An optimal multi-channel coordination scheme for IEEE 802.11p based Vehicular Adhoc Networks (VANETs)

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***Abstract*—The Wireless Access in Vehicular Environment (WAVE) architecture enables V2X communication through an IEEE 802.11p and 1609.1-4 standards for improving safety and comfort of users. The 1609.4 standard supports multi-channel operations with a Control Channel (CCH) and six Service Channels (SCH). Transmission of critical safety messages and improving network throughput are challenging tasks with the fixed channel interval. Moreover, the highly dynamic wireless vehicular network and non-predictable traffic load demands the dynamic adjustments in the channel interval. To cope this, an optimal Dynamic Channel Interval MAC (DCI-MAC) protocol is proposed which regulates the duration of SCH interval and CCH interval based on number of vehicles, message priority, and packets in Access Category (AC) queues. DCI-MAC determines the optimal CCH interval which is proportional to the time needed to transmit the safety messages waiting in the AC queues. The remaining channel interval is utilized for the transmission of non-safety messages on SCH. To validate the proposed DCI-MAC protocol, the simulations are carried out in NS3 along with SUMO tool for real-time mobility in urban/highway scenarios. The simulated results reveal that the proposed DCI-MAC protocol outperforms the fixed and other variable channel interval schemes.**

I. Introduction

The Connected vehicular technology includes Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communication that supports various vehicular applications such as mobility-based, environmental-based and safety-based applications. These applications are broadly classified into two classes namely safety and non-safety applications. The safety applications are used to ensure the road safety whereas the non-safety applications are utilized to enhance the comfort of users. Most of the researches focused on road safety than improving comfort. In safety applications, each vehicle broadcasts Basic Safety Message (BSM) for every 100ms which contains information such as location, speed and direction [1]. Due to these repeated transmission, the probability of congestion and collision are very high which degrades the entire network performance. To address this problem, IEEE802.11p MAC protocol adopts Enhanced Distributed Channel Access (EDCA) method for channel access with four Access Categories (AC) varying contention parameters [2]. Wireless Access in Vehicular Environment (WAVE) framework defines overall vehicular communications which covers a set of standards for different layers including IEEE 802.11p and IEEE 1609 stack. The WAVE employs Dedicated Short Range Communication (DSRC) technique which reserves 75MHz licensed spectrum with 5.9GHz band for vehicular applications. The DSRC spectrum is divided into seven channels each with 10 MHz bandwidth as shown in Fig. 1. Among seven channels, the channel number 178 is used as Control Channel (CCH) for transmitting safety messages and remaining six channels are used as Service Channels (SCH) for transmitting non-safety messages [3] [4].

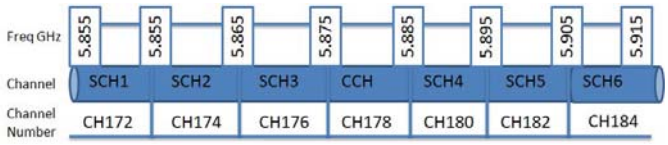

Fig. 1. DSRC spectrum allocation

IEEE 1609.4 standard is designed for multichannel operation that operates on the top of IEEE802.11p protocol. The GPS enabled vehicles are synchronized to periodically switch between CCH and SCH channels. This Synchronization Interval (SI) is set as 100ms to support the transmission of low latency safety messages by visiting CCH channel for every 100ms. The SI value is shared for CCH channel as CCH interval (CCHI) and SCH channel transmission as SCH interval (SCHI). The 1609.4 protocol uses default channel coordination scheme that assigns a fixed 50ms channel interval for each SCH and CCH channels [5]. As shown in Fig. 2, the vehicle utilizes the guard interval about 4ms to switch between channels. During CCHI, all the vehicles listen to CCH channel to send or receive safety messages and to receive WAVE Service Advertisement (WSA) frame. Irrespective of traffic load and number of vehicles, the fixed channel interval during the communication may degrade the network performance. So there is a high demand to enrich the dynamic channel interval adjustment scheme in VANET that is discussed in the following subsection.

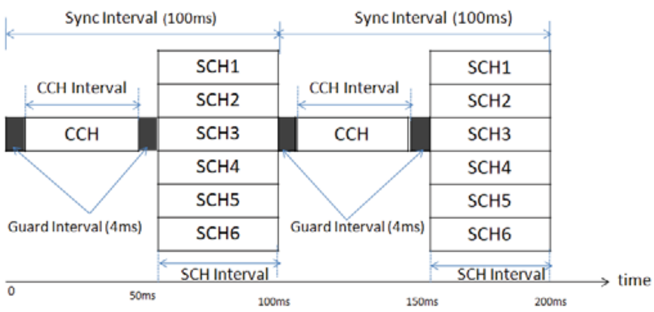

Fig. 2. IEEE 1609.4 multichannel operation

A. Motivation

When the number of vehicle increases in the network, the generation of periodic safety messages increases that demand more CCH interval for successful transmission. As a consequence, it also decreases the chances of transmitting non-safety applications. Moreover, in case of low traffic in CCH, bandwidth of this channel is unnecessarily wasted due to fixed access duration. This may be given to SCH for transmitting non-safety messages. In short, if CCH interval is increased, the reliable transmission of safety messages is also increased but throughput of SCH non-safety application is decreased which degrades the entire network performance. So keeping fixed channel interval is not recommended for dynamic vehicular network which motivates us to focus on measuring an optimal channel interval. To achieve this, Dynamic Channel Interval MAC (DCI-MAC) protocol is proposed which measures channel interval of both CCH and SCH independently based on the various dynamic factors such as the number of vehicles, message priority and the messages in the respective Access Categories (AC). The advantage of measuring CCH and SCH intervals is that both intervals cooperatively share the remaining intervals without compromising the reliable transmission of safety messages. The rest of the paper organizes as follows: section II discusses the related work on the variable channel interval. The proposed DCI-MAC protocol with measuring optimal channel intervals is described in section III. The section IV portraits the simulated results and followed by the discussions. Section V concludes the paper.

II. Related Work

The 1609.4 standard supports alternating channel switching method in which vehicles are switched between CCH and SCH channels alternatively for every 100ms. The main objective of adjusting the length of the channel intervals is to ensure that all the safety messages are transmitted successfully and also to efficiently utilize the SCH bandwidth for non-safety applications. Some of the existing research works that focused on variable channel interval are discussed in the following section.

Jiang et. al [6] proposed the concept of immediate switching to SCH if there are no safety packets from neighbours while listening to the CCH. This scheme suffers with s communication overheads to intimate the vehicles to switch between CCH and SCH channels and also safety packets may lost with the frequent switching. Qing Wang et. al [7] proposed a variable CCH interval mechanism to adjust the channel interval dynamically. In this, the CCH interval is divided into WSA interval and safety interval. The length of safety interval is computed by considering the broadcasted Basic Safety Messages (BSM) which is almost fixed because the number of BSM is proportional to the number of vehicles in the network. However, the VCI-MAC protocol works with the help of Road Side Unit (RSU) for optimal computation and the event-driven safety messages are not considered while computing safety interval.

Yuan Yao et. al [8] proposed Flexible multi-channel coordination MAC protocol where the safety messages are broadcasted in SCH and non-safety messages are transmitted in CCH channel with the fixed channel interval. In a heavy vehicle density, the safety messages are allowed to transmit in both CCH and SCH channels in a flexible way. The advantage of this protocol does not need extra time for synchronization. However, SCH channels are underutilized with the short safety messages. RendyMunadi [9] presented an adaptive control channel interval mechanism with the fixed topology and the CCH interval is computed based on the number of connected vehicles. The CCH length is proportional to the number of connections with the adjacent vehicles. It is difficult to compute CCH interval with high mobility vehicular network where the communication links are disconnected within a short time.

Shin-Kyung Lee et. al [10] measured CCH interval based on message load which is computed by various factor including lanes, number of vehicles, message size and message repeat rate. From the experiment, the CCI interval is limited between 30ms and 70ms to gain better throughput. The Optimal Channel Access (OCA) [11] algorithm is proposed for increasing the probability of successful transmission within the allotted CCH interval. It is based on the assumption that all vehicles known their neighbors within its communication range. Each vehicle chooses its time slot randomly from 0 to CCHI for sending its safety messages. If more than one vehicle selects the same interval may lead to message collisions which degrades the throughput of the network.

S.Babu et.al [12] proposed a Context Aware Variable Interval (CVAC) MAC protocol which updates CCH interval based on the context of the network and vehicles density within a single-hop. The CCH context is defined as the steady state which considers only periodic safety messages and the non-steady state is defined with event driven messages. The CCH interval is measured for both cases but separately evaluated. The CVAC is protocol not focused on non-safety messages to realize the utilization of SCH channels.

It is infer from the related works that most of the proposed works have encouraged the dynamic adjustment of

CCH interval with the help of RSU or distributed manner. However, the focus was only on computation of CCH interval and then the remaining interval is simply assigned to SCH channels thereby leading to under-utilization of SCH channel bandwidth.To overcome these problems, an adaptive Dynamic Channel interval MAC (DCI-MAC) is proposed that computes channel interval of both CCH and SCH separately based on run time parameters. This cooperative dynamic adjustment of channel intervals further increases the overall network throughput.

III. Proposed DCI-MAC Protocol

The length of CCH interval and SCH interval are critical because the allotted interval decides the number of successful message transmission from safety and non-safety applications. The basic model with fixed channel interval cannot accommodate the dynamic vehicular environment in terms of vehicle density, high mobility, priority messages etc. The proposed DCI-MAC protocol utilizes the features of IEEE 1609.4 standard multichannel operation and enhances the channel coordination scheme by dynamic adjustment of channel intervals based on number of vehicles, message size, and message in the AC queues. The schematic representation of the proposed MAC protocol is shown in Fig. 3. The generated messages by vehicles are queued to respective Access Categories (AC) queues based on its priority. The Access Categories named AC0, AC1, AC2 and AC3 are configured with the different contention parameters as specified by IEEE 802.11p standard [2]. The event-driven safety messages are given highest priority than the basic safety messages followed by the IP-based packets for non-safety application. Therefore the event-driven messages are mapped with AC3 queue, periodic safety messages are mapped with AC2 and rest of the queues mapped to the non-safety messages. These mapping of messages to different queue lead to an internal contention.

The next important phase is to compute an optimal CCH interval and SCH interval independently based on various factor and then the algorithm finalizes channel intervals without compromising the transmission of safety messages. The computation of optimal CCH interval and SCH interval in the proposed DCI-MAC protocol is formulated in the following subsection. After setting the new CCHI and SCHI, the channel scheduler assigns the SCH channel in the round robin method to utilize all six channels reserved for the communication.

The channel coordinator decides the channel switching mechanism from the channel access assignment schemes such as continuous access, alternating access, immediate access and extended access. In the proposed DCI-MAC protocol, immediate alternating channel access method is used as a switching mechanism where the vehicles are listening to CCH during CCH interval and then switching to any one of the SCH channel negotiated by channel scheduler. The vehicle needs to send the non-safety applications in the next SCHI broadcasts through the WSA frame. The channel scheduler selects any SCH channels and inserts the channel number in the WSA frame. Finally, the vehicle contends for the channel using Carrier Sense Multiple Access and Collision Avoidance (CSMA/CA) mechanism.

A. *Computation of an optimal channel intervals*

The following notations are used in analyzing the optimal channel intervals. Let SI, CCH_I, SCH_I, SA_I and WSA_I are the synchronization interval, CCH interval, SCH interval, Safety interval and WSA interval respectively. The guard interval is included within the CCHI and SCHI and hence it is not mentioned explicitly.

The SI is divided into CCH and SCH intervals. Further CCHI is divided into safety interval and WSA intervals are expressed as follows:

$$SI = CCH_I + SCH_I, CCH_I = SA_I + WSA_I, SI = SA_I + WSA_I + SCH_I \quad (1)$$

Each vehicle broadcasts the Basic Safety Messages (BSM) at the starting of CCH interval that means the total number of BSM to be transmitted equals to the number of vehicles in the network. So the Safety interval [7] is expressed as in equation (2).

$$SA_I = \left(\frac{\alpha \times N \times M_S}{R} \right) \times 10^3 \quad (2)$$

where α be the predefined constant used as scale up factor which is approximately equal to 1.62 [12], N is the number of vehicle, M_S is the message size and R is the data rate.

Event-driven messages also need to be transmitted in the CCH interval and is not broadcasted periodically. Since the event-driven messages assigned with highest priority, it will be queued to access category AC3. This is also incorporated into the proposed DCI algorithm; accordingly equation (3) is rewritten as follows,

$$SA_I = \left(\frac{\alpha \times N \times M_S}{R} + \frac{Q_{AC3} \times M_S}{R} \right) \times 10^3 \quad (3)$$

$$WSA_I = \frac{N_{wsa} \times M_S \times 1000}{R} \quad (4)$$

where $Q_{AC3}$is the number of frames in the AC3 queue, $N_{wsa}$is the number of WSA frames. From the equations (3) and (4), the CCH interval is recomputed as follows:

$$CCH_I = SA_I + WSA_I \quad (5)$$

In most of the existing algorithms [7] [10] [11], the remaining duration is assigned with SCH interval that is $SCH_I = SI - CCH_I$.However the proposed DCI-MAC protocol calculates the SCH interval based on the non-safety messages inside the AC queues as in equation (6). The advantage of computing SCH interval is that if the required SCH interval is much lesser then the remaining intervals can be used by the CCH channel.

$$SCH_I = \frac{N_{AC} \times M_S \times 1000}{R} \quad (6)$$

where N_{AC} is the number of non-safety messages in the AC queues.

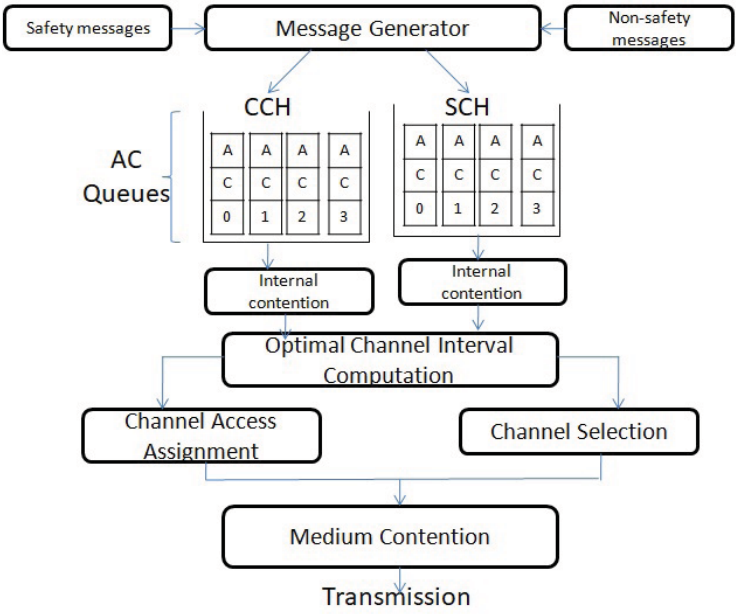

Fig. 3. Schematic of proposed model

With these computed channel intervals, the procedure of the proposed algorithm is depicted in Algorithm 1.

Algorithm 1: **Proposed DCI-MAC Protocol**

procedure
 CCH_{old} : Previous Sync. Cycle CCH Interval
 CCH_{new} : Next Sync. Cycle CCH Interval
 SCH_{old} : Previous Sync. Cycle SCH Interval
 SCH_{new} : Next Sync. Cycle SCH Interval
 SI : Sync. Interval
 // Set default intervals
 CCH_{old}= SCH_{old}=50ms
 for each $Sync\ Interval$ **do**
  $ChannelCoordinator()$
 end for
 // update the new CCH and SCH interval
 $T1 = ComputeCCHI()$ as per the equation (5)
 $T2 = ComputeSCHI()$ as per equation (6)
 $CCH_{new} = SetCchinterval(T1)$
 $SCH_{new} = SetSchInterval(T2)$
 if $(CCH_{new} + SCH_{new}) > SI$ **then**
  CCH_{new}= CCH_{old}
  SCH_{new}= SCH_{old}
 else if $SCH_{new} < CCH_{new}$ **then**
  CCH_{new}= SI - SCH_{new}
 else
  SCH_{new}= SI - CCH_{new}
 end if
 CCH_{old}= $SetCchInterval$(CCH_{new})
 SCH_{old}= $SetSchInterval$(SCH_{new})
end procedure
end

The channel coordinator is initially set the default CCH interval and SCH interval as 50ms as per the IEEE1609.4 standard. Then the proposed algorithm computes new CCH interval and SCH interval based on the equations (5) and (6). However, when the required SCH interval is much lesser than the remaining Sync interval, the CCH interval is utilized for the remaining interval to increase the transmission of safety messages. Similarly, if obtained CCH interval is lesser the default channel interval, the remaining interval duration can be used by SCH interval and vice versa. Thus the entire sync interval can be completely utilized to improve the throughput of the network. This proposed DCI-MAC protocol is tested in NS3 with SUMO tool and the obtained simulation results are discussed in the next section.

IV. Simulation Results and Analysis

In this section, the proposed Dynamic Channel Interval MAC (DCI-MAC) protocol is evaluated against the default 1609.4 MAC standard and Variable Channel Interval MAC (VCI-MAC) [7] for different urban and highway traffic scenarios. The following section discusses simulation environment followed by the simulation results and their analysis.

A. Simulation setup

To verify the effectiveness of the proposed DCI-MAC protocol, the simulations are carried out in NS3.26 discrete event network simulator that supports IEEE 1609.4 multi-channel operation in WAVE module [13] [14]. Each IEEE802.11p-based vehicle can communicate with a 10MHz CCH and six SCH channels. Safety messages are broadcasted during CCH interval and non-safety messages are transmitted during SCH intervals. The immediate alternating channel switching method is adopted to switch between CCH and SCH channels.

TABLE I
SIMULATION PARAMETERS AND ITS VALUES

Parameter	Value
Data Rate	6 Mbps
Propagation Model	Nakagami
Guard Interval	4 ms
Frequency of BSM	100 ms
Size of BSM	100 bytes
Service Packet Length	1024 bytes
Mobility Generator	SUMO
Transmission Range	300 m
Simulation Time	100 s

Simulation of Urban Mobility (SUMO) sumo0.32.0 is used for the real time mobility generation with varying number of vehicles from 10 to 100. For highway traffic, four lane highway roads are captured using Openstreet map. Among the vehicles, half of the vehicles are service providers and remaining vehicle are users. For every 100ms, the BSM message will be generated and the event-driven messages are randomly transmitted by the vehicles. It is assumed that all the nodes are within the communication range with ideal channel condition. The basic simulation parameters are shown in Table I.

B. Simulation Results and Analysis

In this subsection, the performance of DCI-MAC is evaluated with respect to Packet Delivery Ratio (PDR) of safety messages, throughput on SCH channels of non-safety messages.

1) Packet Delivery Ratio (PDR): PDR is defined as the ratio between the number of packets sent and the number of packets received which is formulated in equation (7).

$$PDR = \frac{Number\ of\ received\ safety\ messages}{Number\ of\ transmitted\ safety\ messages} \quad (7)$$

The packet delivery ratio is measured for different cases like PDR for only Basic Service Messages shown in Fig.4, PDR of both BSM and event-driven safety messages depicted in Fig.5. For every synchronization interval, the variable CCH interval is computed by the proposed DCI-MAC and VCI-MAC [7]. In addition to this, the proposed protocol computes SCH interval with respect to dynamic vehicular environment. In case of IEEE 1609.4 MAC protocol utilizes static channel interval as 50ms for each CCH and SCH. When the vehicle density is lower, all the protocols achieved almost the same PDR values because BSM are periodically broadcasted in every fixed interval. However, in case of heavy vehicle density the PDR values vary as shown in Fig. 4 because the fixed interval is not enough to transmit all the messages. It is inferred from Fig.4 that the dynamic access interval schemes DCI-MAC and VCI-MAC outperforms the IEEE 1609.4 standard. As expected, static channel interval in the standard does not reflect the dynamic VANET environment leading to lesser PDR. Between the proposed DCI-MAC and VCI-MAC, the proposed algorithm performs better than VCI-MAC. This is mainly due to the dynamic independent estimation of both CCH and SCH intervals with respect to various parameters such as number of vehicles, message priority and messages in the AC queues.

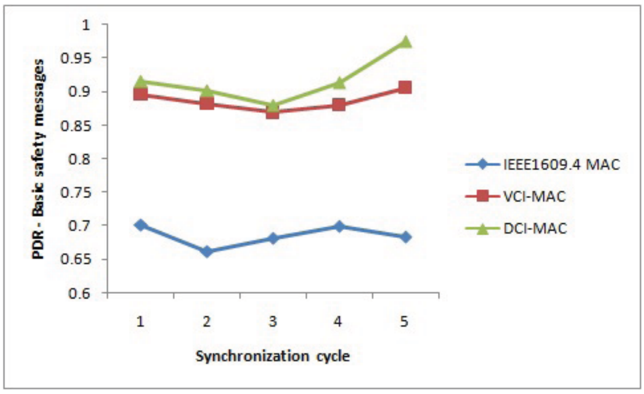

Fig. 4. Packet Delivery Ratio of BSM

The Fig.5 shows the average PDR values obtained by varying the number of vehicles for the highway scenario. If the number of vehicles is less than 20, then the generated traffic is also lesser. Consequently the achieved PDR is high, more specifically above 96%. If the number of vehicles are increased, the generated safety messages are also increased which are required to be transmitted within the CCH interval. In addition, the randomly chosen source nodes trigger the transmission of event driven messages. Due to the randomness in the selection of source nodes and the amount of messages, the lines depicting PDR in Fig.5 fluctuates for varying number of vehicles. However, it is observed from the Fig.5 that the proposed DCI-MAC algorithm outperforms other two methods when the number of vehicles increases because the DCI-MAC considers transmission of event-driven safety messages in the optimal CCH safety interval as in equation (3).

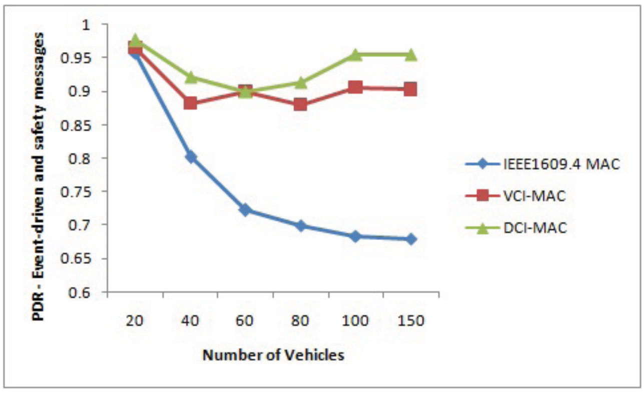

Fig. 5. PDR of both BSM and Event-driven safety messages

2) Throughput: The throughput on SCH is important to measure the entire network performance. Because most of the algorithms [7] [10] [11] focused on CCH interval computation and SCH channels utilizes the remaining interval in the synchronization cycle. The 1609.4 standard allows six SCH channels to transmit non-safety messages for increasing the comfort of the user. Throughput on SCH channels is measured by varying the number of vehicles and the results are depicted in Fig. 6. The main drawback of default IEEE1609.4 MAC protocol is that it does not utilize the SCH channels because the vehicles are not allowed to transmit in the fixed interval. Even though the traffic load on SCH is high, it is not allowed to be transmitted in the unused CCH. But the proposed algorithm computes SCH interval based on the messages in the AC queues and also it uses all the SCH channels are used in a round robin fashion.

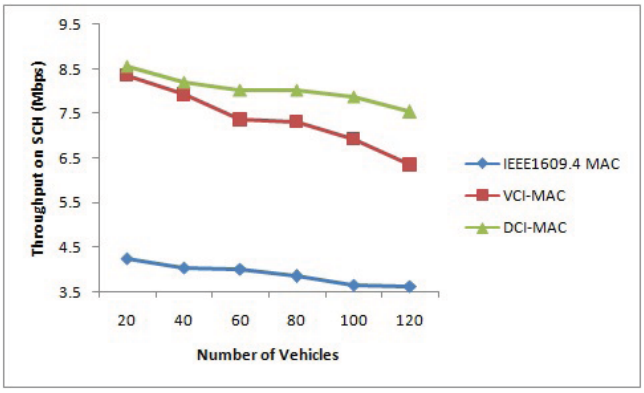

Fig. 6. Throughput

It is concluded from the Fig.6 the proposed DCI MAC protocol obtains the better throughput by constantly utilizing the SCH channels.

V. Conclusion

IEEE 802.11p/1609.4 standards are designed with the intention of enhancing the performance of vehicular communication by adopting multi-channel operations with CCH and SCH channel. The communication among vehicles is established through safety and non-safety messages for improving users safety and comfort. The access duration to these channels are decided by the CCH interval and SCH interval and the default value is 50ms. The dynamic vehicular communication cannot ensure the reliable safety message transmission using the fixed channel intervals. To mitigate this, the Dynamic Channel Interval MAC (DCI-MAC) protocol is proposed for adjusting the CCH channel interval and SCH channel interval dynamically based on the vehicle density, message priority and messages in the AC queues. These runtime dynamic parameters help to determine the proper adequate access duration to improve the network throughput. The simulation results are shown that the DCI-MAC performs better than the default 1609.4 and VCI-MAC protocols in terms of PDR of safety messages and SCH throughput.

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