The Cross-layer Message-broadcasting Mechanism for Active Road Safety Application Based on Dynamic Priority

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Abstract -- Nowadays, cooperative ITS is the trend and the focus of the world, which can solve traffic safety problems through data dissemination in Vehicular Ad-hoc Networks (VANETs). Messages generated by different applications have different levels of urgency, thus they should have different priorities and Quality of Service (QoS) requirements. At present, most researches simply prioritize messages based on the message type, and set fixed priorities for messages according to the empirical urgency level. The fixed priority setting cannot adapt to the actual dynamic traffic environment. Therefore, according to the urgency level of different applications, we propose a dynamic priority algorithm and a cross-layer prioritymapping method to implement broadcasting messages with different priorities. In order to reflect more accurate priority of messages timely, several aspects are considered, including the current transportation situation, effective range and multi-hop broadcasting. Then the priority is mapped to the MAC layer in reference to the EDCA protocol. Several parameters in MAC layer are adjusted to provide different QoS levels for different messages. The simulations verify the performance of broadcasting messages with different priorities and the advantages of the proposed broadcasting mechanism.

Index Terms-VANETs, cross-layer design, QoS, dynamic priority

I. INTRODUCTION

ITS is significant for smart city, which can provide safer and more convenient transportation environments. Cooperative ITS, the next generation intelligent transportation systems, focuses on localized vehicle-tovehicle (V2V) and vehicle-to-infrastructure (V2I) communication to support safety, mobility and environmental applications by organizing vehicular ad hoc networks (VANETs). Many active safety applications, such as emergency electronic brake lights, pre-crash warning, cooperative forward collision warning, left turn assistant, lane change warning, can be implemented by broadcasting warning messages timely in VANETs. The messages exchanged in VANETs for active safety can be divided into two categories: periodical beacon messages and event-driven messages, like traffic signal violation warning. The event-driven messages are usually those produced in emergencies or traffic accidents. In VANETs, the messages need to be transmitted to specific hazardous area through data dissemination. When the traffic density is large and the environment is complex, a large number of messages may be produced, for example, emergency electronic brake lights and pre-crash warning. Messages generated by different applications have different communication requirements, like delay, maximum transmission distance and transmission frequency. If all of them are broadcasted in the same way, it must cause serious problems such as packet loss and high delay, which may easily cause the messages of really emergent events not to be delivered with the first priority. The literature [1,13,14] prioritizes the messages of different applications according to the level of urgency. For example, pre-crash warning and cooperative forward collision warning, they need to be transmitted to the nearby vehicles timely, which have strict requirements on delay and reliability of communication. Therefore, those messages with higher priority require better QoS in the broadcast mechanism.

In the research of broadcast mechanism based on priority, Chakkaphong Suthaputchakun et al. [2][3] have done a lot of work. They proposed to use 802.11e EDCA (Enhanced Distributed Channel Access) [7] mechanism to provide different Quality of Service (QoS) for different application businesses in VANETs. Thev used rebroadcasting mechanism to guarantee reliable dissemination, especially for the messages of emergency events. However, the definition of message's priority in this paper is too simple, which does not combine with the actual traffic environment, and does not consider the change of priority during multi-hop transmission in the network. For example, when forwarding the message of cooperative forward collision warning, its importance will reduce with the increase of distance and time. Therefore, the emergency level of safety-related messages should be reassessed and the broadcast strategy should be adjusted accordingly.

In the research of broadcast mechanism based on dynamic priority, the literature [6] put forward a scheduling mechanism based on time-space correlation with dynamic priority. The messages for active safety application in VANETs are sensitive to time and space. This is because with the increase of distance and time during transmission, the urgency degree of safety-related messages will reduce. This paper uses a correlation

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function of time and space to formulate the dynamic characteristics of priority, and uses time and space to limit the range of broadcast. Such dynamic priority mechanism can adapt to the change of urgency degree of safety-related messages and traffic densities. But application class in VANETs is different, so simply calculating priority via time and space has certain limitations, and it is also hard to meet the needs of different applications through the same function. In addition, the calculation of message's priority does not combine with the actual traffic environment, which may cause improper Quality of Service (QoS) guarantee.

When vehicles move with high speed and traffic condition is complex as well, the emergency degree of the same messages will not be the same in different scenarios. For example, when there is no vehicle behind or the speed of the current vehicle is very low, the impact or the damage caused by the event of emergency brake is very small. Therefore, the priority of such messages is relatively low. On the contrary, if there are many vehicles on the road and the vehicle speed is fast, the event of the emergency brake may cause serious accidents. Consequently, the message's priority is relatively high in this environment. Fixed priority setting, therefore, makes message's priority not adapt to the dynamic traffic environment, and easily cause the messages of really emergent events not to be delivered with the first priority.

Combining with the actual traffic environment, we propose a dynamic priority algorithm and a cross-layer priority-mapping method in reference to the EDCA protocol. Based on different application classes, and combining with the current traffic situation through environmental perception, this mechanism provides a more accurate quantification for message's priority. Then the priority is mapped into the MAC layer, and related parameters in MAC layer are adjusted to provide different messages with different QoS levels. The data dissemination based on dynamic priority gives a possible solution to the safety problems in traffic system, which can provide smarter transportation.

This paper is organized as follows: Section II describes the dynamic priority calculation algorithm, including the dynamic priority algorithm when messages being produced, the dynamic change of priority with time and distance, and the dynamic priority in multi-hop transmission. Section III describes the strict cross-layer priority-mapping method referring to the 802.11e EDCA [7] mechanism and an optimized broadcast mechanism is proposed. In section IV, the simulations verify the performance of the advantages of the broadcasting mechanism proposed in this paper. The last part makes a conclusion.

II. DYNAMIC PRIORITY CALCULATION ALGRITHM

Firstly, we assume that all vehicles are equipped with GPS. Each vehicle is supposed to broadcast and receive beacon messages through the communication module of

DSRC periodically in the process of movement. The messages contain the basic information of the vehicle, including ID, speed, acceleration, position, driving direction and so on. By receiving beacon messages of other vehicles, every vehicle maintains a dynamic updating neighboring table so as to perceive the driving environment in real time.

Effective bandwidth and effective capacity are general models to analyze the capacity of QoS guarantee. The effective capacity can be thought of as dual of the effective bandwidth model [8]. The effective capacity model is proposed to describe the relationship between the QoS constraints and the channel state. This model can be used to accurately estimate QoS metric through some simple channel estimation methods [9]. And the effective bandwidth can model the statistical traffic behavior of arrival queue. In VANETs, the messages, which have harder constraints on delay, are relatively short. And it is difficult to predict the dynamic network environment. Therefore, the node transmits one message after another with work-conserving policy. The ordering of the messages in the arrival queue is thus the key to guarantee the QoS. By using the effective bandwidth model, the QoS problem of VANETs can be formulated as a probability bound [8]:

$$\sup_{t} \Pr\{Q(t) > B\} \le \varepsilon \tag{1}$$

where Q(t) is the length of arrival queue at time t, B is the buffer size, $\varepsilon > 0$ is the QoS requirement parameter, $\sup_{t} \Pr\{.\}$ is the supremum probability of an event.

The buffer size of vehicular node is usually large enough relative to the message length. The messages generated by various applications differ significantly on delay, reliability and validity [11]. Thus the QoS problem in VANETs can be rewritten as:

$$\sup_{t} \Pr\{S(i,t) > B_{it}\} \le U_{it}(.)$$
 (2)

Considering the transmission rate at time t and the delay constraint of message i, The delay bound B_{ii} is the maximum total size of the messages that can be allowed to transmit before message i. According the scheduling scheme S(i,t) gives the sum of the sizes of the messages that will be transmitted before message i in the message queue sorted by the urgency level. The function $U_{ii}(.)$ gives the violation probability of delay bound for message i at time t.

To guarantee the QoS in real environment, the input parameters of U_{it} (.) should include many environment factors [12], such as message type, mean velocity, distance among vehicles, effective distance of message, distance between source and destination, and so on.

Based on the above model, we propose a practical scheduling scheme. Firstly, the QoS requirement is

calculated based on the above mentioned real-time environment parameters in VANETs. And then the QoS requirement maps into the message priority that will be refreshed periodically. Based on a strict priority-mapping method in MAC level, a broadcasting mechanism is proposed to adjust the order of message queue.

A. Priority Calculation of Beacon Messages

The priority of beacon messages is closely related to the urgency degree of them. The existing definition methods of priority are mapping each message to a specific priority based on experience judgement of urgency degree. Those methods are easy to be implemented, but the priority just considers the message itself and ignores the driving environment of the vehicle when it produces the message. However, they are likely to cause inaccurate judgement of priorities. Take the emergency electronic brake lights for example. The priority of the message will varies with different driving environment factors, such as the speed of the vehicle before it brakes, whether there are other vehicles in the rear safety driving distance and how many vehicles there are.

The dynamic priority algorithm (DPA) is based on the probability of accidents which may happen or happen again, and the seriousness of them. The former is judged by vehicular surrounding actual environment. However, the latter takes the urgency degree of messages and current traffic environment into consideration. The algorithm calculates relevant parameters and quantifies them based on the two assessment indexes mentioned above, which can provide more accurate priority for messages. Taking the urgency degree of messages and the actual traffic environment into account, the priority calculation of beacon messages is given below:

$$DP = w_0 \cdot l + w_1 \overline{V} + w_2 \cdot \sum_{i=1}^{N} \left(\frac{d_i}{v_i}\right)^{-1} \quad (3)$$

where DP is the priority of messages, and bigger values of DP represent higher priorities. W_0, W_1, W_2 are weighting factors and $w_0 + w_1 + w_2 = 1.1$ stands for initial priority, which is subject to different message type. Based on experience judgement of urgency degree, the initial value is set by referring [1], which suggests the communication requirement of messages for various application classes. For example, pop-up airbags mean that accidents have happened, the priority is higher than the message of left turn assistant. V is the mean velocity of the current vehicular neighbors, which can be acquired by perceiving the mean velocity of the vehicle itself and the neighbors during the OTI (Observe Time Interval). The status information of the current vehicle itself and its neighbors during the period of OTI will be stored into a queue. When the vehicle produces a message, the mean velocity can be calculated by using those information, as indicated below.

$$\overline{V} = \frac{\sum_{k=1}^{M_k} v_j}{N} \tag{4}$$

where N is the update frequency of neighbor list during the period of OTI, and M_k is the number of vehicles within one-hop communication range and v_j is the velocity.

In formula (3), d_i stands for the distance between message source V_s and vehicle i within one-hop communication range, and v_i is the velocity of vehicle i. N denotes the number of vehicles within the d_s (dangerous spacing) of $V_s.d_s$ is the distance that may collide with other vehicles, and $d_s = \overline{V}\tau$, where τ is a constant value that is decided by response time of drivers, braking time and other factors. $W_2 \sum_{i=1}^{N} (\frac{d_i}{v_i})^{-1}$

calculates the close degrees of vehicles within d_s to V_s , that is to say, the probability of collision. The sum of all the probabilities for the vehicles within d_s stands for the severity of the potential accident.

The first part of formula (3) evaluates the urgency degree of different message type. The second part denotes the mean velocity of surrounding vehicles. It assesses the severity of potential accidents, and the faster the velocity is, the more serious the accidents will be. The last part evaluates the severity by calculating the collision time. Taking the priority of message itself and other factors that affect the driving environment into consideration, the algorithm provides a more feasible method to acquire more accurate quantification for message's priority.

B. The Determination of the Effective Distance of Messages

The standard of cooperative ITS [5] enacted by ETSI (European Telecommunications Standards Institute) defines the transmission range of messages for each application class, which is also called message's effective distance (Effective Distance, ED). The method for determining such distance does not consider the traffic environment of message sources, it may bring security problems during data dissemination that the additional distance may cause network overhead or that the distance is too short to cause messages inaccessible. Taking the emergency electronic brake lights for example, when all the speeds are fast, those rear further vehicles may also have the potential danger, and thus the Effective Distance should be larger; on the contrary, when the speed is slow, the effective distance will be shorter.

In order to calculate the dynamic priority more accurately, the effective distance is calculated as follows:

$$ED = l_d (1 + Sgn(\overline{V} - V).e^{\frac{|\overline{V} - V|}{V}})$$
(5)

where l_d is the initial Effective Distance corresponding to each message, and it can be set according to ETSI. The calculation method of average velocity \overline{V} is the same as the formula (4). V is a standard value which corresponds to the initial Effective Distance, and it can be set referring to current road speed limit. *Sgn* is the sign function. As it can be seen from the formula (5), when the actual vehicle speed is greater than the standard value, the Effective Distance increases.

C. Dynamic Priority in Multi-hop Broadcasting

If one-hop broadcasting range cannot achieve message's Effective Distance during data dissemination, then multi-hop broadcasting is needed. When the relay vehicles far away from the message source forward messages, the urgency degree of messages for the surrounding nodes is bound to be reduced owing to the increase of distance. Thus dynamically adjusting the priority of the message is needed to get the appropriate QoS in the message queue of forwarding nodes. The messages source includes time, location and priority when the messages are generated. The value of DP can be calculated by formula (3). When a forwarding node receives a message, the message's priorities are recalculated at first, as indicated below.

$$DP' = DP.e^{-k\frac{d'}{ED}} \tag{6}$$

where d' is the distance between forwarding nodes and the messages source. k is the proportional coefficient. ED is the effective distance calculated by the formula (5). The forwarding nodes insert the new priority value DP' into the corresponding AC (Access Category) queue, according to the four different value intervals of priority [Pi, Pi+1], $i \in \{0,1,2,3\}$. The attenuation exponent is the ratio of d' to ED rather than simply d', which can accurately reflect the dynamic change of message's priority in different ED and in various traffic environments and thus provide a more accurate message's priority.

III. BROADCASTING MECHANISM BASED ON CROSS-LAYER OPPTIMIZAYION

A. Cross-layer Mapping of Message'S Priority

In distributed VANETs, IEEE 802.11p [7] supports Outside the Context of a BSS (basic services set) mode (OCB) for communication. That is to say, a node can communicate with other nodes without accessing specific BSS, which makes it possible for moving vehicles to communicate with others in ad-hoc networks. As a consequence, IEEE 802.11p [7] uses distributed coordination function (DCF) based on CSMA/CA as its MAC protocol. It regulates that safety-related message should be broadcasted on control channels, and nonsafety-related message should be broadcasted on service channels, and different messages have different priorities. Safety-related messages in various situation also have different urgency degree and OoS requirements. In section II, a method calculating more accurate priority by combining application classes and actual traffic environment is proposed. When controlling medium access, the messages with higher priority need more chance to access channels. This section proposes a strict priority-mapping method in MAC by referring to Enhanced Distributed Channel Access (EDCA) [7] in 802.11e. Based on the existing protocol 802.11e, the method adjusts parameters of mapping and sort queued messages according to their priorities, which can ensure that the messages with higher priority will have more chance to access channels.

1) Parameters of strict priority setting

EDCA differentiates messages into four kinds of FIFO queues according to the importance and urgency degree, which are called Access Categories (ACs). By referring AC index (ACI), application allocates specific AC to every message. Each AC has its own frame sequence and independent parameter set of accessing medium. The set includes parameters of MAC layer: CWmin (Minimum contention window), CWmax (Maximum contention window) and Arbitration Inter-frame Space (AIFS). Parameters of the four ACs are shown in Table 1, where AC[0] has the lowest priority and AC[3] has the highest priority. CWmin and CWmax are used to confine the size of contention window. In addition, AIFS is the specific parameter in 802.11e [7], which stands for the slots that need to be waited before the contention window. Different messages have different AIFS, therefore, the AIFS of messages with higher priority is shorter, which can ensure them to have more chance to access channels compared with messages with lower priority. The value of AIFS is defined as AIFS[i] = SIFS+AIFSNx σ .

TABLE I: PARAMETERS OF THE FOUR ACS IN MAC LAYER

	AC[3]	AC[2]	AC[1]	AC[0]	
CWmin	3	7	15	15	
CWmax	7	15	1023	1023	
AIFSN	2	2	3	7	
AIFSN'	2	5	12	27	

As for parameter setting in standard MAC layer, AC with higher priority has smaller CWmin and AIFSN to ensure them to have more chance to access channels. However, existing setting can't guarantee the QoS requirement. In some cases, messages with lower priority may access channels instead of ones with higher priority. For example, lower priority AC[2] selects 0 as its contention window while AC[3] selects 3. After waiting for corresponding slots, the messages with lower priority access channels successfully. That is to say, the messages with higher priority must wait for service, and thus emergent messages can't be transmitted timely. Therefore,

this paper proposes a new method to calculate AIFS of ACs, as indicated below.

$$AIFS'[i] = AIFS'[i+1] + CWW[i+1], i = 0, 1, 2$$
 (7)

where AIFS [3] = 2 and each new AIFS is shown in Table I. In this case, the minimum sensing time for nodes with lower priority messages is still longer than the sum of the AIFS of higher priority AC and maximal backoff time. The method can avoid conflicting priorities within nodes and ensure higher priority messages to access channels first, so emergent messages can be transmitted timely. Fig. 1 shows the time sequence of strict priority setting.

2) Sorting queued messages based on priority

In EDCA mechanism, messages are assigned to different queues according to their priorities, and each queue has its own AC. However, the traffic environment is very complicated, and there are so many different application classes in cooperative ITS. For instance, the literature [1] illustrates as many as 34 kinds of active safety applications. The existing method that assigning messages with four kinds of priorities can't satisfy the QoS requirements of various applications. When a vehicle needs to transmit many messages at the same time, the delay of emergent messages with high priority may become too long because of waiting. Hence, this paper proposes a message queue mechanism based on orderly priority. In Fig. 2, when new message needs to enqueue, it will be inserted into the queue by calculating the specific priority by using DPA and AC queues are sorted in an ascending order. The method ensures that higher priority message gets access to channels first. Active safety application can acquire channel resource to broadcast messages timely, even in a situation with heavy traffic load and lots of messages queues.







Fig. 2. Message inserts into orderly AC queues procedure.

Cross-layer mapping of message's priority divides the priorities calculated in application layer into four intervals, each of which has its own AC. The application adds corresponding ACI to the message frame, as illustrated in Fig. 3. In MAC layer, messages are inserted into different AC queues based on ACI and priorities, whose priorities are sorted in an ascending order. AC with higher priority has smaller CW and *AIFS*'. The

method of setting strict priority makes sure that messages with higher priority access channels first, even though they choose the maximum contention window. For example, the CW of AC[2] is 0 and CW of AC[3] is 3. After waiting for the same time, queues of AC[2] and AC[3] complete backoff at the same time. Then virtual collision happens inside the node, and the scheduling mechanism of virtual collision selects the higher priority queue to access channels, the lower priority queue for backoff. When nodes accessing channels compete with others, smaller CWmin and *AIFS*' can help reduce collision probability of higher priority message, which can acquire channel source successfully.



Fig. 3. Cross-layer mapping model of message's priority.

B. Broadcasting Mechanism

In order to prioritize messages generated in the application layer and exchange information with the lower layer, the data frame of the application layer is defined as shown in Table II. ID is a unique identifier of message and produced by the timestamp and vehicle ID. DPorigin stands for the original priority of messages. DPcurrent is the message priority that recalculated by the nodes in multi-hop broadcasting. ACI is acquired based on the value of DPcurrent. The range of ACI is from 0 to 3, and 0 represents the lowest priority while 3 stands for the highest priority. ED is the effective distance of message. Loc marks the latitude and longitude of the location where messages are produced. Type is the type of message, corresponding to the application that produced the message. Data stands for the message content.

TABLE II: DATA FRAME OF THE APPLICATION LAYER.

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The broadcasting process of vehicle nodes is shown in Fig. 4.

1) When vehicles encounter unexpected circumstances, an emergency message is produced in application layer. At that time, the mechanism calculates the DP and the ED according to the type of messages and the surrounding traffic environment, and writes the value of DP to the DPorigin field and the DPcurrent field, and writes the type of messages to the Type field. If receives a message sent from other nodes, the vehicle calculates the distance D between its own position and the location where the message produced. If D is greater than ED of the message, then the message will be dropped. If D is less than ED, which means that the message need be broadcasted to other nodes, then it will calculate the dynamic priority DPcurrent according to the DPorigin and the ED.

2) According to the value of DPcurrent in the frame, calculate the corresponding priority interval of AC, and thus get the corresponding ACI.

3) In MAC layer, messages are inserted into different AC queues based on ACI and priorities, whose priorities are sorted in an ascending order.

4) Messages compete to access channels according to the strict priority parameters set at MAC layer, and are broadcasted while channel resource is acquired.



Fig. 4. Flow chat for broadcasting messages based on dynamic priority

IV. SIMULATION AND PERFORMANCE

In order to evaluate the performance of the proposed broadcasting mechanism based on dynamic priority, we simulate the broadcasting of different priorities and analyze the results by using the joint simulation tools VISSIM and NS3.

A. Simulation Settings

We simulate highway scenarios with different vehicular density in a 3km bidirectional road with 4 lanes.

The velocity range is from 60km/h to 130km/h. To avoid edge effects, we select the simulation results from the middle 1km to evaluate the performance. By referring to the parameters of the physical layer and MAC layer in IEEE 802.11p [7], we modify relevant parameters to set priorities for messages, including the transmitting power of physical layer, contention window and AIFS of MAC layer. Specific parameters are listed in Table III.

TABLE III: SIMULATION PARAMETERS.

PARAMETER	VALUE	
Communication protocol	IEEE 802.11p [7]	
Central frequency	5.890GHz	
Channel bandwidth	10MHz	
Propagation model	Nakagami	
Length of minimum slot	13us	
SIFS	32us	
Propagation delay	1us	
Date rate	6Mbps	
Message rate	10 packets/s	
Packet size	1000 Bytes	
Vehicle speed	60 - 130km/h	
Vehicular density (normalized)	0.1 - 0.9	

B. Performance Analysis

We use two metrics to analyze the performance of the proposed broadcasting mechanism. The first metric is the end-to-end average delay which means the average time the packets need to be transmitted from the source node to the destination node. In addition, the delay includes the latency time in queue, competition time of accessing channels and propagation time, etc. The second one is the packet successful transmission ratio.

$$D = \frac{\sum_{i=0}^{N} (rt_i - st_i)}{N} \tag{8}$$

where N stands for the number of messages which are successfully transmitted. rt_i and st_i represent the time when the message is successfully received and the time when it's produced, respectively.

1) Performance comparison between strict priority setting and standard priority setting

Fig. 5 depicts the end-to-end average delay of the proposed strict priority setting and the standard priority setting of EDCA [7] in IEEE 802.11e. The delay results derive from the scenario that the vehicular normalized density is 0.7. As can be seen from the figure, the higher the message priority is, the less the end-to-end delay is. Messages with higher priority can continue to be transmitted during the process of the internal competition, and access channels as soon as possible. By comparing the performance of the two mechanisms, we can find that AC[3] and AC[2] in strict priority setting have smaller end-to-end delay than those in standard priority setting.

That is because that strict priority setting increases the gap of AIFS to make sure that higher priority messages access channels first, and avoids the completion with low priority messages resulting from the selection of contention window. On the other hand, the AIFS of low priority messages increases. They are strictly limited to access channels with more time, with the result that the delay is longer than that of standard protocol. The proposed method can ensure that higher priority messages, which are usually very urgent, are forwarded to other nodes at lower latency, so that the vehicles located in hazardous zone can receive the message in time and take appropriate measures to avoid accidents.



Fig. 5. The end-to-end delay comparison between strict priority setting and standard priority setting.

2) Performance comparison of different AC in strict priority setting



Fig. 6. The end-to-end delay various scenarios.

Fig. 6 describes the comparison of end-to-end delay of those including all priorities of messages in the strict priority setting. We can see that the end-to-end delay of messages with different priorities increases as the increase of vehicle density. Especially, the delay of AC[0] messages has a marked increase when the number of vehicles are too sparse. If the traffic becomes congested, the network load increases and the channels become busy. Due to the strict priority setting, lower priority message will not compete with higher priority messages if they happens to be transmitted at the same time, which results in more chance to access channels for higher priority messages. At the moment, lower priority messages will wait for some time and try to access channels again. When finding that channel is idle, because of the bigger AIFS and contention window, the channel is likely to be occupied by higher priority messages again after the waiting time. Thus they may have to wait more time to acquire channel resource. However, for higher priority messages, such as AC3, smaller AIFS and contention window make them have more advantages during the process of external competition and internal competition, so they can access channels and be transmitted quickly. Therefore, the delay of higher priority messages is smaller. As shown in Fig. 6, under the circumstance of diverse traffic density, the delay of AC[2] messages is below 25ms, while the delay of AC[3] messages is below 10ms, which can meet the communication requirement of safety-related messages.

We also introduce the packet successful transmission ratio as a metrics to reflect the broadcasting performance of different priorities in strict priority setting. As shown in Fig. 7, the packet successful transmission ratio of messages with different priorities declines with the increase of vehicular density. There is no doubt that the network load and the probability of message collision increase due to the increase of traffic density. The higher the priority is, the higher the packet successful transmission ratio is. Messages with higher priority have advantages while competing for channel resource. So they can occupy more resource and be transmitted successfully as soon as possible. Fig. 7 shows that the packet successful transmission ratio of AC[3] achieves 60% even if the traffic density reaches maximum, and thus ensure reliable transmission of emergency messages with higher priority.



Fig. 7. Packet successful transmission ratio in various scenarios.

3) Performance comparison between fixed priority and dynamic priority

In order to verify the effect of the proposed dynamic priority algorithm on communication, we compare the performance by calculating dynamic priorities with formula (3) and setting parameters of the MAC layer. We assume that the initial priority I is AC[2], and w_0, w_1 , w₂ are 0.5, 0.2 and 0.3, which means that message type plays a more important role in priority. Fig. 8 shows the simulation results. It can be seen that the end-to-end delay of dynamic priority is larger than that of fixed priority when traffic density is low. This can be explained that when the vehicles are sparse, maybe there are only a few vehicles nearby. Under the circumstance, the sphere of influence of emergency event is very small, so the urgency degree decreases, and the priority decreases as well. With the increase of traffic density, the gaps among vehicles become smaller. However, the traffic is still smooth and vehicles move very fast. In this case, emergency events will have a serious effect on nearby vehicles, which mean that the message priority is higher than fixed priority. As a consequence, the average delay is smaller. Fig. 8 shows that when the traffic density is 0.6, the average delay is even smaller than that of lower density. With the further increase of traffic density, the traffic may become congested and the vehicular speed may slow down, and thus the urgency degree of emergency event also decreases. However, the sphere of influence is still very large, which is easy to cause serial accidents. Hence the priority is higher than fixed priority, and the delay is relatively smaller. Through comparative analysis, it can be seen that dynamic priority algorithm can acquire more accurate priorities based on actual traffic environment and provide better QoS for safetyrelated messages.



Fig. 8. The end-to-end delay comparison between dynamic priority and fixed priority.

V. CONCLUSION

Considering that the messages of different application classes have different priorities, which will change as traffic environment varies, and the messages with different priorities also need different QoS guarantee during transmission, a cross-layer broadcasting mechanism based on dynamic priority is proposed in this paper. Based on different application classes, and combining with the current traffic situation through environmental perception, this mechanism analyzes the effective range and the dynamic change of importance and emergency level of safety-related messages with time and distance, and thus provides a more accurate the message priority quantification for during transmission. The next steps for data dissemination based on dynamic priority include: transfer more accurate priority information timely to the MAC layer through the cross-layer mapping, and configure the strict priority setting referring to the EDCA mechanism [7] defined in 802.11e, and insert such messages into the ordered Access Category (AC) queue, and finally adjust the parameters of packet scheduling in the MAC layer according to the priority level. Simulation experiments show that the proposed broadcasting mechanism based on dynamic priority can adjust the message priority as traffic environment changes, with the result that higher priority messages can get shorter average end-to-end delay and higher packet delivery ratio. In particular, the messages of emergency events with the highest priority can get the best communication performance, and meet the transmission requirements of active road safetv applications in terms of low delay and high reliability, which help provide a safer traffic environment.

REFERENCES

- DSRC Committee of the SAE. PA 1596-001 (SAE J2735-2009) Dedicated Short Range Communications (DSRC) Message Set Dictionary. SAE: Society of Automotive Engineers, Oct. 2009, pp. 230-235.
- [2] C. Suthaputchakun, "Priority based inter-vehicle communication for highway safety messaging using IEEE 802.11e," *International Journal of Vehicular Technology*, vol. 2009, p. 12, 2009.
- [3] C. Suthaputchakun and Z. Sun, "Priority based routing protocol with reliability enhancement in vehicular ad hoc network," in *Proc. International Conference on Communications and Information Technology*, June 2012
- [4] J. R. Gallardo, D. Makrakis, and H. T. Mouftah, "Performance analysis of the EDCA medium access mechanism over the control channel of an IEEE802.11p WAVE vehicular network," in *Proc. IEEE International Conference on Communications*. 2009, pp. 1-6
- [5] F. Hrizi and F. Filali, "On congestion-aware broadcasting in V2X networks," in Proc. IEEE International Conference on Ultra Modern Telecommunications & Workshops, 2009, pp. 1-8.
- [6] J. Sun, "A dynamic priority based scheduling and congestion control for the safety message of vehicular adhoc networks," Master thesis, Xian, 2012.
- [7] IEEE Std 802.11TM: 2012, IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications
- [8] S. Ren and K. B. Letaief, "Maximizing the effective capacity for wireless cooperative relay networks with QoS

guarantees," *IEEE Transactions on Communications*, vol. 57, no. 7, pp. 2148-2159, 2009.

- [9] E. Kafetzakis, K. P. Kontovasilis, and I. Stavrakakis, "Effective-capacity-based stochastic delay guarantees for systems with time-varying servers, with an application to IEEE 802.11 WLANs," *Performance Evaluation*, vol. 68, pp. 614-628, 2011.
- [10] D. Wu and R. Negi, "Effective capacity: a wireless link model for support of quality of service," *IEEE Transactions on Wireless Communications*, vol. 2, no. 4, pp. 630-643, 2003.
- [11] F. Cunha, L. Villas, A. Boukerche, G. Maia, A. Viana, R. A. F. Mini, and A. A. F. Loureiro, "Data communication in vanets: Protocols, applications and challenges," *Ad Hoc Networks*, vol. 44, pp. 90-103, 2016.
- [12] S. Zeadally, R. Hunt, Y. S. Chen, A. Irwin, and A. Hassan, "Vehicular ad hoc networks (vanets): Status, results, and challenges," *Telecommunications Systems*, vol. 50, no. 4, pp. 217-241, 2012.
- [13] X. Li, F. Liu, and N. N. Van, "Enhanced channel estimation algorithm for dedicated short-range

communication systems," *Telkomnika*, vol. 13, no. 3, pp. 870-879, September 2015.

[14] X. Li, F. Liu, and N. N. Van, "Improved detection metric and oversampling-based frame detector for DSRC receiver," *Journal of Engineering Science and Technology Review*, vol. 9, no. 2, pp. 146-153, 2016.



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