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ResVMAC: A Novel Medium Access Control Protocol for Vehicular Ad hoc Networks

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Abstract

Efficient medium access control (MAC) is a key part of any wireless network communication architecture. MAC protocols are needed for nodes to access the shared wireless medium efficiently. Vehicular Ad hoc networks (VANETs) are an emerging network technology on the verge of large-scale deployment. The dynamic network topologies in VANETs caused by high mobility rates of vehicles presents a great challenge in reliable data transfer. A MAC protocol that enables quick reservation of packet transmission slots by vehicles that wish to send packets is crucial in addressing this challenge. In this paper, we propose a new distributed MAC algorithm ResVMAC for VANETs. We demonstrate using simulations, that our algorithm outperforms two state-of-the-art algorithms in key performance metrics.

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Keywords: VANETs; Medium Access Control Protocols; Time Division Multiple Access(TDMA); Intelligent Transportation Systems (ITS)

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1. Introduction and Related Work

Each year road accidents cause million of deaths and non-fatal injuries[1]. Moreover, traffic congestion results in estimated losses of several billion dollars from wasted time and fuel[2]. So it is desirable to have some method of communication between vehicles that can warn drivers and passengers, and reduce the likelihood of accidents and congestion. Vehicular networks can also improve passenger comforts. Intelligent Transportation Systems (ITS)[1] are used to improve road safety, increase the efficiency of transportation and enhance passenger and driver experience. Vehicular Ad hoc Networks (VANETs) form an important part of ITS. Nodes in VANETs are vehicles that comply with street traffic regulations while moving. VANETs support both vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. In V2V communications, vehicles exchange information with each other. V2I communications involve message exchanges between vehicles and traffic lights or between vehicles and roadside monitors known as road side units (RSUs). The vehicles can access the internet through RSUs. Each vehicle is equipped with a controller called on-board unit (OBU) that supports the V2V and V2I communications. The Federal Communication

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Commission (FCC) in the USA has allocated 75 MHz of frequency spectrum (5.850 – 5.925 GHz) for Dedicated Short-Range Communications (DSRC) technology for ITS[3].

In wireless networks, packets may collide when nodes contend for the shared medium. Collisions waste energy, increase packet delay, and decrease throughput. The highly dynamic topologies in VANETs, caused by fast movement of vehicles, results in increased collisions. Thus, designing VANET MAC protocols that enable fast access of the shared medium with fewer collisions is crucial for high performance. Various VANET MAC protocols have been proposed and implemented. IEEE 802.11p[4] protocol is the common standard for vehicular communication protocols. IEEE 802.11p extends the IEEE 802.11[4] standard, and utilizes the DSRC frequency spectrum. There are several limitations of IEEE 802.11p. First, it is not suitable for broadcast communications, because it uses the RTS/CTS mechanism. However, the hidden terminal problem cannot be alleviated without the RTS/CTS mechanism. Second, it does not work well when node density is very high and it cannot ensure high reliability when the traffic load is high. Distributed TDMA based VANET MAC protocols can eliminate these limitations and provide broadcast and reliable communications. We survey some TDMA-based MAC protocols next. We do not attempt to survey other classes of MAC algorithms due to space constraints.

1.1. TDMA-based VANET MAC protocols

TDMA based MAC protocols for VANETs fall in two categories those that follow the DSRC standard, and those that do not. VeMAC[5], VeSOMAC[6], TC-MAC[7], e-VeMAC[8] and HER-MAC[9] fall in the first category. The second category includes RR-ALOHA[10], CAH-MAC[11], eCAH-MAC[12], MS-ALOHA[13], RR-ALOHA+[14] and ECCT[15].

The protocols in the second category attempt to reserve packet transmission slots quickly. Notable among these are MARR-ALOHA[16] and RR-ALOHA[10]. In both MARR-ALOHA and RR-ALOHA, a vehicle cannot reserve an available time slot (or BCH) immediately after sending its REQ packet. Instead, the vehicle waits one frame to get acknowledgements from all the active one-hop neighbours about its BCH reservation attempt. It starts sending data from the next frame. Since our work improves on RR-ALOHA and MARR-ALOHA, we outline these protocols next.

1.1.1. RR-ALOHA[10]

RR-ALOHA is a distributed protocol that splits time into fixed length virtual frames. Each virtual frame consists of the previous N perceived slots $[1 \dots N]$ known as Basic Channels (BCHs). A vehicle must reserve a BCH in order to access the wireless channel. A vehicle that wants to send data monitors the channel for one virtual frame. Then it contends for a free BCH by broadcasting a FI (Frame Information) packet in that BCH. The FI packet contains the request for the reservation and the status of the perceived BCHs of previous frame: e.g., which BCH is reserved by which neighbour and which BCH is free. The FI packet that is used for reservation is known as REQ packet.

Let us suppose that a vehicle V wants to reserve a free BCH j. So it broadcasts its REQ packet in j after observing the channel for one virtual frame. Then it waits for the FI packets from its active one-hop neighbours. These neighbours broadcast their views about the previous virtual frame through their FI packets in their reserved BCHs, as shown in Figure 1. The one-hop neighbours that receive the REQ packet of V properly, assign j to V in their FI packets. If they detect collisions in j, they make j free in their FI packets. If j is assigned to V by all the active one-hop neighbours in their FI packets, then V starts to access the channel in j from the next frame and continues to broadcast its FI packets in j until a collision occurs. Thus, each vehicle knows about its two-hop neighbours by receiving the FI packets from its active one-hop neighbours which helps to avoid the hidden terminal problem.

Structure of FI packets. Each vehicle that has reserved a BCH sends its FI packet along with a payload. The FI packet contains as many fields as the number of BCHs in a virtual frame. Each field includes the following information:

- STI (Source Temporary Identifier) : The STI is used to uniquely identify the vehicle that has reserved this BCH. It is 8 bits long.
- PSF (Priority Status Field): The 2 bits long PSF sets the priority of the transmitted data.
- BUSY : If this BCH is free then BUSY bit is 0 otherwise 1.
- PTP : This bit is used to set up point-to-point communication.

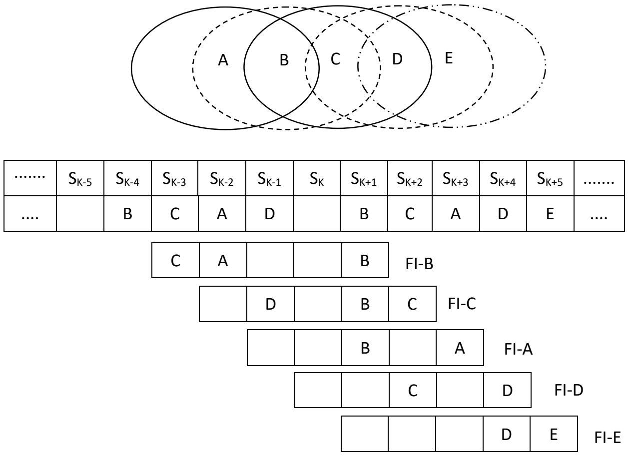

Fig. 1. Propagation of FI packets

1.1.2. MARR-ALOHA[16]

In RR-ALOHA, a vehicle broadcasts a packet (FI or REQ) at the beginning of its reserved BCH; so a collision occurs if several vehicles transmit in the same BCH. MARR-ALOHA uses CSMA and a backoff algorithm within a BCH to reduce the possibility of collision of REQ and FI packets. The FI packet is transmitted after a FI Backoff Timer (FIBT) expires. The FIBT is the product of the the Backoff time unit and the Backoff timer value. If a vehicle senses the transmission of a packet before the expiration of its FIBT, it gives up its attempt and tries to reserve another free BCH. The backoff timer value for the REQ packet is larger than the FIBT, so the REQ packet does not interfere the transmission of the FI packet. To avoid the collision in the common neighbours, shorter REQ packets are used that includes the STI of the vehicle, priority of the data and BUSY bits for all BCHs of the previous virtual frame. If a collision occurs at a common neighbour because of the REQ packets, then the common neighbour broadcasts about the collision. If the common neighbour gets more than one REQ packets for a specific BCH, it selects one vehicle for that BCH using an arbitration mechanism.

2. Algorithm ResVMAC

Our proposed algorithm ResVMAC is designed to reserve BCHs as quickly as possible. It uses a faster reservation scheme to reserve a BCH quicker than MARR-ALOHA and RR-ALOHA.

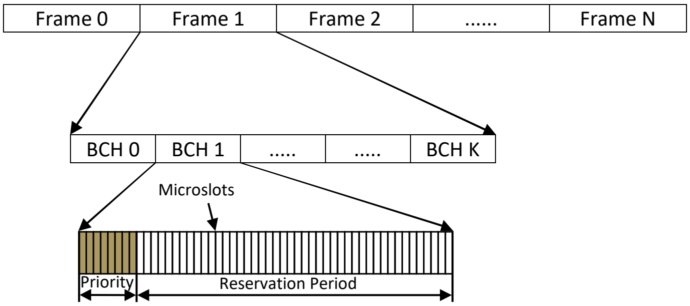

Fig. 2. Frame and Basic Channel structure of ResVMAC

- **Frame Structure:** ResVMAC uses the same frame structure like RR-ALOHA and MARR-ALOHA as shown in figure 2. It divides the time into fixed length virtual frames. Each virtual frame consists of a fixed number of BCHs. A vehicle that wants to send data must reserve a free BCH first.

- **REQ and FI packets:** Like RR-ALOHA and MARR-ALOHA, ResVMAC uses a REQ packet to reserve a free BCH. The REQ packet contains the sender address and the free BCH number that the sender wants to reserve. After reserving a BCH, a sender periodically sends FI packets in its reserved BCH until a collision occurs or it releases the BCH voluntarily. A FI packet contains the status of the slots of the previous frame.
- **Contention BCH:** If a vehicle wants to reserve a free BCH, then it estimates the total number of free BCHs in the upcoming frame by monitoring the previous frame. The first free upcoming BCH is known as the contention BCH for this vehicle. The contention BCH has two parts – a Priority period followed by a Reservation period. The Priority period prioritizes the vehicles that already have BCH, over the vehicles that want to reserve one. Vehicles that wish to send data contend in the Reservation period to get a free BCH.

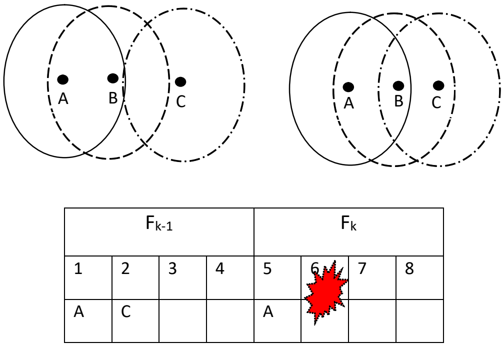

Fig. 3. Collision due to the movement of vehicles (B wants to reserve the BCH which is occupied by C)

- **Priority period:** If a vehicle sends REQ packet to reserve a free BCH immediately after entering into the radio range of another vehicle that has already occupied that BCH, then a REQ packet may collide with a FI packet, as shown in figure 3. To avoid this situation, the Priority period is defined, and a vehicle cannot send its REQ packet in this period. Instead, a vehicle must broadcast its REQ packet in the Reservation period. The vehicle that has already reserved the BCH starts broadcasting data at the beginning of the Priority period, and so the vehicle that wants to reserve this BCH finds the BCH busy and postpones its attempt.

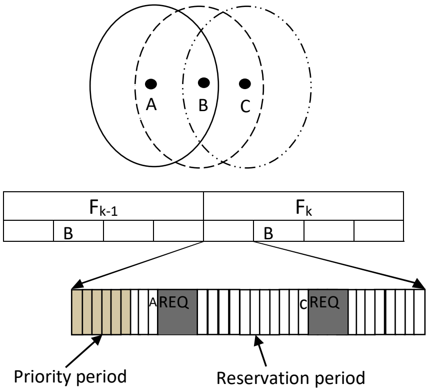

Fig. 4. Reservation of free BCH

- **Reservation period:** The Reservation period is virtually divided into n microslots[17]. If a vehicle wants to reserve a free BCH randomly selects a microslot number in $[1 \ldots n]$, and uses it as the initial value of a countdown timer. When the timer expires, the vehicle broadcasts its REQ packet. The free BCH number indicated in the REQ packet is reserved by the sender if all the active one-hop neighbours receive the REQ packet as shown in figure 4. If a collision occurs at any active one-hop neighbour during this transmission, the neighbour broadcasts a NACK as shown in figure 5. Moreover, if the sender wants to reserve a BCH that is already reserved by one of its two-hop neighbours, then the common neighbour broadcasts a NACK after receiving the

REQ packet. If the sender receives a NACK from any of its active one-hop neighbours, it contends again in the upcoming contention BCH. Other one-hop neighbours that want to reserve a free BCH freeze their timers during this whole transmission. They resume their timers when the transmission is over, and try to reserve a BCH from the remaining free BCHs if there is enough time left.

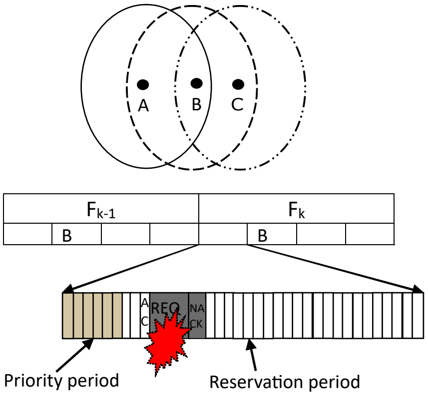

Fig. 5. Negative Acknowledgement from node B

- **Broadcasting data:** The sender starts broadcasting data in its reserved BCH if it does not receive any NACK from its active one-hop neighbours. If more than one receivers reply with NACKs then a collision occurs and the channel remains busy so sender considers it as a NACK.
- **Hidden Terminal Problem:** REQ packets may collide in ResVMAC due to hidden terminals. However, the small size of REQ packets ensure that these happen with very low probability.
- **Significance of Negative Acknowledgement:** In VANETs, it is necessary to establish communication link with neighbouring vehicles as quickly as possible. The NACK helps the colliding senders to get the information immediately after the collision, so that the senders can contend for the remaining free BCHs very quickly. Moreover if a sender sends a REQ packet for a BCH that is already reserved by another vehicle then the common neighbour sends a NACK immediately after getting the REQ packet. As a result, the sender can attempt for a free BCH in the upcoming contention BCH.

3. Performance evaluation of ResVMAC

In this section, we describe the models and metrics that we used to compare the performance of ResVMAC, MARR-ALOHA, and RR-ALOHA.

3.1. *Traffic Models and metrics*

We have simulated many different geographical scenarios. Here we present results for one artificial scenario and an actual city map. In order to generate realistic traffic, we used SUMO[19]. In the first scenario, we assume each vehicle can move along a square-shaped loop road (figure 6(a)) with side length 500m. The road has two lanes with 5 m width. All the vehicles in a lane move in the same direction and vehicles in the other lane move in the opposite direction. The car model with default parameters in SUMO were used to generate traffic on this map. We assume that each vehicle moves with a fixed velocity. In the second scenario, we use a portion of Khulna city, Bangladesh, shown in figure 6(b) to simulate urban conditions. We used both cars and trucks (both with default SUMO parameters) in SUMO to generate traffic. The maximum velocity of each vehicle in each model is 60 km/h but actual velocities are varying and set by SUMO. Since the duration of each BCH is very small, our simulations assume that the vehicles change their positions after each frame rather than after each BCH. We use a simple packet generation model in which each vehicle generates one packet in each frame.

Fig. 6. (a) A square-shaped loop road ; (b) A portion of Khulna city

We use average time responsiveness and packet delivery ratio (PDR) to evaluate the performance of our algorithm. The average time responsiveness is defined as the average amount of time each vehicle takes to reserve a BCH. PDR is the fraction of data packets successfully delivered to the intended receivers. We record the PDR in each scenario after varying the number of vehicles and the number of BCHs per frame.

3.2. Environment and Results

We implemented RR-ALOHA, MARR-ALOHA, and ResVMAC in Matlab R2013a. We use a very simple radio model in our simulations and postpone the implementation of more realistic radio models (e.g., as in[18]) to future work. The transmission rate is assumed to be 10 Mbps. This is consistent with the hardware available currently. We averaged the measurements over 20 runs. The duration of a BCH is set to 0.5 ms. For ResVMAC, the duration of one microslot is 0.01 ms, and the duration of a REQ packet and a NACK packet are 0.03 ms and 0.01 ms respectively. The duration of a REQ packet for MARR-ALOHA is set at 0.06 ms and for RR-ALOHA it is set at 0.5 ms. The Priority period and the Reservation period of ResVMAC are set to 0.05 ms and 0.45 ms respectively. The Max_Backoff and the Backoff_Unit of MARR-ALOHA are set to 5 ms and 0.01 ms respectively.

3.2.1. Average Time Responsiveness

We simulated 100 vehicles on the squared shaped roadway. We evaluated the average time responsiveness of RR-ALOHA, MARR-ALOHA, and ResVMAC for 35, 45, and 55 BCHs per frame when the radio range is 200 m. In a second set of simulations, we used 55, 65, and 75 BCHs for a radio range of 300 m.

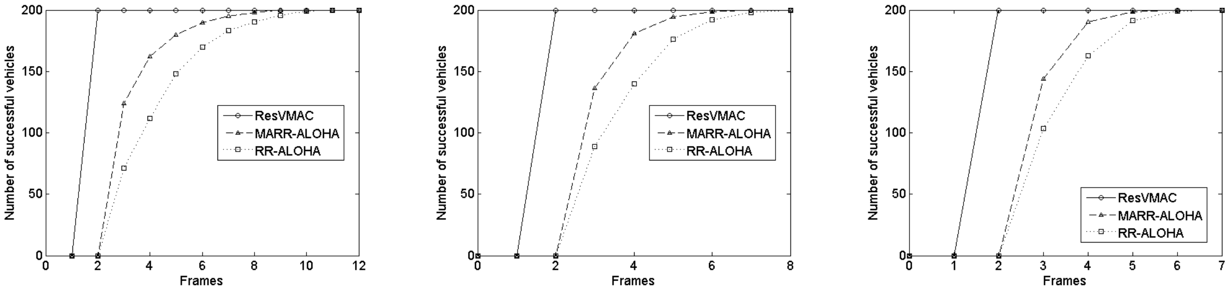

Fig. 7. Average Time Responsiveness for (a) 35 BCHs/ frame, (b) 45 BCHs/ frame, (c) 55 BCHs/ frame (radio range= 200m)

Figure 7 shows the number of frames needed to reserve a BCH by each vehicle when the radio range is 200 m. In each case, ResVMAC allows nodes to reserve a BCH much faster than the two existing protocols. For example, figure 7(a) shows the time responsiveness when the BCH per frame is 35. ResVMAC takes only one frame when MARR-ALOHA and RR-ALOHA takes 8 frames and 11 frames respectively. Note however, that most of the vehicles reserve their BCHs within 6 frames in MARR-ALOHA and 8 frames in RR-ALOHA.

A similar set of results are obtained when the radio range of each vehicle is set to 300 m. Figure 8(a) through figure 8(c) compares the average time responsiveness of ResVMAC to RR-ALOHA and MARR-ALOHA for 55, 65,

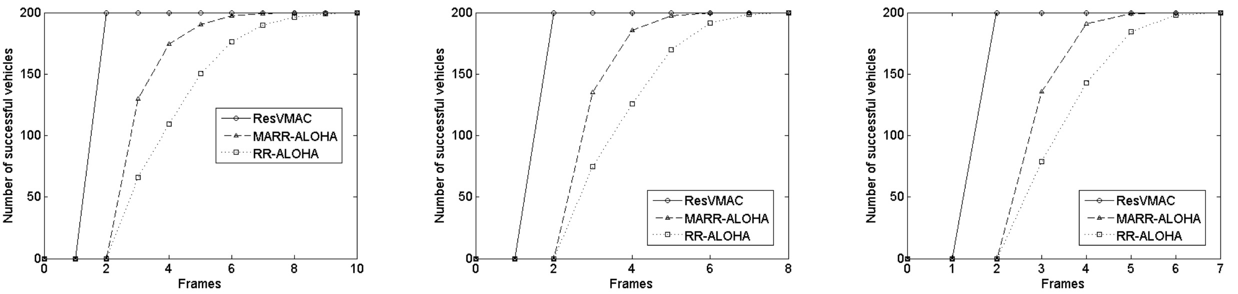

Fig. 8. Average Time Responsiveness for (a) 55 BCHs/ frame ; (b) 65 BCHs/ frame ;(c) 75 BCHs/ frame (radio range= 300m)

and 75 BCHs per frame. We observe again that ResVMAC has lower average time responsiveness than RR-ALOHA and MARR-ALOHA.

3.2.2. Packet Delivery Ratio

In this set of simulations, we placed half of the vehicles in each lane on the square-shaped loop road. The radio range is set to 200m. In figure 9(a) we varied the number of vehicles from 50 to 120 by keeping the BCHs per frame fixed to 40. In each protocol, PDR decreases as the number of vehicles increases, but ResVMAC attained higher PDR than MARR-ALOHA and RR-ALOHA. Figure 9(b) shows the variation of PDR with the number of BCHs per frame for 80 vehicles. We observe again that PDR in ResVMAC is better than MARR-ALOHA and RR-ALOHA.

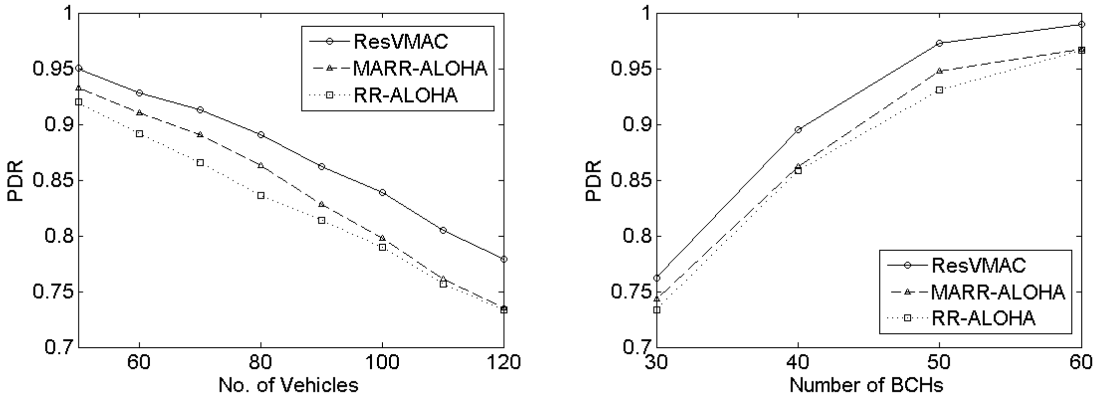

Fig. 9. (a) PDR vs Vehicles ; (b) PDR vs BCHs

In the last set of simulations, vehicles were placed randomly in a portion of Khulna city. At first, we varied the number of vehicles from 40 to 80 while keeping the BCH fixed at 40. The results (figure 10 (a)) show that ResVMAC provides better PDR than MARR-ALOHA and RR-ALOHA. Figure 10(b) shows the improvement of ResVMAC over MARR-ALOHA and RR-ALOHA for 40, 50, 60 BCHs per frame respectively.

4. Conclusions

In this paper we propose a new VANET MAC protocol ResVMAC that allows vehicles to reserve BCHs quicker than existing protocols. In ResVMAC, if a node wants to send data it contends for a free BCH by selecting a random microslot within the Reservation period. If it does not get any NACK from the one-hop neighbours immediately after sending its REQ packet, it sends data in its reserved BCH. On the other hand, if it gets at least one NACK then it contends again in the next contention BCH. We have used realistic mobility models in two scenarios to evaluate the

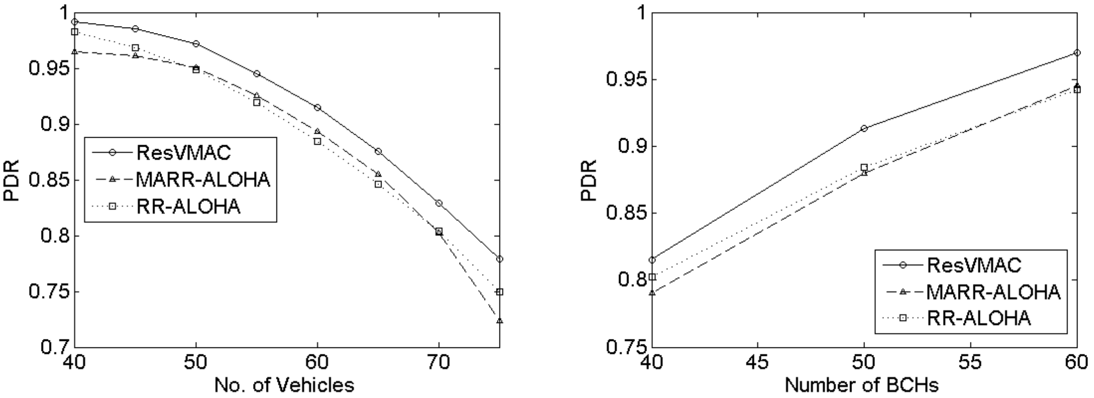

Fig. 10. (a) PDR vs Vehicles ; (b) PDR vs BCHs

performance of ResVMAC, and present simulation results to show that ResVMAC outperforms MARR-ALOHA and RR-ALOHA.

Acknowledgements

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References

1. World health organization. `http://www.who.int/features/factfiles/roadsafety/en/`; 2013.
2. Texas transportation institute. `http://www.its.dot.gov/index.htm`; 2013.
3. Kenney, J.. Dedicated Short-Range Communications (DSRC) Standards in the United States. *Proc of the IEEE* 2011;**99**(7):1162–1182.
4. Jiang, D., Delgrossi, L.. IEEE 802.11p: Towards an International Standard for Wireless Access in Vehicular Environments. In: *Vehicular Technology Conference, 2008. VTC Spring 2008. IEEE*. 2008, p. 2036–2040.
5. Omar, H., Zhuang, W., Li, L.. VeMAC: A TDMA-Based MAC Protocol for Reliable Broadcast in VANETs. *Mobile Computing, IEEE Transactions on* 2013;**12**(9):1724–1736.
6. Yu, F., Biswas, S.. Self-Configuring TDMA Protocols for Enhancing Vehicle Safety With DSRC Based Vehicle-to-Vehicle Communications. *Selected Areas in Communications, IEEE Journal on* 2007;**25**(8):1526–1537.
7. Almalag, M., Olariu, S., Weigle, M.. TDMA cluster-based MAC for VANETs (TC-MAC). In: *World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2012 IEEE International Symposium on a*. 2012, p. 1–6.
8. Nguyen, V., Dang, D.N.M., Jang, S., Hong, C.S.. e-VeMAC: An enhanced vehicular MAC protocol to mitigate the exposed terminal problem. In: *The 16th Asia-Pacific Network Operations and Management Symposium*. 2014, p. 1–4.
9. Dang, D.N.M., Dang, H.N., Nguyen, V., Htike, Z., Hong, C.S.. HER-MAC: A hybrid efficient and reliable MAC for vehicular ad hoc networks. In: *2014 IEEE 28th International Conference on Advanced Information Networking and Applications*. 2014, p. 186–193.
10. Borgonovo, F., Capone, A., Cesana, M., Fratta, L.. RR-ALOHA, a Reliable R-ALOHA broadcast channel for ad-hoc inter-vehicle communication networks. In: *Proceedings of Med-Hoc-Net 2002*. 2002, .
11. Bharati, S., Zhuang, W.. Performance analysis of cooperative ADHOC MAC for vehicular networks. In: *GLOBECOM*. 2012, p. 5482–5487.
12. Bharati, S., Thanayankizil, L.V., Bai, F., Zhuang, W.. Effects of time slot reservation in cooperative ADHOC MAC for vehicular networks. In: *2013 IEEE International Conference on Communications (ICC)*. 2013, p. 6371–6375.
13. Scopigno, R., Cozzetti, H.. Mobile Slotted ALOHA for VANETs. In: *Vehicular Technology Conference (VTC 2009-Fall)*. 2009, p. 1–5.
14. Cozzetti, H., Scopigno, R.. RR-ALOHA+: A slotted and distributed MAC protocol for vehicular communications. In: *Vehicular Networking Conference (VNC), 2009 IEEE*. 2009, p. 1–8.
15. Nguyen, V., Kazmi, S.M.A., Hong, C.S.. ECCT: an efficient-cooperative ADHOC MAC for cluster-based TDMA system in vanets. *IJDSN* 2015;**11**:746438:1–746438:12.
16. Liu, R., Xiang, Y., Yang, Y.. MARR-ALOHA: A mobility adaptive variety of RR-ALOHA for vehicular Ad-hoc networks. In: *Consumer Electronics, Communications and Networks (CECNet), 2012 2nd International Conference on*. 2012, p. 3304–3309.
17. Ray, S., Demirkol, I., Heinzelman, W.. ATMA: Advertisement-Based TDMA Protocol for Bursty Traffic in Wireless Sensor Networks. In: *Global Telecommunications Conference (GLOBECOM 2010), 2010 IEEE*. 2010, p. 1–5.
18. Saponara, S., Giannetti, F., Neri, B.. Design exploration for millimeter-wave short-range industrial wireless communications. In: *IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society*. 2016, p. 6038–6043.
19. Krajzewicz, D., Erdmann, J., Behrisch, M., Bieker, L.. Recent development and applications of SUMO - Simulation of Urban MObility. *International Journal On Advances in Systems and Measurements* 2012;**5**(3&4):128–138.