e-VeMAC: An Enhanced Vehicular MAC Protocol to Mitigate the Exposed Terminal Problem

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***Abstract*—The VeMAC, a TDMA-based MAC protocol for Vehicular Ad-hoc NETworks (VANET), assigns disjoint sets of the time slots to vehicles moving in opposite directions and to road side units. So the VeMAC protocol reduces the access and merging collisions. Moreover, the VeMAC protocol employs slot release prevention condition which avoids unnecessarily releasing time slots when a node just enters the communication range of each other. Although VeMAC supports reliable and efficient transmission, it is still not full applicable for VANET in parallel transmission. In this paper, we propose an e-VeMAC protocol: an enhanced vehicular MAC protocol to mitigate the exposed terminal problem. The simulation results show that the e-VeMAC protocol supports more parallel transmissions than the VeMAC protocol.**

***Index Terms*—VANET, MAC, VeMAC, parallel transmission.**

I. Introduction and Related Works

Vehicular Ad-hoc NETwork (VANET) consists of moving vehicles to create dynamical networks. VANET is one of special types of Mobile Ad-hoc NETworks (MANET) but it does not have an existing infrastructure or centralized administration. VANET supports many applications in safety entertainment and vehicle traffic optimization. The VANET classifies of a set of vehicles equipped with communication device and a Global Positioning System (GPS) receiver, called On-Board Unit (OBU) and a set of stationary units along roads, called Road Side Units (RSUs). Based on OBU and RSU, VANET has two essential communications: Vehicle-to-Vehicle (V2V) and Vehicle-to-RSU (V2R). To support V2V and V2R communications, the United States Federal Communication Commission (FCC) dedicated 75MHz radio spectrum in the 5.9GHz band for Dedicated Short Range Communications (DSRC) spectrum [1]. The DSRC spectrum is divided into seven 10MHz channels: six Service CHannels (SCH) and one Control CHannel (CCH), as shown in Fig. 1. A Sync Interval (SI) comprises of a CCH Interval (CCHI) - 50 milliseconds and SCH Interval (SCHI) - 50 milliseconds. Both CCHI and SCHI have guard interval 4 milliseconds to switch between the CCH and the SCH, as shown in Fig. 1.

One of the important services is high priority safety application proposed for VANETs. Each vehicle broadcasts its information within one-hop neighborhood [2] for the V2V applications such as pre-cash, blind spot warning, emergency electronic brake light and cooperation forward collision avoidance [3]. For V2R applications such as the curve speed warning and traffic signal violation warning, RSUs broadcast to all vehicle which approach them [4]. One of great importance

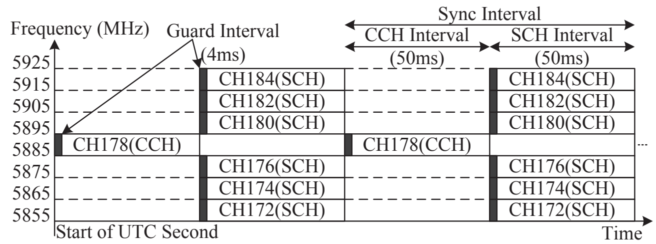

Fig. 1: DSRC spectrum allocation.

to support the high priority safety application in VANET is Medium Access Control (MAC) protocol which provides efficient broadcast services.

Many papers proposed various MAC protocols for VANET, such as the IEEE 802.11p [5], Code Division Multiple Access (CDMA) [6], VER-MAC [7], Time Division Multiple Access (TDMA) [8]-[12]. The ADHOC MAC protocol [8] uses slotted structure and employs a dynamic TDMA, called Reliable Reservation ALOHA (RR-ALOHA). The additional information, called Frame Information (FI) is included packet to broadcast on its time slot by all nodes. FI in the ADHOC MAC protocol includes many 12 bits FI_j: STI (source temporary identifier - 8 bits), PSF (priority status field - 2 bits), BUSY (1 bit) and FTP (bit used point-to-point transmissions - 1 bit. Based on FIs, each node is provided with full knowledge about the time slot status on the channel and one-hop or two-hop neighbors. However, the ADHOC MAC protocol [8] has the drawback of generating excess re-transmission, resulting in a highly inefficient use of bandwidth.

The RR-ALOHA+ [9] protocol does not support the constrained multi-hop announcement of channel state. To overcome this, an optimal slot management involves the re-use of a slot as close as possible. The MS-ALOHA protocol [10] is an improvement of the RR-ALOHA protocol. MS-ALOHA protocols define a new flag, called a further bit (CLS), to broadcast announcement of channel state. This protocol assures that the information on the channel status is not forwarded more than two-hop far from the transmitting node. The MS-ALOHA protocol [10] uses 2 bits (BUSY = 1, CLS = 1) to limit the number of nodes used to forwarded FI.

The VeMAC protocol [11] is based on the direction of moving vehicles and RSUs to classify a set of time slots of a frame on the CCH. A frame on the CCH consists of

3 sets of time slots: vehicles moving in left ($\mathcal{L}$) and right ($\mathcal{R}$) directions and RSUs ($\mathcal{F}$). Each node must to acquire exactly one slot in a frame on the CCH. Each node broadcasts a packet during its time slot even if node has no data to exchange. The packet AnM (Announcement Message) transmitted on the CCH has 4 main fields: header, announcement of services (*AnS*), acceptance of services (*AcS*), and a high priority short application.

This paper presents the e-VeMAC, a new TDMA-based protocol solves the drawback in parallel transmission in the VeMAC protocol. This scheme also increases the reusing of time slots on the SCH.

The rest of paper is organized as follows. Section 2 presents the VeMAC protocol in parallel transmission. The e-VeMAC protocol is presented in Section 3. The simulations of the e-VeMAC protocol are shown in Section 4. Section 5 concludes this research and suggests some future works.

II. The VeMAC protocol in parallel transmission

A. Advantage of the VeMAC protocol in parallel transmission

In the VeMAC protocol, once neighbor nodes receive data included in AcS field transmitted by the destination node, the nodes will update time slots in this data. This time slots must not use on the SCH $\mathtt{T}_m()$ to avoid the collision in the upcoming time slots, where *m* is index of the SCH, *m = 1, 2, 3, ..., 6*. An example of parallel transmissions in the VeMAC protocol is shown in Fig. 2. In this case, node *d* includes time slots $\beta_2(x) = \{1, 2, 4\}$ into AcS field of its packet transmitted on the CCH if node *x* offers the reliable service to node *d* on time slots $\beta_2(x)$. Neighbor node *y* overhears the packet transmitted by node *d* and updates $\mathtt{T}_2(y)$ to avoid using the same time slots in the next frame on the SCH. Node *v* has a reliable packet to offer to node *z* on the time slots $\beta_2(v) = \{1, 2, 4\}$ on the SCH 2. Because $\beta_2(v)$ is not in $\mathtt{T}_2(z)$, node *z* accepts this service on $\beta_2(v) = \{1, 2, 4\}$. Hence, parallel transmissions from node *x* to node *d* and from node *v* to node *z* are allowed on the SCH 2.

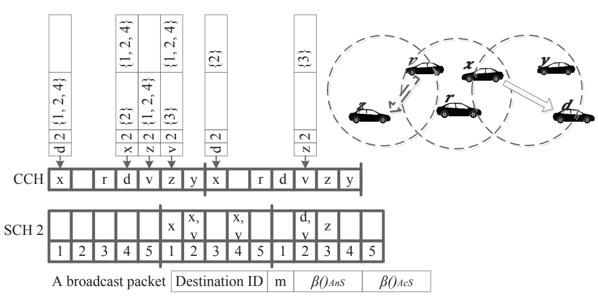

Fig. 2: Operation of the VeMAC protocol.

B. Criticalities of the VeMAC protocol in parallel transmission

1) Criticality 1: "Exposed" terminal problem in the VeMAC protocol: Complying with the VeMAC protocol, we consider two-hop and three-hop scenarios, as shown in Figs. 3a and 3b, respectively. In both scenarios, node *z* does not overhear packet transmitted by node *d* and does not update $\mathtt{T}_2(z)$. The node *v* announces the reliable service to node *z* on the time slots $\beta_2(v)$ after the node *x* announced the service to node *d* on the time slots {1, 3, 4} on the SCH 2. Once node *z* accepts this service offered by node *v*, node *z* includes $\beta_2(v) = \{2, 3, 5\}$ into AcS field of the packet transmitted on the CCH. After this announcement, node *v* will transmit data on the time slots $\beta_2(v)$ on the SCH 2. Since node *x* overhears the packet transmitted by node *z*, node *x* includes $\beta_2(v)$ into $\mathtt{T}_2(x)$ to avoid the collision at node *z*. As a result, node *x* cannot transmit a packet on time slot {3} on the SCH 2. After node *x* receives the acknowledgement packet, node *x* recognize this missing packet and the other packet incorrectly received by node *d*. Node *x* re-transmits them to node *d*.

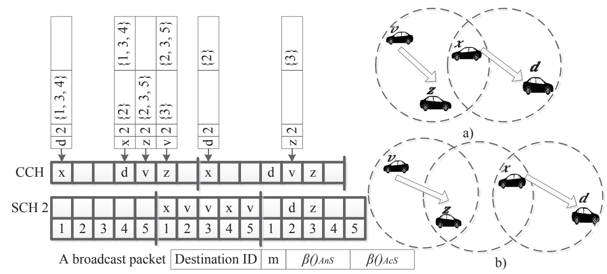

Fig. 3: Exposed terminal problem in the VeMAC protocol.

2) Criticality 2: A drawback of the VeMAC protocol in the parallel transmission: The VeMAC protocol has drawback when two or more nodes receive packets from other source nodes, as shown in Figs. 4a and 4b. Once node *d* accepts the reliable service offered by node *x*, it includes $\beta_2(x) = \{1, 3, 4\}$ into the AcS field of its packet transmitted on the CCH. Node *z* overhears the packet transmitted by node *d*, it will include $\beta_2(x)$ into $\mathtt{T}_2(z)$ to avoid collision at node *d*. Because node *v* does not overhear the packet transmitted by node *d*, node *v* can announce reliable service to node *z* on the time slot {2, 3, 5} on the SCH 2. Once node *z* receives the packet transmitted by node *v* and checks $\beta_2(v) \cap \mathtt{T}_2(z) \neq 0$, node *z* eliminates these time slots and includes new time slots, i.e $\beta_2(z) = \{1, 2, 5\}$ into AnS field of its packet transmitted on the CCH. Once node *v* accepts these time slots, node *v* includes $\beta_2(v) = \{1, 2, 5\}$ into AnS field of its packet transmitted on the CCH ($\beta_2(v) \cap \mathtt{T}_2(v)$ = 0). Node *z* receives the packet transmitted by node *v* and includes $\beta_2(v)$ in AcS field of the packet transmitted on the CCH. After this announcement, node *v* will transmit data on the time slots $\beta_2(v)$. The VeMAC protocol does not support parallel transmissions of nodes *x* - *d* and nodes *v* - *z* even through the transmission between nodes *x* and *d* does not affect transmission between nodes *v* and *z*.

III. e-VeMAC protocol

The e-VeMAC is a MAC protocol based on full knowledge of one-hop neighbor nodes to improve the VeMAC protocol in parallel transmission. The protocol inherits the framework of the VeMAC protocol. However, several extensions are

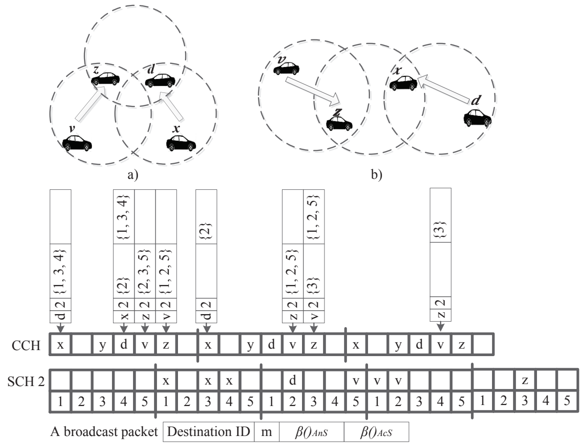

Fig. 4: A drawback of the VeMAC protocol in the parallel transmission.

proposed in e-VeMAC aiming to solve the problems presented in Section. II.

A. The Neighbor One-hop List

Each node maintains the neighbor one-hop list (NOL) to keep track of the status of the one-hop neighbors. The NOL consists of 5 parameters:

1) $N(x)$: the set of IDs of one-hop neighbor nodes on the CCH.
2) SCH: the index of service channel which is used by the corresponding node.
3) $\mathtt{T}_m$: the time slots used by the corresponding node.
4) S/R: 1: source node or 0: receiver node.
5) $BUSY$: the status bit on time slot (1: busy or 0: free).

TABLE I: The meaning of S/R and $BUSY$.

S/R	$BUSY$	$Meaning$
0	0	Node is Idle.
0	1	Node is receiving packets on time slots $\mathtt{T}_m$.
1	0	Node is waiting for acceptance from destination node.
1	1	Node is sending packets on time slots $\mathtt{T}_m$.

The status ($BUSY$,S/R) of a source node changes from (1,0) to (1,1) on the NOL's neighbor nodes if and only if neighbor nodes overhear packet confirmed by source node. Based on the packet transmitted on the CCH, node updates S/R and $BUSY$ in the NOL.

ID	AnS

Fig. 5: Format of the packet CfM on the CCH.

We define a new packet CfM (Confirmation Message) confirmed on the CCH in Fig. 5. Each packet confirmed on the CCH consists of 2 fields: *ID* and AnS. When destination node accepts a reliable service, source node transmits packet CfM to confirm within on time slot of destination node, as shown in Fig. 6.

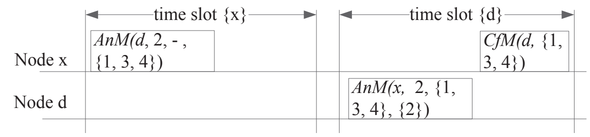

Fig. 6: The handshake between nodes x and d.

B. Improvement of SCH reservation algorithm

Based on the NOL, we propose an improvement of SCH reservation algorithm of the VeMAC protocol. If the conditions of $\beta_m() \cap \mathtt{T}_m() \neq 0$ and $S/R = 1$ are satisfied, the node does not accept these time slots and choose other time slots to communicate, as shown in Fig. 7.

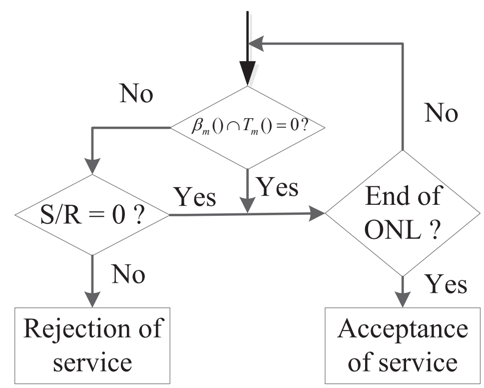

Fig. 7: Improvement of SCH reservation algorithm.

IV. Simulations

Under the same scenario, we simulate by using Matlab within 200 frames (200 frames * 10 ms/frame = 2 seconds) to evaluate the performance of the e-VeMAC and VeMAC protocols with parameters as shown in Table. II.

A. Highway scenario

To compare the VeMAC and e-VeMAC protocols, we consider that the scenario is a segment of a two-way traffic highway. Each vehicle can communicate with all vehicles within its communication range. The number of vehicles on the highway segment remains constant during the simulation time. In this section, we simulate with two-hop neighbor set and extend full segment highway scenario, as shown in Fig. 8.

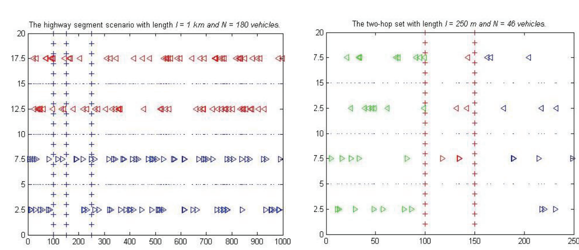

Fig. 8: A snapshot of highway segment.

TABLE II: Simulation parameters.

$Parameter$	$highway$
# lane/direction	4/2
# highway length	$1km$
Speed	$100km/h$
Transmision range	$150m$
# slots of left directions	50
# slots of right directions	50
# slots of RSUs	0
# slots of a frame on the SCH	100
Slot duration	$1ms$
# vehicles	180
# simulation time	2 seconds
Access the CCH	VeMAC protocol

B. Simulation Results

Each node has to broadcast packet on the CCH even if it does not have data to exchange. We assume that the number of packets can be modeled by a Poisson process with rate parameter λ_m messages/slot [12]. In our simulation, we choose $\lambda_m = 10$ messages/slot.

In the first scenario, we choose two-hop set (THS) within 250m, as shown in Fig. 8. Within 46 nodes in THS, we performance by setting up rate of source-destination pairs (λ pairs) to be 1, 2 and 3 under the same condition. The rate of source-destination pair increases as the number of nodes resent packet increases but the e-VeMAC protocol has lower nodes resent packet than the VeMAC protocol, as shown in Fig. 9. The rate of source-destination pair is set up to 1 and we run full highway segment 1 km in the second scenario, as shown in Fig. 10. We simulate with 3 runs times and compare between the VeMAC and e-VeMAC protocol. Because each vehicle can communicate with all vehicles within its communication range and affects to neighbor nodes, the number of nodes resent packet is low in the VeMAC protocol, and seem zero in the e-VeMAC protocol.

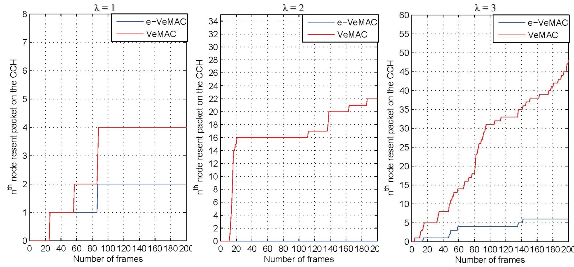

Fig. 9: The two-hop set with length l = *250m*, N = *46 vehicles*, *2* directions and rate with λ = 1, 2 and 3 pairs/frame.

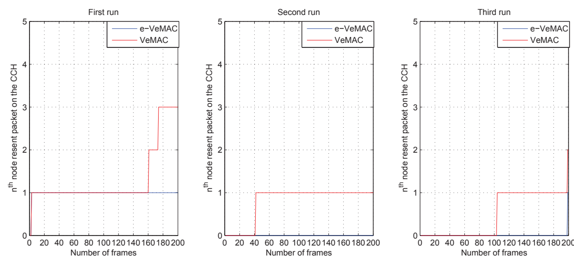

Fig. 10: The highway segment with length l = *1000m*, N = *108 vehicles*, *2* directions and rate with λ = 1 pair/frame.

V. Conclusions and Future Work

In this paper, a novel TDMA-based MAC protocol, called the e-VeMAC protocol, is proposed for VANETs based on the VeMAC protocol. As simulation results, in the e-VeMAC protocol the number of nodes resent packet on the CCH is lower than the VeMAC protocol in parallel transmission. In the future, the impact of the dynamic vehicle on the performance of the e-VeMAC protocol will be investigated in both highway and city scenarios.

VI. Acknowledgment

This research was supported by Basic Science Research Program through National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2014R1A2A2A01005900). Dr. CS Hong is the corresponding author.

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