An Adaptive TDMA Slot Assignment Strategy in Vehicular Ad Hoc Networks

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Abstract

Improving road safety is among the main objectives of Vehicular Ad-hoc NETworks (VANETs) design. This objective would be achieved essentially by the use of efficient safety applications which should be able to wirelessly broadcast warning messages between neighbouring vehicles in order to inform drivers about a dangerous situation in a timely manner. To insure their efficiency, safety applications require reliable periodic data dissemination with low latency. Medium Access Control (MAC) protocols play a primary role to provide efficient delivery and avoid as much as possible data packet loss. In fact, in distributed MAC approaches, packet loss is a consequence of collisions resulted from well known situations of the exposed and hidden node situations. This paper introduces an Adaptive TDMA Slot Assignment Strategy (ASAS) for VANET based on clustering of vehicles. The main aim of this work is to provide a MAC layer protocol that can reduce inter-cluster

interference under different traffic loading conditions without having to use expensive spectrum and complex mechanisms such as CDMA or OFDMA. An analysis and simulation results are presented to evaluate the performance of ASAS. Moreover, we compare its performance with two TDMA MAC protocols DMMAC and VeMAC.

Keywords: VANET, QoS, MAC protocols, CDMA, TDMA, FDMA.

1 Introduction

The Vehicular Ad-hoc NETwork (VANET) is a sub class of Mobile Ad-hoc NETwork (MANET), which has some special characteristics such as the high dynamicity of the nodes, the lack of infrastructure and diverse quality of service (QoS) requirements. In VANETs, communications can either be between nearby vehicles V2V (Vehicle To Vehicle) or between vehicles and road side units V2I [9] (Vehicle To Infrastructure). Due to the importance of V2V communications, several research projects are underway to standardize V2V communication in Europe and around the world such as the Car2Car consortium [5] which seeks to improve road safety. In the US, the FCC (Federal Communication Commission) [2] established the DSRC service (Dedicated Short Range Communications) in 2003. The DSRC [3] radio technology is defined in the frequency band of 5.9 GHz with a total bandwidth of 75 MHz. This band is divided into 7 channels of 10 MHz for each one. These channels comprise one Control CHannel (CCH) and six Service CHannels (SCHs), each one offering a throughput from 6 to 27 Mbps. The CCH is reserved for the network management messages, but is also used to transmit messages of high priority. The six SCHs are dedicated to data transmission.

However, the V2V communication is based on the exchange of beacon messages (current status, aggregate data, and emergency messages). If several vehicles broadcast these messages at the same time, then a collision will occur. Thus, it is crucial to avoid collision on the Control CHannel CCH in order to ensure a fast and reliable safety messages exchange. To provide a QoS and reduce the collision on the CCH, we introduce an adaptive TDMA slot allocation strategy that takes into account the specificity of VANETs networks. The strategy proposed operates at the stable clusters heads which are responsible for assigning disjoint sets of time slots to the members of their clusters according to their directions and positions. Thus, by using

a centralized means of slots reservation, we ensure an efficient utilization of the time slots and thereby decrease the rate of merging collision [13] and hidden node collisions caused by vehicles moving in opposite directions.

The remainder of this paper is organized as follows. Section 2 reviews related works on MAC protocols in VANET. Section 3 sets out the challenges of TDMA based MAC solution deployment. We give a detailed description of ASAS in Section 4. In Section 5, we present and discuss the simulation results. Conclusion and perspectives are presented in Section 6.

2 Related Work

Several distributed MAC protocols have been designed for inter-vehicle communications. They can be classified into three categories, the contention-based medium access method CSMA/CA such as IEEE 802.11p [6], and the contention-free medium access method using Time Division Multiple Access TDMA, such as VeMAC [13, 14], TC-MAC [15]. The third category is a hybrid of the two previous methods such as DMMAC [17].

Recently, the TGp Task Group of IEEE [10] has proposed the IEEE 802.11p [6] to support VANET communications. Based IEEE 802.11, this standard tends to improve the QoS by using different messages priorities. In fact, IEEE 802.11p implements the Enhanced Distributed Channel Access EDCA [7] technique for packet prioritization. Nevertheless, a major problem of the IEEE 802.11p standard comes from the lack of bounded channel access delays guarantees [1], since it is based on a contention MAC method.

In [13] the authors propose a contention-free medium access control protocol for VANET called VeMAC. Vehicles in VeMAC are equipped with two radio interfaces, where the first is always tuned to the control channel CCH while the second one can be tuned to any service channel. CCH slot allocation is performed in a distributed manner where each vehicle randomly gets an available time slot. It is not the case for the SCH slot allocation. This task is ensured by service providers in a centralized way. However, packets transmitted by VeMAC on the CCH are large (Vehicle ID, current position, set of one-hop neighbours and the time slot used by each node within one-hop neighbourhood), which induces a high overhead on the CCH. Moreover, its random slot allocation technique is not efficient due to the appearance of free slots.

Günter and al. [14] propose a cluster based medium access control protocol (CBMAC). In their protocol each cluster head is responsible for time slot

assignment to its cluster members for messages transmission. The aim of this protocol is to limit the effect of the hidden node problem and offer a fair medium access. In CBMAC protocol, the access time is divided into periodic frames and each frame is divided into time slots. The CH generates and manages the TDMA slot reservation schedule for its vehicles members according to the amount of data needed to send.

Recently a novel multi-channel MAC protocol called TDMA cluster-based MAC (TC-MAC) for Vehicular Ad hoc NETworks has been proposed by Almalag and al. [15]. It is based on stable clusters heads which are in charge of TDMA time slot assignment. TC-MAC provides an efficient time slots utilization for the exact number of active vehicles. Unlike WAVE MAC architecture, in TC-MAC protocol, the frame is not divided into two intervals CCHI and SCHI. In fact, each vehicle may switch to the Control Channel (CCH) or to a specific service channel (SCH) when needed during the time slot.

In [17], the authors introduce the Dedicated Multi-channel MAC (DMMAC) protocol. The DMMAC architecture is similar to WAVE MAC with the difference that in DMMAC, the CCH Interval is divided into an Adaptive Broadcast Frame (ABF) and a Contention-based Reservation Period (CRP). The ABF period composed of time slots, each time slot is dynamically reserved by an active vehicle as its Basic Channel (BCH) for collision-free delivery of the safety message or other control messages. The CRP employs CSMA/CA to organize its channel access. During the CRP, the vehicles negotiate and reserve the network resources on SCHs for non-safety applications. In addition, it is restricted to the only scenario of a straight highway road with an available number of slots higher than the maximum number of cars.

3 TDMA based MAC Protocol Challenges in VANETs Networks

The first aim of a MAC protocol for VANET is to ensure that each vehicle is granted an access to the channel in a bounded delay in order to send safety messages without collisions. TDMA is a method that can be used to assign one time slot to each active vehicle. We will study below the challenges of MAC solutions in VANETs focusing particularly on the TDMA technique. In the following we highlight the major problems faced in the case of a distributed TDMA slot allocation technique and in the case of a cluster based TDMA slot allocation technique.

3.1 Distributed TDMA Slot Allocation Challenges

When a distributed scheme is used to allocate a time slot, two types of collision on the time slots can happen [12] : access collision between vehicles trying to allocate the same available time slots, and merging collision between vehicles using the same time slots. The ***access collision problem*** [13] occurs when two or more vehicles within the same two-hop neighbourhood set attempt to allocate the same available time slot. This problem is likely to happen when a distributed scheme is used to allow the vehicle to reserve a time slot. As shown in Figure 1., the two vehicles attempt to access the same slot when they are within two-hops range. While ***the merging collision*** [12] is a basic problem for vehicular ad hoc network, this problem occurs when two vehicles in different two-hops sets using the same time slot become members of the same two-hop set due to their mobility. Figure 2 shown an example of the merging collision problem, when vehicle B in the first two-hop set is moving in opposite direction to vehicle E in the second two-hop set which is using the same time slot as B. Since B and E become members of the same two-hop set, then a collision will occur at vehicle D.

3.2 Centralized TDMA Slot Allocation

When the slot assignment schedule is centralized in the clusters heads, an inter-clusters interference problem can arise. There are two types of inter-cluster interference [4]: One Hop neighbouring Collision and Hidden Node Collision.
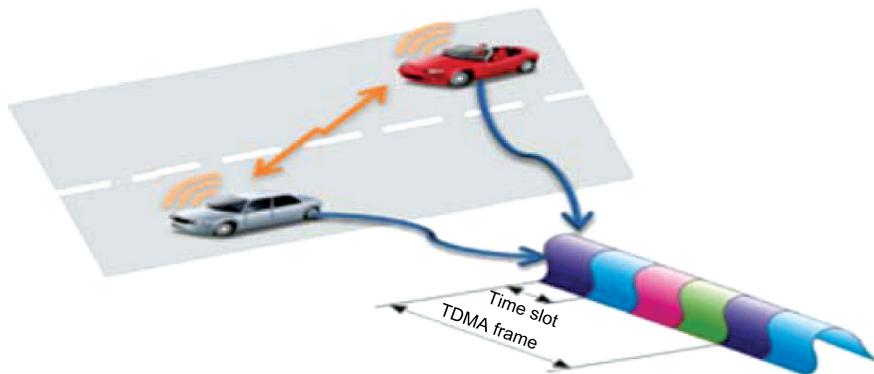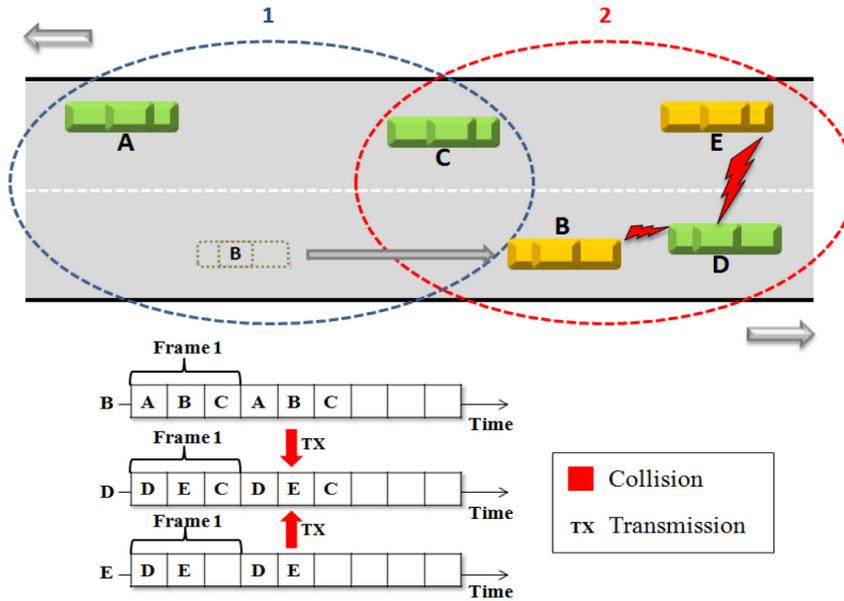

Figure 1   Access collision problem

Figure 2 Merging collision problem

The ***One-Hop neighbouring Collision*** (OH-Collision) occurs when the same time slot is used by two neighbouring vehicles belonging to neighbouring clusters. Figure 3 shows an example of OH-collision situation, when vehicle C in cluster 1 and vehicle D in cluster 2 are using the same time slot. Since C and D are within transmission range of each other, then a collision will occur at vehicle C and D.
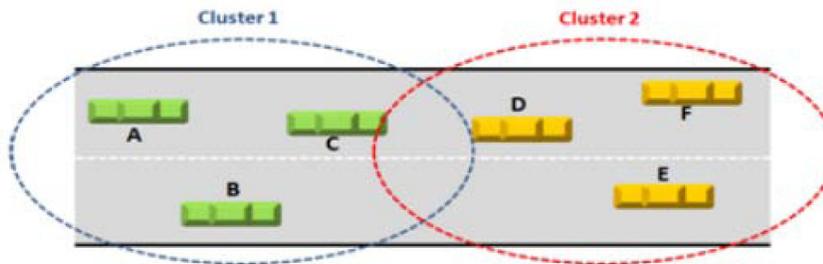

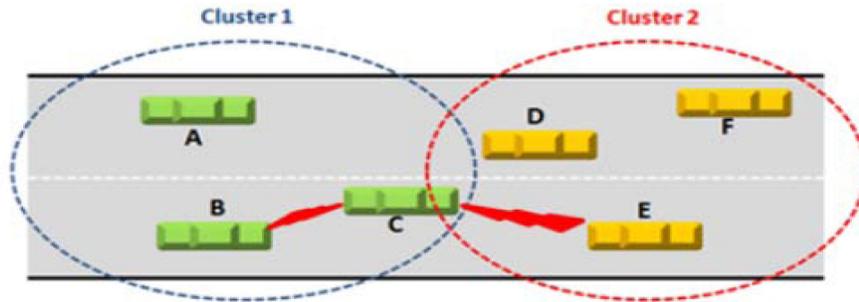**Figure 3** One-Hop neighbouring Collision (OH-Collision)

Figure 4   Hidden Node Collision (HN-Collision)

On the other hand, the ***Hidden Node Collision*** (HN-Collision) occurs when two vehicles are in range to communicate with another node, but not within transmission range of each other. Let us consider a situation in Figure 4 when vehicle B in cluster 1 and vehicle E in cluster 2 are using the same time slot. Since these two vehicles are outside transmission range of each other, a collision will occur at vehicle C in the cluster 1.

4 ASAS Protocol Description

ASAS strategy is based on a time division multiple access (TDMA) method, in which the medium is divided into frames and each frame, is divided into time slots. Only one vehicle is allowed to transmit in each time slot. This proposed strategy is centralized in stable cluster heads that continuously adapt to a high dynamic topology. The main idea is to take the direction and position of the vehicles into consideration in order to decide which slot should be occupied by which vehicle. The allocation of time slots is based on the requests from the vehicles in their HELLO messages, which are used by the cluster head to calculate the slot transmission schedule. The strategy is robust in the sense that it provides an efficient time slot reservation without intra-cluster and inter-cluster interferences. In this section, we address two important challenges: Cluster formation and the TDMA slot assignment mechanism for intra-cluster and inter-cluster communications.

4.1 Cluster Formation

Clustering technique is the process that consists to divide all vehicles in a network into organized groups called clusters. Several algorithms have

been proposed for cluster formation that take into account the specific characteristics of VANET network such as [11] and [16]. We have proposed a cluster formation algorithm based on information of the vehicle's position and direction, and which uses the Euclidean distance to divide the vehicles into clusters. To provide more stable clusters, our cluster formation scheme takes into account the direction of vehicles, i.e. only vehicles moving in the same direction can be members of the same cluster. If the direction is not taken into account in a highway environment with two ways, the vehicles that are moving in opposite direction to the cluster head will only be part of the cluster for a very short time and a new cluster will have to be formed almost immediately. Through the Euclidean distance and transmission range (i.e. the DSRC range is 1km), we can decide whether two vehicles can be grouped in the same cluster.

Initially, all vehicles are in the Undecided State US. To divide the network into clusters, each vehicle broadcasts its state (direction, position and speed) to notify its presence to its one-hop neighbours. Then, based on the received messages each vehicle can build its one-hop neighbouring list. To determine the most stable CH, the elected cluster head is a vehicle which has the minimum average distance, the closet speed to the average speed and the maximum number of neighbouring vehicles. All the vehicles that are within transmission range of the elected CH become CMs and not allowed to participate in another cluster head election procedure. Once the clusters heads are elected, they maintain two sets of vehicles (see Figure 5): F (Front) and B (Back).

- B is a set of vehicles that are behind of the CH
- F is a set of vehicles that are ahead of the CH

Let C_i a cluster of size m and of cluster head CH_i defined by position $(x,\ y,\ z)$.

- $F_i = \{V_{1 \leq i \leq m}(x', y', z'), x' \geq x\}$
- $B_i = \{V_{1 \leq i \leq m}(x', y', z'), x' < x\} = C_i - F_i$

After the cluster heads are elected as shown in Figure 5, each cluster head manages a local TDMA MAC frame. Moreover, after a cluster member CM receives its slot allocation from its cluster head, it transmits safety or control messages only during this slot and receives safety messages during the other time slots.
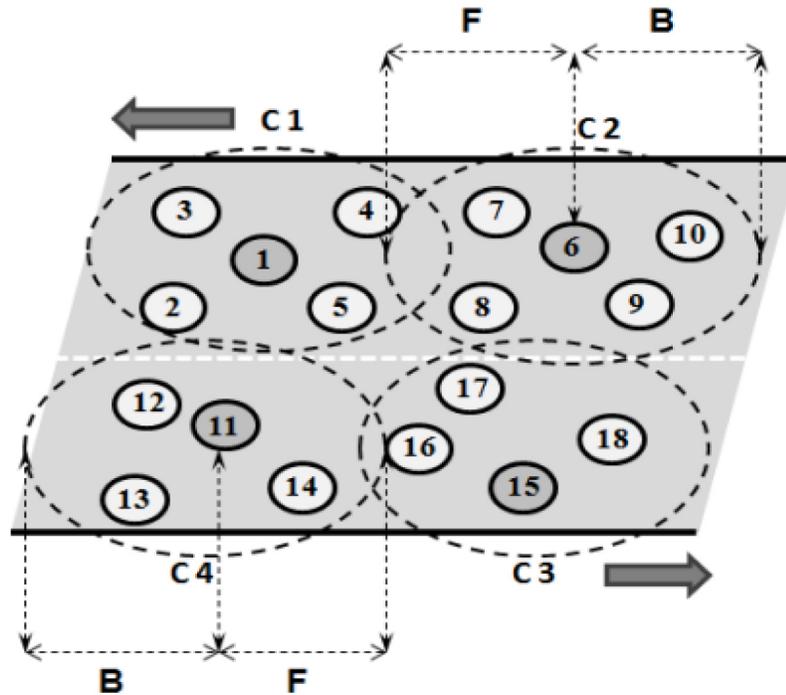
Figure 5   Network model

4.2 TDMA Slot Assignment in ASAS

In the scope of this work, we assume that each vehicle is equipped with a positioning system e.g. GPS (Global Positioning System) which can provide an accurate real-time three-dimensional position (latitude, longitude and altitude), direction, velocity and exact time. The synchronization among vehicles may be performed by using GPS timing information.

4.2.1 System Architecture

A vehicle is said to be moving in a left (right) direction if it is currently heading to any direction from north/south to west (east), as shown in Figure 6. Based on this definition, if two vehicles are moving in opposite directions on a two-way road, it is certain that one vehicle is moving in a left direction while the other vehicle is moving in a right one [13]. In ASAS, the channel access time is partitioned into frames and each frame is divided into ABS period and CRP period. The ABS period consists of a set of time slots where each time
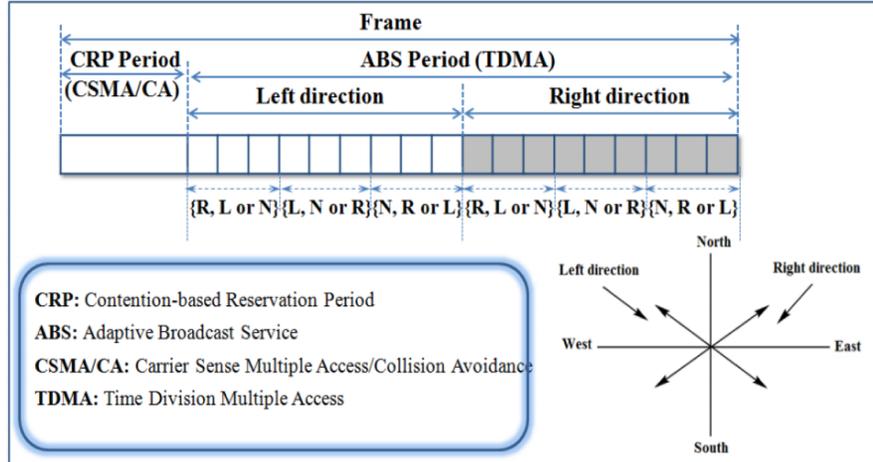
Figure 6   System Architecture

slot can be used by one vehicle only (CM, CG or CH) to broadcast a safety messages or other control messages such as topology management. The ABS period uses TDMA method as its channel access scheme. As defined in [13], to avoid merging collision problem, each ABS frame is divided into two sets of time slots, the first set is used by vehicles moving in left direction (see Figure 6) and the other is used by vehicles moving in right direction. The CRP period uses the contention-based method CSMA/CSA as its channel access scheme. During the CRP, if a vehicle needs to broadcast a message, it sends a request to the cluster head CH to reserve a periodic time slot. Then the CH responds to each reservation request from vehicle and assigns an available time slot in each ABS frame. We assume that each set of time slots Right or Left is partitioned into three subsets of time slots: *L, R* and *N*, as shown in Figure 6.

- L is the subset of time slots reserved for vehicles belong to the F set of vehicles.
- R is the subset of time slots reserved for vehicles belong to the B set of vehicles.
- N is the subset of unused time slots, in which all vehicles in the cluster remain inactive.

Moreover, to avoid the inter-cluster interference problem, the orders of the time slots subsets are different between neighbouring clusters. Hence, ASAS

can reduce the inter- cluster and intra-cluster interferences without the use of other complex techniques such as CDMA, FDMA, SDMA and OFDMA.

4.2.2 TDMA slot reservation

In this section we provide a detailed description of our TDMA slot allocation strategy. When a vehicle V needs to access network, it first sends a reservation request to the cluster head CH for a periodic time slot. When CH receives the reservation request and depending on the vehicle position, it determines whether the current time slot belongs to the L, R set, and then it selects to V the first available slot as its owner slot. Each cluster head CH determines its distribution of three subsets of time slots "MAP" according to the MAPs of their neighbouring clusters. The CH can obtain the MAP information of the neighbouring clusters heads through the cluster gateways CG. Once a CH has selected a time slot for a CM, it sends a reservation which includes the slot identifier. However, ASAS requires that every CH should periodically send frame information FI to its two neighbouring clusters heads via its CGs. This information contains the following (see Figure 7):

1. CH-ID indicates the identifier of CH that sends the FI packet.
2. MAP {{R, L, N}; {L, N, R} or {N, R, L}}.
3. The sizes of R, L, N subsets.
4. The state of each time slot reserved for its moving direction.

The second information element is transmitted only once time and the third is transmitted if the cluster head updates the size of the *L, R* or *N* subsets. Unlike other slots reservation techniques based on FI broadcasts where each vehicle must determine the set of time slots used by all vehicles within its two-hop neighbourhood in order to acquire a time slot. In our reservation technique, the CH discovers the available slots while requiring less overhead than the others techniques. Moreover, the CH knows also all the time slots which likely to cause a collision at the transmission channel (i.e. N set). As shown in Figure 8, especially in the frame information of cluster head number 6 (FI-6), there is one available time slot for new vehicle moving behind of the cluster head. However, the reservation of any time slot which identifier belong to

CH-ID	MAP			Size			Slot Status SS_[1]	......	Slot Status SS_[K/2]
	R, L or N	L, N or R	N, R or L				Free, VehID or N		Free, VehID or N

Figure 7 Frame information

Time Slot ID / Cluster ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1										1	2	3	4	5		N	N	N
2										9	10		N	N	N	6	7	8
3	18			N	N	N	15	16	17									
4	11	12	13	14			N	N	N									

Figure 8   An example of slot assignment

[13 . . . 15] may cause a collision. When all the slots in L or R subsets are busy, the CH must communicate with its two neighbouring clusters heads to reserve a time slot in the N set for new vehicles respectively belonging to the F or B set.

The time slots are allocated according to the vehicle's movement and positions. By using a centralized approach we change the slot allocation process from random reservations to optimal allocations, which can improve the convergence performance of the MAC protocol and achieves an efficient broadcast service for a successful delivery of real-time safety information.

4.2.3 Release of TDMA Slot

If a cluster head does not receive a beacon message after a specific time from a CM to signal its presence, then the CH immediately releases the time slot allocated to that CM and it removes this CM from its cluster members list (i.e. the F or B set).

5 Performance Evaluation

In this section, we evaluate the effect of transmission range variation and we carry out a comparison of ASAS with the DMMAC and the VeMAC protocols. The simulation is based on an event-driven simulator implemented using Java language. We have used VanetMobiSim [8] to generate a mobility scenario.

5.1 Mobility Scenarios and Simulation Parameters

The mobility scenarios implemented for the highway are with two-way and different density levels (see Figure 5). The vehicles are moving at different speeds and have different transmission ranges. During simulation

Table 1   System parameters for simulation

Highway length	2km
Ways	2
Lanes/way	2
Transmission range/scenario	{150, 350, 550, 750, 1000}m
Slots/ Frame	50
Slots for left direction	25
Slots for left direction	25
Slot duration	1ms
Simulation time	120s
Number of vehicles/scenario	60
Speed mean value	100 km/h
Speed standard deviation	30 km/h

System parameters for simulation

time, each vehicle moves at a constant speed, and the number of vehicles on the highway remains constant. Table 1 summarizes the simulation parameters.

5.2 Performance Metrics and Simulation Results

We have evaluated ASAS based on the following performance metrics:

- MR-Collision rate: MR-Collision rate is defined as the average number of merging collisions.
- AC-Collision rate: The AC-Collision rate is computed as the average number of access collisions.
- IC-Collision rate: The IC-Collision rate is defined as the average number of inter-cluster collisions due to HN-Collision and OH-Collision. However for the DMMAC and the VeMAC protocols, the IC-collision rate is defined as the rate of collisions between the adjacent sets of two-hop neighboring vehicles that are moving in the same direction.

Due to the high dynamic topology, the number of clusters varies during the simulation time (new cluster are added and clusters are merged) and this variation should be as low as possible. Thus the cluster formation algorithm proposed reduces the number of new clusters created due to the high mobility of the vehicles. Moreover, it creates stable clusters and keeps the current clusters as stable as possible.

Figure 9, shows the rate of access collisions as function of different vehicle densities. Notice that there is no access collisions generated by ASAS, whereas both the DMMAC and the VeMAC protocols suffer from collisions. This can
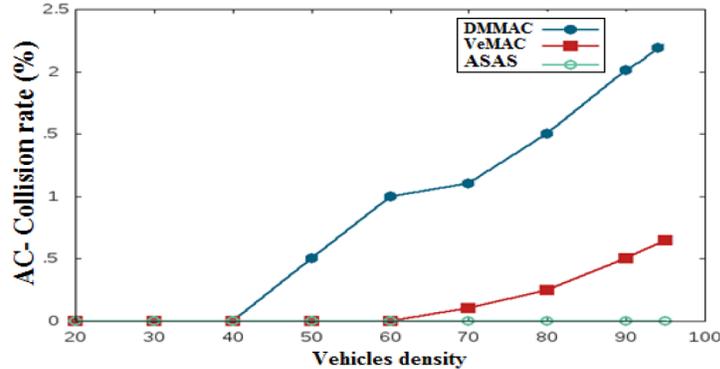
Figure 9   The access collision rate as a function of vehicle density

be explained by the centralized nature of the ASAS protocol, where cluster heads are in charge of time slots allocation. The DMMAC protocol as well as the VeMAC protocol generate higher rate of access collisions than ASAS, particularly for high traffic load. These results show the effectiveness of the ASAS technique.

Figure 10, shows the rate of merging collision for ASAS, VeMAC and DMMAC as function of transmission range. The ASAS protocol eliminates all merging collisions for the different transmission ranges studied. This comes from the fact that ASAS protocol assigns different sets of time slots to vehicles moving in opposite directions. The figure shows also that the merging collision rate is reduced by 100% compared to the DMMAC and VeMAC protocols.

In Figure 11 we depict the rate of IC-Collisions for the ASAS, VeMAC and DMMAC protocols. It is easy to see that ASAS have a lower rate of IC-Collisions than the two other protocols. The IC-Collision rate is reduced by 50% compared to VeMAC and by 5–15% compared to DMMAC. The main reason is that ASAS protocol allocates distinct sets of time slots to vehicles moving ahead and behind the cluster head. Consequently, ASAS protocol reduces collisions between neighboring clusters, which decreases the rate of Inter-cluster collisions compared to the DMMAC, and VeMAC protocols. We can also see that the IC-Collision rate decreases as the transmission range increases. This is because increasing the transmission range, decreases the number of clusters in the network and thus the inter-cluster collision rate will automatically decrease. We can conclude that ASAS protocol performs successfully under the DSRC architecture since the transmission range in DSRC is equal to 1000m. However, in case of low transmission range (less
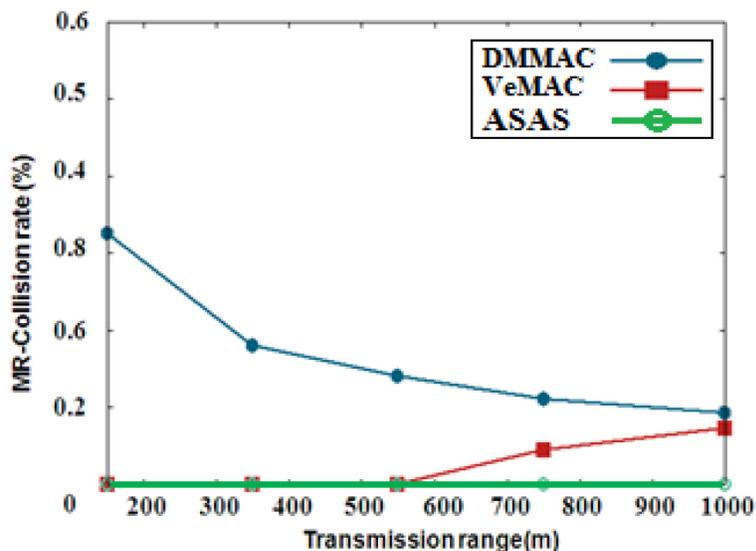
Figure 10   The merging collision rate as function of transmission range
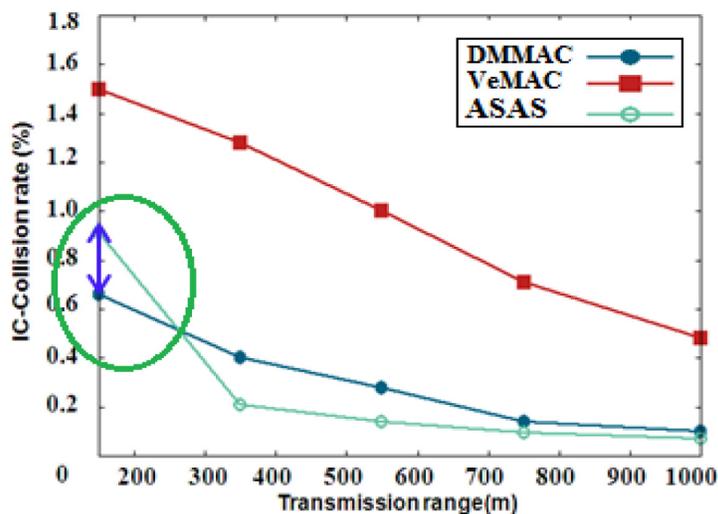

Figure 11   The inter-cluster collision rate as function of transmission range

than 250m) the DMMAC protocol presents better results than ASAS, because in this case, the large number of clusters increases the rate of inter-cluster collisions.

6 Conclusion and Future Work

This paper has studied the MAC protocol challenges to satisfy the requirements of real time and reliable broadcast of safety messages while achieving the fairness of the channel access. We have designed the Adaptive TDMA Slot Assignment Strategy (ASAS) to overcome these problems in which the assignment of time slots to vehicles is performed by the cluster heads in order to avoid any access collision problems. From the simulation results we conclude that this strategy achieves an efficient reservation and utilization of the available time slots without access collisions and decreases the rate of merging collisions as well as the rate of the inter-cluster collisions caused by the hidden node problem. Compared with the DMMAC and VeMAC protocols, ASAS generates a lower rate of transmission collisions in different transmission ranges and traffic load conditions. ASAS achieves this without having to use expensive spectrum management mechanisms such as CDMA or FDMA.

In future work, we will study the effect of various speeds and vehicles densities on the performance of ASAS. In addition, the dynamic adjustment of the length of the three subsets will be scrutinized. Moreover, we plan to extend ASAS to support multichannel operation and to provide reliable broadcast on both the control and service channels. In addition, we will carry out extensive simulations comparison with the IEEE 802.11p standard that operates with the DSRC architecture.

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Biographies

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