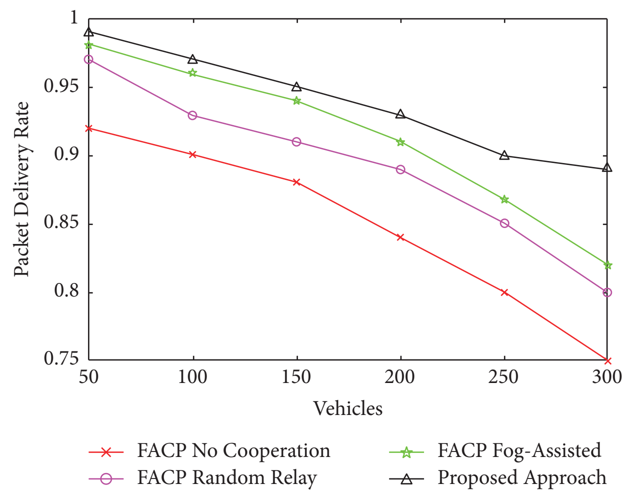

Figure 5: Packet delivery rate.

4.2. Packet Delivery Performance. Similarly, we compare the performance of the proposed approach with other data transmission protocols for variable vehicle density. Figure 6 shows the comparative performance with the IEEE 802.11p multihop and MTS C-V2X protocols.

In this experiment, we obtained an average performance of 0.8483, 0.8917, 0.9133, and 0.9383 using multihop IEEE, MTS C-V2X, FACP fog assisted, and the proposed approach, respectively. This scheme shows that as the number of vehicles increases, collisions occur, which degrades the performance of the packet delivery. However, the proposed approach is able to handle this issue and hence outperforms when compared with existing schemes. This scheme shows that the performance of the proposed approach is improved by 10.60%, 5.22%, and 2.73% compared with the IEEE multihop MT C-V2X and FACP fog-assisted approaches.

4.3. End-to-End Delay Performance. During this virtual queueing model process, data transmission delay is one of the tedious tasks. To overcome this issue, we present the subchannel selection scheme, which selects the channel near the transmission window. This helps to minimize transmission delay and prevents collisions. We present an end-to-end delay performance comparison, as depicted in Figure 7.

In this experiment, we measure the delay performance for a varied number of vehicles. The performance obtained is depicted in Figure 7. As the number of vehicles increases, congestion on the network also increases, leading to a longer delay in packet delivery. The average end-to-end delay is obtained as 0.18, 0.14, 0.12, and 0.09 s using multihop IEEE 802.11p, MTS C-V2X, FACP fog-assisted, and proposed approaches, respectively.

4.4. Packet Drop Rate. In addition, we measure the result in terms of the packet drop rate for varying vehicle densities.

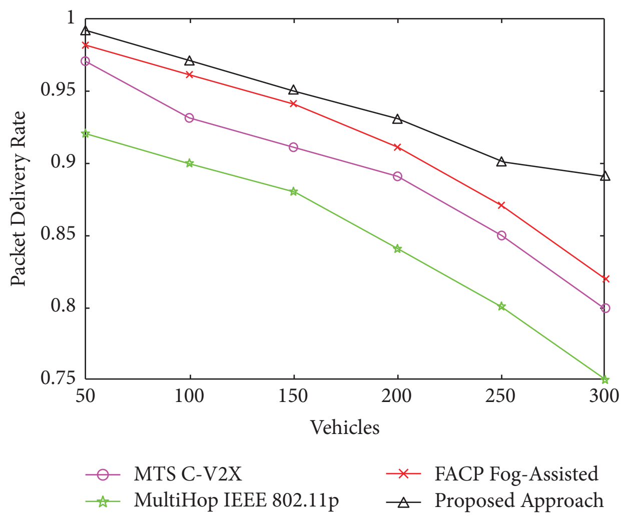

Figure 6: Packet delivery performance.

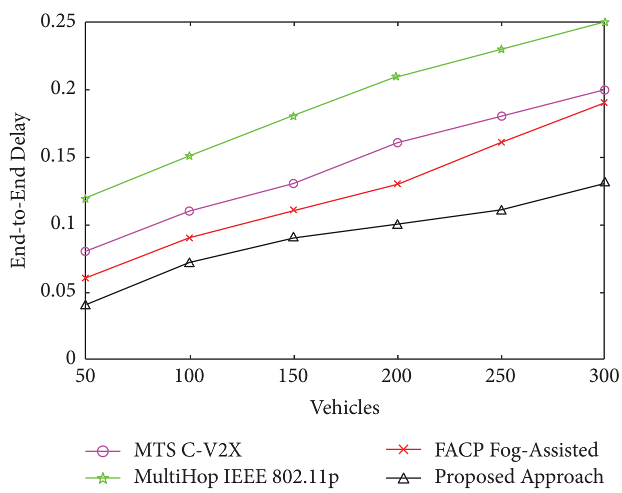

Figure 7: End-to-end delay performance.

Figure 8 illustrates the comparative analysis of the packet drop rate. The average packet drop rate is obtained as 0.1517, 0.1083, 0.0867, and 0.0617 using the IEEE 802.11p multihop approach, MTS C-V2X, FACP fog-assisted approach, and proposed approach, respectively. This study shows that as the number of vehicles increases, the vehicular nodes suffer congestion, which affects the probability of packet delivery.

4.5. Packet Delivery Performance for Varied Distances. Finally, we evaluated the performance of 300 vehicles and simulated the variation in distance between the transmitter and receiver nodes.

Figure 9 shows the comparative analysis for this scenario. This study reveals that the average packet density is obtained as 0.9855, 0.9758, 0.9711, 0.9612, and 0.9585 for 50, 100, 150, 200, and 250 m distance scenarios.

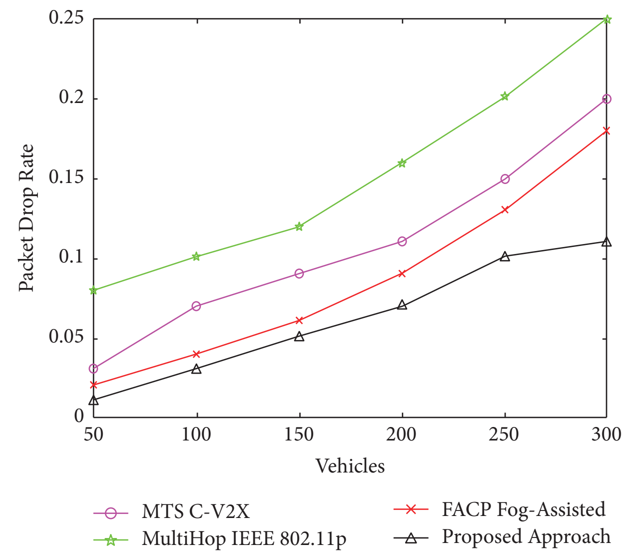

Figure 8: Packet drop rate performance.

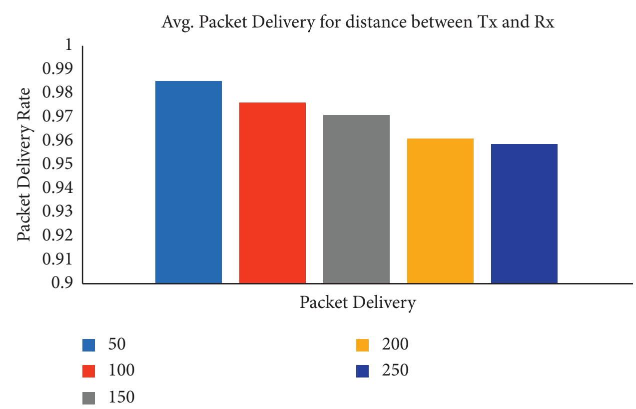

Figure 9: Packet delivery performance for varied distances (300 vehicles).

5. Conclusions and Future Works

Currently, vehicle-to-everything (V2X) has gained great popularity in the intelligent transport system to improve road safety by efficiently transmitting road traffic and related information. Currently, the 3GPP communication standard has introduced two new modes, mode 3 and mode 4 to allow communication between cellular vehicles with everything. Mode 3 uses cellular coverage to establish communication, while mode 4 can operate without cellular coverage. In this work, we presented a scheduling approach for C-V2X mode 4 communication. First, we identify the vehicle positions and select the subchannel. However, channel selection increases packet collision, and hence, the communication performance degrades. To overcome this issue, we present a virtual queue model and arrange the vehicle position virtually so that vehicles that use the same channel are placed far from each other in virtual mode. In addition, we present the efficient subchannel selection mechanism. Comparative performance reported a significant improvement in communication performance. In the future, the performance of these VANET models can be improved by incorporating deep reinforcement learning and security mechanisms to support the 5G communication system and the reliability of dense networks.

Data Availability

The data used to support the findings of this study are included within the article. If further data or information is required, we will provide it upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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