# A Near Collision Free Reservation based MAC Protocol for VANETs

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*Abstract*—Compared with the CSMA based MAC protocols, the slotted reservation solutions could be more adaptable for VANETs. However, the high mobility and mobile hidden terminal (MHT) issues in vehicular environments cause a challenge of efficient and scalable slotted scheduling for TDMA MAC protocols. This paper proposes a novel near collision free reservation (CFR) MAC which is based on a recent VeMAC protocol to provide near collision free scheduling and address the mobile hidden terminal issue in VANETs. In former distributed TDMA MAC proposals like VeMAC, on the control channel of DSRC communication system, each vehicle randomly reserves dedicated time slots. However, the slot reservation of CFR MAC is more structural, based on the driving status and traffic flow of each vehicle. The performance of CFR MAC is verified via simulations and comparisons with IEEE 802.11p and VeMAC to demonstrate that superiority of CFR MAC.

***Keywords- VANET; Performance Evaluation; TDMA; MAC***

## I. 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.

The primary traffic of safety messages has stringent requirements on real time and highly reliable transmissions. Apparently, the performance of a VANET has much dependence on the underlying medium access mechanism, as it determines the scheduling of physical resources. The IEEE 802.11p [2] proposes to employ the CSMA/CA as the basic channel access mechanism in VANETs. Although CSMA/CA is widely applied owing to its simple and distributed operations, it suffers from some intrinsic drawbacks that contradict the requirements of transmissions of safety messages in VANETs [3]. Broadcasting is the primary traffic for safety services as all vehicles are stakeholders for the safety and smooth of transportation systems. Since broadcast in CSMA lacks collision detection as it is unacknowledged, it suffers from the hidden terminal problem as RTS/CTS are only applied to unicast and the transmission delay is unbounded due to its probabilistic nature. To satisfy the hard real-time and reliability requirements of safety messages, the Time Division Multiple Access (TDMA) have been considered in many VANET literatures.

In [4], the authors evaluated the ability of IEEE 802.11p and a self-organizing TDMA based MAC (STDMA) method under the periodic broadcasting scenario in VANETs. It has shown that STDMA performs better than CSMA in term of fairness, channel access delay and packet loss rate. However, when traffic density is high, transmission collisions become serious in STDMA. Under high vehicular mobility, the reservation coordination becomes difficult and needs further investigation.

Another well-known TDMA based MAC protocol, ADHOC MAC [5] based on the Reliable Reserved ALOHA (RR-ALOHA) [6], has demonstrated that it can support reliable broadcast for safety messages and avoid the hidden terminal problem. However, in ref. [7], the authors pointed out that a fixed frame length was not adaptable to the varying traffic density. The Adaptive ADHOC (A-ADHOC) protocol was proposed to adjust the number of time slots per frame according to the vehicle density. Another drawback of ADHOC MAC is that it is single-channel operating, not compatible with DSRC multichannel operation. VeMAC [8] solves the problem. Moreover, vehicles reserve time slots much faster in VeMAC than in ADHOC MAC for the same number of vehicles and available time slots per frame by adopting the random choosing reservation mechanism.

As for the performance evaluation, ref. [9] provided a quantitative comparison between ADHOC and CSMA. It pointed out that TDMA MAC should combat high mobility and guarantee real-time slot availability in vehicular environments. In [10], the authors showed that the throughput of ADHOC MAC would go down by 30% when the speeds of vehicles are increased from 0 to

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50Km/h. Ref. [11] has pointed out that there are two kinds of collisions in TDMA protocols, access collisions and merging collisions. Access collisions are likely to occur between nodes that attempt to reserve the same slot, which make the reservation nondeterministic. Merging collisions are inevitable because of the unique mobile hidden terminal (MHT) problem [12] in VANETs. MHT refers to the problem that the vehicles using the same slot become two hop neighbors because of the high vehicle mobility and disturb the communication of each other. Therefore, the reservation procedures in TDMA protocols should consider the mobility features to alleviate the slot collisions. In this paper, we propose a near Collision Free slotted Reservation MAC (CFR MAC) protocol, which is based on VeMAC for VANETs. This mechanism considers the mobility features of VANET and assigns disjoint sets of time slots to vehicles according to their driving statuses, so as to alleviate the MHT problem and resolve collisions caused by high node speeds. Meanwhile, the enhanced reservation technique reduces the reservation delay and detects access collisions faster than VeMAC. The performance of CFR MAC is verified via simulations and comparisons with VeMAC. Furthermore, IEEE 802.11p is also included in the performance evaluation and comparisons.

The rest of the paper is constructed as follows. Section II briefly presents the system models and the not well addressed problems in former time slotted mechanisms. Section III explains the CFR MAC and how it solves MHT that was not addressed in VeMAC. Extensive simulations and comparison results are presented in Section IV. Section V concludes the paper with future investigation suggested.

## II. SYSTEM MODEL & PROBLEM STATEMENT

### A. *System Model*

As CFR MAC is based on VeMAC, accordingly the system model and slot accessing scheme in VeMAC will be briefly discussed in this section in order to better explain why CFR MAC is superior for slot reservation and adaption to high mobility.

In the considered VANETs, all nodes are supposed to share a common synchronization source. A simple solution is to utilize the 1PSS signal in the GPS receiver. When the GPS signal is lost, other pulse synchronization methods [13] [14] can be employed. The carrier sensing range of each vehicle is assumed to be the same as the communication range. The transmission range of each vehicle is supposed to be the same and the radio link is assumed to be symmetric. The road segment has balanced traffic on two opposite directions.

In VeMAC, the slot accessing on the control channel does not require central management. The RSUs access the channel via the same approach as vehicles. Time is partitioned into a periodic frame structure which is further divided into slots to provide contention free communication channels for different vehicles. Each frame contains a fixed number of time slots, denoted as $N_{TS}$. A time slot is the smallest time unit for a single transmission and it is identified by its index within a frame. On the control channel, each vehicle is required to reserve at least one time slot to transmit the safety messages and its knowledge about the statuses of the time slots. A node knows the statuses of all nodes within its two-hop set (THS) and it must not reserve the same slot with all other nodes in the same THS. Consequently, the nodes that are at least three hops away are allowed to reuse the busy slots. Since each vehicle randomly chooses a slot that it perceives to be available after listening to the channel for a frame, access collisions are unavoidable between nodes attempting to reserve the same slot.

### B. *Problem Statement*

When the traffic density becomes high, the number of access collisions will increase rapidly, which is characterized by long slot reservation delay. Moreover, the reservation outcome is only known after one frame, and the node cannot contend for any other time slots until the next frame, which causes the reservation delay longer. When a node detects an access collision, it will redo the reservation procedure until it successfully reserve a time slot.

Once a node has successfully reserved a time slot, the corresponding slots in the subsequent frames will be dedicated for its use until a merging collision happens. Based on the received frame information in each time slot, each node can detect whether or not a merging collision has happened. If a merging collision happens, the nodes involved will release their slots and redo the reservation procedures.

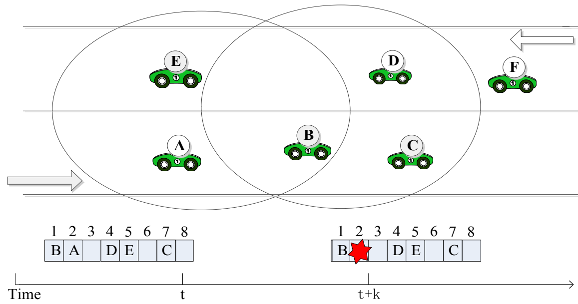

Fig.1 Example of the merging collision in VANETs

Merging collisions happen among the MHTs due to the vehicles' high mobility. The scenario in Fig.1 explains the merging collision problem. Assume vehicle A and vehicle F are MHTs to each other. Both vehicles have reserved the 2nd time slot in a frame. Initially, vehicle F was far away from A, therefore there is no transmission collision. Because of vehicle mobility, A and F move toward each other, encounter, and disturb the transmissions. Consequently, merging collision happens at the 2nd time slot. Assuming that there are $N$ number of THS neighbors around vehicle A, each of them has reserved a separated time slot for transmission and there are $M$ MHTs like vehicle F. The total number of slots in a frame is $N_{TS}$. The probability of merging collision is given as

$$p = 1 - \frac{(N_{TS} - N)! \times (N_{TS} - M)!}{(N_{TS} - N - M)! \times N!}$$

This equation represents the merging collision probability from a snapshot view, i.e. not considering the movement of the vehicles. It shows that when the number of MHTs becomes high, the probability of merging collision will increase rapidly. The serious merging collision problem in VANETs triggers the vehicles to release their slots frequently, thus the radio resources are utilized inefficiently. According to the analysis in [8], the merging collisions mainly happen between encounters driving in opposite directions, or with high relative speeds. Therefore, we propose an innovative *vehicle status based* reservation strategy to address the MHTs caused by fast-changing vehicular topology.

## III. Collision-Free Reservation MAC Protocol

CFR MAC is designed to reduce the reservation delay and solve the MHT problem. Each vehicle is required to include how the channel is perceived using a field called frame information (FI), in order to realize the slot reservations. CFR MAC extends the FI to contain the speed and the acceleration of the nodes rather than just the status of each slot. Each FI contains as many fields $FI_i$ as the number of slots in each frame. The *Status* field contains the status of each slot, indicating whether the slot is Idle, Busy or Collides. If the *status* is busy, then the node ID of the occupant of the slot is also put in this field. The Hop number indicates whether the status information of a time slot is received immediately or heard from other FIs.

When a node needs to reserve a time slot, it needs to sense the channel for a continuous frame interval to determine the available time slots set it is allowed to reserve.

- If the node hears exactly one node transmission in a time slot directly, it will set the status of the slot to be busy-1(the hop number of the FI, indicating that the slot has been occupied by one of its one hop neighbors), and record the corresponding node ID.
- If the node receives multiple FIs indicating a slot is occupied by different vehicles, it set the status of the slot as collide.
- If the node does not hear anything from a slot directly, but receives any FIs recording the status of the slot as busy-1, it will record that status of the slot as busy-2, indicating that the slot has been occupied by one its two-hop neighbors.
- If the node doesn't hear anything from a slot directly, but receives any FIs recording the status of the slot as busy-2, it will record that status of the slot as free. And the free slot will always be recorded as free.

By correlating the two-hop FIs, the node will get a whole view about the reservation statuses of all the slots in a frame, and determine the set of its THS neighbors. The node must not reserve a time slot that has been acquired by one of its THS neighbors to avoid the hidden terminal problem. Then the node will determine the available time slot set and attempt to access one of them randomly.

As aforementioned, the merging collision problem can be alleviated by reducing the number of MHTs. MHTs that are driving in opposite directions or with higher relative speed will encounter each other in relatively shorter time. Therefore merging collisions happens much more frequently than vehicles driving in the same direction and low relative speed. To reduce the merging collisions and increase the occupancy time of the slots, CFR MAC is designed to manage the reservation decisions according to the driving statuses of the nodes.

The time slots in each frame are evenly divided into two sets *L* and *R*, associated with the vehicles going on the left and right respectively. Furthermore, the *L* and *R* sets are respectively further partitioned into three sets to associate with nodes with three levels of speed: *High, Medium*, and *Low.* After a node determined its THS neighbors, it calculates the average speed of its neighbors and the relative speed between the speed of its own and the average speed. The relative speed $\Delta v$ of a vehicle with speed $v_i$ to the average speed $\bar{v}$ is calculated as: $\Delta v = v_i - \bar{v}$. Then the node limits the available time slot set according to its direction and speed level, as depicted in Fig.2. The value of $\upsilon$ requires being determined according to the speed interval of the vehicles and the speed deviation in the real traffic scenarios. When the traffic is in a dense condition, the value of $\upsilon$ will be decreased as the speed between vehicles may be not that much. But when in such as the highway scenario, the value of $\upsilon$ will be much higher. In our simulation, it is set as the value of the speed standard deviation.

| Direction | *R* | | | *L* | | |
|---|---|---|---|---|---|---|
| Relative speed | $\Delta v < -\upsilon$ | $-\upsilon < \Delta v < \upsilon$ | $\Delta v > \upsilon$ | $\Delta v < -\upsilon$ | $-\upsilon < \Delta v < \upsilon$ | $\Delta v > \upsilon$ |
| Speed level | *Low* | *Medium* | *High* | *Low* | *Medium* | *High* |

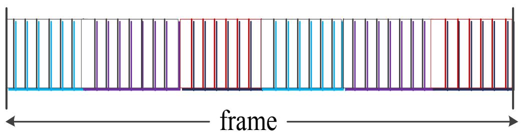


Fig. 2: Partitioning of each frame into 6 subsets of time slots.

While in the unbalanced traffic scenarios, it is possible that some vehicles cannot acquire a time slot for a long time as it has a larger number of competitors. Therefore the number of time slots associated with each direction and speed interval requires being determined according to the real traffic scenario. If after $\tau$ frames, the node cannot reserve a time slot, then it is allowed to reserve any slot that is associated with its driving direction. If after $\tau$ more frames, the node still cannot reserve a slot, it is allowed to reserve any available slot, including the slots associated with the opposite direction. It is shown that the transmission collision rates are highly affected by the value of $\tau$ and the traffic flows of the opposite directions [15]. The optimal of $\tau$ will be examined and investigated in the future works, while in this paper we simply investigate two scenarios where $\tau = 0$ and $\tau = \infty$.

After the reservation attempt, the node determines whether the reservation was successful by listening to the FIs in the next frame. If all the THS FIs indicate that the slot has been reserved by the node, the reservation is considered successful. Otherwise, it considers that there is some other node within its THS reserving the same slot and a collision has happened. Then, it will redo the reservation procedure until it successfully reserves a time slot. Once a node has successfully reserved a time slot, the corresponding slots in the subsequent frames will be dedicated for its use until a merging collision happens. Based on the received frame information in time slot, each node can detect whether or not a merging collision has happened. After a collision happens, each corresponding node will release the slot and redo the reservation procedure.

Fig.3 outlines the integrated operation of CFR MAC protocol. The FI in each packet can be used as an implicit acknowledgement to determine whether the reservation is successful or not. Therefore collisions are detected faster in this way. By transmitting the FIs two hops away and assigns different slots to the nodes in the THS, the hidden terminal problem is avoided. Vehicles with opposite driving directions and different speed levels are associated with different slot sets. Thus the access collisions are reduced as the nodes are contending with fewer rivals for fewer available slots, and the mobile nodes that occupy the same slot can remain far away from each other for a much longer time. Consequently, both the access and merging collisions are much reduced. The CFR MAC is able to support reliable and near collision free transmissions for safety messages on the control channel with deterministic delay.

**CFR ALGORITHM: STAGE: FI(Frame Information) determination**

while stage==FI determination;

for: slot index: i==1 $\longrightarrow$ $N_{TS}$

if exactly one node heard in the i$^{th}$ slot directly

$slot \leftarrow NID_i$ ; status=*Busy*; hop++; speed= $v_i$ ;

elseif more than one node heard in the i$^{th}$ slot

status=*Collide*; hop=1;

elseif the i$^{th}$ slot is sensed *Busy* from other node, hop==1;

$slot \leftarrow NID_i$ ; status=*Busy*; hop++; speed= $v_i$ ;

elseif the i$^{th}$ slot is sensed Busy from other node, hop>1;

status=free; hop reset;

else status=free; hop++;

end

**CFR ALGORITHM: STAGE: Slot reservation**

while successful==0

determine: driving direction and speed level;

and determine the available time slots

then do reservation: attempt number++;

if successful==1 after a chip successful=1, reservation finished;

else

if attempt number >= $\tau$ && attempt number < $2\tau$

determine: driving direction

and update the available time slots with ignoring the speed level

then do reservation: attempt number++;

elseif attempt number > $2\tau$

update the available time slots with ignoring the direction and speed

end

Fig. 3. The outline of the reservation algorithm in CFR MAC

## IV. SIMULATIONS AND COMPARISONS

We have carried out extensive simulations to validate the performance of CFR MAC and compare it with VeMAC and the CSMA MAC of IEEE 802.11p. In VeMAC, time is partitioned into synchronized same duration frames. Each frame contains 100 time slots each of which lasts for 0.35ms. While in IEEE 802.11p, the synchronized interval is 100ms during which each vehicle is required to transmit a safety or control message. To compare fairly between these mechanisms, we adjust the duration of each time slot in CFR MAC and VeMAC to be 1ms and the synchronized duration is 100ms. Vinf and V0 are two different schemes in VeMAC with the value of $\tau$ set to $\infty$ and 0 respectively. When $\tau = 0$, CFR MAC performs in the same way as V0. The simulation is carried out using the typical highway scenario that consists of four lanes of two opposite directions. The initial positions of vehicles are uniformly distributed on the road segment. When a vehicle reaches one end of the road segment, it is assumed to enter the highway from the other end so that the number of vehicles remains constant during the simulation. The simulation is conducted using the MATLAB. The other simulation parameters are listed in Table 1.

TABLE1: Parameter Settings in Simulations

| **Parameter** | **Value** |
|---|---|
| Number of lanes | 4 |
| Highway length | 1000m |
| Lane width | 5m |
| Number of vehicles | 80,100,120, …, 320 |

| | |
|---|---|
| Speed mean | 100km/h |
| Speed standard deviation | 20km/h |
| Contention Window in CSMA | 32 |
| Slot time in CSMA | 16 $\mu s$ |
| Packet size | 400Byte |
| Data rate | 12Mbps |
| Simulation time | 60s |
| Transmission range | 150m |
| Number of simulation runs | 20 |
| The split parameter $\tau$ | 0 / ∞ |

Fig.4 displays the average broadcast coverage ratio of the four different schemes. The coverage ratio is calculated as the ratio of the number of vehicles that successfully receive the messages to the total number of neighbors within the transmitter's transmission range. As the results demonstrate, 802.11p performs poorly and coverage ratio decreases rapidly as the traffic density becomes high. This is due to the high collision rate, the hidden terminal problem, and the lack of collision detection and retransmission capacity in CSMA. While the TDMA schemes perform much better and the broadcast in CFR MAC almost reach the full coverage. The performances of the three TDMA based schemes are close to each other because they can provide similar dedicated channel access after slot reservations.

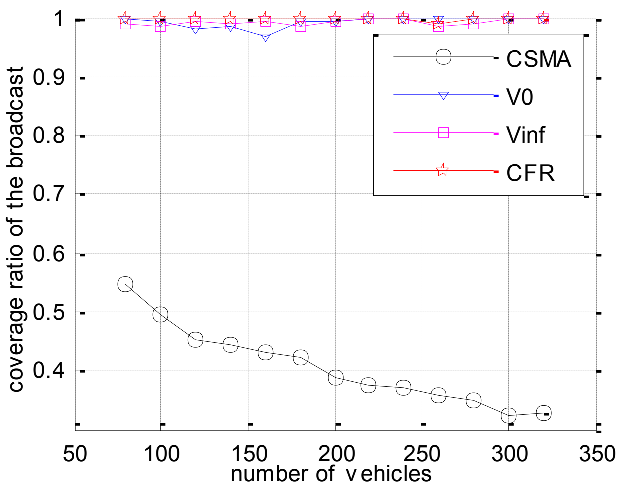


Fig.4. the coverage ratio of broadcast under various traffic densities

Fig.5 demonstrates the overall reservations delay that is defined as the time required for all vehicles within a THS to reserve time slots successfully. THS occupancy measures the ratio of the number of nodes in one THS to the total number of time slots available for a THS. For V0 scheme, it requires the longest time for all vehicles to reserve time slots as the access collisions are more serious due to the more unrestricted reservation range of each node, as depicted in Fig.6. The access collision rate is defined as the average number of access collisions that happen within a slot in one THS. While the CFR MAC has the smallest reservation delay, so that the vehicles can reach steady states and utilize the slots more efficiently.

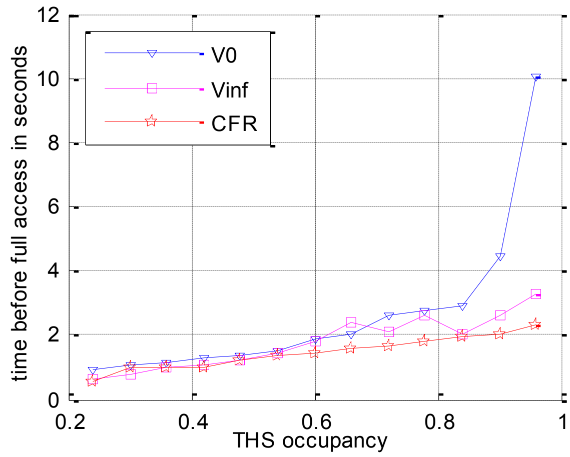


Fig.5. the overall reservations delay under various THS occupancies.

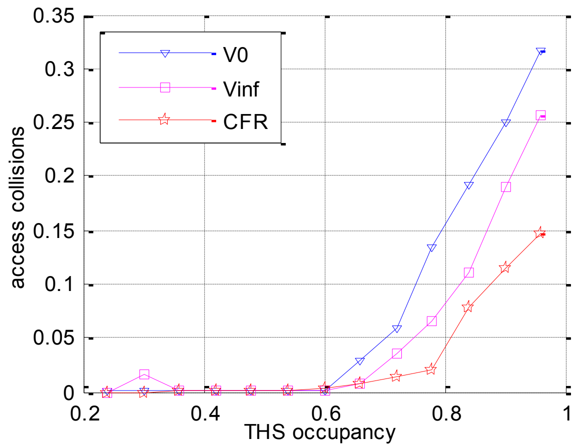


Fig.6. the access collision rates under various THS occupancies.

Figure.7 shows the merging collision rates of the three TDMA based MAC schemes under consideration in the highway scenario. The merging collision rate is defined as the average number of merging collisions that happen within a frame interval in one THS. The V0 has the highest rate of merging collisions and CFR MAC achieves the lowest rate of merging collisions. In V0, the available time slot sets are the same for vehicles in the same THS without considering their driving directions and speed levels. Therefore merging collisions happen frequently between MHTs driving toward each other and at high relative speeds. While in our mechanism, the vehicles driving in opposite directions and different speed levels are restricted to reserve separate sets of time slots, therefore even they encounter each other, merging collisions rarely happen between them. While the nodes occupy the same slot remains far apart for a much longer time, therefore the channel resource are utilized more efficiently.

The overall collision rates of all the MAC protocols under consideration are demonstrated in Figure.8. The collisions in IEEE 802.11p happen when more than one vehicle in the same THS attempts to access the channel at the same time. The transmission collisions in the three TDMA mechanisms include all the access collisions and merging collisions. It can be seen that our scheme acquires the lowest collision rate so its average channel access interval time is the lowest among the three TDMA schemes, closest to the optimal, 100ms in our simulation scenario.

In summary, our mechanism resolves disputes among nodes, avoids the hidden terminal and MHTs, mitigates the mobility effect and consequently realizes the deterministic delays and reliable transmissions for safety messages in VANETs.

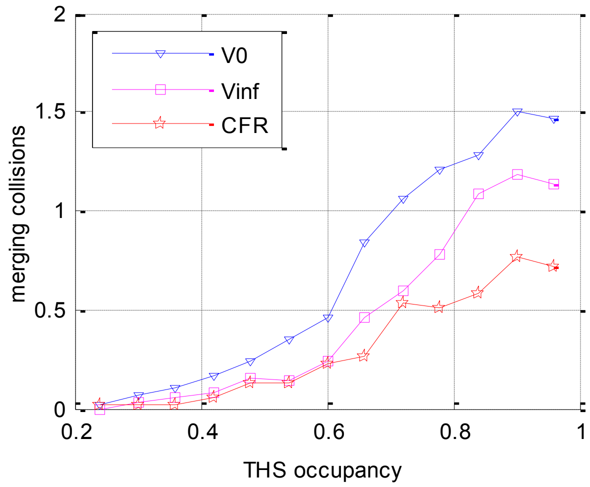


Fig.7. the merging collision rates under various THS occupancies

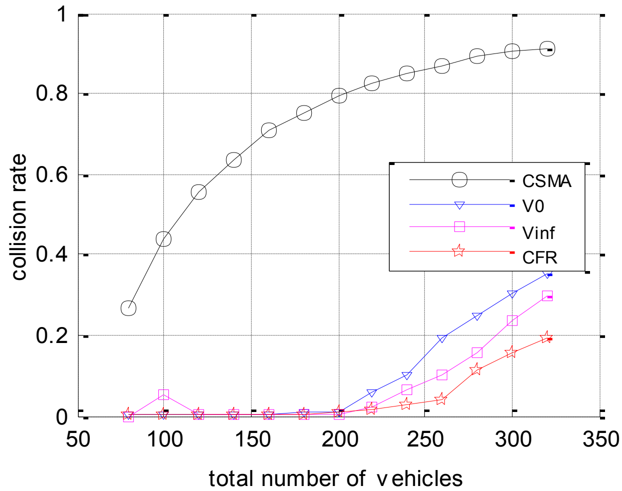


Fig.8. the overall collision rates under various traffic densities

## V. Conclusion and Future Works

In this paper, a TDMA based MAC protocol called CFR MAC is proposed for VANET. Its most important contributions include: 1) it provides deterministic transmission delay for safety messages on the control channel 2) by assigning different groups of slots to vehicles according to their driving statuses, it solves disputes among vehicles, shortens the reservation time, avoids the hidden terminal problem and reduces transmission collisions in the vehicular environments. The simulation results show that, compared with the IEEE 802.11p and VeMAC, CFR MAC is more adaptive and reliable in the reduction of reservation delay and the collision rate.

In the future, the mechanism will be extended to allow each node to reserve more than one time slot per frame on the control channel and the condition to support various QoS requirements for different traffic flows. Meanwhile, the broadcast and unicast on the service channel will be investigated, extended and compared with the IEEE standard.

## References

[1] Papadimitratos, P., de la Fortelle, A., Evenssen, K., Brignolo, R.,Cosenza, S., “Vehicular communication systems: enabling technologies, applications, and future outlook on intelligent transportation”, IEEE Communications Magazine, vol.47, pp. 84-95, 2009.

[2] IEEE 802.11p/D10.0, Part11: Wireless LAN Medium Access Control (MAC) and the Physical Layer (PHY) Specifications: Amendment 7: Wireless Access in Vehicular Environment, Draft 7.0, January 2010.

[3] Lin Zhang, Zishan Liu, Rui Zou, Jinjie Guo and Yu Liu,” A Scalable CSMA and Self-Organizing TDMA MAC for IEEE 802.11 p/1609.x in VANETs”, Wireless Personal Communications, Springer, 2013, accepted.

[4] Katrin Bilstrup, Elisabeth Uhlemann, ErikG Ström and Urban Bilstrup., “On the Ability of the 802.11p MAC Method and STDMA to Support Real-Time Vehicle-to-Vehicle Communication”, EURASIP Journal on Wireless Communications and Networking, 2009.

[5] Borgonovo F., Capone A., Cesana M., Fratta L., “ADHOC: a new. Flexible and reliable MAC architecture for ad-hoc networks,” Wireless Communications and Networking, WCNC, vol.2, pp: 965-970, 2003.

[6]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.

[7].Limin Miao,Fengyuan Ren; Chuang Lin and Anan Luo, "A-ADHOC: An adaptive real-time distributed MAC protocol for Vehicular Ad Hoc Networks",China Comm. and NEt.,pp:1-6,2009.

[8] Omar, H.A., Weihua Zhuang, Li Li, “VeMAC: A TDMA-based MAC Protocol for Reliable Broadcast in VANETs”, Mobile Computing, IEEE Transactions on, vol.12, pp. 1724 – 1736, 2013.

[9] Menouar, H.; Filali, F.; Lenardi, "A survey and qualitative analysis of MAC protocols for VANETs," Wireless Comm., vol.13, no.5, pp.30-35,2006.

[10]Borgonovo, F. ; Campelli, L. ; Cesana, M. ; Fratta, L.,"Impact of user mobility on the broadcast service efficiency of the ADHOC MAC protocol", VTC, 2005-Spring.

[11]F. Borgonovo, L. Campelli, M. Cesana, L. Coletti, ”MAC for ad-hoc intervehicle network: service and performance”, IEEE Vehicular Technology Conference (VTC) Fall, vol.5, pp.2789-2793,2003.

[12]Kazi Atiqur Rahman, Kemal E. Tepe, “Extended sliding frame R-Aloha: Medium access control (MAC) protocol for mobile networks”, Ad Hoc Networks, ELSEVIER, vol.10, pp. 1017–1027, 2012.

[13]D. Lucarelli and I.-J. Wang. “Decentralized synchronization protocols with nearest neighbor communication,” ACM SenSys, pp. 62–68, 2004.

[14]G. Werner-Allen, G. Tewari, A. Patel, M. Welsh, and R. Nagpal. “Firefly-inspired sensor network synchronicity with realistic radio effects,” ACM SenSys , pp. 142–153. 2005.

[15] Omar, H.A., Weihua Zhuang, Li Li, “Evaluation of VeMAC for V2V and V2R Communications under Unbalanced Vehicle Traffic” , Vehicular Technology Conference (VTC) Fall, pp.1-5, 2012.