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

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ABSTRACT

The primary goal of Vehicular Ad Hoc Networks (VANETs) is to support the secure transmission of applications via vehicles. Broadcasting is an important form of communication in the VANET network. Since there is no recovery for broadcast frames in the VANET network, the rate of receiving safe messages can become very low, especially in dense network conditions. In this paper, we present a new broadcast coordination mechanism with the aim of adaptive control of CW size to improve the received rate of safety messages. Each vehicle in the VANET can identify current local conditions of the network such as collisions or congestion by analyzing recently successfully sent and received frames. Based on the analysis of the received frame rate at each vehicle, the proposed mechanism controls the CW size and uses the EDCA mechanism to prioritize the important data flows. Using a combination of simulation tools in VANET, we build simulation scenarios in different network conditions to evaluate the received rate of safety messages compared to the default mechanism in the 802.11p standard. Simulation results have demonstrated that the proposed mechanism improves the received rate of safety messages better than the default mechanism in the 802.11p standard in all cases.

KEYWORDS

VANET, DSRC, EDCA, MAC, CW.

1. INTRODUCTION

Vehicular Ad Hoc Networks (VANETs) are a type of Mobile Ad Hoc Networks (MANETs) with nodes as vehicles. In addition to the characteristics inherited from MANETs, some unique characteristics of VANets including high mobility, rapidly changing network topology, high vehicle density, limited mobility model, unlimited power, etc. are used to control wireless communication in vehicular environments. In the VANET network, the IEEE 802.11p protocol has been approved as the standard supporting Intelligent Transportation Systems (ITS) applications [1] [2]. In IEEE 802.11p, the PHY layer and MAC layer are two important components that determine the use of transmission channels between data flows. In the PHY layer, Dedicated Short Range Communication (DSRC) technology offers the potential to effectively support secure Vehicle to Vehicle communication (V2V) and Vehicle to Infrastructure (V2I) [3]. The lower layers of DSRC in the 802.11p standard are similar to those of IEEE 802.11a [4]. The majority of messages sent on the DSRC control channel are broadcast messages.

The intended use of broadcast is to send emergency warning messages and periodically broadcast vehicle status (e.g. vehicle speed, acceleration, position, and direction). The DSRC standard only provides one control channel, this channel is used to transmit different types of messages, and the

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data flow on the channel must be decentralized to ensure the required Quality of Service (QoS). Enhanced Distributed Channel Access (EDCA) [5] uses a differentiated vehicle access method, using a different priority for each type of data flow. The various data frames are mapped to the Access Categories (AC) before the frame is placed on the channel. The main difference is that the MAC layer of IEEE 802.11p only supports four AC types instead of the eight AC types in IEEE 802.11e for supporting high mobility [6]. For reliable broadcasting in the VANET network, some major technical changes are required to address the issues raised in the related studies.

In the paper [7], the received rate of broadcast traffic is affected by the change of *CW* parameters and the size of the Arbitration Inter-Frame Space (AIFS). After each failed transmission, the 802.11p standard increases the CW exponentially to adapt to changing network conditions. However, since there is no notification of successful transmission or not in broadcast transmission, the unchanged CW is kept fixed for subsequent transmissions. On the other hand, the collision rate of broadcast frames increases as the distance from the sending source increases. In dense network conditions, the broadcast frame reception rate drops sharply at distances greater than 66% due to the hidden node problem. One solution to increase the reception rate is to have a message retransmitted multiple times. However, the repeated transmission generates too much traffic which wastes network bandwidth.

In addition to the aforementioned issues, broadcast transmission suffers from the "ACK explosion problem", so it is not possible to determine exactly whether broadcast frames were received successfully or not [8]. And it does not adjust the transfer parameter based on the success or failure of the previous transmission. If a large number of nodes are gaining access, it will increase the chance of collision.

On the other hand, using the EDCA mechanism together with different AIFS values, collisions can occur between threads of the same AC type. If the number of competing threads with equal priority is significant, the likelihood of a collision increases. The number of vehicles competing to access the wireless in heavy traffic areas can become very large. One limitation of using EDCA is that the MAC layering parameters do not adapt the channel correctly in network conditions. In other words, the MAC layering parameters will not change as the number of contentious means attempting to access the channel increases over time. In case of high vehicle density, it is appropriate to increase the initial size of the CW to reduce the probability of collision. The size of the CW will also increase accordingly as network traffic continues to increase to adapt to changing network conditions. Vehicles can also benefit from the opposite situation where the size of the *CW* is reduced due to low traffic density.

Through the problems analyzed above, it is shown that the broadcast transmission at the MAC layer in the 802.11p standard is not reliable in the VANET network. Our main concern in this paper is to improve the received rate of safety messages. Therefore, we propose a novel broadcast coordination mechanism with the aim of adaptive control of CW size. To implement this mechanism, the QoS parameters at the MAC layer are optimized. In addition, we prioritize messages according to the urgency of the data by incorporating an EDCA mechanism for the fastest transmission of high-priority messages to the destination.

The rest of the paper is structured as follows. Section 2 presents the published research related to broadcasting in VANET. Section 3 presents the IEEE 802.11P EDCA mechanism. Section 4 presents the QoS parameter optimization method in the MAC layer. Section 5 presents the simulation and results. Conclusions are presented in section 6.

2. RELATED WORK

Broadcast transmission is mainly used in VANET for Inter-Vehicles Communication (IVC) to reduce collisions, contention, message redundancy, hidden node problems, and improve message reliability [9]. Two approaches can be used to get feedback from the network: the active network monitoring method and the passive network monitoring method. An active network monitoring method uses nodes to monitor the network and exchange information with neighboring nodes. However, this method increases the network load resulting in additional bandwidth consumption. In a VANET, bandwidth is a rare resource, so it is desirable to reduce the number of messages. The proactive network monitoring method increases the number of messages sent resulting in a further increase in congestion. A passive network monitoring method can be used to get feedback. In a wireless network, a node hears all messages transmitted within the same transmission range. Nodes can receive responses from the network simply by listening to messages sent from other nodes. The benefit of the passive network monitoring method is that it does not require additional network resources.

Some authors provide a workaround for the problem of sending broadcast messages in VANET. In the paper [7], the authors showed that under saturation conditions, at a distance of 100m from the sending source, the probability of receiving broadcast messages can be reduced by 20% - 30% and even further at a greater distance. The main cause of the drop in the received rate is the hidden node problem. The authors implement a priority access method between nodes based on channel access time scheduling to improve the received rate of broadcast messages, but still do not achieve 100% reliability.

In the paper [10], the authors considered broadcast transmission power in VANET based on local vehicle density estimation. The local vehicle density of a given vehicle, calculated as the ratio of the actual number of vehicles (AN) on the road present in its transmission range to the total number of vehicles (TN) may appear on the line within the current transmission range. However, the method calculated local traffic density based solely on vehicle movement, it may not always give an accurate estimate of local traffic density. For example, when a certain vehicle is traveling at a low speed, the method will estimate that the local vehicle density is high, while traveling at a high speed, the vehicle will estimate the low traffic density. In the paper [11], the authors proposed a Location-Based Broadcast (LBB) protocol to increase the probability of receiving a message by sending the message many times. On other hand, paper [12] again proposed a Vehicle Collision Warning Communication protocol (VCWC) to transmit emergency warning messages. It is based on a state machine and the multiplicative rate decrease algorithm. When an accident occurs, vehicles begin to transmit emergency warning messages at the highest rate and decrease over time. However, the proposed protocol does not increase reliability with low-priority traffic and in multi-hop broadcast modes. Both [11] and [12] increase the probability of receiving a message by broadcasting the same message multiple times, which leads to increasing the load on the network.

In some other papers such as [13] [14], they propose to reduce the frequency of message transmission to reduce synchronization collisions on the transmission channel. However, safety applications have strict frequency requirements, so reducing the frequency of message transmissions is not useful for safety applications. In the paper [15], the authors proposed to incorporate the 802.11e EDCA mechanism in VANET based on priority for V2V communication. Each message IVC is assigned a priority level based on the urgency of the security event, different QoS requirements in terms of communication reliability, and average delay. To increase communication reliability in broadcast-based IVC, the authors applied retransmission mechanisms that provided proportional reliability differences for each prioritized message. However, the authors did not solve the problem of adjusting QoS parameters according to local network traffic conditions.

3. IEEE 802.11P EDCA MECHANISM

The EDCA mechanism is based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). It is designed to support QoS, providing separate channel access for traffic types with different priorities such as voice, video, best-effort, and background. EDCA defines four ACs for different data types and has differentiated services for each AC, as shown in Figure 1 [5].

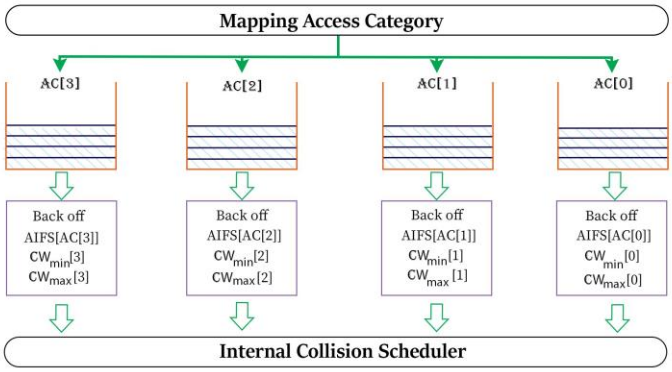

Figure 1. EDCA mechanism in a station

Whether different data frame which is mapped for each AC will depend on the QoS requirements of the upper layer. Each AC operates on an independent Distributed Coordination Function (DCF) mechanism to compete for transmission opportunities using its own EDCA parameters, such as *AIFSN*, aCW_{min}, and aCW_{max}, as listed in Table 1 [6].

Table 1. IEEE 802.11p EDCA specifications

AC	CW_{min}	CW_{max}	AIFS
AC[0]	aCW_{min}	aCW_{max}	9
AC[1]	aCW_{min}	aCW_{max}	6
AC[2]	$(aCW_{min}+1)/2 -1$	aCW_{min}	3
AC[3]	$(aCW_{min}+1)/4 -1$	$(aCW_{min}+1)/2-1$	2

Each vehicle will have four different queues, priority traffic uses different QoS parameters such as inter-frame spaces AIFS [AC[i]] and CW_{min} *[AC[i]]* instead of standard values. The inter-frame spaces AIFS [AC[i]] are determined by the following equation:

$$\text{AIFS [AC[i]]} = aSIFSTime + \text{AIFSN[AC[i]]} * aSlotTime \quad i = (0, 1, 2, 3) \quad (1)$$

Where *aSIFSTime* and *aSlotTime* are a time interval Short Inter Frame Space (SIFS) and a slot time, both are defined by the physical layer. As shown in Table 1 and Equation (1), the duration of AIFS [AC[i]] is influenced by the value of AIFSN [AC[i]]. The AC with a smaller AIFSN will have a higher priority for channel access. Also, different CWs (e.g. CW_{min} and CW_{max}) are assigned to different AC queues. The AC queues with short *CW* sizes have a higher chance of channel access than queues with large *CW* sizes.

As shown in Figure 1, there are four independent AC queues in each station. In a station, if AC[i], in a new packet is generated for transmission, the station checks the status of the channel and senses that the channel is idle for at least a period of AIFS [AC[i]]. The backoff counter of AC[i], which is an integer value out of the uniformly distributed [0, *CW*], will be checked. If its value is zero, the packet will be transmitted by the station imvehicletely. If the channel is sensed to be idle for a slot time, the backoff counter is decremented by one and paused when the channel is busy. The backoff counter is re-triggered after sensing the channel to be idle again during the AIFS [AC[i]] time. If the channel is busy (during the AIFS [AC[i]] period), access will be deferred. The station will continue to monitor the channel until the channel is idle during AIFS [AC[i]]. At this point, a backoff procedure is performed to minimize the probability of a collision. When the backoff counter drops to zero, the frame will be transmitted. However, in each station with four ACs, when more than one AC queue is transmitting at a time, collisions may occur within a station. Each station maintains a scheduler to control this local collision by prioritizing the transmission of frames to the high-priority AC queue while delaying the lower-priority AC queue. Then the backoff procedure is called to restart the transmission.

4. QoS Parameter Optimization Method in MAC Layer

The goal of MAC layering is to decentralize access to shared medium and the wireless channel. As network density increases, the size of the *CW* will also increase to accommodate the increase in the number of nodes trying to access the channel. Without using coordination methods, collisions can occur frequently. To reduce the problems associated with unreliable broadcasts in VANET, it is necessary to modify the broadcast protocol in the IEEE 802.11p standard to improve the received rate of broadcast traffic.

4.1. Method of Monitoring Network Conditions

In the paper, we have implemented the priority mechanism described in IEEE 802.11p that focuses on the transmission of broadcast messages and therefore does not affect unicast message transmission. To incorporate the EDCA mechanism in VANET, we classify the different messages according to their urgency and delay requirements as listed in Table 2.

Table 2. 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 [16] [17]. 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 [18]. Based on observing recently received frames, a node can determine the current local conditions of the network. The paper approaches in direction of using passive network monitoring to receive feedback from the network. From there, adaptively adjust the QoS parameters at the MAC layer to improve the received rate of safety messages.

4.2. 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 Table 3. It is used to record the response messages from neighboring nodes which has been received in the message frames recently.

Table 3. A data structure in a table

MAC Address	Sequence Number	Received Rate	Time Stamp

The entries in the table include:

- **MAC Address:** The MAC address uniquely identify each node in the table.
- **Sequence Number:** Sequence number to record the sequence number of the last frame received from a node.
- **Received Rate:** Weighted received rate to determine the percentage of frames successfully received from a node.
- **Time Stamp:** The time stamp records the transmission time received from a node.

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.

4.3. Calculating the Received Rate Method

In a table, a category is used to record the received rate for a node. A node's received rate is an important factor in determining whether the *CW* size should be adjusted. To determine the received rate, a value called RR_{avg} 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}, the difference between the received sequence numbers is checked through a parameter called SN_{diff}. The SN_{diff} value is calculated by equation (2).

$$SN_{diff} = \begin{cases} 1, & if\ SN_{rev} - SN_{prev} = 1 \\ 0, & if\ SN_{rev} - SN_{prev} > 1 \end{cases} \quad (2)$$

In equation (2), SN_{rev} is the number of sequences a node has received at present time, and SN_{prev} is the number of sequences a node has received previously. The SN_{diff} value will contain either one or zero. The value one is used if a message is received exactly with some sequence number, otherwise, the value zero is used. If the distance between sequence numbers is greater than one, then RR_{avg} is counted multiple times. In a rapidly changing network in VANET, a weighted average is used. RR_{avg} is calculated using equation (3) as follows:

$$RR_{avg} = (1-\alpha) * SN_{diff} + \alpha * RR_{avg} \quad (3)$$

In equation (3), the value of α to adjust for RR_{avg} changes rapidly with the condition of the network. As the value of α moves closer to one, less weight is placed on the current network conditions. On the other hand, when the value of α moves to zero, more weight is placed on the current network conditions. 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.

Based on the information gathered in the table, a node can adjust the transmission parameters when the timer ends. Once the timer has ended, a node will have its own calculated received rate for each node. A node calculates the local received rate to predict the network conditions. RR_{local} is the average value of RR_{avg}. In other words, the average value of the received rate was calculated.

As explained earlier, RR_{avg} 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 (4) is used to calculate RR_{local}.

$$RR_{local} = \sum RR_{avg} / N \quad (4)$$

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

4.4. 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 4.3. RR_{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 4. Algorithm adaptive contention window control

Algorithm Adaptive Contention Window Control

Input: Default *CW* values ∀ ACs [5] and threshold value τ_1
Output: Adapted *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 Section 4.3;
   if RR_local > τ1 then
      for (level = 0; level < MAX_PRI; level++)
          set cw_old ← cw_[level]
          calculate new_window ← (cw_old / scaling_factor)
          calculate win_size ← ((new_window) – 1)
          set cw_[level] ← win_size;
          if (cw_[level] < cwmin_[level])
             cw_[level] = cwmin_[level]
          end if
      end for
   else if RR_local < τ1 then
      for (level = 0; level < MAX_PRI; level++)
          set cw_old ← cw_[level]
          calculate new_window ← (cw_old * scaling_factor)
          calculate win_size ← ((new_window) + 1)
          set cw_[level] ← win_size
          if (cw_[level] > cwmax_[level])
              cw_[level] = cwmax_[level]
          end if
      end for
   else
   Maintain corresponding CW;
   end if
end for
```

The algorithm shows that a node maintains a fixed threshold value τ_1 for adaptive control of the *CW* size. If a small threshold value τ_1 is set, the algorithm will respond more quickly to the state of the network than when setting a large threshold value. Thus, to ensure the performance of the network, the choice of threshold value τ_1 in *CW* tuning is important.

5. SIMULATION AND RESULTS

In this section, we use a combination of Network Simulator (NS-2.35) [19], SUMO 0.12.3 [20], and MOVE [21] network simulation tools to build simulation scenarios in VANET.

The simulation scenario is designed as a simple circular expressway with an inner radius of 300m, including eight lanes of vehicles going in both directions four lanes in each direction, and a distance between lanes of 5m. 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).

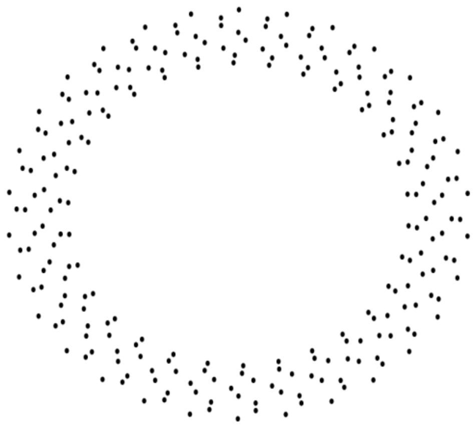

Figure 2. Expressway simulation scenario in VANET

Table 5. 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	500 [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_1	0.05
α	0.8
scaling_factor	2
MAX_PRI	4

Table 6. Priority data flow parameters in a simulation

Message Types	Priority	CW_{min}	CW_{max}	AIFS	Packet size
Accident messages	Priority 1	3	7	2	500 Bytes
Periodic broadcast message	Priority 3	15	1023	6	250 Bytes

As shown in Table 6, to describe closely the actual conditions, we use two classes of Priority 1 and Priority 3 traffic to represent event-driven data traffic. Where Priority 1 is used to transmit emergency messages (accident or emergency vehicles), Priority 3 is used to periodically broadcast the vehicle's status. The packet size for Priority 1 is 500 bytes and Priority 3 is 250 bytes. In the simulations, Priority 1 accounted for 20%, and Priority 3 accounted for 80% of network traffic. The channel is configured using the parameters of the DSRC standard such as the bandwidth is initially set to 6 Mbps, and the frequency being set to 5.9 GHz.

Eight scenarios with variable vehicle density under different network conditions were created to evaluate the adaptive *CW* control algorithm. Each scenario has a consecutive increase of 40 vehicles (5 vehicles/lane) to simulate the VANET network in cases close to real conditions such as low, medium, high, and very high vehicle density. Our densest network scenario shown in Table 7, will have an approximate channel load as calculated by the following equation:

Channel Load = [Number of Vehicles] * [Packet Size] B/pkt * 10 pkts/s * 8 bits/B (5)

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

Table 7. Loading channels for each simulation scenario

Scenario	Number of Vehicles	Channel Load (Mbps)		Total Channel Load (Mbps)
		Priority 1 (20%)	Priority 3 (80%)	
1	80	0.64	1.28	1.92
2	120	0.96	1.92	2.88
3	160	1.28	2.56	3.84
4	200	1.6	3.2	4.8
5	240	1.92	3.84	5.76
6	280	2.24	4.48	6.72
7	320	2.56	5.12	7.68
8	360	2.88	5.76	8.64

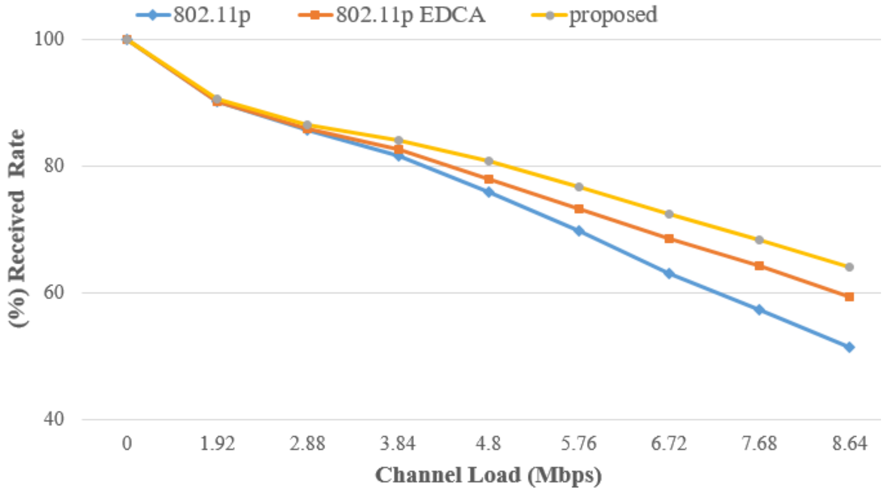

Figure 3. Received rate of all traffic

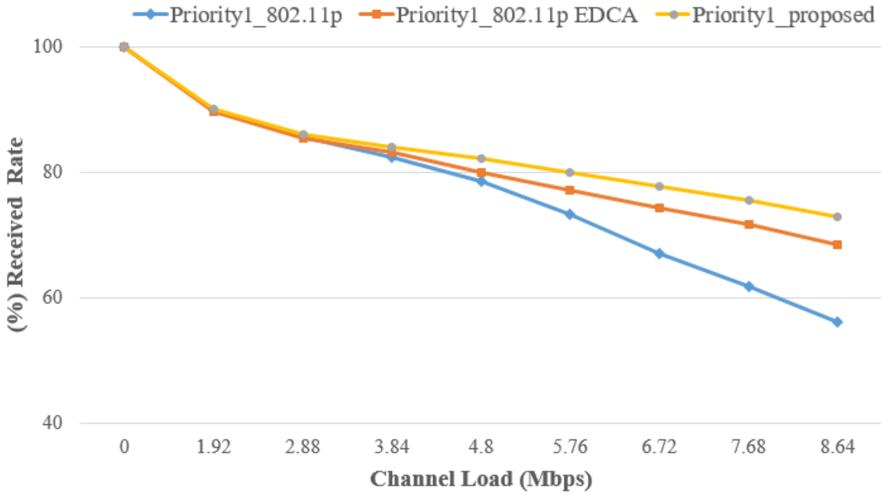

Figure 4. Priority 1 traffic received rate

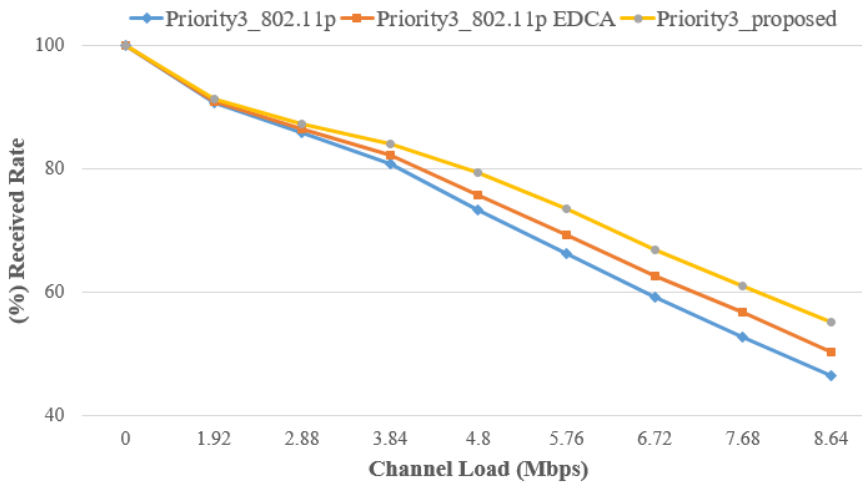

Figure 5. Priority 3 traffic received rate

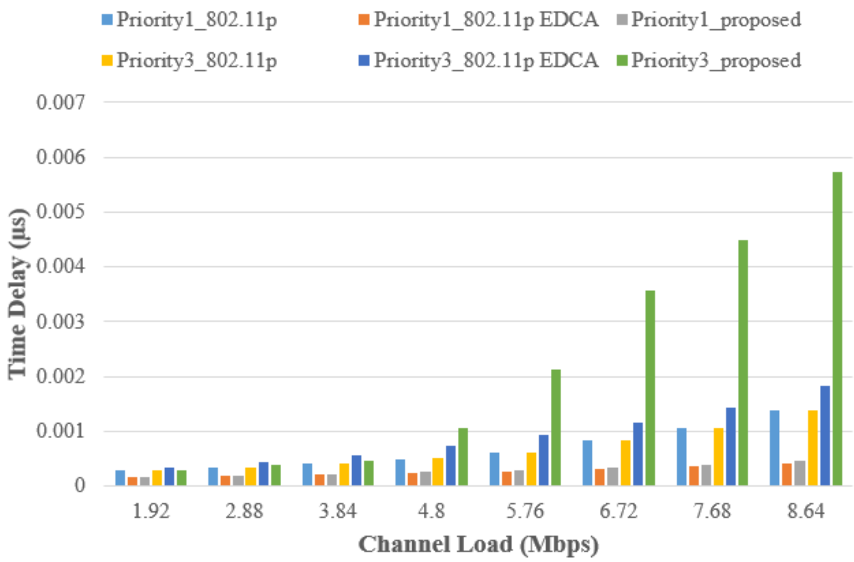

Figure 6. Access delay

The results show that our adaptive *CW* control algorithm has improved the security message received rate compared to the default mechanism in the 802.11p standard. As shown in Table 5, the bandwidth in the VANET is initially set to 6 Mbps. In low channel load, simulation results show that the adaptive *CW* control algorithm has little effect on the message received rate. The main reason is that when the network traffic is low, the message received rate of both the default mechanism and the proposed mechanism is already quite high, reaching approximately 85% - 90%. The access delay of the proposed mechanism in these cases is lower than that of the mechanism in the 802.11p standard.

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. On the other hand, can be noticed when the network traffic increases the difference in received rates between Priority 1 and Priority 3 traffic types also increases. Because our algorithm has adjusted the transmission priority for the messages according to the urgency of the data.

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. The reason for this is that when a node tries its best to transmit it may allow a slot time in the backoff counter to expire before transmission occurs. Thus, increasing the *CW* size when the network traffic is overloaded only leads to an increase in access delay. However, all traffic classes in these cases maintain access delay well below the 100ms target.

6. CONCLUSION

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 proposed mechanism is a combination of a CW size control algorithm and 802.11e EDCA mechanism in VANET. The algorithm controls the CW size for all ACs based on the data received rate in the network. Each vehicle in the network relies on the analysis of recently sent and successfully received frames to calculate the data received rate. The EDCA mechanism is used to prioritize different security messages according to the urgency of the data traffic. The proposed mechanism adds little complexity to the vehicles and does not use additional network resources. Simulation results under different channel load conditions of the network show that the received rate of safety messages is better than the default mechanism in the 802.11p standard. We also noticed an increase in access latency when the network was in a dense state, but still below the latency requirements specified in the 802.11p standard. Our future work will focus on priority scheduling mechanisms to ensure differential between different data flows thereby adjusting CW to changing network conditions.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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