Adaptive Sliding Contention Window Design to Minimize Safe Message Collision Rates with Different Priority Levels in VANET

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***Abstract*—In Vehicular Ad Hoc Networks (VANETs), the broadcast is an important form of communication and occupies the main traffic in the network. However, since there is no recovery for broadcast frames in the VANET network, the collision rate between safe message traffic can become very high, especially in vehicle-dense network conditions. This paper proposes a new coordination mechanism that adaptively controls the *Contention Window (CW)* size for broadcast to reduce the safe message collision rate with different priority levels. In our mechanism, each vehicle in the VANET can automatically adjust the *CW* based on the perception of the current network condition by analyzing the percentage of successfully received frames. The algorithm controls the *CW* size by sliding the window with a dynamic persistence factor according to each type of safe message traffic. Each data traffic chooses a backoff timer dynamically varying in the range [*0, CW[AC[i]]*], which can overlap the *CW* range with other data traffic to improve efficient bandwidth depending on the network conditions. Simulation results prove that the proposed mechanism significantly reduces the collision rate for both safe message traffic in high-priority and low-priority in vehicle-dense network conditions.**

***Keywords*—VANET, dedicated short range communication (dsrc), enhanced distributed channel access (EDCA), medium Access control (MAC), adaptive sliding contention window (ASCW)**

I. Introduction

Vehicular Ad Hoc Network (VANET) is a subclass of Mobile Ad Hoc Networks (MANETs). It is designed for using in Intelligent Transportation Systems to connect wireless between vehicles. In addition to the outstanding characteristics in communication inherited from MANET, such as flexible infrastructure, mobility, better connectivity, secure transfer between different networks, etc [1]. VANET has some unique characteristics, including high mobility of vehicles, rapidly changing network topology, high density of the network, predictable roads pattern, unlimited energy, no restriction on network size, etc. used to control wireless communication in vehicular environments [2].

In VANET, the PHY layer and MAC layer are two important components in IEEE 802.11p standard that have a great influence on channel usage [3]. In the PHY layer, Dedicated Short Range Communication (DSRC) [4] regulates the channel access time divided into synchronous intervals of a fixed length of 100 ms. Where the duration of the Control Channel (CCH) and the Service Channel (SCH) divided respectively is 50ms (of which 4ms are reserved for guard time) [5, 6]. In the MAC subclass, the Enhanced Distributed Channel Access (EDCA) mechanism [7] only supports four distinct Access Categories (AC) types instead of eight AC types in IEEE 802.11e to support high mobility [8].

Broadcast is the main method of exchanging information between vehicles in the network. Its purpose is to send emergency warning messages and periodically broadcast vehicle status (e.g. vehicle speed, acceleration, position, and direction). However, broadcast transmission suffers from several technical problems that affect the performance of the VANET network. Then it leads to a severe issue ensuring effective maintenance of priority differentiation and reducing collision between safe message traffic types.

In the IEEE 802.11p EDCA mechanism, emergency messages have higher access priority than other messages. However, the EDCA mechanism cannot adapt to changing network conditions [9]. The value of *CW* and Arbitration Inter-Frame Space (AIFS) can affect the collision rate of safe message traffic. The EDCA mechanism still leads to conflict among concurrent threads of equal priority. Especially in high-traffic areas, the number of vehicles competing to access the wireless environment can become very large. The high-priority safe message traffic can be degraded in bandwidth because the low-priority safe message traffic often occupies the channel. Moreover, there is additional latency due to backoff counter freezing for high-priority safe message traffic in a delayed state. The reason is that the backoff mechanism selects backoff

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values in the range [*0, CW[AC[i]]*] for all safe message traffic [10].

The *CW* mechanism implemented based on [11] shows that it improved the limitations of the EDCA mechanism. It prioritizes according to the urgency levels of the data then increases the safe message received rate. However, this mechanism does not ensure providing a strict distinction between the *CW* ranges of each data traffic type in the case of high vehicle density.

Our paper aims to solve the problem of effectively differentiating by priority and reducing the safe message collision rate. The method to recognize the current local condition of the network is based on [11] analyzing the percentage of successfully received frames. Our mechanism slides the *CW* size adaptively and prioritizes safe message traffic.

The rest of the paper is structured as follows. Section II presents the related work of broadcasting in VANET. Section III presents the adaptive sliding contention window design. Section IV presents simulations and results. Conclusions and future work are presented in Section V.

II. Related Works

The issue of broadcast transmission in VANET has been attracting much research in terms of: reducing collisions, contention, redundancies, and hidden node problems. Torrent-Moreno *et al.* [9] showed that under saturation conditions the probability of receiving broadcast messages can be reduced by 20%–30%. The paper claims that the main reason for the adoption rate is the hidden node problem. The authors implement a preemptive access method based on channel access time scheduling to improve the reception rate of broadcast messages.

Chien and Giang [11] proposed an Adaptive Contention Window Control (ACWC) algorithm to improve the safe messages received rate. The *CW* size control algorithm is based on sequence number analysis of recently successfully received frames. The EDCA mechanism is used in combination to set priority for different safe messages according to the urgency of the data traffic. The proposed mechanism has been shown to be effective in improving the safe message received rate. However, when a vehicle-dense network, there is a possibility of collisions due to simultaneous channel contention between data traffic types of equal priority. It may load the mechanism not effective in maintaining priority separation between different data traffic.

Korkmaz and Ekici *et al.* [12] proposed a new Urban MultiHop Broadcast (UMB) protocol to solve broadcast storms, hidden nodes, and reliability problems without sharing information between vehicles in urban areas. Directional broadcast and intersection broadcast are the two main scenarios of UMB. In their method, the forwarding task is assigned only to the vehicle furthest within the transmission range without using information about the network topology. The ACK packet is sent by the vehicle chosen to forward the packet. Intersection broadcasting performs message dissemination in all directions using repeaters that are installed at road segments to forward messages to destinations. However, the proposed protocol does not take into account the V2V communications model.

Alasmary and Zhuang [13] introduced a clustering approach to periodically advertise vehicle information such as average speed and the number of neighboring vehicles in one hop. Each cluster is maintained by a cluster head node that broadcasts the message to the vehicles in its cluster. Due to the high mobility, the cluster head node needs to be constantly changed, resulting in reduced network performance.

Balador and Calafate *et al.* [14] proposed DBM-ACW (Density-Based Method for Adjusting the *CW* size). The mechanism calculated the network traffic density by estimating the channel conditions using the packet transmission state then the results are stored in a channel state vector. An essential part of the protocol is maintaining a channel state for vectors achieving bandwidth efficiency to update the *CW*.

Reinders and Eenennaam *et al.* [15] analyzed the network performance by the exchange state messages called beacon. Vehicles use these beacons to establish communication. Their method aims to control the vehicle in real-time by improving the broadcast efficiency in IEEE 802.11p. The *CW* size will adapt based on vehicle density to improve latency performance received probability.

TABLE I. Comparison of Different Approaches for VANET

Approach	Protocol	MAC Type	Traffic Type	Types of messages	Adjustment of CW	Messages Received Rate Calculated	Access Delay Calculated
Torrent-Moreno *et al.* [9]	802.11a	EDCA	Broadcast	Periodic Messages	Based on the power control	Yes	Yes
Chien and Giang [11]	802.11p	EDCA	Broadcast	Both Periodic Messages and Event Driven Messages	It adjusts adaptive the CW size based on messages received rate of the nodes.	Yes	Yes
Korkmaz *et al.* [12]	802.11b	DCF	Broadcast	Periodic Messages	Based on multi-hop broadcast protocol in urban areas	Yes	Yes
Alasmary and Zhuang [13]	802.11p	EDCA	Broadcast	Periodic Messages	Adjust CW sizes according to the three fixed CW ranges based on their speed	Yes	No
Balador *et al.* [14]	802.11a	EDCA	CBR	Periodic Messages	Based on the network traffic density	Yes	Yes
Reinders *et al.* [15]	802.11p	EDCA	Broadcast	Periodic Messages	It adjusts the CW size based on traffic density	Yes	Yes
Suthaputchakun *et al.* [16]	802.11a	EDCA	Broadcast	Both Periodic Messages and Event Driven Messages	It defines min and max CW size	Yes	Yes

Authors of [14, 15] focus on improving network performance by adaptive *CW* size control based on vehicle density and reception probability. It leads to increases in the load on the network.

Suthaputchakun *et al.* [16] proposed to incorporate the 802.11e EDCA mechanism in VANET based on priority for V2V communication. Each Inter-Vehicle Communication (IVC) is assigned a priority level based on the urgency of the safety event, different QoS requirements in terms of communication reliability, and average latency. In order to increase communication reliability in broadcast-based IVC, the authors applied retransmission mechanisms that can provide a proportional difference in reliability for each prioritized message. However, the authors did not address the problem of tuning QoS parameters according to local network traffic conditions

Table I provides a comparison of the existing approaches in terms of protocol, MAC type, traffic type, types of messages, adjustment of *CW*, message received rate, and access delay.

The analysis of the above-related research results shows that the authors have tried to find solutions to improve broadcast performance in VANET. However, these methods do not provide a mechanism to ensure QoS, strict distinction between the *CW* ranges of each data traffic type, and bandwidth efficiency. Overcoming these problems, we propose a new mechanism that controls the *CW* size by using the sliding contention window size for each different data traffic. The proposed mechanism greatly improves bandwidth efficiency, separates priority among data traffic flows, and consumes fewer network resources.

III. Adaptive Sliding Contention Window Design

The goal of MAC layering in the 802.11 standards is to decentralize access to shared media and the wireless channel between safe message traffic. Therefore, each vehicle should be assigned suitable MAC-specific parameters to calculate the backoff timer for each AC[*i*]. Each AC[*i*] safe message traffic uses dedicated parameters such as AIFSN[AC[*i*]], $CW_{min}[AC[i]]$, and $CW_{max}[AC[i]]$. MAC Service Data Units (MSDUs) are delivered through multiple separate backoff timers instead of using a single instance.

This results in high-priority safe message traffic receiving more transmission time than low-priority traffic. However, using the same Arbitration Inter-Frame Space (AIFS) for each traffic type could lead to conflict between traffics in the same AC[*i*]. If the number of traffic contentions in the same AC[*i*] is significant, the collision rate increases. Moreover, in IEEE802.11p EDCA the MAC layer parameters do not adapt to changing network conditions.

In the case of high vehicle density, it should appropriately increase the initial *CW* size to reduce the probability of collision. The *CW* size will also increase the network traffic accordingly to adapt to the changing conditions of the network. Vehicles also operate in the opposite situation where the *CW* size is reduced due to low vehicle density. Therefore, our mechanism can reduce the congestion rate significantly.

A. Priority Access Control Mechanism

We propose a new *CW* size control mechanism by sliding the window with a dynamic persistence factor coefficient to set the channel access for the different data traffic types based on the information of network conditions [11]. On the CCH, we classify messages according to different priorities for each data traffic type to combine with the proposed mechanism, as listed in Table II.

TABLE II. Priority of Message Types in VANET

Priority	Message Types in VANET
Priority 1: (AC[3])	Accident messages, etc.
Priority 2: (AC[2])	Accident indication message
Priority 3: (AC[1])	Periodic broadcast message
Priority 4: (AC[0])	Service advertisement message

In the Adaptive Sliding Contention Window (ASCW) control mechanism, each AC[i] is provided with separate *CW* ranges. Therefore, each different data traffic type will select a dynamically variable backoff timer in the range [*0, CW[AC*[*i*]]] respectively. By strict distinction between the *CW* range of each data traffic type, ASCW solves the problem of bandwidth reduction of high-priority data traffic due to low-priority traffic frequently occupying the channel. Moreover, it can help high-priority safe messages access the channel faster and minimize the collision between safe messages. The bandwidth efficiency can be improved if the *CW* range overlap between different data traffics under different channel load conditions. In ASWC, the parameter $ASCW_{size}[AC[i]]$ is *CW* size for a data traffic type. It is calculated by Eq. (1) as follows:

$$ASCW_{size}[AC[i]] = 2 \times SF[AC[i]] \tag{1}$$

In Eq. (1), $SF[AC[i]]$ is the slip coefficient for each type of data traffic to appropriately determine the level of slip-up or slip-down of the *CW*. If AC[*i*] has high priority, the slip coefficient $SF[AC[i]]$ is small, and vice versa. $SF[AC[i]]$ is used instead of the *PF (Persistence Factor)* parameter in the IEEE 802.11p EDCA mechanism after each failed transmission. The *PF* parameter represents a fixed multiplier provided for each AC[*i*] to adjust for increasing the *CW* range. In addition, $ASCW_{size}[AC[i]]$ parameter specifies $CW_{LB}[AC[i]]$ as the lower bound and $CW_{UB}[AC[i]]$ as the upper bound of the *CW* at any given time. These limits are adjusted when the window slides but remain between $CW_{min}[AC[i]]$ and $CW_{max}[AC[i]]$. Initialization of parameters $CW_{LB}[AC[i]]$ and $CW_{UB}[AC[i]]$ is calculated by Eqs. (2, 3) as follows:

$$CW_{LB}[AC[i]] = CW_{min}[AC[i]] \tag{2}$$

$$CW_{UB}[AC[i]] = CW_{min}[AC[i]] + ASCW_{size}[AC[i]] \tag{3}$$

Fig. 1 illustrates the ASCW control mechanism for three data traffic types with different priorities, as shown in Table II. The parameters $CW_{LB}[AC[i]]$ and $CW_{UB}[AC[i]]$ specify the time interval from which the AC[*i*] randomly selects the backoff value. The $backoff_{new}$ parameter is a new backoff timer that a vehicle uses to adjust the *CW* size, and it is randomly selected in the range [$CW_{LB}[AC[i]]$, $CW_{UB}[AC[i]]$] calculated by the Eq. (4) as follows:

$$backoff_{new} = CW_{LB}[AC[i]] + random((CW_{UB}[AC[i]] - CW_{LB}[AC[i]] + 1)) \quad (4)$$

In Table III, we set the parameters for the proposed mechanism to prioritize by controlling the sliding contention window.

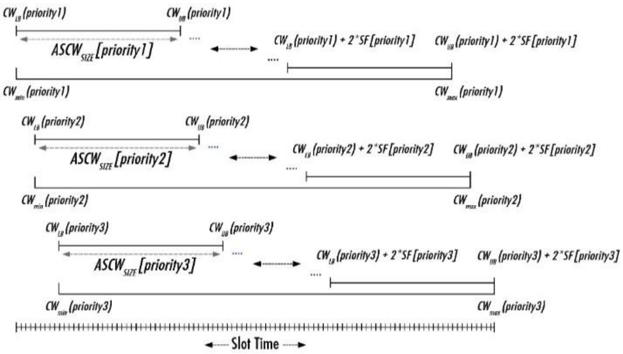

Figure 1. Adaptive sliding contention window control mechanism.

TABLE III. PRIORITY DATA FLOW PARAMETERS

Message Types	Priority	CW_{min}	CW_{max}	*SF[AC[i]]*	$ASCW_{size}[AC[i]]$	AIFSN
Accident messages	Priority 1	0	28	2	4	2
Accident indication message	Priority 2	8	56	4	8	3
Periodic broadcast message	Priority 3	16	256	16	32	6

B. Adaptive Sliding Contention Window Control Algorithm

The safe message collision rate is an important factor in the VANET network. For adaptive control of the *CW* size, the backoff timer needs to be tuned according to the states of the network, such as the safe message collision ratio and the local vehicle density. The proposed mechanism to adjust the contention window size has implemented the idea to adjust *CW* size based on [11] the analysis of the number of frame sequences received in the MAC layer. A node calculates the RR_{local} parameter to predict the network state, and this value is calculated only periodically. Therefore, when a node identifies RR_{local}, this value will be compared to the previously saved RR_{local} value to adjust the *CW* size. Each node maintains a fixed threshold value τ and uses the parameter *SF[AC[i]]* to adaptively control the $ASCW_{size}[AC[i]]$ size as shown in section III.A. The threshold value τ is determined by the change of the RR_{local} parameter between successive measurements and selected in the range [0, 1] to determine the low or high collision rate according to the network state. When the value of τ moves to zero, the algorithm will respond more quickly to conditions that change the network state and vice versa. However, when the channel load is high, if threshold τ is selected too small, it can affect the accurate prediction of network conditions. Thus, to ensure the performance of the network, the selection of threshold value τ in *CW* adjusting is important. The control algorithm of the adaptive sliding contention window is presented as follows:

Algorithm: Adaptive Sliding Contention Window Control

Input: Sliding *CW* values ∀ ACs in Section III.A and threshold value τ
$CW_{LB}[AC[i]]$ is the lower bound of sliding $CW_{min}[AC[i]]$;
$CW_{UB}[AC[i]]$ is the upper bound of sliding $CW_{min}[AC[i]] + ASCW_{size}[AC[i]]$;
Output: Adapted Sliding *CW* values ∀ ACs
When a packet is sent to the MAC layer
for each *Time* **do**
Estimate the RR_{local} based on the approach mentioned in [11];
if $RR_{local} > \tau$ **then**
for (i = 0; i < MAX_PRI; i++)
if ($CW_{LB}[AC[i]] - SF[AC[i]] >= CW_{min}[AC[i]]$)
set $CW_{LB}[AC[i]] \leftarrow CW_{LB}[AC[i]] - SF[AC[i]]$
set $CW_{UB}[AC[i]] \leftarrow CW_{UB}[AC[i]] - SF[AC[i]]$
else
set $CW_{LB}[AC[i]] \leftarrow CW_{min}[AC[i]]$
set $CW_{UB}[AC[i]] \leftarrow CW_{min}[AC[i]] + ASCW_{size}[AC[i]]$
end if
end for
else if $RR_{local} < \tau$ **then**
for (i = 0; i < MAX_PRI; i++)
if ($CW_{UB}[AC[i]] + SF[AC[i]] <= CW_{max}[AC[i]]$)
set $CW_{LB}[AC[i]] \leftarrow CW_{LB}[AC[i]] + SF[AC[i]]$
set $CW_{UB}[AC[i]] \leftarrow CW_{UB}[AC[i]] + SF[AC[i]]$
else
set $CW_{LB}[AC[i]] \leftarrow CW_{max}[AC[i]] - ASCW_{size}[AC[i]]$
set $CW_{UB}[AC[i]] \leftarrow CW_{max}[AC[i]]$
end if
end for
else
Maintain corresponding *CW;*
end if
end for

IV. EVALUATE THE RESULTS BY SIMULATION

In this part, we use a combination of network simulation tools Network Simulator (NS-2.35) [17], SUMO 0.12.3 [18], and MOVE [19] to build simulation scenarios in VANET.

A. Simulation Parameters

We evaluate the proposed mechanism by actual traffic network simulation conditions in two models. One is the urban highway model with an inner radius of 300 m to present the straight highway which includes 8 lanes of vehicles with 4 lanes in each direction and a distance between lanes is 5 m. The vehicles have a minimum speed of 16.7 m/s (60 km/h) and a maximum speed of 25 m/s (90 km/h). The distance between vehicles is 20 m.

The other is the rural freeway model with an inner radius of 400 m to present the straight freeway which includes 10 lanes of vehicles with 5 lanes in each direction and a distance between lanes is 6 m. The vehicles have a minimum speed of 25 m/s (90 km/h) and a maximum speed of 33.3 m/s (120 km/h). The distance between vehicles is 25 m.

In scenarios, the vehicles broadcast and update their status to their neighbors every 100 ms, where the packet rate is 10 packets/s.

The simulation scenario is close to the actual conditions; we use three traffic categories Priority 1, Priority 2, and Priority 3, as in Table III. Where Priority 1 is represented event-driven emergency messages (accident notifications or emergency vehicles), Priority 2 is represented event-driven emergency warning messages, and Priority 3 is represented periodic messages about the state of the vehicle (vehicle speed, acceleration, position, and direction). The packet size for Priority 1, and Priority 2 is 500 bytes, while Priority 3 is 300 bytes. In the simulations, Priority 1 and Priority 2 accounted for 5% respectively, and Priority 3 accounted for 90%. The channel is configured to use the parameters of the DSRC standard as in Table IV.

TABLE IV. NETWORK PARAMETERS

Parameters	Value
PHY	
Channel Type	Wireless Channel
Radio Propagation	Two-ray ground
Antenna type	Omni direction
Network Interface Type	WirelessPhy
MAC Type	802.11e
Interface queue	DTail/Pri
Link Layer Type	LL
Ifqlen	50
Simulation time	450 [s]
CSThresh	-96dBm
RXThresh	-90dBm
bandwidth	6Mbps
Freq	5.9GHz
Pt (200m)	375.4μW
MAC	
SlotTime	13 µs
SIFS	32 µs
PreambleLength	32 µs
PLCPDataRate	6Mbps
basicRate	6Mbps
dataRate	6Mbps
threshold τ	0.03
MAX_PRI	4

The vehicles were generated in nine scenarios for each model to evaluate the adaptive sliding contention window control algorithm in different vehicle densities. In each scenario, the number of vehicles increases continuously by 40 vehicles (5 vehicles/lane for urban highway or 4 vehicles/lane for rural freeway) to simulate the VANET network to present low, medium, high, and very high vehicle density special. The channel load is defined in Eq. (5):

$$\text{Channel Load} = [\text{Number of Vehicles}] \times [\text{Packet Size}] \times [\text{Packet Rate}] \quad (5)$$

By using Eq. (5), we can observe the effect of increased network traffic on the performance of network protocols.

As shown in Table V, the channel load is due to the vehicle density. In simulation scenarios, the channel load increases from low to high relative to represent network traffic that varies according to the different conditions of the network. We evaluate the proposed mechanism by comparing it with other mechanisms the original IEEE802.11p EDCA and ACWC. The simulation parameters for the proposed mechanism are shown in Table III.

TABLE V. CHANNEL LOAD FOR EACH SIMULATION SCENARIO

Scenario	Number of Vehicles	Channel Load (Mbps) Priority 1 (5%)	Priority 2 (5%)	Priority 3 (90%)	Total Channel Load (Mbps)
1	80	0.16	0.16	1.73	2.05
2	120	0.24	0.24	2.59	3.07
3	160	0.32	0.32	3.46	4.10
4	200	0.40	0.40	4.32	5.12
5	240	0.48	0.48	5.18	6.14
6	280	0.56	0.56	6.05	7.17
7	320	0.64	0.64	6.91	8.19
8	360	0.72	0.72	7.78	9.22
9	400	0.80	0.80	8.64	10.24

B. Simulation Results

1) Urban Highway Model

In the urban highway model, we simulate nine scenarios with vehicle densities that vary according to different network conditions to evaluate the effectiveness of the proposed mechanism compared to others in terms of collision rate and access delay.

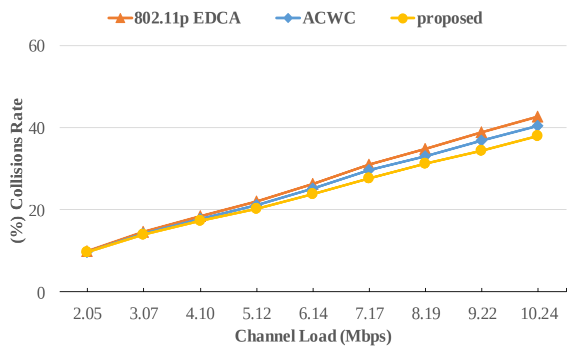

Figure 2. Collision rate of all traffic in urban highway model.

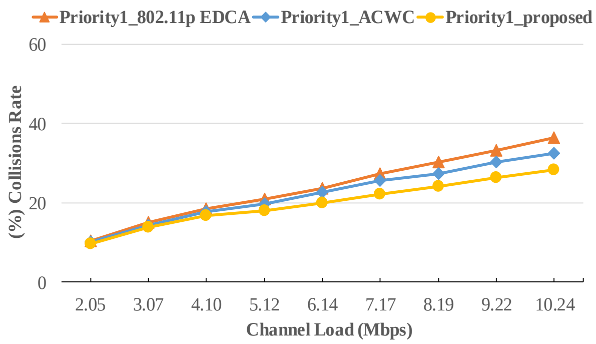

Figure 3. Priority 1 traffic collision rate in urban highway model.

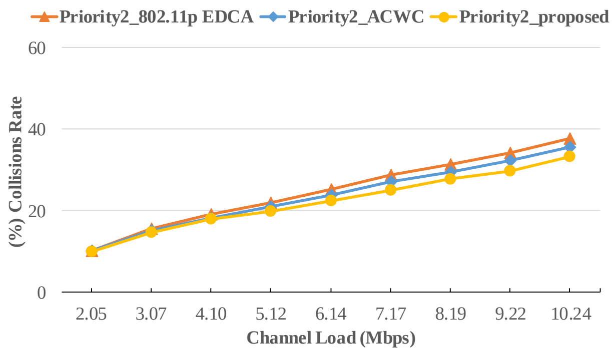

Figure 4. Priority 2 traffic collision rate in urban highway model.

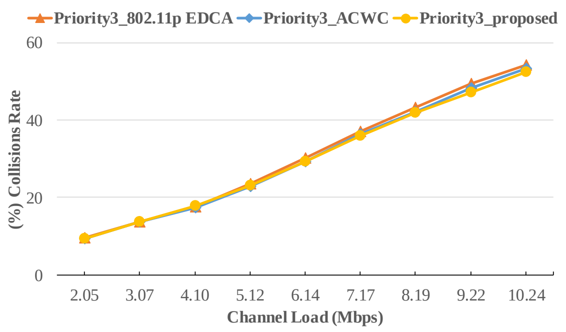

Figure 5. Priority 3 traffic collision rate in urban highway model.

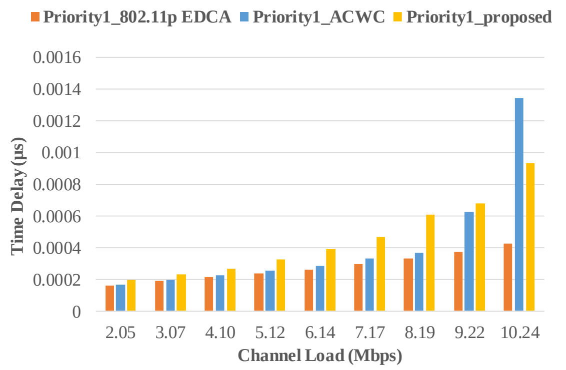

Figure 6. Priority 1 traffic access delay in urban highway model.

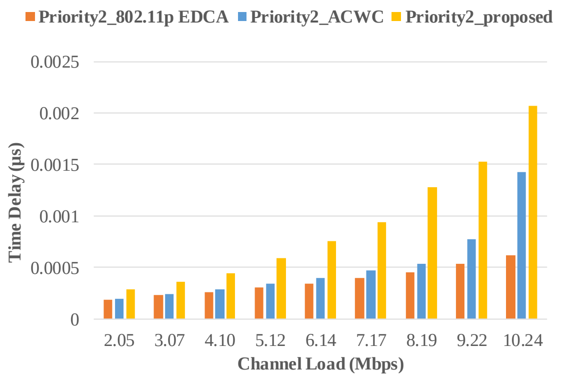

Figure 7. Priority 2 traffic access delay in urban highway model.

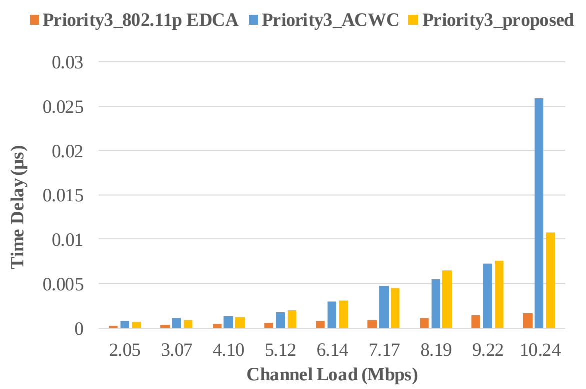

Figure 8. Priority 3 traffic access delay in urban highway model.

2) Rural Freeway Model

We simulate the rural freeway model to evaluate the effectiveness of the proposed mechanism in different road models. Nine scenarios with different vehicle densities under the same priority in Table V are generated to evaluate the effectiveness of the proposed mechanism similar to that in the urban highway model.

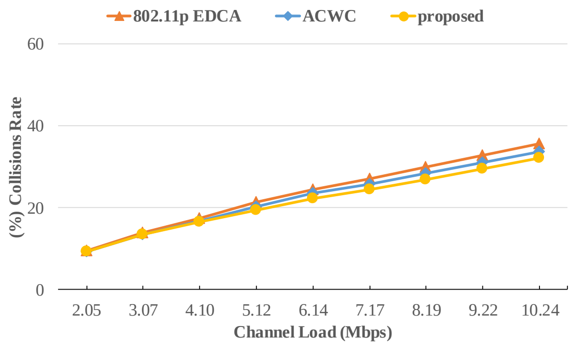

Figure 9. Collision rate of all traffic in rural freeway model.

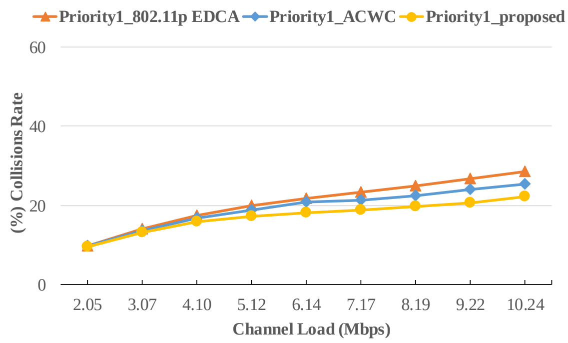

Figure 10. Priority 1 traffic collision rate in rural freeway model.

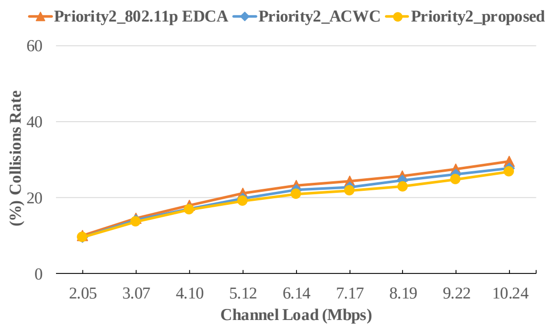

Figure 11. Priority 2 traffic collision rate in rural freeway model.

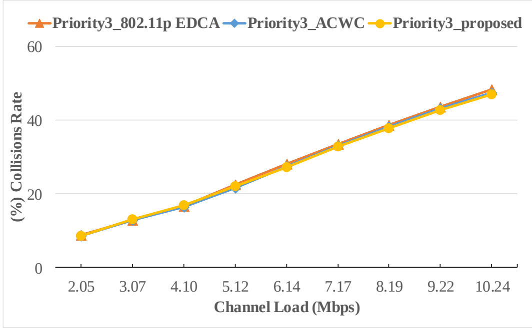

Figure 12. Priority 3 traffic collision rate in rural freeway model.

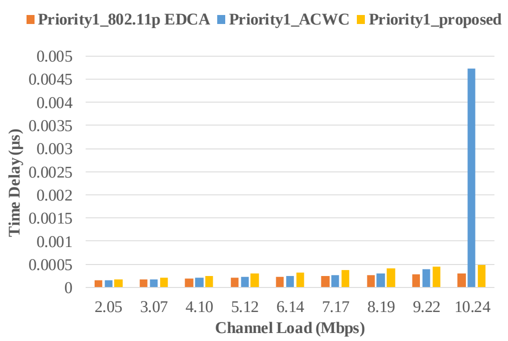

Figure 13. Priority 1 traffic access delay in rural freeway model.

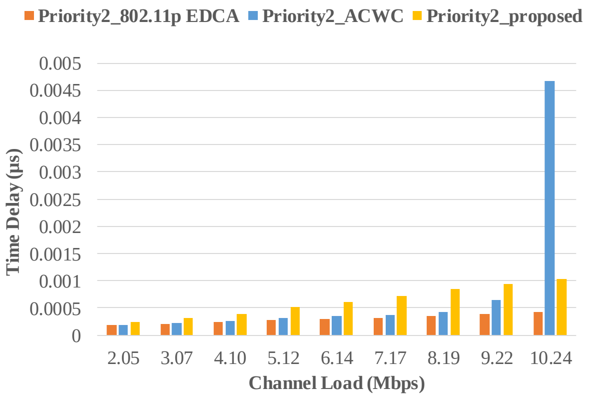

Figure 14. Priority 2 traffic access delay in rural freeway model.

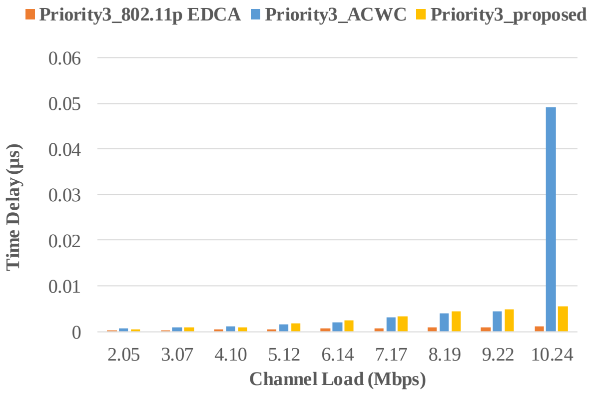

Figure 15. Priority 3 traffic access delay in rural freeway model.

C. Simulation Results Analysis

The simulation results in Fig. 2 and Fig. 9 show that our method has achieved the best result in reducing message collision in both models. The reason is that the original IEEE802.11p EDCA and ACWC mechanisms use a *CW* control method based on a random selection of backoff timers in the range [*0, CW[AC[i]]*] with uniform distribution. However, the optimized value of *CW* should reflect the priority and the channel condition. Therefore, the proposed mechanism controls the backoff timer by providing a strict distinction between the *CW* ranges of each data traffic type to achieve the best results.

When the channel load is low, the simulation results in both models show that the adaptive sliding contention window control algorithm has little effect on the safe message collision rate. The reason is that when the network traffic is low, the number of vehicles simultaneously contenting for accessing the channel is not much. The safe message collision rate of all traffics in the proposed mechanism reduces by 1% when compared to 802.11p EDCA and ACWC mechanisms. When the channel load is at medium and above bandwidth related to a channel load from 5.12 Mbps to 6.14 Mbps, the proposed mechanism achieves better collision rate performance. Simulation results in both models show that both high-priority and low-priority security messages of the proposed mechanism have a reduced security message collision when compared to 802.11p EDCA and ACWC mechanisms. For the urban highway model, the rate is reduced from 5% to 8% when compared with the proposed mechanism in the 802.11p EDCA standard and from 2.6% to 4.5% when compared to the ACWC mechanism. For the rural freeway model, the rate is reduced from 5.4% to 6.7% when compared with the proposed mechanism in the 802.11p EDCA standard and from 2.1% to 3.9% when compared to the ACWC mechanism. Especially, when the network is in a dense and saturated state, the channel load is 1.2 to 1.7 times larger than the bandwidth related with a channel load from 7.17 Mbps to 10.24 Mbps. The proposed mechanism significantly reduces the collision rate of all safe message traffic. For the urban highway model, the rate is reduced from 9% to 14% compared to the mechanism in the 802.11p EDCA standard and from 6% to 7% compared to the ACWC mechanism. For the rural freeway model, the rate is reduced from 7.5% to 10.5% compared to the mechanism in the 802.11p EDCA standard and from 3.7% to 4.7% compared to the ACWC mechanism.

On the other hand, the 802.11p EDCA standard provides a mechanism for prioritizing data traffic based on the setting parameters with differing priority traffic. Therefore, when a dense network of vehicles, the possibility of contention between threads with the same priority is enormous, leading to an increase in the collision rate. The ACWC mechanism also reduced the collision rate, however, it is not really effective in maintaining separation by priority for data traffic classes. To solve the above problem, in Figs. 3–5 and Figs. 10–12 we can see that as network traffic increases, the proposed mechanism ensures good segregation between flows of the same priority in the network. Both Priority 1, and Priority 2 high-priority data traffic, and Priority 3 low-priority data traffic lead to reduced collision rates. Our proposed mechanism increases access delay in comparison with other methods Figs.6–8 and Figs.13–15. The reason is that in the 802.11p EDCA standard the *CW* size is not adjusted and the vehicles just make the transmission as fast as possible without regard to the safe message collision rate so there will be lower access delay. However, all traffic classes in these cases maintain access latency at a level lower than the synchronization interval specified in the IEEE 802.11p standard.

V. Conclusion

The paper's main objective focuses on maintaining priority segregation and reducing the safe message collision rate in VANET. We propose a new mechanism to control the *CW* size using the adaptive sliding contention window size $ASCW_{size}[AC[i]]$ for each data traffic. Each vehicle in the network relies on the analysis data received rate. The mechanism applies the 802.11p EDCA standard to set priority for each different type of security message according to the urgency of the data traffic. The proposed mechanism adds little complexity to the vehicles and does not need additional network resources. The simulation results in different channel load conditions show that the proposed mechanism reduces the rate of safe message collision. Especially in the case of the high vehicle dense network, the urban highway model reduced from 6 to 12 % for high-priority data traffic and from 1% to 3% for low-priority data traffic. The rural freeway model reduces from

4 to 9 % for high-priority data traffic and from 0.4% to 1.4% for low-priority data traffic when compared to the mechanism in the 802.11p EDCA standard and ACWC. However, the proposed mechanism increases access latency compared to other methods but is still lower than the latency requirements specified in the 802.11p standard. Our future work will focus on adaptively tuning transmission range and transmission rate to minimize access latency, improving network performance under different conditions. On the other hand, we also research and propose more flexible contention window control mechanisms for intelligent transportation systems based on the Internet of Vehicles (IoV).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

H. C. Nguyen proposed the idea and performed the measurements, processed the experimental data, performed the analysis, drafted the manuscript, and designed the figures. T. G. Pham was involved in planning, supervised the work, and revised the paper. All authors discussed the results and approved the final version.

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