MINISTRY OF EDUCATION AND TRAINING

VIETNAM ACADEMY OF SIENCE AND TECHNOLOGY

GRADUATE UNIVERSITY OF SIENCE AND TECHNOLOGY

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ENHANCE PERFORMANCE IN VANET NETWORKS BY IMPROVING ACCESS CONTROL METHODS

SUMMARY OF DISSERTATION ON INFORMATION SYSTEM

Major code: 9 48 01 04

Ha Noi - 2023

The dissertation is completed at: Graduate University of Science and Technology, Vietnam Academy of Science and Technology

Supervisor: Prof. Dr. Pham Thanh Giang

Reviewer 1:

Reviewer 2:

Reviewer 3:

The dissertation will be examined by Examination Board of Graduate University of Science and Technology, Vietnam Academy of Science and Technology, at hour, date month year 2023

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LIST OF PUBLICATIONS

1 Nguyen Hoang Chien and Pham Thanh Giang, "Controlling Adaptive Contention Window to Improve Safe Message Received Rate in VANET", *International Journal of Computer Networks and Communications (IJCNC)*, 2022, vol. 14, no. 5, pp. 51-64. (SCOPUS Q4)

2 Nguyen Hoang Chien and Pham Thanh Giang, "Adaptive Sliding Contention Window Design to Minimize Safe Message Collision Rates with Different Priority Levels in VANET", *Journal of Communications (JCM)*, 2023, vol. 18, no. 6, pp. 369-376. (SCOPUS Q3)

3 Nguyễn Hoàng Chiến, Phạm Thanh Giang, "Đánh giá hiệu năng của giao thức định tuyến với mô hình đường cao tốc trong mạng VANET", *Hội thảo quốc gia lần thứ XXII: Một số vấn đề chọn lọc của Công nghệ thông tin và truyền thông - Thái Bình*, 28-29/6/2019, pp. 65-70.

4 Phạm Thanh Giang, Nguyễn Hoàng Chiến, "Nâng cao khả năng chấp nhận gói tin của giao thức truyền quảng bá trong chuẩn IEEE 802.11p", *Hội thảo quốc gia lần thứ XXIV: Một số vấn đề chọn lọc của Công nghệ thông tin và truyền thông - Thái Nguyên*, 13-14/12/2021, pp. 337-342.

INTRODUCTION

1. The necessity of the thesis

Vehicular Ad hoc Network (VANET) is used in Intelligent Transportation Systems (ITS) to control wireless communication in vehicular environments. In VANET, the IEEE 802.11p protocol has been adopted as the standard to support intelligent transportation applications. Within the IEEE 802.11p standard, the Physical (PHY) layer and the Media Access Control (MAC) layer are two important components that determine the use of the transmission channel between data streams [5-7]. In recent years, a research area that has received significant attention is deeply addressing key issues at the MAC sublayer in the IEEE 802.11p standard, aiming to improve performance and enhance service quality for applications in VANETs. The problems in this layer encompass multiple issues that need to be addressed in VANETs, with complex technical constraints. Among them, the most significant concern is congestion control caused by resource contention and communication collisions between vehicles and data traffic streams within the network. Thus, by increasing the vehicular density, the collision rate on the channel increases, leading to congestion in the network. The occurrence of congestion increases packet delay and loss rate (especially for safety messages), resulting in reduced performance of the VANET. To ensure reliability, safe vehicle communication, and enhance VANET's performance, Quality of Service (QoS) needs to be supported. Congestion control is an effective approach that should be used to support QoS. By controlling congestion, packet delay and loss rate can be managed, thus improving the performance of VANET to create a safer and more reliable environment for VANET users [8-12].

Therefore, new methods to address these issues need to be developed to enhance performance in VANETs through congestion control, especially in emergency situations where safety messages must be transmitted quickly without significant packet loss and delay.

2. Research objectives of the thesis

Based on the analysis of urgency and research motivation, the researcher has chosen the topic **"Enhance Performance in VANET Networks by Improving Access Control Methods".** To ensure feasibility within the limited time and existing infrastructure, the main objective of the thesis is to research and propose new improvements to congestion control methods at the MAC layer to enhance performance in VANETs. The proposed improvements focus on contention control in the network by adjusting the adaptive *Contention Window (CW)* size and optimizing QoS parameters for efficient broadcast transmission, aiming to increase the success rate of message reception, maintain priority differentiation, and reduce collision rates of safety messages. The improvements are specifically outlined as follows:

1. Proposing an adaptive contention window control method to improve the successful reception rate of safety messages in VANETs.
2. Propose a method for adaptive sliding contention window control to enhance the maintenance of separation between different priority data streams and minimize the safe message collision rate in VANET networks.

3. Main research contents of the thesis

Enhancing performance in VANETs is a broad and complex research topic. To achieve the research objectives, the thesis focuses on the following objects and scope within VANETs:

1. Research objects:
   i. The Medium Access Control (MAC) layer in the 802.11 standard for VANETs.
   ii. The Enhanced Distributed Channel Access (EDCA) mechanism for channel access control in IEEE 802.11p.
2. Research scope:
   i. Investigating adaptive contention window control solutions within the Enhanced Distributed Channel Access (EDCA) mechanism of IEEE 802.11p. This includes optimizing QoS parameters for efficient broadcast transmission of safety message streams to enhance network performance.

CHAPTER 1. OVERVIEW OF VANET NETWORKS RESEARCH

1.1 Introduction to Wireless Ad hoc Networks

1.2 Introduction to VANET Networks

1.3 Protocol Components in VANETs

1.4 VANET Network Performance

1.4.1 Concept of Performance

1.4.2 Network Performance Metrics

1.4.3 Factors Affecting Performance

1.4.3.1 Multipath Phenomenon in Transmission

1.4.3.2 Signal Attenuation and Channel Capacity Loss

1.4.3.3 Routing Variations

1.4.3.4 Congestion Control

When multiple packets from different sources arrive at a network node with the same output port at the same time, only one packet is forwarded to other network nodes, while the remaining packets are pushed into a queue at the requested output link. If the packet transmission rate from the network node is slower than the packet arrival rate, the queue will eventually become full, leading to congestion. In practice, the congestion control method of the Transmission Control Protocol (TCP) is proposed for wired networks where congestion is the main cause of packet loss. However, in MANETs, packet loss can occur due to congestion, routing failures, and channel errors. Indeed, MANETs face contention issues due to the shared wireless environment among all mobile nodes, resulting in an increased number of lost packets in the network. Mobility is a major factor causing routing failures and consequently packet loss in the network. Moreover, there are several challenges related to wireless links that cause packet loss in wireless networks, such as attacks, link errors, channel errors, and unfair bandwidth sharing [23, 52-54]. Existing congestion control methods in MANETs are not effective in VANETs due to the specific characteristics of VANETs compared to MANETs. Some congestion causes that need to be considered are [55]:

- *Network traffic*
- *Limitations of network nodes*
- *Heterogeneity among linked networks*
- *Protocol limitations*

1.4.4 Performance Evaluation Methods in VANETs

1.5 Conclusion of Chapter 1

In this chapter, the thesis has presented an overview of the model, control structure, protocol components, and factors affecting performance in VANET networks. It deeply analyzes the existing issues that significantly impact the performance in VANET networks. Based on these issues, the research direction of the thesis is determined to propose congestion control mechanisms and solutions to improve performance and quality of data transmission services in VANET networks.

The content of this chapter is synthesized from specialized literature and partly extracted from a publication in a specialized scientific article [CT3].

CHAPTER 2. ANALYSIS, EVALUATION OF CONGESTION CONTROL METHODS IN VANET NETWORKS

2.1 Congestion Control in VANET Networks

2.1.1 Congestion Control Principles

2.1.2 Cross-Layer Congestion Control Architecture

In Figure 2.1 [62], a management entity is considered to detect and control congestion. Congestion detection utilizes information from the application layer to identify congestion occurrences in the network. Additionally, congestion can be detected by sensing the transmission channel at the physical layer and measuring parameters such as channel utilization level.

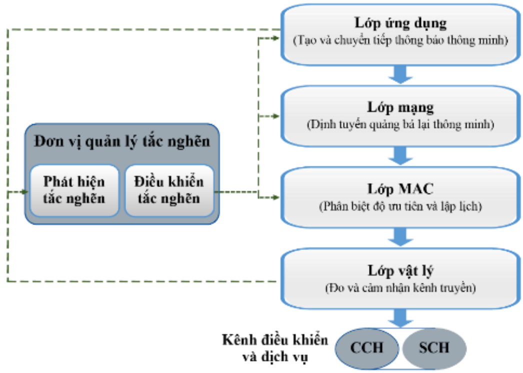


Figure 2.1Cross-layer congestion control architecture in VANET [62]

Congestion control can be carried out in different ways in different network layers.

2.1.3 Congestion Detection Methods

In VANET, congestion detection utilizes two methods: event-based and measurement-based [62, 64]. Event-based congestion detection relies on event-driven safety messages to detect congestion.

Measurement-based congestion detection periodically senses the transmission channel and measures parameters such as the number of messages in the queue [19], channel occupancy time [65], and channel utilization level [62].

2.1.4 Congestion Control Methods

Congestion control methods in VANET can be classified based on different criteria. They are based on the prevention or control of congestion, and can be divided into three types: proactive, reactive, and hybrid methods [11, 62, 66].

In proactive methods, congestion is prevented by adjusting transmission parameters based on information such as the number of neighboring vehicles and data initialization models. Reactive methods use information about channel congestion conditions to decide on congestion control methods by adjusting transmission parameters. Hybrid methods combine the advantages of proactive and reactive methods.

2.2 Some congestion control problems exist with the broadcast mechanism in the VANET network.

Based on the above analysis, congestion control in VANET faces many challenges and issues due to the unique characteristics of VANET. Some remaining issues include the inefficient resource management of IEEE 802.11 technology, especially in the case of broadcasting safety messages. Specifically:

- Retransmission is not possible for unsuccessful broadcast transmissions because errors cannot be detected.

- The contention window size cannot be changed due to the lack of recovery at the MAC sublayer for broadcast frames.

- Hidden node problem exists due to the absence of RTS/CTS exchange.

Due to the direct determination of channel access by the CSMA/CA protocol in the MAC layer, channel congestion issues can be addressed by reducing channel access capability through modifying the control parameters of the CSMA/CA protocol. Congestion control is achieved by determining appropriate values for the *CW* and AIFS sizes to control channel access. The existing issue with the use of EDCA is that MAC layer parameters are not adaptive to changing network conditions, especially when the network is saturated. The number of contending vehicles for accessing the wireless environment can become very large, leading to increased collision rates between high-priority and low-priority data streams competing for transmission opportunities.

2.3 Approaches to Address Congestion Control Issues

2.4 Approach and Research Direction of the Thesis

Based on the analysis of existing approaches to address congestion control issues, the thesis identifies the best approach to improve performance in VANET by using a passive network monitoring method. According to this approach, the thesis focuses on improving the broadcasting protocol by incorporating dynamic adjustment of the contention window size for congestion control. The objective is to enhance reception capability, prioritize differentiation effectively, and minimize collision rates of safety messages under high network loads.

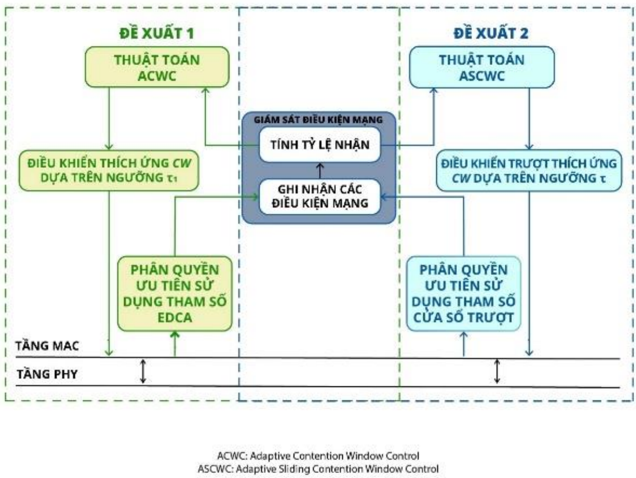


Figure 2.7 Model comparing two proposed solutions

Figure 2.7 shows that to solve the problem at hand, the thesis proposes two main suggestions:

Proposal 1: Propose an Adaptive Contention Window Control (ACWC) method to improve the successful reception rate of safety messages in VANET.

Proposal 2: Propose an Adaptive Sliding Contention Window Control (ASCWC) method to enhance the separation between different priority data streams and minimize collision rates of safety messages in VANET.

2.5 Conclusion of Chapter 2

In this chapter, the thesis delves into the analysis of congestion control principles, cross-layer congestion control architecture, congestion detection and control methods in VANET, while identifying the existing issues. The thesis also reviews relevant research in recent years from both domestic and international perspectives, focusing on major approaches. Based on this foundation, the thesis presents research directions to address the selected issues. The content of the chapter is synthesized from specialized literature and partially extracted from a scientific publication [CT4].

CHAPTER 3. CONTROLLING ADAPTIVE CONTENTION WINDOW TO IMPROVE SAFE MESSAGE RECEIVED RATE IN VANET

3.1 Introduction

3.2 Related Work

3.3 ACWC adaptive contention window control solution

3.3.1 Method of monitoring network conditions

To incorporate the EDCA mechanism in VANET, we classify the different messages according to their urgency and delay requirements as listed in Table 3.1.

Bảng 3.1 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

According to the DSRC standard in VANET, each vehicle broadcasts its status to its neighbors about 10 times per second [93, 94]. Thus, a node in VANET can detect collisions and congestion by analyzing the sequence number of the frames that the node has successfully received from its neighbors [95]. Based on observing recently received frames, a node can determine the current local conditions of the network.

3.3.2 Data structure for recording network conditions

To determine the local state of the network, each node maintains a table with the data structure shown in Figure 3.3, It is used to record the response messages from neighboring nodes which has been received in the message frames recently.

MAC Address	*Sequence Number*	*Received Rate*	*Time Stamp*

Figure 3.3 A data structure in a table

Table entries are updated periodically, and data in previously updated entries are discarded so as not to affect the calculation of local network conditions. After a timeout threshold, if a broadcast is not received from a node, the entry is dropped from the table assuming that the node has gone out of transmission range.

3.3.3 Calculating the received rate method

To determine the received rate of a node *i*, a value called RR_{avg}^{i} is used to calculate the value of the average received rate. The sequence number is an important parameter to determine the received rate. To determine the RR_{avg}^{i}, the difference between the received sequence numbers is checked through a parameter called SN_{diff}. The SN_{diff} value is calculated by equation (3.1).

$$SN_{diff} = \begin{cases} 1, & if\ SN_{rev} - SN_{prev} = 1 \\ 0, & if\ SN_{rev} - SN_{prev} > 1 \end{cases} \quad (3.1)$$

In a rapidly changing network in VANET, a weighted average is used. RR_{avg} is calculated using equation (3.2) as follows:

$$RR_{avg}^{i^{new}} = (1-\alpha) * SN_{diff} + \alpha * RR_{avg}^{i^{old}} \quad (3.2)$$

In equation (3.2), the value α is chosen in the range [0, 1] to adjust the information update in the table from which the calculation of RR_{avg}^{i} changes rapidly with the condition of the network. Each node uses an update timer and, through a variable, adjusts the timer operation to determine whether a node's state is maintained, or terminated. When the timer has ended, a node determines the condition of the network and thus adjusts the transmission parameters.

As explained earlier, RR_{avg}^{i} is determined for each node whenever a frame is received. Otherwise, the average value of the received rate is used to determine the RR_{local}, and this value is calculated only periodically. Equation (3.3) is used to calculate RR_{local}.

$$RR_{local} = \sum_{i=1}^{N} \frac{RR_{avg}^{i}}{N} \quad (3.3)$$

Where N is the number of nodes received within the transmission range determined based on the method in section 3.3.1. When a node determines RR_{local}, this value is compared with the previously stored RR_{local} value to adjust the size of *CW*.

3.3.4 Adaptive Contention Window Control Algorithm

For efficient message transmission, it is necessary to adjust the backoff counter according to the condition of the network, in particular, according to the message received rate and local vehicle density. The *CW* sizing mechanism is based on the analysis of the sequence number of frames received in the MAC layer as in Section 3.3.3. RR^{i}_{avg} is an indication of how congested the network is and the data traffic from a medium needs to be controlled. The adaptive *CW* control algorithm is presented as follows:

Table 3.2 Algorithm adaptive contention window control

Algorithm Adaptive Contention Window Control

Input: Default *CW* values ∀ ACs and threshold value τ_1

Output: Adapted *CW* values ∀ ACs

When a packet is sent to the MAC layer

for each *Time* **do**

/*Calculate RR_{local} parameters based on the method proposed in section 3.3.3*/

if $RR_{local} > \tau_1$ **then**

for (*level* = 0; *level* < MAX_PRI; *level*++)

CW_old ← *CW_[level]*

new_window ← (*CW_old* / scaling_factor)

win_size ← ((new_window) – 1)

*/*Calculate the new value of CW size*/*

CW_[level] ← win_size

if (*CW_[level]* < CW_{min}*_[level]*)

CW_[level] = CW_{min}*_[level]*

end if

end for

else if $RR_{local} < \tau_1$ **then**

for (*level* = 0; *level* < MAX_PRI; *level*++)

```
            CW_old ← CW_[level]
            new_window ← (CW_old * scaling_factor)
            win_size ← ((new_window) + 1)
        /*Calculate the new value of CW size*/
            CW_[level] ← win_size
            if (CW_[level] > CW_max_[level])
                CW_[level] = CW_max_[level]
            end if
        end for
    else
    Maintain corresponding CW;
    end if
end for
```

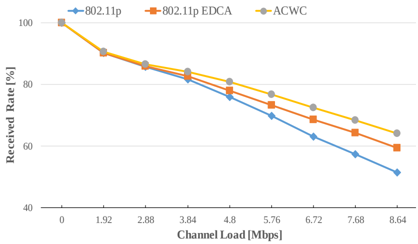
3.4 Simulation and Results

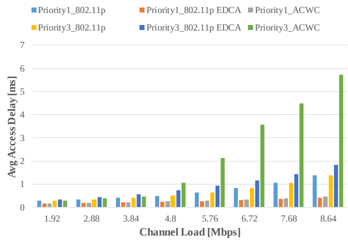
3.4.1 Set up network models and simulation parameters

The simulation scenario was designed to be a straight highway represented circular [17] with an inner radius of 300 m, including eight lanes of vehicles going in both directions four lanes in each direction, and a distance between lanes of 5 m. All lanes 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 vehicles broadcast and update the status to their neighbors every 100 ms (10 packets/s).

3.4.2 Performance metrics

3.4.3 Analyze and evaluate simulation results





Hình 3.6 Received rate of all traffic   *Hình 3.9 Access delay*

Simulation results are shown in Figure 3.6, show that our adaptive *CW* control algorithm has improved the security message received rate compared to the default mechanism in the 802.11p standard. In low channel load, simulation results show that the adaptive *CW* control algorithm has little effect on the message received rate.

In medium channel load, it is shown in scenarios with channel loads of 3.84 Mbps, 4.8 Mbps, and 5.76 Mbps. We found that when the channel load increased to nearly the bandwidth, the adaptive *CW* control algorithm showed an effective impact in improving the received rate of safety messages. The simulation results show that the rate of receiving safe messages of the proposed mechanism increases approximately from 3 to 7% compared to the mechanism in the 802.11p standard.

In high channel load, especially when the network is in a highly dense state, the network traffic exceeding the channel bandwidth is shown in the cases of channel loads of 6.72 Mbps, 7.68 Mbps, and 8.64 Mbps. We found that the algorithm significantly improved the acceptance rate of all safe messages by approximately 5% - 14% compared to the mechanism in the 802.11p standard. However, in this case, when the adjustment algorithm increases the size of *CW* to improve the rate of a safe message received, it leads to an increase in access delay as the simulation results shown in Figure 3.9. However, all traffic classes in these cases maintain access delay well below the 100ms target.

3.5 Conclusion Chapter 3

In this paper, we propose a new coordination mechanism for adaptive broadcast transmission based on *CW* size control to improve the received rate of safety messages. The research results of this chapter are published in the International Journal of Computer Networks and Communications under the category SCOPUS [CT1].

CHAPTER 4. ADAPTIVE SLIDING CONTENTION WINDOW DESIGN TO MINIMIZE SAFE MESSAGE COLLISION RATES IN VANET

4.1 Introduction

4.2 Related Work

4.3 ASCWC adaptive sliding contention window control solution

4.3.1 Priority access control mechanism

In the Adaptive Sliding Contention Window Control (ASCWC) 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, ASCWC 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. To improve bandwidth efficiency under different channel load conditions, the *CW* range can overlap between different data traffics. In ASCWC, the parameter $ASCW_{size}[AC[i]]$ is *CW* size for a data traffic type. It is calculated by equation (4.1) as follows:

$$ASCW_{size}[AC[i]] = 2 * SF[AC[i]] \quad (4.1)$$

In equation (4.1), *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*.

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 equation (4.2), (4.3) as follows:

$$CW_{LB}[AC[i]] = CW_{min}[AC[i]] \quad (4.2)$$

$$CW_{UB}[AC[i]] = CW_{min}[AC[i]] + ASCW_{size}[AC[i]] \quad (4.3)$$

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 $backoff_{new}$ parameteris a new backoff timer that a vehicle uses to adjust the *CW* size, it is randomly selected in the range [$CW_{LB}[AC[i]]$, $CW_{UB}[AC[i]]$] calculated by the equation (4.4) as follows:

$$backoff_{new} = CW_{LB}[AC[i]] + random((CW_{UB}[AC[i]] - CW_{LB}[AC[i]] + 1)) \quad (4.4)$$

In Table 4.1, we set the parameters for the proposed mechanism to prioritize by controlling the sliding contention window.

Table 4.1 Priority data flow parameters

Message Types	**Priority**	CW_{min}	CW_{max}	*SF[AC[i]]*	$ASCW_{size}$ *[AC[i]]*	**AIFS**
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

4.3.2 Adaptive Sliding Contention Window Control Algorithm

The proposed mechanism to adjust the contention window size has implemented the idea to adjust *CW* size based on [97] 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 as shown in section 3.3.3.

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 4.3.1. The control algorithm of the adaptive sliding contention window is presented as follows:

Table 4.2 Algorithm adaptive sliding contention window control

Algorithm Adaptive Sliding Contention Window Control

Input: Sliding *CW* values ∀ ACs in Section 4.3.1 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**

/*Calculate RR_{local} parameters based on the method proposed in section 3.3.3*/

```
        if RR_local > τ then
            for (i = 0; i < MAX_PRI; i++)
                if (CW_LB[AC[i]] - SF[AC[i]] >= CW_min[AC[i]])
                    CW_LB[AC[i]] ← CW_LB[AC[i]] - SF[AC[i]]
                    CW_UB[AC[i]] ← CW_UB[AC[i]] - SF[AC[i]]
                else
                    CW_LB[AC[i]] ← CW_min[AC[i]]
                    CW_UB[AC[i]] ← CW_min[AC[i]] + ASCW_size[AC[i]]
                end if
            end for
        else if RR_local < τ then
            for (i = 0; i < MAX_PRI; i++)
                if (CW_UB[AC[i]] + SF[AC[i]] <= CW_max[AC[i]])
                    CW_LB[AC[i]] ← CW_LB[AC[i]] + SF[AC[i]]
                    CW_UB[AC[i]] ← CW_UB[AC[i]] + SF[AC[i]]
                else
                    CW_LB[AC[i]] ← CW_max[AC[i]] - ASCW_size[AC[i]]
                    CW_UB[AC[i]] ← CW_max[AC[i]]
                end if
            end for
        else
        Maintain corresponding CW;
    end if
end for
```

4.4 Evaluate the results by simulation

4.4.1 Simulation Parameters

4.4.2 Performance metrics

4.4.3 Simulation Results

4.4.3.1 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.

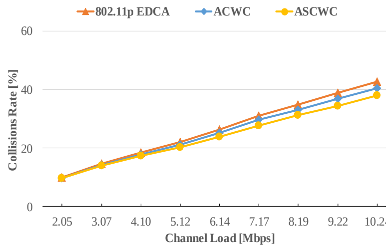


Figure 4.3 Collision rate of all traffic in urban highway model.

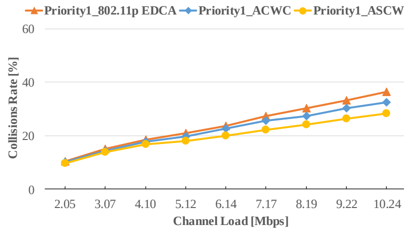


Figure 4.4 Priority 1 traffic collision rate in urban highway model.

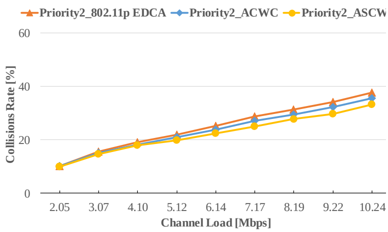


Figure 4.5 Priority 2 traffic collision rate in urban highway model.

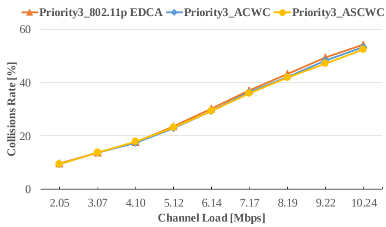
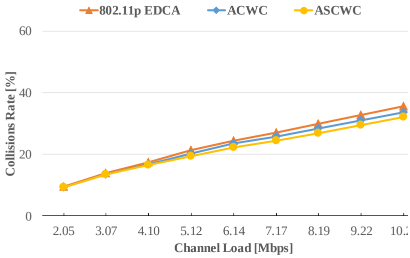


Figure 4.6 Priority 3 traffic collision rate in urban highway model.

4.4.3.2 Mô hình đường cao tốc nông thôn

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 4.4 are generated to evaluate the effectiveness of the proposed mechanism similar to that in the urban highway model.



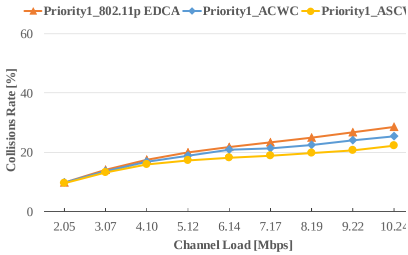
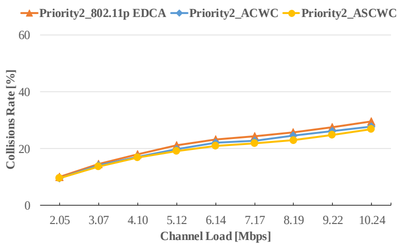


Figure 4.10 Collision rate of all traffic in rural freeway model.

Figure 4.11 Priority 1 traffic collision rate in rural freeway model.



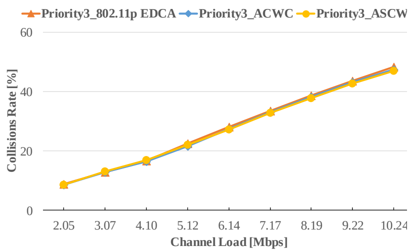


Figure 4.12 Priority 2 traffic collision rate in rural freeway model.

Figure 4.13 Priority 3 traffic collision rate in rural freeway model.

4.4.4 Simulation Results Analysis

The simulation results in Figure 4.3 and Figure 4.10, 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.

4.5 Conclusion Chapter 4

The main objective of the chapter focuses on maintaining priority segregation and reducing the safe message collision rate in VANET. The research results of this chapter are published in the International Journal of Communications under the category SCOPUS [CT2].

CONCLUSION AND RECOMMENDATIONS

Improving performance in VANETs is essential and practically significant, providing solutions to support QoS in unstructured media networks. After a period of research, the dissertation **"Enhance Performance in VANET Networks by Improving Access Control Methods"** has achieved some novel results, although there are still limitations that require further research and development.

(a) Achieved Results

The dissertation contributes to research by presenting two novel aspects as follows:

(1) The dissertation proposes an adaptive contention window control method to improve the successful reception rate of safety messages in VANETs. Through network monitoring in the proposed mechanism, each vehicle analyzes recently successfully received frames to identify the current local network conditions such as collisions or congestion. Based on the obtained results, the proposed mechanism controls the size of the *CW* and utilizes the Enhanced Distributed Channel Access (EDCA) mechanism

to transmit data streams with different priorities. The results of this proposal have been published in an international journal on computer networks and communications listed in SCOPUS Q4 [CT1].

(2) The dissertation proposes a method to enhance the adaptability of the contention window through the design of a sliding window. The *CW* size control algorithm slides the window with a dynamic change coefficient to reduce collision rates among different types of safety message traffic. Each data traffic selects a dynamically changing backoff timer within the range [0, *CWi*], which can overlap with the *CW* range of other data traffic to improve bandwidth efficiency under different network conditions. The proposed mechanism ensures separate differentiation among different priority data streams and significantly reduces collision rates. The results of this proposal have been published in an international journal on communications listed in SCOPUS Q3 [CT2].

(b) Limitations

Alongside the achieved results, the dissertation still has some limitations that need further research, particularly regarding congestion control, to enhance performance in VANETs.

(1) The proposed mechanisms have not considered other factors that affect VANET performance, such as the impact of transmission power and range, and the influence of transmission speed to increase system throughput while reducing the latency of safety messages.

(c) Future Development

Based on the research results in this dissertation, some future research directions can be recommended as follows:

(1) Research the use of network monitoring combined with transmission range adjustment through power control to maintain network load below a certain threshold. Evaluate the factors influencing network load by adjusting parameters related to transmission range according to the requirements of safety applications.

(2) Utilize the proposed network monitoring method in the dissertation to study the integration of efficient transmission speed control for all classes of safety message traffic under different network conditions.

(3) Research and propose more flexible contention window control mechanisms for Intelligent Transportation Systems based on the Internet of Vehicles (IoV) platform.