Efficient Time Slot Allocation to Minimize Collision in TDMA Based VANETs

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Abstract – Vehicular ad hoc network differ from traditional networks and wireless sensor networks due to their high speed, mobility constraints and information's variety they gathered. TDMA is the medium access control protocol which assign channels to each vehicle and then vehicles can communicate with each other on the given time slots. In a VANET, when two or more nodes occupies the same time slot and drive into each other's communication ranges, a reservation collision occurs, and all of the colliding nodes release their slots. TDMA based MAC is beneficial in many aspects in vehicular ad hoc networks. It has the ability to prevent the hidden-terminal problem, and the guarantee of strict quality-of-service for providing real-time applications. In VANETs, time slot assignments to vehicles could suffer from an unstable problem, called merging collisions. This problem is due mainly to the changing network topology of a VANET, which can be characterized by vehicles joining into or leaving from a cluster of vehicles. In this paper, a technique has proposed which focus on the problem of unstable time slot assignments. An algorithm has proposed which predicts the possible merging collisions due to the overtaking of fast vehicles. It predicts the collisions within 2-hops neighborhood and recommends the vehicle to acquire a new time slot in the control channel. The proposed MAC provides bounded access delay, minimize the merging and access collisions. The simulation result reveals that PCVeMAC significantly outperforms VeSOMAC and ADHOCMAC in terms of collisions and packet loss rate.

Index Terms – TDMA, MAC, VANETs, DSRC, IEEE 802.11, V2V SCH, CCH.

1. INTRODUCTION

Vehicular Ad-hoc Networks (VANETs) are envisaged to contribute to the safety and smooth of the transportation system. By enabling Inter-Vehicle communications (IVC) and Roadside-to-Vehicle communications (RVC), VANETs will support three categories of applications, primarily safety applications, additionally entertainment services and transportation management [1]. Motivated by the enormous potential benefits of VANETs, the United States Federal Communication Commission (FCC) has allocated the 5.850-5.925GHz band, known as the Dedicated Short Range Communication (DSRC) spectrum dedicated for the vehicular communications. The 75MHz band is divided into one control channel (CCH) for the safety applications and six service channels (SCHs) for the safety and non-safety related applications. There are two types of access to multiple channels, namely Service Channel (SCH) and Control Channel (CCH) in Vehicular Ad Hoc Networks (VANETs). Continuous access (e.g. continuous CCH access) does not require channel coordination, where alternating access (e.g. switching between CCH and SCH) requires channel coordination [3]. In either access method, accessing to CCH has to be designed carefully to prevent collisions, where both management frames and WSM (WAVE Short Message) data frames including safety messages are transmitted over the CCH. Each vehicle has to monitor the CCH continuously (or alternately for alternating access to CCH and SCH) to receive and to transmit management frames and WSM data frames. Before initiating data transfer on SCH, vehicles have to announce the recipient and the SCH parameters over the CCH. Collisions or delays on accessing the CCH affect the service delivery on SCH. High network load e.g. due to the high traffic density will increase the collision probability, which consequently affect the utilization of CCH and SCH.

Preventing collisions at CCH is essential both for service delivery in SCH and safety and control messaging in CCH. Collision prevention approaches for VANET generally use the slot allocation approach between neighboring vehicles where each slot is assigned to a vehicle in vicinity in a distributed manner. Collisions may occur on simultaneous attempts by multiple vehicles to reserve the same slot. Once slots are reserved, collision free transmissions can be guaranteed. However, due to the overtaking of fast moving vehicles, slot co-incidence may happen which causes collisions and invokes rearrangement of slot allocation. In high density traffic, such kind of slot arrangement may further cause a global rearrangement affect. In this paper the main aim is to prevent collisions and to minimize the packet loss rate.In slot reservation schemes, vehicles compete to reserve a time slot in a frame interval. In case two or more nodes attempt to access the same free time slot, access collisions may occur. After collision resolution, vehicles can be assigned free time slots.

Afterwards, vehicles transmit their packets on the allocated slots of CCH without collision.

However, due to overtake of fast moving vehicles; merging collisions might occur if any overtaking vehicle uses the same allocated slot. While there are many studies to prevent access collisions, there are scarce studies to prevent merging collisions. Meanwhile, if the merging collisions cannot be prevented, slot allocation mechanism will be reinitiated after each collision which will cause inefficient use of the CCH and, accordingly, SCHs. In case of collisions, vehicles will again compete to reserve free time slots, eventually causing delay on transmissions. As a result, access and merging collisions will hinder the SCHs to be used efficiently. With a careful design, merging collisions can be prevented. In our approach, similar to the schemes [4][5], vehicles exchange the neighboring information and slot allocation information with its neighbors. By considering the overtaking vehicles and vehicle speed, our proposed scheme, namely Prevent Collision MAC Algorithm (PCVeMAC), anticipates merging collisions and prevents both the merging collisions and the slot reallocation among all neighboring vehicles. Only the overtaking vehicle is required to acquire a new time slot from the available time slots. The rest of study is organized as follows. Section 2 describes the related works on MAC algorithms those aim to prevent collisions. The proposed prevent collision approach is described in Section 3. In Section 4, the simulation environment and the performance results are given in comparison with similar approaches. Finally, Section 5 concludes the paper.

2. RELATED WORK

There are many studies in the literature aiming to prevent collisions or aiming to provide more efficient or fair channel access. While carrier sense multiple access (CSMA) based approaches are good for fast topology changing networks, time division multiple access (TDMA) based approaches generally perform better with the use of channel allocation or assignment mechanisms. Token-based approaches are generally preferred for fair channel access in addition to prevent contentions and collisions. On the other hand, vehicular traffic characteristics introduce the merging collisions in addition to the access collisions. While some studies include road side units (RSUs) to solve these problems, the others aim to solve in a distributed manner.

2.1. Solutions for Access Collisions

In [6], a priority based hybrid MAC scheme is proposed that integrates TDMA and CSMA/CA schemes. Communication takes place between vehicle and road side units. The proposed hybrid MAC algorithm divides the channel into time frames. Each time frame is further divided into time slots. Based on the transmission priority, at the beginning of time frames each node determines the slot ownership. Remaining non-slot owners choose slots randomly from available slots. VeSOMAC (Self-Organizing MAC Protocol for DSRC based Vehicular Ad Hoc Networks) [7] uses an in-band control mechanism to exchange TDMA slot information during distributed MAC scheduling. VeSOMAC can operate in both synchronous and asynchronous modes. In the synchronous mode, all the vehicles are assumed to be time-synchronized by using GPS where they share the same frame and slot boundaries. In the asynchronous mode, each vehicle maintains its own frame boundaries. In [8], a MAC protocol which is a combination of CSMA and self-organizing TDMA is proposed for VANETs. The authors assume that vehicles form clusters. Switching mechanism between the CCH and the SCH is determined based on the vehicle density. A chip timer mechanism is used in switching. Chip is divided into transmission (TS) and reservation (RS) periods. TS part is based on TDMA and RS part is based on CSMA. The numbers of TS slots are equal to the number of vehicles in the cluster. For new slot requests, RS period is used. CCH and SCH duration are based on the node density. Mammu et al. [9] proposed two cluster based MAC approaches for traffic safety applications in VANETs where one of the approaches is contention-based and the other is contention-free. In the proposed approaches, RSU selects a cluster head (CH) based on a weighted equation composed of relative speed, total distance to the neighbors and total distance to the RSU. Contention-free approach is based on the TDMA where RSU is used to divide the frame into time slots and assigns portion of slots to CHs. Furthermore, each CH allocates the assigned slots to its cluster members. The contention-based approach is based on CSMA/CA where there are no slot assignments for CHs and cluster members.

2.2. Solutions for Both Access and Merging Collisions

AD HOC Medium Access Control (ADHOC MAC) [4] is a MAC architecture where the vehicles are grouped into a set of clusters with no cluster head; each cluster contains a restricted number of vehicles that are one-hop away. ADHOC MAC provides an efficient broadcast service for inter-vehicle communications and solves MAC issues such as the hidden-exposed terminal problem and QoS provisioning. ADHOC MAC is a contention-free medium access protocol which implements a dynamic TDMA mechanism that is able to provide prompt access based on distributed access technique. ADHOC MAC also implements an optimal multi-hop broadcast service and parallel transmissions that use a minimum set of relaying terminals able to cover the whole network. Omer et al. proposed a multichannel TDMA MAC protocol for VANET called VeMAC [5]. Time is divided into frames and time slots. Three slot sets are defined on the control channel frame which are assigned to RSU, vehicles moving in the same direction and opposite direction. Each node first listens the neighbors to collect vehicle ID sets N(x) and used time slots T(x).

After the transmitted messages, node determines its control channel time slot randomly considering the collected information. When the vehicle reserves a time slot, it uses same slot in next frames until a collision occurs. For service channel reservations, vehicles add service time slots and channel number into the control message. RCMAC [11] method is the extended version of VeMAC [5] algorithm. In RCMAC, each node selects its time slot randomly and shares its time slot with neighbors. RSU collects all messages from neighbors and transmits its message including the reserved time slots of vehicles. Vehicles can check their reserved time slot whether in used or not. If current time slot is already reserved, vehicle selects a free time slot randomly.In [12], a collision free slotted reservation MAC (CFR MAC) protocol is proposed which is based on VeMAC. CFR MAC aims to reduce time slot collisions and reservation problems due to random slot selection. In this paper proposed approach, PCVeMAC, is a distributed approach where nodes acquire time slots dynamically.

3. METHODOLOGY

The proposed method is a multichannel TDMA protocol based on VeMAC [5]. Vehicles are synchronized to a common time base using the time synchronization approaches defined in IEEE 1609.4 [3]. On the control channel as shown in Figure 1, time is partitioned into frames which have a constant number e.g. 100 of fixed duration time slots. Neighboring vehicles compete to get a time slot in a time frame. Once a slot is acquired by a vehicle, the same slot is used by that vehicle in subsequent frames until a collision occurs. Each vehicle transmits its beacon message at its time slot. Beacon messages include neighboring information and slot allocation information. Merging collisions are prevented using the neighboring information and slot allocation information by predicting the collisions within 2-hops neighborhood. Overall process is completed in four steps: i) exchange of beacon messages, ii) prediction of possible merging collisions, iii) announcing the possible collision, and iv) time-slot replacement (only one of two vehicles with possible collision).

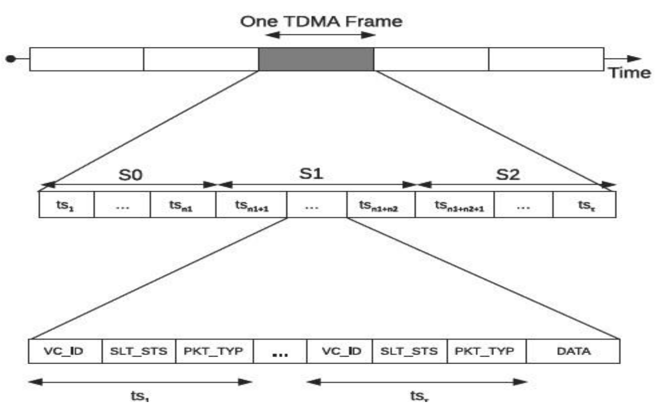

Fig.1. Time frame is divided into time slots

3.1. Prediction of probable merging collisions

By exchanging the slot allocation information in beacons, nodes can learn the slot allocation within 2 hops. The beacon format is given in Figure 2. Each vehicle inserts its ID, speed, current time slot and neighborhood information into the beacon message, and broadcasts the beacon (shares this information within 1-hop neighborhood). Neighbor's information is a list of neighboring vehicles containing neighbor's id, speed and reserved time slot. Reserved slot information is used to predict the collision in advance. Speed information will be used to alleviate the possible merging collision, which will be discussed later. A sample case on predicting the merging collision is illustrated in Figure 3.

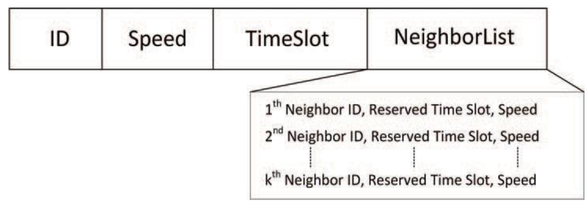

Fig. 2 Beacon Message

Let's assume that vehicles NA, NB, NC, ND and NE reserved time slots 3, 6, 8, 4 and 3, respectively. By beaconing, each node is aware of the neighborhood and time slot allocation in a time frame. At time t1, NB builds a slot allocation table for its 1-hop neighborhood where slots 3 and 6 are in use by NA and itself, respectively. Similarly, NC builds a slot allocation table for its 1-hop neighborhood where slots 3, 4 and 8 are in use by NE , ND and itself, respectively. At time t1, although slot 3 is used by both NA and NE, there is no collision probability, because these two nodes are not within their communication range.

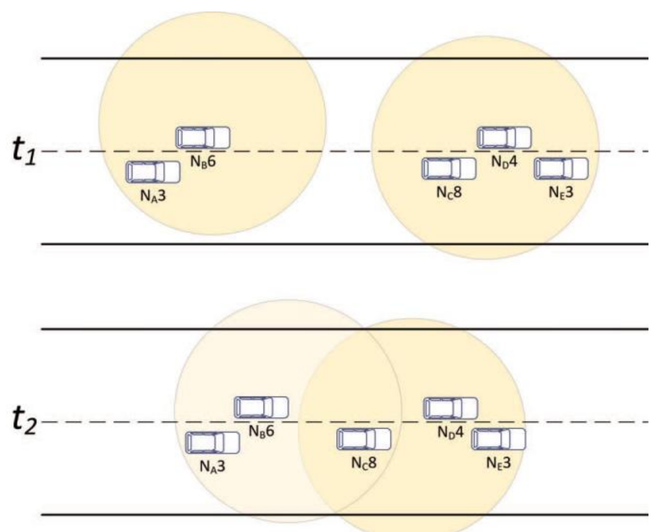

Fig. 3 Illustration of predicting the merging collisions within 2-hops

At time t2, fast moving NB enters into the communication range of NC. After beaconing, both NB and NC detect that slot 3 is used by both NA and NE, where there is a possibility of merging collision. Meanwhile, there is no hidden terminal problem at either NB or NC. Either NB or NC will issue a warning message for a possible collision.

3.2. Announcing the collision

For ensuring collision-free transmission of collision warning messages, we reserved time slot 0 (TS0) in the time frame only for the transmission of collision warning messages. When a vehicle detects a probable collision, it schedules the warning message to be transmitted at the first time slot of the next time frame. To avoid a probable collision, it is enough if one vehicle switches to a free time slot. Therefore, one of the two vehicles which might experience collision is selected as the node that has to acquire new free time-slot.

Vehicles which predict the possible collision (PVi) also determine in a distributed manner the vehicle which will replace its time-slot. Selection mechanism considers vehicle speed and vehicle id. The vehicle that is faster compared to its neighbors is selected as the node that has to acquire new slot. Detection of faster vehicle compared to its neighbors is described using the Figure 3 in which each vehicle in the network already knows the average speed and the standard deviation of the speeds of its neighbors by using (1) and (2), where AvgSpeedi is the average speed of neighbor list of Ni, and Vh std_dev, i is the standard deviation of the speeds of the neighboring vehicles.

Each PVi vehicles calculate the normalized speed values of the slot colliding vehicles using the vehicle PVi's neighbor's information with the use of (3) where Vh norm,i is the normalized speed of the node i. Because neighbors and their speeds are already shared in the beacon messages (shown in Figure 2), each PVi is able to calculate each slot colliding vehicles' normalized speeds. In other words, each PVi has the same information about the slot colliding vehicles. Using this information, they (PVi) can select the vehicle which will acquire a new time slot.

The slot colliding vehicle which has greater normalized speed value is selected to acquire a free time slot. If both slot colliding vehicles' normalized speed values are equal, then the vehicle with lowest id is selected. Meanwhile, only one of the PVi has to announce the collision warning to avoid the collision on the time slot 0. Therefore, the PVi which is the neighbor of the selected vehicle that has to acquire a new time slot announces the collision warning message. It schedules the message to be transmitted at TS0 of the next time frame. The message contains the id of the possible colliding node, its time slot, 2-hops neighborhood and allocated time slots. The equations used for calculating vehicle average speed, standard deviation and vehicle normalized speed are given next.

$$AvgSpeed = \frac{1}{N_i^{nb}} \sum_{i=1}^{N_i^{nb}} Vh_{speed,i} \cdots\cdots (1)$$

$$Vh_{std\_dev,i} = \sqrt{\frac{1}{N_i^{nb}-1} \sum_{j=1}^{N_i^{nb}} \left(Vh_{speed,j} - AvgSpeed, i\right)^2} \,..(2)$$

$$Vh_{norm,i} = \left(Vh_{speed,i} - AvgSpeed\right) / Vh_{std\_dev,i} \cdots\cdots (3)$$

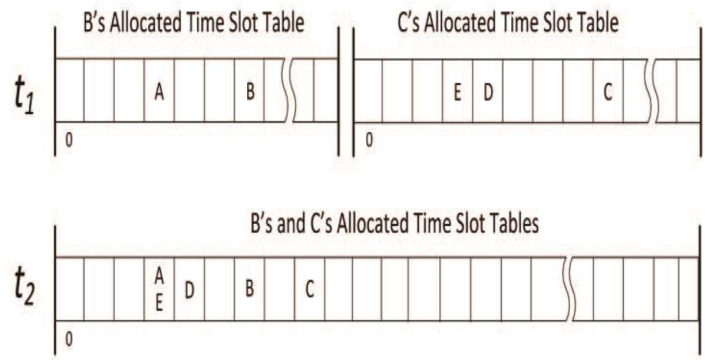

Fig.4. Announcing the collision

3.3. Changing the time slot

Upon reception of a collision warning message from a PVi, each node checks the identity of the possible colliding node (the warned vehicle). The node with matching identity cancels its scheduled messages in its time slot. Then, it aims to find a time slot which is not used by the any other nodes within 2-hops. This information is available in the warning message. After changing its time slot, it schedules its messages and beacons to be transmitted in the new time slot.

3.4. Implementation

In Algorithm 1, after receiving a beacon, the vehicle Ni checks the collision situation. First, it checks whether the sender node Nj is a new neighbor or not. If Nj is already exists in the neighbor list (NListi), then Ni checks whether Nj 's time slot is changed or not. If Nj time slot is not changed, Ni checks whether reserved time slots of the Nj 's neighbors changed or not. In other words, Ni checks whether there is state change in terms of neighbors or slot allocation. If there is a state change, PredictCollision() function is triggered to determine a possible collision within 2-hops neighborhood. PredictCollision() function returns the id of time slot colliding vehicles and their time slot, if there is such a probable collision. In such a probable collision, Algorithm 2 is called to determine which vehicle will acquire a new time slot. Then, the node Ni schedules a collision warning message to be broadcasted at time slot 0 (TS_0).

Algorithm1. Determination of a Probable Collision

Require: Upon receiving Beacon from N_j

```
identify Collision = NO
if N_j ∉ N List_i then
check Collision = YES
else if N_j ∈ N List_i and N_j time slot altered then
 identify Collision = YES
else if N_j ∈ N List_i and N List_j is altered then
identify Collision = YES
end if
Update N List_i
if identify Collision then
collision = Predict Collision ()
if collision then
   call Recommend substitute Timeslots (N_A, N_B)
    Set {Collision aware Msg} to the TS_0
end if
    end if
```

Algorithm 2 is used to determine the node that has to acquire a new time slot due to a probable message collision. In Algorithms 2, equations (1)-(3) are applied to determine fast moving vehicle compared to its neighbors. If speed differences cannot be used for this purpose, the node with lowest id is selected to acquire a new time slot.

If the node Ni is elected as the node PVi to announce the collision warning message, it inserts the 2-hops neighbors list (NList2H) and their corresponding slot allocation into the message.

Algorithm2. Recommended Alternative Time Slots

```
Locate Collided Nodes (N_A, N_B)
Calculate V_norm,A
Calculate V_norm,B
if V_norm,A > V_norm,B then
  timeslot_SwitchingNode = N_A
else if V_norm,B > V_norm,A then
   timeslot_SwitchingNode = N_B
else
   timeslot_SwitchingNode = get the LowestID(N_A,N_B)
 endif
 if timeslot_SwitchingNode is in NList_i then
 Create two hops Neighbour list NList_2H
 Add NList_2H to the Collision message
Add timeslot_SwitchingNode to the Collision aware msg
 end if
```

4. SIMULATION

The performance of the proposed approach evaluated using a realistic road traffic simulator SUMO and network simulator NS2 [14]. In the evaluations, the performance of the proposed approach, PCVeMAC is compared with VeSOMAC [5] and ADHOC-MAC [4] with a realistic scenario for highway, as shown in figure 5. Vehicles are located on a highway with 2-lanes and 2 km length in each direction (Table I). Vehicle speed is generated from Normal Distribution with mean 100 km/h and standard deviation 20 km/h. Other simulation parameters are listed in Table I

TABLE I SIMULATION PARAMETERS

Metrics	Value
Area for Simulation	Highway (Dual Carriageway)
Length of Road	2 km
Number of Lanes	4 lanes (2 lanes in each direction)
Vehicle Densities	60-120 vehicle/km
Transmission Range	200,250,300,350
Avg. Vehicle Speed	100 km/h
Time Frame Length	100 ms
Time Slot Duration	1 ms
Simulation Time	90 s

In VeSOMAC, vehicles acquire time slots based on the direction. Time frame is divided into two parts and each half part is reserved only for the same directions. Similarly, ADHOC-MAC uses two parts where the vehicles contend to acquire a slot in one of these two parts.

On the other hand, PCVeMAC chooses any free time slot. Because the main aim is preventing merging collision, only this performance metric is measured for various vehicle densities (Figure 6) and vehicle transmission ranges (Figure 7). As shown in Figure 6, PCVeMAC, VeSOMAC and ADHOC-MAC are tested with various vehicle densities ranging from 60 veh/km up to 120 veh/km. As expected, the number of collisions increases as the density increases. The rate of increase is exponential which points the necessity of a solution to prevent collisions on high traffic.

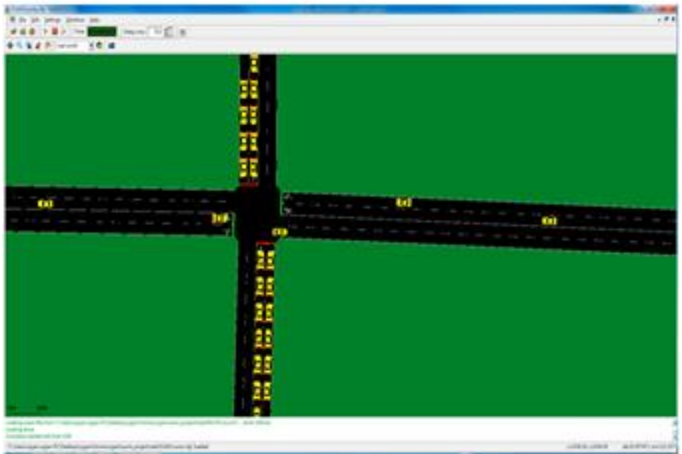

Figure 5 shows a road traffic scenario in SUMO

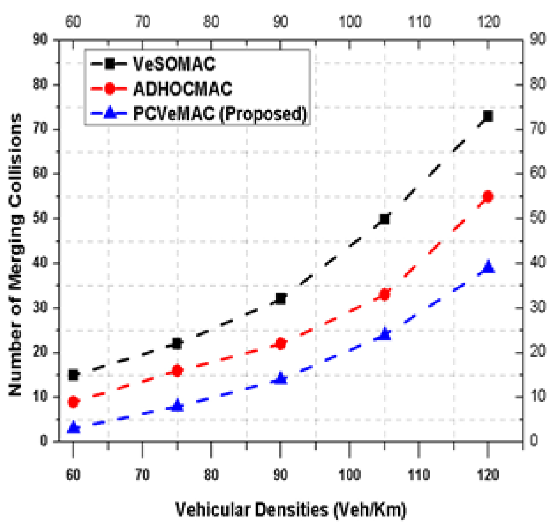

Figure 6 number of merging collisions in various node densities

It is seen that, proposed approach PCVeMAC presents better results compared to VeSOMAC and ADHOC-MAC. For instance when the vehicle density is 90 veh/km, there are around 14 collisions in PCVeMAC although for ADHOCMAC it has calculated 23 collisions on average and VeSOMAC has more than 30 collisions. As the vehicle density increases, collisions in PCVeMAC also start to increase. However, the number of collisions for PCVeMAC is always calculated less, compared to the ADHOCMAC and VeSOMAC.

In Figure7, the results belong to the scenario with the transmission range. Transmission range also affects the collision rate on a transmission channel. Figure 7 shows the number of merging collisions for the transmission ranges varying from 180 meters to 360 meters. The results belong to the scenario with a moderate vehicle density 90 veh/km. It is seen that as the transmission range increases the number of merging collisions increase. However, the number of merging collisions of PCVeMAC is always less than VeSOMAC and ADHOC-MAC even in the high transmission ranges. It has noticed that at the transmission range 350m, proposed PCVeMAC has approx. 90% less number of merging collision as compared to VeSOMAC and around 42% in contrast to ADHOCMAC. Similar to results with various vehicle densities, it is seen that increasing the range increases the collision rate. Greater transmission range means more coverage area leading to more nodes accessing the same channel. Therefore, when the number of neighbors increased then finding the free time slot will be competitive and, therewith, the number of merging collision will increase.

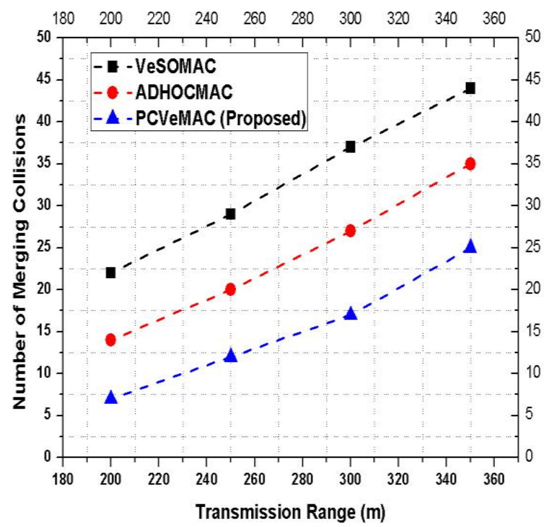

Fig. 7 number of merging collisions in various transmission ranges

Figure 6 and Figure 7 also show the effects of increased number of vehicles in channel access in terms of merging collisions. Although all approaches present different results for each scenario and the number of merging collisions tend to increase while the differences among approaches tend to decrease.

In figure 8, A parameter has used named as area occupancy (AO), which is equal to $T_{AV} \times R \div H_L \times N_{TS,}$ where T_{AV} is the number of total vehicle which are active, R is the total range of communication , H_L is the highway length and N_{TS} is the total number of time slots. Figure shows the rate of merging collision for PCVeMAC (proposed), VeSOMAC and ADHOCMAC protocols when varying the area occupancy. Proposed PCVeMAC prevents almost double merging collision than VeSOMAC in a high AO. For instance at area occupancy AO=1.8, PCVeMAC merging collision rate calculated 0.80 % which is less than ADHOCMAC which has around 1.3% and it has calculated 1.6% in case of VeSOMAC which is almost double than proposed MAC. Moreover, it has clear from the simulation calculated values that PCVeMAC performs better than both ADHOCMAC and VeSOMAC even in low area occupancy.

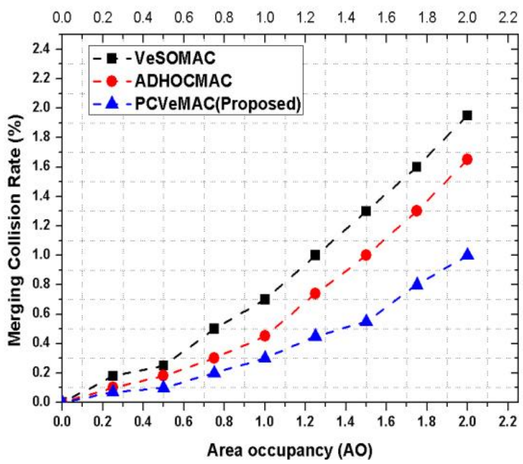

Fig. 8 Rate of merging collision

Figure 9 shows access collision rate of TDMA based MAC protocols. It has seen that PCVeMAC achieves a considerably very less rate of access collision than VeSOMAC and ADHOCMAC, especially in the high area occupancy. It has noticed that at AO =1.2 access collision rate of proposed MAC (PCVeMAC) calculated 0.55 in contrast to ADHOCMAC 0.80 which is approximately 30% higher than proposed MAC and for VeSOMAC access collision rate is almost double at the same AO which is around 1.1.

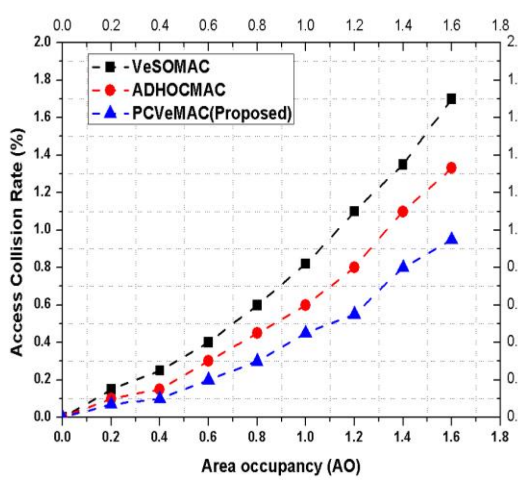

Fig. 9 shows the rate of access-collision

In figure 10 it can be seen that the proposed PCVeMAC has the lowest packet loss rate, especially for the high area occupancy due to its capability to handle the more merging collisions. For instance at AO = 1.5, PCVeMAC shows the value of packet loss rate around 1.25% which is less as compared to ADHOCMAC which has calculated 1.75% and on the other hand for the same AO it has noticed that VeSOMAC packet loss rate is approximately 2.60% which is very high in contrast to the proposed MAC.

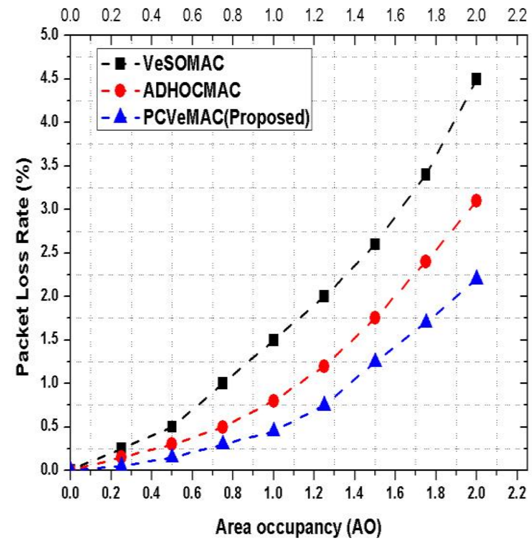

Fig. 10 shows the rate of packet loss

5. CONCLUSION

TDMA-based MAC algorithms perform better in accessing the channels in wireless communications. Slot allocation mechanisms reduce the access collisions in VANETs. However, high mobility and the traffic characteristics of the vehicles cause the merging collisions. In this paper, a prevent collision approach introduced to minimize collisions. The proposed approach, PCVeMAC, predicts the possible collisions within 2-hops neighborhood, and informs the neighborhood vehicles. The slot colliding vehicle acquires a new time slot among available time slots within 2-hops neighborhood. The contributions of the PCVeMAC are in twofold: first, it reduces the merging collisions, access collisions and secondly, it also minimizes the packet loss rate. So the proposed PCVeMAC significantly outperforms VeSOMAC and ADHOCMAC in terms of collision and packet loss rate.

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