A Cooperative – Efficient – Reliable MAC for VANETs

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Abstract

Vehicular Ad hoc Networks (VANETs) should provide the vehicles with reliable safety message broadcasts and efficient non-safety message transmissions. In this paper, we propose a Cooperative – Efficient – Reliable multi-channel MAC for VANETs, named CER-MAC, which supports both TDMA and CSMA in accessing the control channel (CCH) and provides the cooperation in broadcasting the safety messages. The CER-MAC allows vehicle nodes to send safety messages in the reserved time slot on the CCH and to utilize the service channel (SCH) resources during the CCH Interval (CCHI).

Key word: Cooperative, VANETs, Multi-channel MAC, TDMA, CSMA.

1. Introduction

VANET consists of Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications. VANET provides a variety of safety applications and non-safety applications for more driving efficiency, comfort and safety. The IEEE 1609.4 [1] is the standard of the multi-channel MAC for VANETs.

The variable CCH interval (VCI) [2] multi-channel MAC scheme tries to adjust the CCH interval (CCHI) according to the network conditions. A Dedicated Multi-channel MAC (DMMAC) [3] adopts the Basic Channel reservation from RR-ALOHA [4] to provide the collision-free and delay-bounded transmission for safety messages. Like the IEEE 1609.4, the SCH resources are not utilized during the CCHI in the VCI and DMMAC. The Vehicular Efficient and Reliable MAC (VER-MAC) [5] allows nodes to broadcast safety messages twice in CCHI and SCHI and to exchange non-safety messages during the CCHI. Since the VER-MAC still uses CSMA access scheme for safety message broadcast, it cannot guarantee the QoS of the safety message or other real-time applications.

We propose the CER-MAC as a combination of the dynamic TDMA slot assignment technique and the cooperation in safety message broadcast for VANETs. To improve the reliability, each safety message is broadcast twice and vehicle node can use its neighbor's free time slots or unreserved time slots to broadcast its safety messages. Moreover, the throughput of the non-safety message is improved significantly by utilizing the SCH resources during the CCHI and providing the collision-free on the SCHs.

2. The proposed CER-MAC protocol

In this protocol, we assume that each vehicle node has one half-duplex transceiver. All vehicle nodes are time-synchronized using the Global Positioning System (GPS). Time is divided into 50ms Sync Interval (SI), as shown in Fig. 1. Each SI is further divided into Reservation Period (RP) and Contention Period (CP) on the CCH, into many Service Slots (SerSlots) on each SCH. The RP consists of Emergency Slots (EmgSlots) which are reserved by vehicle nodes. The length of RP is dynamically adjusted according to the number of vehicle nodes. A vehicle node broadcasts its safety messages without any collision in the reserved EmgSlot, and rebroadcast them in the EmgSlot of the next SI. Nodes perform 3-way WSA/RFS handshake to select a SerSlot for non-safety message transmissions during the CP. Then, nodes switch to the selected SCH during the selected SerSlot for non-safety data transmissions.

Sync Interval #1

Node	N_1	N_2	1	2	3	4	5	6	7	8
A	8	8	1	E	F		B	A		G
D	3	5	D		C		1			
E	6	8	I	E	1		B	A		1
F	6	8		1	F		1	A		1
G	8	8		1	1		1	A		G
H	6	5	1		C		1			

Table. 1. Frame Information Map.

A. EmgSlot reservation

Each node has to maintain a Frame Information Map (FIM), for example as given in Table.1 to store the EmgSlot occupancy of two-hop transmission range. Each EmgSlot in the FIM can be either empty or occupied (marked as ``1'' or a node ID). N_1 and N_2 are the last EmgSlots occupied by the one-hop neighbor node and by all neighbor nodes, respectively. Every node has to send Hello message (Fig. 2) to maintain the EmgSlot occupancy, and the FIM is updated from the overheard Hello messages from neighbors. When a new node joins the network, it has to listen to the

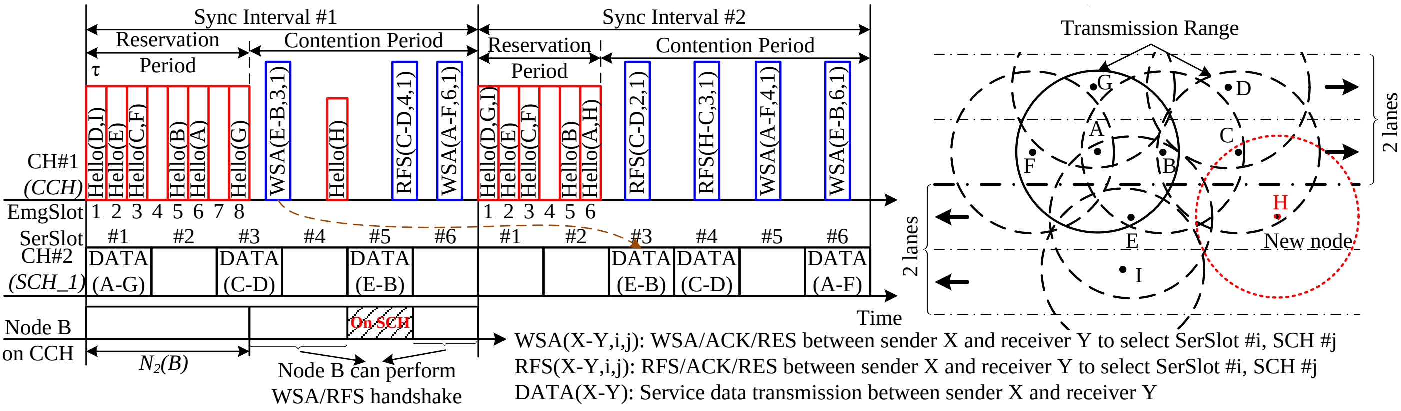

Fig. 1. The operation of the CER-MAC protocol.

whole RP to get the complete information about the EmgSlot occupation. This node tries to send the Hello message during the CP to reserve EmgSlot #(N_2+1). Due to the topology changed, some EmgSlots will be empty. To minimize the RP's length, the node which occupies the last EmgSlot will switch to another available EmgSlot by sending a Switch message (Fig. 3). In Table.1, node G sends the Switch message to switch from the EmgSlot #8 to EmgSlot #1.

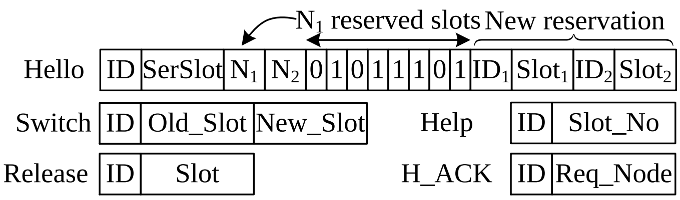

Fig. 2. Frame format.

B. Safety message broadcast

Once a vehicle node reserves an EmgSlot successfully, it can broadcast its safety messages within its EmgSlot without any collision. Since some one-hop neighbor nodes may be on the SCHs for the non-safety message transmissions, they cannot receive the safety message. That is why each safety message has to be broadcast again in the next SI.

However, in some cases, the vehicle node needs more time to broadcast the safety messages due to the limited EmgSlot duration. In such cases, the vehicle node can reserve available EmgSlots for the temporary use (Fig. 3). After finished broadcasting the safety messages, the vehicle node has to send Release message (Fig. 2) to release the temporary EmgSlot. If there is no available EmgSlot, the vehicle node broadcasts the Help message (Fig. 2) to ask its neighbor nodes for using their EmgSlots. The Help message should specify how many EmgSlots are needed. After receiving the acknowledgement (H_ACK message in Fig. 2) for using the EmgSlot from the neighbor node, that vehicle can use the neighbor node's EmgSlot to broadcast its safety messages.

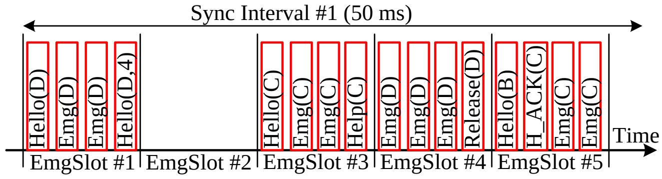

Fig. 3. Cooperation in safety message broadcasting.

C. Non-safety message transmissions

For the non-safety message transmissions, node has to maintain the Neighbor Information List (NIL) and SerSlot Usage List (SUL). The NIL shows the SerSlots that the one-hop neighbor nodes use to exchange the non-safety messages in the current SI and the next SI. The Next_SerSlot is updated from the overheard WSA/RFS messages whereas the Current_SerSlot is updated from the Next_SerSlot or the overheard Hello messages. The NIL also stores the EmgSlots index N_2 of its one-hop neighbor nodes. Based on the N_2 and Current_SerSlot, node knows when its one-hop neighbor node is available on the CCH during the CP of the current SI to perform WSA/RFS handshake.

Neighbor Information List

Node	N_2	Current_SerSlot	Next_SerSlot
B	8	5	3
E	8	5	3
F	8	4	6

SerSlot Usage List

SCH	Avail_SerSlot
2	2, 4, 6
3	3, 4
4	4

Table. 2. a) Node A's NIL; b) Node A's SUL

The SUL shows the availability of the SerSlot on each SCH. Since a node has to be on the CCH during its reserved EmgSlot to send its Hello message and its safety messages, the Avail_SerSLot does not include its EmgSlot. Also, a node is not allowed to reserve the same SerSlot consecutively because each safety message is broadcast in the same EmgSlot of two consecutive SIs. In the 3-way WSA/RFS handshake, the receiver has to select a common available SerSlot based on the sender's SUL and its SUL. The SUL is updated from the overheard WSA/RFS messages.

3. Simulation Results

We evaluate our proposed CER-MAC protocol on the event-driven simulation program written in Matlab. Some simulation parameters are given in Table. 3.

Parameter	Value
Safety slot duration	1,000 us
Number of SerSlot	4 slots/Sync
Hello / Switch message	20 / 10 bytes
WSA / RFS message	100 / 100 bytes
ACK / RES message	14 / 14 bytes
Safety / non-safety message	100 / 800 bytes
Safety / non-safety PAR	40 / 400 packets/s

Table. 3. Simulation parameters.

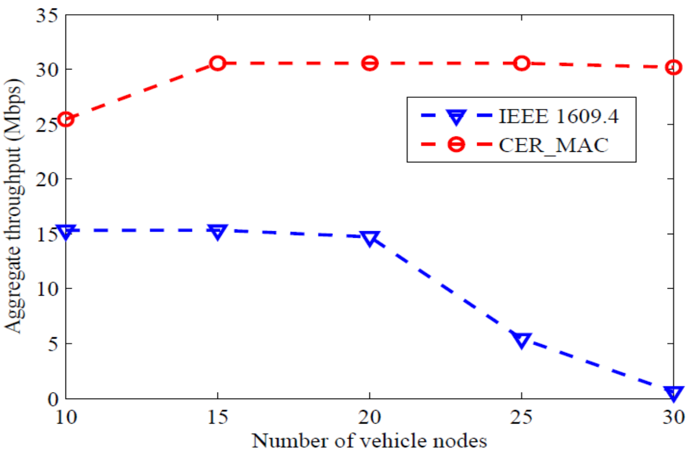

Fig. 4. Aggregate throughput of non-safety messages.

Fig. 4 shows the aggregate throughput comparison between the CER-MAC and the IEEE 1609.4. Since the CER-MAC utilizes the SCH resources during the CCHI, the maximum aggregate throughput of the CER-MAC is double compared to the IEEE 1609.4. The safety message has higher priority than WSA/RFS messages. When the number of node increases, the collision probability on the CCH increases and the number of successful SCH negotiation decreases. That is why the throughput of the IEEE 1609.4 decreases when the number of nodes is too large.

Fig. 5 shows the average packet delivery ratio (PDR) of safety message. The CER-MAC uses reserved EmgSlot with retransmission and cooperative transmission whereas the IEEE 1609.4 uses the CSMA to contend the CCH for broadcasting the safety message. Therefore, the average PDR of the CER-MAC is higher than the IEEE 1609.4.

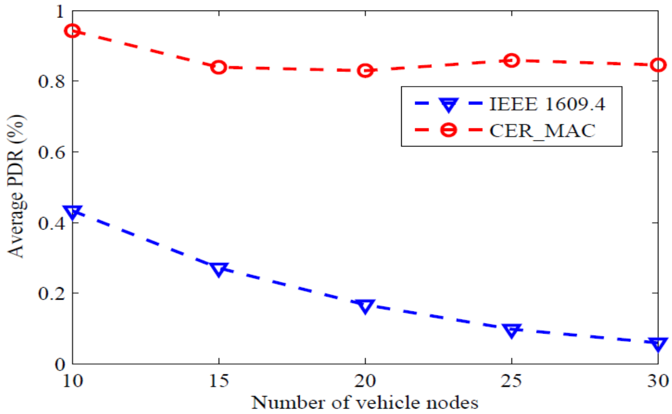

Fig. 5. Average PDR of safety messages.

4. Conclusion

In this paper, we propose a cooperative, reliable and efficient multi-channel MAC protocol for VANETs, named CER-MAC. The CER-MAC provides the reliable safety message broadcast and efficient SCH utilization compared to the IEEE 1609.4.

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