Enhanced Self-sorting Based MAC Protocol for Vehicular Ad-Hoc Networks

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Abstract. Self-sorting based MAC protocol by Zhongyi Shen is proposed to improve the performance of safety application in high density Vehicular Adhoc Networks (VANETs). The protocol, however, has not taken into account the mechanism for control message transmission of service application. This paper proposed an access mechanism that enhances the self-sorting protocol in the aspect of effective time usage for safety application and incorporates the mechanism for service application transmission. The proposed protocol's performance is investigated through comparing with self-sorting protocols and others in various network scenarios.

Keywords: VANETs · Multi-channel MAC · TDMA · Queuing

1 Introduction

Vehicular Adhoc Networks (VANETs) have drawn lots of attention since it is the key component to develop the Intelligent Transportation Systems. VANETs define two applications: safety and service applications. Safety application is related to safety on the road; for example the alert of dangerous driving situations or traffic condition. Due to its characteristics, safety application needs to be guaranteed on packet delivery ratio and bounded delay. Service application is infotainment related and demands more on throughput. 75 MHz in the 5.9 GHz band are allocated for the Dedicated Short Range Communication. The overall bandwidth is divided into seven channels, in which, one Control Channel (CCH) for safety application and control messages of service application transmission, and six Service Channels (SCHs) for the transmission of service application. The medium access mechanism on those channels follows IEEE 1609.4 and IEEE 802.11p standards.

2 Related Works

The original IEEE 1609.4 [1] is developed as a synchronized protocol. In IEEE 1609.4, time consists of 100-ms-sync intervals, each is equally divided into a control channel interval and a service channel interval. CCH is permitted to use

during control channel interval; six SCHs are permitted to use during service channel interval. With this access mechanism, IEEE 1609.4 has a lot of disadvantages in performance and resource utilization. As many issues have been confirmed for the IEEE 1609.4 standard, a lot of research works on MAC protocol for VANETs have been conducted. VeMAC [9], a TDMA based multi-channel protocol, assigns disjoint sets of time slot on CCH for different direction moving vehicles and for road side units in order to reduce the rate of access and merging collisions. Enhancing VeMAC in case of unbalanced traffic, a decentralized adaptive TDMA scheduling protocol (DATS) [7] has been proposed. DATS protocol allows the disjoint sets of time slot to be adjustable according to the network traffic. Combining TDMA and CSMA access schemes to improve the safety message broadcast performance, CS-TDMA [12] dynamically adjusts the ratio between CCHI and SCHI on CCH for better utilization of channel resources. Also using a combination scheme, HER-MAC [3] divides time into 50-ms-SI, which include adjustable reservation periods (TDMA based) and contention periods (CSMA based). HER-MAC guarantees a collision free safety message transmission, and exploits the SCH resources during CCH interval. A cooperative scheme, which enables the help of vehicle node relaying packets to the destination, is used in CAH-MAC [2] to improve the network throughput. As CAH-MAC is a single channel protocol, RMSB-MAC [6] is designed for multiple channels. RMSB-MAC introduces Multihop Forwarders (MF) for multihop transmission. Incorporating the cooperative scheme in a different way, CER-MAC [4] allows nodes to borrow unused time slots of their neighbors or reserve available time slots to broadcast safety messages. Dynamic-cooperative MAC (DC MAC) protocol [8] distributes time slots over a virtual frame. Under different nodes' point of view, contention period on the CCH in DC MAC is vary from node to node to solve the synchronized collision problem.

A lot of MAC protocols, both synchronous based and asynchronous based, are proposed for VANETs to achieve more reliability for safety application and higher throughput for service application. Self-sorting protocol [10] is asynchronous and specifies for safety application in high density VANETs. The protocol proposed in this paper inherits the queuing process of the self-sorting protocol in a way that will enhance the self-sorting protocol on the aspect of effective time usage. The proposed protocol also incorporates the mechanism for service application. In comparison with other protocols, the performance analysis in this paper is done with IEEE 1609.4, self-sorting protocol, the proposed protocol and dynamic-cooperative MAC protocol [8] since it is an asynchronous based protocol.

The rest of this paper is organized as follows: Sect. 3 describes the proposed protocol in details, the performance analysis and evaluation is in Sect. 4. Then Sect. 5 comes the conclusion.

3   Protocol Description

In this paper, each vehicle in the network is referred to as a node. Each node is equipped with a half-duplex transceiver and a GPS that are very common

in nowadays vehicles. Time on control channel consists of 100-ms-sync-intervals, each interval includes three periods: queue formation, channel reservation and slotted TDMA as in Fig. 1. Six service channels are also timely slotted with fixed duration.
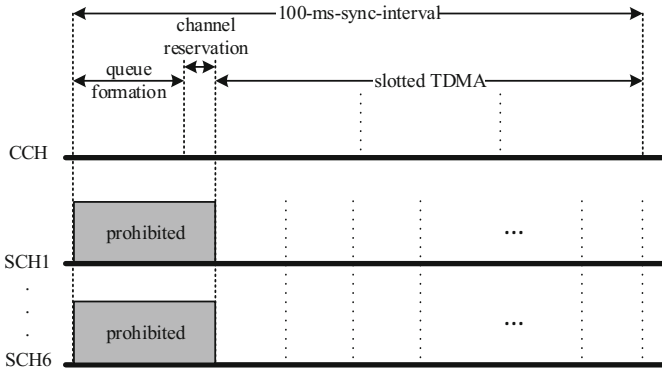

Fig. 1. Time on control channel.

With respect to the time manner mentioned, the proposed protocol has the following phases:

– Queue formation: dividing nodes into groups/queues based on their physical locations and collecting safety messages of the queue members.
– Channel reservation: reserving control channel for the whole queue.
– Safety message forwarding and WSA handshaking: forwarding safety messages of the whole queue and exchanging WSA handshakes for service messages of the queue members. This phase is done during the slotted TDMA on control channel.
– Service data transmission: transmitting service messages on service channels.

3.1 Queue Formation

– QH declaration messages and end-queue messages are transmitted with range $R/2$, which is one half the regular transmission range R
– Safety messages and ACK during queue formation phase are transmitted with range $R/2$. Two adjacent QH nodes will be in the distance R of each other.

Upon the start of queue formation interval, a node with safety packet in its buffer will send a queue head (QH) declaration message if there has not been any queue sensed in its range. The QH declaration message contains the node ID and a sequence number 1 as stating that there has only one member in the queue [10]. During a timeout, τ_{out}, right after the sending of QH declaration message, if QH node does not receive any safety message from other nodes to join its queue or it receives messages of nodes joining other queue, meaning its QH declaration

message has been failed. This will terminate the node process in forming its own queue. On the other hand, once the QH node receives safety message from other nodes to join its queue, its queue formation will be established.

One hop neighbors of QH node which receive the QH declaration message and have safety packets in their buffer, will send that safety packet with a sequence number 2 to QH node to compete for the second position in the queue. QH node sends ACK immediately after receiving the earliest safety message to confirm the second place in its queue. Like that, other round to compete for a position in the queue will take place. Nodes, which lie between the intersection of two queues, will choose to join one of the queues based on their own preferences. The time amount of the three periods within an SI of this protocol will be distributed based on real-time density of the network and the specific network feature.

3.2   Channel Reservation

After forming queues, during the channel reservation period, QH nodes will reserve TDMA slots for their own queues. Reservation messages are transmitted with regular transmission range R. Due to the synchronous property of this protocol, all QH nodes will send the reservation messages at the beginning of the channel reservation period, which might lead to synchronized collision. To reduce this collision, QH nodes do a random back off before sending out the reservation messages. In addition, to reduce the fail of reservation message due to hidden terminal problem, each QH node will send the reservation message three times [10]. One TDMA slot is used by the whole queue following the usage rule described in the next subsection. QH nodes within two hop range of each other cannot reserve the same TDMA slot.

3.3   Safety Message Forwarding and WSA Handshaking

A reserved TDMA slot used by a queue bases on the following rules:

– QH node uses TDMA slot to forward the safety messages collected of the whole queue and sends out a short finishing message when it is done.
– After the finishing message has been sent, queue members that have service message in the buffer will send a short notice to perform the WSA handshaking. In case of multiple queue members wanting to perform the handshake, the priority to use the remaining TDMA slot is based on their sequence numbers in the queue. While exchanging WSA messages, nodes choose the SCH and the slot on that channel for service message transmission based on the information on the Channel Usage List [5,11] maintained at each node.

3.4   Service Data Transmission

Coming the slot on SCH chosen during WSA handshaking, nodes switch to chosen SCH and transmit service packets. Upon finishing the service transmission, nodes switch back to CCH for the next sync interval queuing. On SCHs, there is a period at the beginning of each sync interval, nodes are prohibited to use SCHs (referring to Fig. 1).

4 Performance Analysis

Since Self-sorting protocol only relates to safety application, the performance analysis in this section will evaluate Packet Delivery Ratio (PDR) of the proposed protocol, Self-sorting protocol, DC-MAC protocol and IEEE 1609.4. In addition, throughput of service application of the proposed protocol will also be evaluated in comparison with DC-MAC protocol and IEEE 1609.4.

4.1 Packet Delivery Ratio of Safety Packets

Assuming that vehicle density β and safety packets come to a node's buffer at arrival rate λ following Poisson process. Only considering the case that a safety packet is dropped only when it reaches the maximum number of retry m or collision due to hidden terminal problem. The queuing process is analyzed following Markov chain in [10] with queue's length l

PDR of safety packet is:

$$PDR = 1 - [(1 - P_{suc})^m + (1 - (1 - P_{suc})^m)\frac{P_{col}}{P_{suc}}] \tag{1}$$

With P_{suc} is the probability that a node acquires safety service and P_{col} is the probability a node acquires service but leads to collision.

$$P_{suc} = \frac{l.\sum_{n=1}^{\infty}\frac{(\beta\rho P_{QH}P_q P_l.R)^n}{n!}.e^{-\beta\rho P_{QH}P_q P_l.R}.[(\frac{n}{W^2} - \frac{1}{W^2})p_{cq} + 1]}{2R\beta\rho} \tag{2}$$

ρ is the probability of a non-empty buffer ($\rho = \lambda E[S]$, with $E[S]$ is the average service time of safety application), P_q is the probability a node with safety packet sends declaration message to become a queue head, P_{QH} is the probability of a QH successfully form its own queue, p_{cq} is the collision probability where there are n queues in the range 2R, P_l is the probability a queue reach the length l.

In Eq. (2),
$P_l = \sum_{n=0}^{\infty}\frac{(\beta\rho R)^n}{n!}.e^{-\beta\rho R}.[1 - (1 - \frac{n}{W}(1 - \frac{1}{W})^{n-1})^W];$
$P_{QH} = \sum_{n=1}^{\infty}\frac{(\beta\rho P_q.2R)^n}{n!}.e^{-\beta\rho P_q.2R}.\frac{(\frac{n}{W^2} - \frac{1}{W^2})(1 - (\frac{W-1}{W})^{n-1})+1}{n};$
with W is the range of backoff timer $[0, \text{W} - 1]$ when there are n nodes want to send queue formation declaration messages.

$$P_{col} = \frac{l.\sum_{n=1}^{\infty}\frac{(\beta\rho P_{QH}P_q P_l.R)^n}{n!}.e^{-\beta\rho P_{QH}P_q P_l.2R}.\frac{1}{W^2}p_{cq}.n}{2R\beta\rho} \tag{3}$$

4.2 Throughput of Service Application

Throughput of service application is calculated through the number of successful handshake performed on the CCH.

$$Throughput = \min(\frac{SI - E[S] - \frac{\lambda E[S^2]}{2(1-\rho)}}{E[TC]}.P_{ser}, SI - E[S] - \frac{\lambda E[S^2]}{2(1-\rho)}) \tag{4}$$

with $E[TC]$ is average length of a transmission cycle, P_{ser} is the probability of successful transmission of handshake for service application.

4.3   Performance Evaluation

The performance evaluation is done by comparing with Self-sorting protocol [10], DC-MAC protocol [8] and IEEE 1609.4. Mathematica is used to solve the equations above and the corresponding ones of three mentioned protocols in [8,10]. Value of parameters used to evaluate all four protocols are listed in Table 1

Table 1. Performance evaluation parameters

Parameters	Value	Parameters	Value	Parameters	Value
l	5	R	300 m	P_q	0.5
l_1	3	σ	9 μs	Data rate	6 Mbps
l_2	5	δ	1 μs	ACK	14 Bytes
W_e	8	SIFS	16 μs	EMG	100 Bytes
$W_{s,0}$	16	DIFS	34 μs	WSA	100 Bytes
M	6	f	4	RES	14 Bytes

Referring to Figs. 2 and 3, the performance of self-sorting and enhanced self-sorting protocol are outperformed DC-MAC and IEEE 1609.4 protocol in the
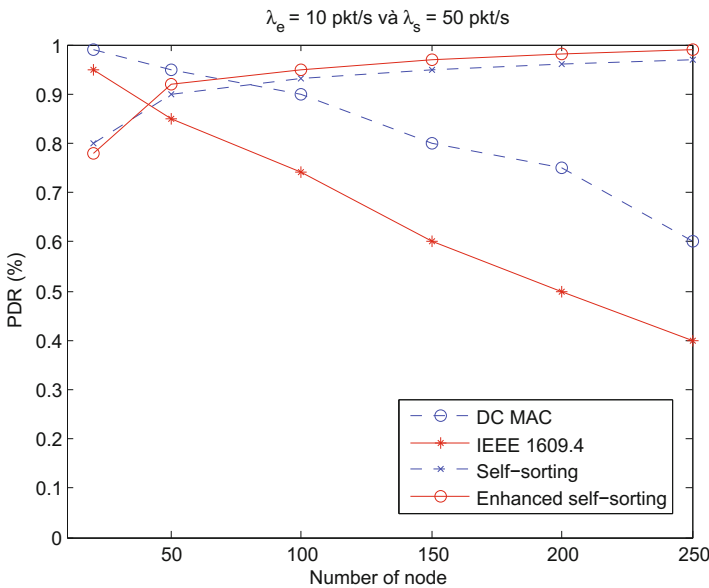

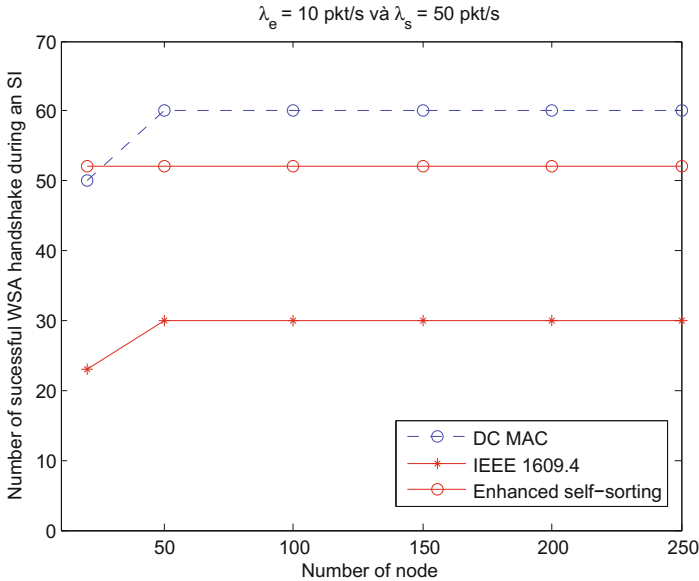**Fig. 2.** Performance comparison in term of PDR

Fig. 3. Performance comparison in term of throughput

situation of high density network. PDR of safety application of the enhanced self-sorting protocol is highest among the four. Throughput, however, does not show that enhanced self-sorting is the most effective protocol. This is due to the fact that on SCHs, there is a prohibited amount of time where nodes cannot use the resources. Self-sorting protocol is not included in throughput evaluation because it does not incorporate the service application in its protocol.

5   Conclusion

Since self-sorting protocol is proposed for high density network and mainly focused on safety application, the enhanced self-sorting protocol proposes a more effective access mechanism that focuses on both safety and service applications in VANETs. Vehicles in the network form queues to reduce the chance of collision when all vehicles want to contend for channel at the same time. During the queuing process, safety messages are also collected. The channel is only contended by queue heads. Each queue uses the channel based on TDMA principle. During reserved slot of a queue, handshakes for service application are also transmitted by the queue members. The performance analysis and evaluation of the proposed protocol are done in term of PDR and throughput. PDR of the protocol gives the best performance out of the four protocols in comparison. Throughput, in contrast, is not the same. However, in dense network, the performance in term of throughput of the protocol is acceptable.

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