Improving Safety Messages Dissemination in IEEE 802.11e Based VANETs Using Controlled Repetition Technique

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***Abstract*— Vehicular ad hoc networks (VANETs) have been proposed to provide safety and non-safety services for the passengers on board. Reliability in broadcasting of safety messages is one of the fundamental challenges in the design of such networks. In this paper, we study the impact of employment of repetition and piggybacking techniques on the performance of safety messages dissemination in an IEEE 802.11e-based VANET. The adequacy of the proposed techniques has been evaluated by a simulation. The results of this simulation show that the performance of VANET improves by setting proper parameters and the number of repetitions per priority class. Further, controlling the number of repetitions by piggyback technique can highly improve the performance of VANET for broadcasting of safety messages.**

Keywords- VANETs; Safety messages; IEEE 802.11e; Repetition Technique; Piggyback Technique (Controlled Repetition Communication).

I. INTRODUCTION

Vehicular ad hoc Networks are forms of mobile ad hoc network, which provide communications among vehicles or between vehicles and fixed roadside equipments. VANETs are equipped with short-range to medium-range communication systems and their prospective applications include safety and comfort applications which share the wireless channel with mobile applications from a large, decentralized array of service providers. Examples of vehicular safety applications include collision avoidance, lane changing assistant and other safety warning services. Non-safety applications include traffic congestion avoidance, alternative route proposal, high-speed tolling and mobile infotainment. Due to the VANETs unique characteristics, such as scalability, high robustness expectation, strict delay requirements and security issues, the design of such a technology becomes an extraordinary challenge for the wireless research community.

As a standardization approach, Dedicated short range communication (DSRC) standard licensed 75 MHz of frequency spectrum at 5.9 GHz band to support low-latency wireless data communications among vehicles and from vehicle to roadside units in USA [1-3]. Essentially, DSRC radio technology is based on IEEE802.11a which is adjusted for low overhead operations in DSRC spectrum and is being standardized as IEEE802.11p [2-4]. Due to the highly dynamic topology and the stringent delay requirements, safety applications usually need a one hop ad hoc communication [5]. In the following, we review some of the available studies on MAC layer which tackle the reliability issues in the message disseminations in VANET.

In [6], the authors propose several single-hop broadcast protocols to improve reception reliability and channel throughput. Torrent-Moreno *et al.* [7] proposes a priority access scheme for IEEE 802.11-based vehicular ad hoc networks and show that the broadcast reception probability can become very low under saturation conditions. Jiang *et al*. [8] raises channel congestion control issues for vehicular safety communication, and introduce feedback information to enhance system performance and reliability. ElBatt *et al*. [9] discusses the suitability of DSRC periodic broadcast message for cooperative collision warning application. None of the above studies consider a message priority scheme. [10-13] are among those few studies which consider message priorities in their analysis. In [10], the authors proposed priority Carrier Sense Multiple Access (P-CSMA) and polling P-CSMA (PP-CSMA). However, the protocol is not compatible with the IEEE 802.11 and IEEE 802.11e standards. In some recent papers, such as [11], repetition techniques are proposed for priority-based scenarios; however no optimized value is derived for the number of transmission repetitions. In fact, a high number of repetitions increase the collisions in the network, and as a result, the performance of the network degrades. In [12], the authors propose the piggyback cooperative idea for controlling the collision rates. In [13], we considered a controlled repetition technique for car-to-car and car-to-infrastructure communications in a network with a fixed number of vehicles. In that study it has been shown that using this framework we can provide better reliability for important safety messages in VANETs.

This work extends the results of [13] in several directions. First of all, we enhance the repetition-based broadcasting mechanism by applying a piggyback technique

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for the dissemination of safety messages based on an IEEE 802.11e medium access protocol with three priority classes. As a result, the messages with higher priorities are transmitted with lower latency and they gain better reliability in comparison with the lower priority messages. Second, we assume that the vehicles are distributed according to a Poisson process in the network under consideration which is closer to reality [14]. Further, we control the number of repetitions with adding one byte overhead to the data frame in car-to-car mode. We also analyze the average end-to-end delay for the three safety message priority classes.

The result of the simulation reveals that the applications of the proposed methods improve the main performance measures of the network, such as throughput and end-to-end delay significantly.

The reminder of this paper is organized as follows: Section II briefly reviews the DSRC communication system and environment, specifies requirements for the safety-Related communication, and presents IEEE 802.11e EDCA MAC protocol in conjunction with repetitive transmissions by applying piggyback technique; Section III, describes the network model and the proposed framework; Section IV presents the results of the analysis. Finally, some conclusion remarks are given in Section V.

II. DSRC System Description and solution to safety message broadcast

The 5.9 GHz DSRC channel is expected to support high speed, short-range wireless interface between vehicles, and surface transportation infrastructure, as well as to enable the rapid communication of vehicle data and other content between on board equipment (OBE) and Roadside Equipment (RSE). The DSRC spectrum consists of seven 10 MHz channels that include one control channel and six service channels. Channel 178 is the control channel, which is reserved for safety communications [2][3]. The DSRC physical layer uses an orthogonal frequency division multiplex (OFDM) modulation scheme for data multiplexing. The DSRC physical layer adopts the same frame structure, modulation scheme, and training sequences as in IEEE802.11a physical layer. However, DSRC applications require reliable communications among OBEs and between OBE and RSUs, as vehicles are moving with the speed of 120 miles/hour and their communication ranges are up to 1000 meters. According to the updated version of the DSRC standard, the MAC layer of the DSRC standard adopts 802.11a MAC layer specifications with minor modifications. As a result, it uses a carrier sense multiple access with collision avoidance (CSMA/CA) mechanism for all associated devices in a cluster. In 802.11a MAC protocol, the fundamental Mechanism for medium access is the distributed coordination function (DCF). DCF is meant to support an ad hoc network without the need of any infrastructure element; however it is not able to provide predictable quality of service (QoS).

In order to provide QoS, the content of a message is an important factor to specify the message priority. Messages which contain safety information should be transmitted faster with a higher reliability. Thus, we use IEEE 802.11e, which is based on message priority as our preferred MAC protocol. IEEE 802.11e EDCA MAC [1][2] protocol uses Arbitrary Inter-Frame Space (AIFS) and Contention Window (CW) to provide QoS for different categories of traffic, such as voice, video, best Effort and background. IEEE 802.11e EDCA MAC protocol provides proportional service differentiation in VANETs in terms of delay by prioritizing messages. High-priority messages wait for shorter AIFS and CW periods which lead to a higher probability of channel access and faster message transmission.

The reliability of safety message dissemination is another challenging issue in IEEE 802.11e broadcast mode. In other words, the use of broadcast communication with no feedback mechanism, such as RTS/CTS and acknowledgement results in lower transmission reliability, as the communication becomes more sensitive to interferences such as collisions and hidden terminal activities [14]. Employment of a repetitive transmissions mechanism can significantly compensate the above deficiency by retransmitting the high-priority messages repeatedly. With this mechanism, the networks can be initialized on the fly without requirement of an infrastructure unit. Although this method improves the performance of VANET in terms of throughput and reliability, sometimes collision will be increased due to the repetition and it results in a lower throughput. To solve this problem, we propose piggyback technique (controlled message repetition method) along with the optimization of the number of transmission repetitions.

In this method we control the message repetition in the network by adding 1 byte header to the message's frame. Each vehicle that receives a message, checks the frame slot. If the header slot is less than defined value of Max_Rep, then it will increase the header slot value and message will be repeated. In the contrary, if the header slot is equal or greater than the predefined value of Max_Rep, the message will be piggybacked. This technique controls the number of repetition for each safety message in VANET. We also present a scenario to find the optimized value of Max_Rep and test our method.

III. Network model and Proposed Framework

In this study, we focus on a Differential Services mechanism to differentiate messages based on their priorities as suggested in IEEE 802.11e. Our modeling adopts the following assumptions. i) We consider a highway where vehicles are exponentially distributed and travel in a free-flow condition. The vehicles move along a one-dimensional highway. Further, they consist of a collection of statistically identical mobile stations which are randomly located on a line. ii) Vehicles are placed on the line according to a Poisson process with network density β (in vehicles per meter). iii) The communication safety messages have few hundred bytes and have three priorities according to the following: Pri(1) is defined as a Accident type, pri (2) is defined as a warning message and pri(3) is defined as a general message.

We let the messages to be transmitted repeatedly where the number of repetitions is assigned based on the priority of a message. To increase the probability of a successful transmission for high priority messages, a high priority message is transmitted more times than a lower priority one. to control the message collision levels resulted from repeated transmission, we propose a piggyback technique. This technique controls the number of repetition for each safety message in VANET. In this method, we add one byte overhead over data frame in MAC layer. Each vehicle checks this field when it receives the message. In order to investigate the efficiency of this proposal, we perform a simulation with the following considerations: We map each priority level of safety messages to a different traffic class. In all vehicles, there will be three different queues for each priority with a virtual collision handler, which handles the internal collision. Each priority class is identified by the following relevant parameters: Minimum contention window size (CW min[i]), maximum contention window size (CW max[i]), arbitrary inter-frame space contention widow size (CW (AIFS[i]), transmission opportunity (TXOP[i]), and number of repetitions (Table 1). After that, we want to improve the performance and reliability of the system with controlling the number of repetitions. Controlling of repetitions is done by piggybacked byte over current message. In this mechanism, each vehicle that receive a message, checks the frame slot. If the header slot is less than defined value of Max_Rep, then it will increase the header slot value and message will be repeated. In the contrary, if the header slot is equal or more than defined value of Max_Rep, the message will be piggybacked.

TABLE I. PRIORITY PARAMETERS

Priority	CWmin	CWmax	AIFS	Number of packet repetition
First (Highest)	CWmin/4	CWmax/2	2	X
Second	CWmin/2	CWmin	3	1
Third	CWmin	CWmax	3	1

IV. PERFORMANCE ANALYSIS AND SIMULATION SETUP

In this section we present two scenarios to examine our method. First, we simulate a scenario to test the repeated transmission in VANETs and find the optimum number of repetitions in car-to-car mode. Second, we examine our framework in controlling number of message repetition in the network, in car-to car mode. As the safety messages with pri(1) are the most important messages, most of the results are due to them.

A. Vanet Performance Based on IEEE802.11e With Repetition Technique

As mentioned in III, we use repetition-based communication to cope with BER of wireless networks and increase the reliability of highest priority messages. We observe that increasing the number of repetitions in the network results in reliability improvement, however after a certain value, it

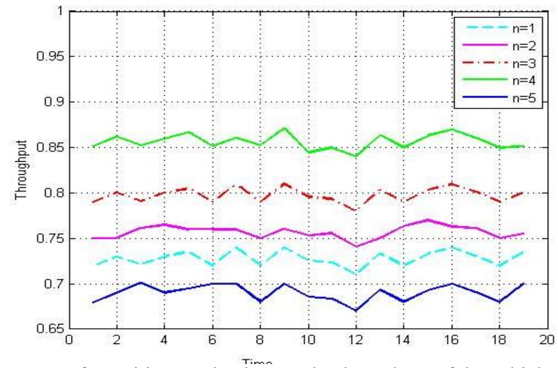

Fig. 1. Impact of repetition mechanism on the throughput of the vehicle to vehicle communication with vehicle density 100vahicle/km

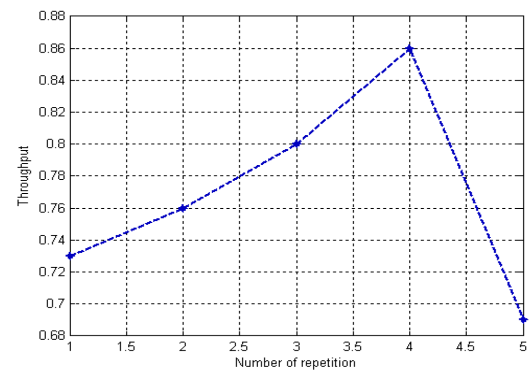

Fig. 2. Performance of the VANET versus number of repetition with vehicle density 100vahicle/km

degrades the throughput as a result of higher collision rates in the network. Thus, we simulate a scenario to find the optimum number of packet repetition. In the first scenario, each vehicle moves on the road with average velocity of 90 kilometer per hour in one direction. Each vehicle on the road is equipped with DSRC wireless ad hoc network capability. The control channel is exclusively used for safety-related broadcast communication. Transmission range of each vehicle is 700 meter.

To validate the proposed model, we developed a simulation program in NCTUNS Ver. 5.0 [15]. Fig. 1 shows the throughput of the pri(1) messages as a function of time with number of repetition as a parameter for vehicle density of 100 vehicle/km. The result shows that increasing the number of repetitions improves the performance of the system until it reaches to 4 repetitions from where the throughput degrades suddenly. This phenomenon is also shown in Fig. 2 for the throughput of the system as a function of repetition value. This means that by repeating the packet we overcame the BER issue of the network and the reliability of highest priority message increases, however, after four repetitions of each packet, the collision would be the dominant factor and throughput decreases. As a result, the optimum number of packet repetition with then given network parameters is four. Fig. 3 shows the impact of various numbers of repetitions on the average end-to-end

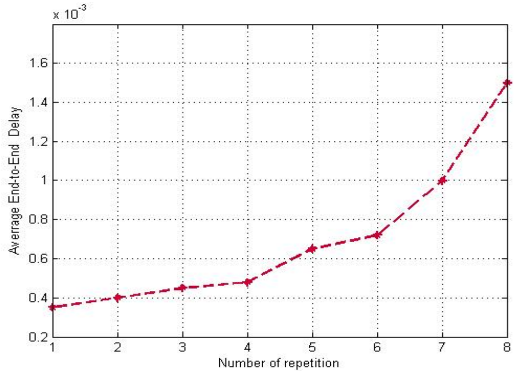

Fig. 3. Average delay of Pri1 as a function of the number of repetitions With Vehicle density 100vahicle/km

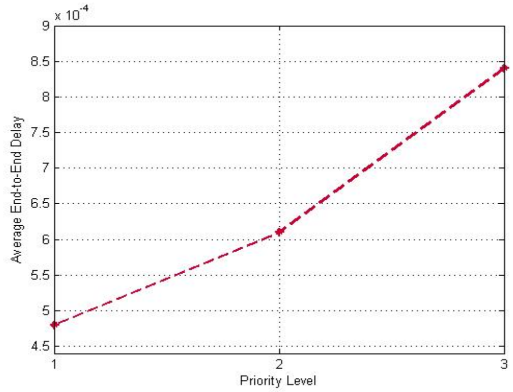

Fig. 4. Average delay of 3 priorities with fixed number of repetition 4 with Vehicular density 100vahicle/km

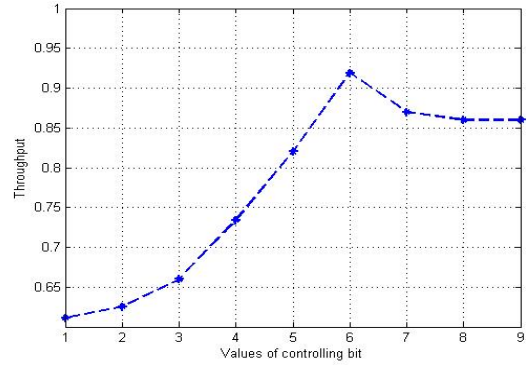

Fig. 5. Impact of controlling mechanism on the system with repetition 4 and different value of controlling header with Vehicular density 100vahicle/km

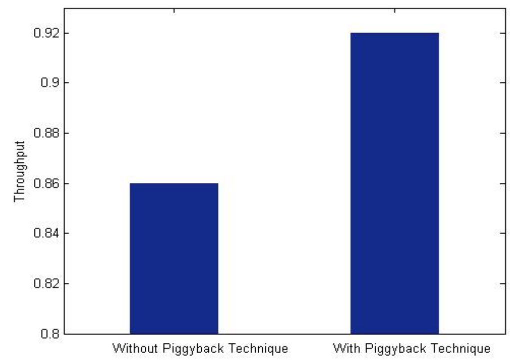

Fig. 6. Comparison between the performance of the controlled system and system without controlling mechanism with number of repetition 4 with Vehicular density 100vahicle/km

delay of pri(1) messages as a function of number of repetitions. As it may be seen, once the number of repetitions increases, the average delay increases. We find that a larger number of repetitions can increase the delay because of the larger transmission time.

Fig. 4 presents the average delay for each priority classes as a function of different priority levels. It shows that the average delay of highest priority is maxima, as according to EDCA priority scheme, the highest priority faces with the lowest delay and the lowest priority faces with the highest delay.

B. VANET Performance Based on IEEE802.11e With Repetition and Piggyback Technique

In this part we evaluate method of controlling message Repetition (Piggyback mechanism), which was explained in III. We use the IV.A topology for this simulation. We simulate the scenario while six cars except the first car repeat each packet of the message (with the highest priority) for four times. Other cars in the scenario do not broadcast the message. We have also tested this method with 1 to 5 and 7 to 9 cars, instead of six. We achieved higher throughput in the monitored car when there was only six cars except the main cars repeating the message. Thus, the the Max_Rep value is six. After finding the maximum message repetition, we simulated IV.A with six cars (except the first car) repeating each packet of the message with the highest priority four times while other cars did not repeat the message. This setting decreases the collision in the network. As a result a better throughput is achieved.

Fig. 5 shows the impact of piggyback mechanism (controlled message repetition method) on the performance of the system. We see that when the value of piggyback mechanism equals to 6, the best performance is obtained.

Finally, Fig. 6 shows the comparison between the performance of the controlled system and system without controlling mechanism. As it may be seen, the application of controlled message repetition method (piggyback technique) in the network increases the throughput of the monitored vehicle compared with the other vehicles which do not use this method. This phenomenon is a result of controlling the collision by piggyback technique.

I. Conclusion

In this paper, we considered a VANET scenario with DSRC standard which includes three classes of safety-related services. We evaluated the main performance measures of the system, i.e., throughput and delay when repetition and piggyback techniques are employed. The results of the simulation show that:

- Repetition technique can enhance the performance of the safety vehicle to vehicle (V2V) communications.
- A larger number of repetitions can improve the performance of the system; however there exists an optimum value for repetitions. This is due to the fact that a larger number of repetitions leads to higher collisions in the system.
- Piggyback technique (controlled message repetition method) can improve the performance of the system by controlling the collision phenomenon. Also there is an optimum value for piggyback header.

This study shows the importance of employments of repetition and piggyback techniques and that it can overcome the lack of handshaking procedures in transmissions of high priority messages in VANETs.

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