Improving Time Slot Acquisition Through RSU's Coordination for TDMA-based MAC Protocol in VANETs

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***Abstract*—Vehicles and Road Side Units (RSUs) are essential units to create a dynamic network, called Vehicular Ad hoc NETwork (VANETs). An RSU plays a role of collecting and analyzing traffic data given from vehicles. RSUs and vehicles have to assign time slots to broadcast service applications on the control channel in VANETs. One of MAC protocol versions named VeMAC is proposed. VeMAC protocol can decrease the rate of transmission collisions and increase the throughput on the control channel. However, VeMAC protocol did not consider to special properties of an RSU in VANETs. In this paper, we propose an improvement of time slot acquisition through RSU's coordination for TDMA-based MAC protocol in VANET, called RCMAC protocol. In our protocol, RSUs exploit time slots assignment and disseminate control information. Hence, RCMAC protocol reduces the rate transmission collisions due to all nodes on the control channel receive a control information from an RSU. Simulation results show that RCMAC protocol outperforms both VeMAC and ADHOC-MAC protocols in term of average of number of frames that all nodes successfully acquire a time slot and average number of access collisions until all nodes successfully acquire a time slot.**

***Index Terms*—VANET, MAC protocol, road side unit, TDMA-based MAC protocol.**

I. Introduction

Intelligent Transport System (ITS) is to support to transport system to make them safe, intelligent and efficient. Vehicular Ad hoc NETwork (VANET) is one of important components in ITS. However, VANETs are dynamic networks because of the high node mobility, the variable node density. Each node vehicle is equipped with a radio interface, called an On-Board Unit (OBU). In addition, to connect to Internet, a set of stationary units is distributed along the road called Road Side Units (RSUs). VANETs provide Vehicle-to-Vehicle (V2V) and Vehicle-to-RSU (V2R) [1] [2] and make them enable to provide a variety of safety applications and non-safety applications. An RSU plays a role of collecting and analyzing traffic data on safety application in VANETs. In other hand, an RSU takes part in controlling traffic low by broadcasting locally analyzed data, forwarding some important message on [3] [4].

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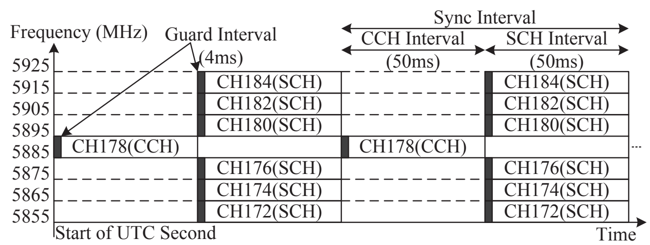

Fig. 1: DSRC spectrum allocation.

The Medium Access Control (MAC) for VANET provides an efficient and reliable broadcast service of safety application. However, because VANET has fast topology changes, high node mobility, and difficult Quality of Service (QoS) requirements, the MAC protocol is difficult to design. Safety applications require high reliability and bounded delay. Non-safety applications require throughput-sensitive. Dedicated Short-Range Communications (DSRC) is used by V2V and V2R communications. The DSRC spectrum is divided into seven channels: one Control CHannel (CCH) and six Service CHannels (SCHs), as shown in Fig. 1. A Sync Interval (SI) comprises of a CCH Interval (CCHI) - 50 milliseconds and a SCH Interval (SCHI) - 50 milliseconds. Both CCHI and SCHI have guard interval - 4 milliseconds to switch the CCH and the SCH.

We focus on the role of an RSU in the MAC protocol in this paper. An RSU has greater transmission range than a node. Hence, all nodes in an RSU transmission range can receive packets transmitted by an RSU. An RSU's coordination schemes outperform the schemes without RSU's coordination in term of packet loss radio and delay. In addition, RSU's coordination schemes can improve the reliable and efficient safety applications [5] [6]. VeMAC protocol [7] [8] shows that it can decrease the rate of transmission collision and provide higher throughput on the control channel than ADHOC MAC. E-VeMAC protocol [9] improves VeMAC protocol in term of the throughput on the service channel by mitigating the exposed terminal problem. However, all of protocol did not consider the special character of RSUs.

In this paper, we propose an improvement of time slot acquisition through RSU's coordination for TDMA-based MAC protocol in VANET, called RCMAC protocol. In RCMAC protocol, RSUs coordinate all nodes in its transmission range. By using RSU's coordination, all nodes can successfully acquire their time slots faster than VeMAC protocol. Hence, RCMAC protocol can improve higher throughput on the control channel than VeMAC protocol.

The rest of this paper is organized as follows. In section II, we introduce the researcher related to RSU's coordination. In section III, we describe the proposed RCMAC protocol. In section IV, we conduct the performance evaluation. Finally, we summarize our work in section V.

II. Related work

In this section, we describe works on the TDMA-based MAC protocol in VANETs. Compared to CSMA/CA scheme, the TDMA scheme has more benefit such as efficient channel utilization without collisions, high reliability of communications and QoS for real-time applications [10]. We classify works into non-RSU's coordination and RSU's coordination for TDMA-based MAC protocol.

Non-RSU's coordination for TDMA-based MAC protocol considers that an RSU can access the control channel as the vehicles [7], [8], [11]–[13]. ADHOC protocol [11] based on a completely distributed access technique (RR-ALOHA). ADHOC protocol can provide an efficient broadcast service and the reservation of point-to-point channels that exploit parallel transmission.

The DMMAC protocol [12] provides collision-free and delay-bounded transmissions for safety applications. DMMAC protocol uses a dynamic TDMA scheme to adjust the Basic channel (BCH) length according to neighbors. However, DM-MAC protocol did not consider to access collision and merging collision.

The VeMAC protocol [7] [8] is a contention-free multi-channel MAC protocol. This protocol provides efficient one-hop and multi-hop broadcast service on the control channel. By separating set of time slots to vehicles moving in opposite direction *Left* and *Right* and to RSU, VeMAC can reduce merging collision.

The ATSA protocol [13] enhances the VeMAC protocol when the densities of vehicles moving in opposite directions are not equal. Based on the binary tree algorithm, the frame length can resize to solve merging collisions under different traffic density.

To ensure real-time and reliable delivery of messages, a TDMA-based MAC protocols exploit the presence of RSUs. RSUs assign time slots and disseminate control information. An RSU broadcasts the control information including the final time slot allocation map to all node in its transmission range [6], [14].

An adaptive collision-free MAC protocol (ACFM) [6] is a centralized TDMA-based MAC protocol. In ACFM protocol, RSUs create and manage the TDMA slot reservation schedule for all nodes in its coverage. ACFM protocol ensures efficient time slot utilization for the number of active nodes.

To extension of ACFM protocol for Vehicular Cooperative Collision Avoidance System, Guo *et al.* proposed Risk-aware Dynamic MAC protocol [14], called RMAC protocol. RMAC protocol supports the real-time and reliable delivery of warning messages.

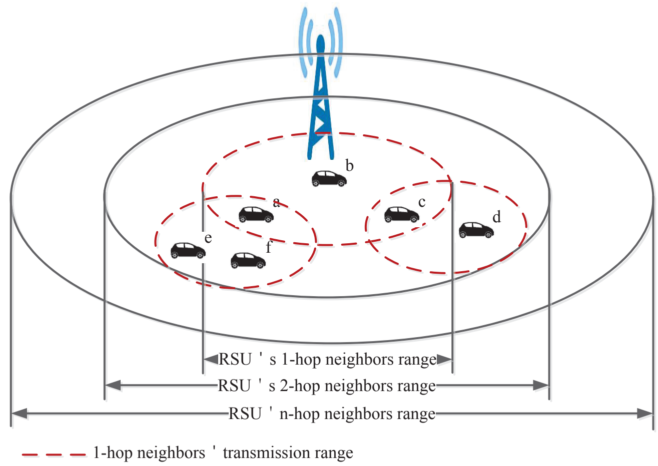

Fig. 2: Sections in coverage of an RSU.

In this paper, we propose an extended scheme of VeMAC, named RCMAC protocol. RSUs manage the TDMA slot reservation for all nodes in its coverage. Then an RSU broadcasts the control message including the final slot allocation map to all nodes.

III. The proposed RCMAC protocol

A. Sections in coverage of an RSU

In our protocol, RSU's coverage can be divided into 3 sections: RSU's 1-hop neighbors, RSU's 2-hop neighbors and RSU's n-hop neighbors' sections, as shown in Fig. 2. All nodes which can connect directly to an RSU are grouped into RSU's 1-hop neighbors section. Upon an RSU receives packets transmitted by nodes in its coverage, an RSU has acknowledgment of all node among RSU's 2-hop neighbors section. For instance, nodes *a, b, c, d, e* and *f* are in RSU's coverage. When an RSU received packets transmitted by nodes *a, b* and *c*, an RSU knows information of all nodes in RSU's 2-neighbors range, as shown in Table. IV.

B. System model

Like VeMAC protocol [7], our proposal considers that the VANET consists of vehicles and RSUs in opposite on two-way road. Each node is equipped with global positioning system (GPS). GPS can provide accurately its position and moving direction. A frame partitions to a constant number of time slot. Each frame consists of 3 sets of time slot: *RSU*, *R* and *L*, as shown in Fig. 3. Each node maintains one-hop neighbors list (ONL). Once it receives packets transmitted on the control channel, it updates its ONL. In Fig. 2, nodes *a, b* and *c* have their ONLs as shown in Table .I, II and III. One-hop neighbors list is defined as follows:

- $N(x)$: The set of IDs of the one-hop neighbor of node on the control channel.
- $T_m(x)$: The set of time slots that considering node must not use on the channel m, $m = 0, 1, 2, \ldots 6$ where control

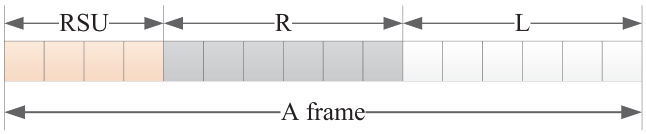

Fig. 3: Each frame on the control channel partitions to *RSU*, *R* and *L*.

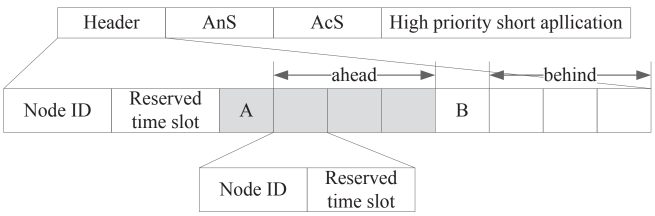

Fig. 4: Format of each packet transmitted on the control channel.

channel is defined by *m = 0* and service channels are defined by *m = 1, 2, ... 6*

where x is a considering node.

C. Acquiring time slots on the control channel

Each node in RCMAC protocol must successfully acquire one time slot in a frame on the control channel. Each node keeps accessing the same time slot on all subsequent frames on the control channel if it does not collide with another nodes in its transmission range. Each node must transmit its packet in its time lot on the control channel. In both VeMAC and RCMAC protocols, a packet transmitted on the control channel is divided into four field: header, announcement of services (AnS), acceptance of service (AcS), and high-priority short applications, as shown in Fig. 4. Unlike to VeMAC protocol, in the header field, each node arranges its neighbor node to two sets: ahead and behind neighbors sets, as shown in Fig. 4. One byte is defined by *A*, and one byte is defined by *B*. *A* and *B* are included into packet to divide disjoint sets of neighbor nodes to node moving ahead and behind of a considering node.

TABLE I: A node a's ONL

$Node$	$Time\ slot$
b	4
c	5
e	3
f	7

TABLE II: A node b's ONL

$Node$	$Time\ slot$
a	8
c	5

TABLE III: A node c's ONL

$Node$	$Time\ slot$
a	8
b	4
d	10

TABLE IV: An RSU's ONL

$Node$	$Time\ slot$
a	8
b	4
c	5
d	10
e	3
f	7

In RCMAC protocol, we consider all nodes in RSU's 2-hop neighbor range because nodes in 3-hop can reuse their time slots [11]. Operation of RCMAC protocol is as follow:

1) Node chooses random time slot based on its ONL and $T_0(.)$.
2) Each node transmits a packet in its reserved time slot on the control channel.
3) Once nodes and RSU receive packets transmitted on the control channel, they update their ONLs.
4) Based on ONL, an RSU will broadcast its packet on the control channel. All nodes in its coverage receive this packet. They will update their ONL to follow packet transmitted by an RSU.
5) Because all nodes receive packet transmitted by an RSU, all nodes know that they successfully or unsuccessfully acquire their time slot. If node(s) did not is included in packet transmitted by an RSU, it knows that it unsuccessfully acquire its time slot.
6) If nodes successfully acquire their time slot satisfied *Rule 1*, they keep accessing the same time slots in all subsequent frame on the control channel. If nodes unsuccessfully acquired their time slot, they will choose new time slots. A new time slot is an RSU's available time slot, $T_0(RSU)$. If there is no available time slot in $T_0(RSU)$, it will choose an available time slot associated with $T_0(x)$ where x is a contending node.

Rule 1: A node successfully acquires its time slot if and only if it satisfies one of two conditions:

- Its information is included into packet transmitted by an RSU in the first time slot of each frame.
- All neighbor nodes confirm its information included into their packets transmitted on the control channel.

Consider that nodes *a, b, c, d, e* and *f* want to acquire time slots on the control channel. They are moving in RSU's 2-hop neighbor range, as shown in Fig. 5. In frame #1, an RSU broadcasts a packet without information of all nodes in its coverage. Nodes *a, b, c, d, e* and *f* will choose random time slots, i.e *8, 4, 5, 10, 3* and *7*, respectively. After frame #1, an RSU identified node *a, b, c, e* and *f* and then, it will include their information into packet transited on the first time slot in next frame. Because all nodes in 2-hop neighbors range receive a packet transmitted by an RSU, they will update their ONLs. In this case, node *d* is not included in a packet transmitted by an RSU, but it will keep accessing time slot. After node *c* broadcasts packet include ID and reserved time time of node *d* and nodes *c* and *d* are neighbors together, node *d* will successfully acquire. After frame #2, an RSU identified node *a, b, c, d, e* and *f* and then, it will include their information into packet transited on the first time slot in next frame. All nodes in RSU's 2-hop neighbor range successfully acquire after 2 frames. An RSU will broadcast a packet include all nodes information in the first time slot in next frame, as shown in Fig. 5.

Rule 2 (Collision avoidance): We assume that two nodes accessed in same time slot and an RSU received their information from its neighbor nodes. If two nodes are in intersection two sets of their neighbors, an RSU will assign a new time slot without the collision for two nodes.

We consider that nodes *d* and *b* are accessing in the same time slot, as shown in Fig. 6. An RSU did not receive

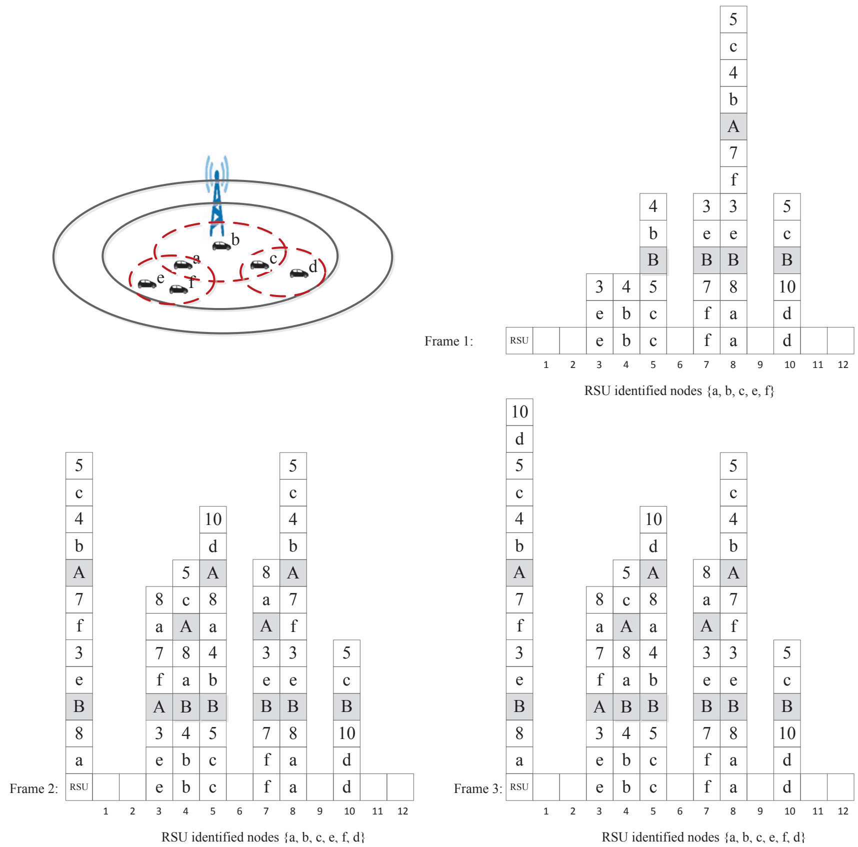

Fig. 5: Example of operation of RCMAC protocol.

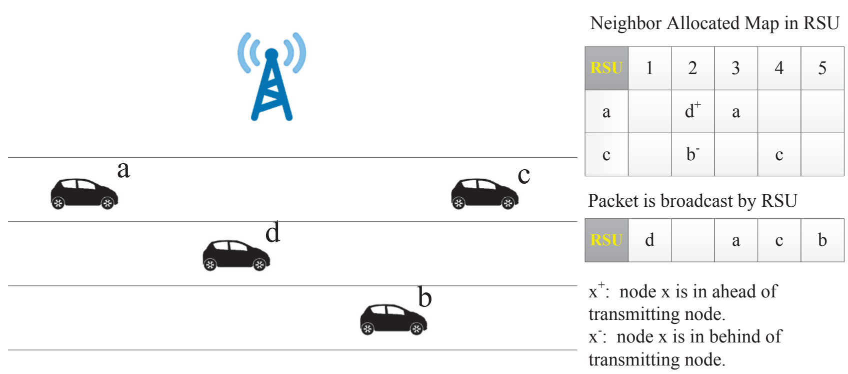

Fig. 6: Example of rule 2.

packets transmitted by nodes *d* and *b* because their packets are collided. However, an RSU received packets transmitted by nodes *a* and *c*. An RSU observes that *d* and *b* are in intersection of nodes *a* and *c*. To avoid merging collision and access collision, an RSU will broadcast packet including new time slots for nodes *d* and *b*, as shown in Fig. 6. Upon all nodes receive packet transmitted by an RSU, they will update their ONLs.

IV. Performance Evaluation

In this section, we evaluate the performance of RCMAC protocol in MATLAB and compare RCMAC protocol with Ve-MAC [7] and ADHOC-MAC [11] protocols. The parameter is listed in Table. V.

The simulated scenario is considered a segment of a two-way traffic highway, as shown in Fig. 7. Each node moves with constant speed and the number of nodes on the highway remains constant during the simulated time. Each node can communicate with all nodes in its transmission range. We vary the node density in the highway scenario. The simulation runs 100 times to compute average of number of frames that all nodes successfully acquire a time slot and average number of access collisions until all nodes successfully acquire a time slot.

In Fig. 8, when a number of nodes increases, the number

TABLE V: Simulation parameters

Parameter	*highway*
# lane/direction	4/2
# highway length	$300m$
Speed	$100km/h$
Transmision range	$150m$
RSU's transmision range	$300m$
# slots of left directions	49
# slots of right directions	50
# slots of RSUs	1
# slots of a frame on the SCH	100
Slot duration	$1ms$

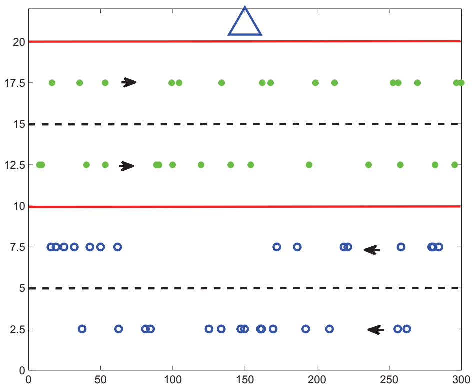

Fig. 7: A snap shot of the simulated highway scenario.

of frames that all nodes successfully acquire a time slot also increases. All nodes in ADHOC-MAC protocol choose random a time slot in the frame. Otherwise, in VeMAC and RCMAC protocols, all nodes moving in opposite direction will choose disjoint set of time slots in the frame. Hence, all nodes use ADHOC-MAC protocol take the number of frames that all nodes successfully acquire a time slot greater than VeMAC and RCMAC protocols. In RCMAC protocol, an RSU will broadcast control information packet to all nodes in the first time slot. All nodes within its coverage will update their ONLs. If a node is included its information into RSU's broadcasting packet, it will successfully acquire a time slot. Therefore, RCMAC protocol takes the number of frames that all nodes successfully acquire a time slot lower than VeMAC protocol.

An access collision is defined as an event when two or more nodes within 2-hop of each other access the same available time slot. As the number of nodes in simulated highway scenario increases, an access collision also increases. RCMAC and VeMAC protocols divide a frame into 3 sets: *L*, *R* and *RSU*. Hence, the number of access collisions is lower than ADHOC-MAC protocol. In RCMAC protocol, an RSU coordinates all nodes within its coverage. Compared to VeMAC protocol, RCMAC protocol can decrease the rate of access collisions, as shown in Fig. 9.

V. Conclusion

In this paper, we proposed an improvement of time slot acquisition through RSU's coordination for TDMA-based MAC protocol in VANET, called RCMAC protocol. An RSU can coordinate all nodes within its coverage by broadcasting control information packet in the first time slot of each frame. All received nodes will update its one-hop neighbors list. If each node is included its information into RSU's broadcasting packet, it successfully acquires its time slot. Simulation results show that RCMAC protocol outperforms both VeMAC and ADHOC-MAC protocols in term of average of number of frames that all nodes successfully acquire a time slot and average number of access collisions until all nodes successfully acquire a time slot. In future works, we will consider to RSU allocation and nodes are in the overlap of the two RSUs.

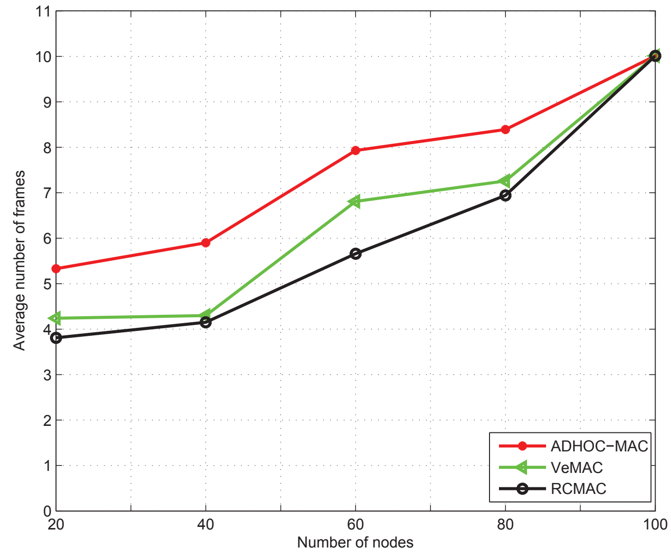

Fig. 8: Average number of frames that all nodes successfully acquire a time slot.

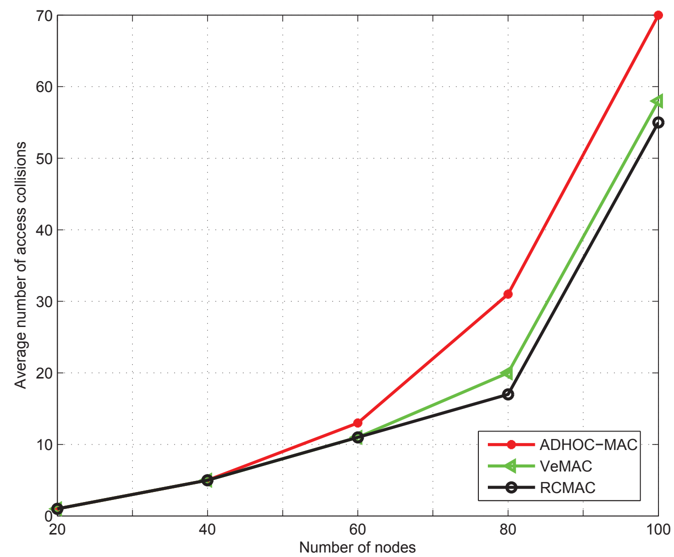

Fig. 9: Average number of access collisions until all nodes successfully acquire a time slot.

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