An Optimal Strategy for Collision-Free Slots Allocations in Vehicular Ad-hoc Networks

Mohamed Hadded, Rachid Zagrouba, Anis Laouiti, Paul Muhlethaler and Leila Azzouz Saidane

Abstract Research in vehicular ad-hoc networks (VANETs) have attracted a lot of attention in the recent years as emerging wireless technologies have opened up the way to many new exciting applications. VANETs are highly dynamic wireless networks that are designed to support vehicular safety, traffic management, and user-oriented applications. Each vehicle can exchange information to inform other vehicles about the current status or a dangerous situation such as an accident. Detecting and sending information about such situations requires a reliable broadcast service between vehicles, thus increasing the need for an efficient medium access control (MAC) protocol. In this paper, we propose ASAS, an Adaptive Slot Assignment Strategy, which takes advantage of bandwidth spatial reuse and reduces intra-cluster and inter-cluster message collisions without having to use an expensive spectrum and complex mechanisms such as CDMA or FDMA. Cluster heads (CHs) which are elected among the vehicles are then responsible for assigning time slots to the other vehicles in their clusters. The evaluation results show the interest of ASAS in terms of slot reuse and collision rates in different speed conditions.

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1 Introduction

VANETs are based on the combination of ad-hoc and cellular technologies to provide a centralized architecture for vehicle to infrastructure communications (V2I, I2 V) and a decentralized architecture for Vehicle to Vehicle communications (V2 V). Due to the importance of V2 V communications, several research projects are underway to standardize V2 V communication in Europe and around the world such as the Car2Car consortium [1] which seeks to improve road safety, FleetNet [2] is a European project aiming to standardize several solutions in order to ensure the safety and comfort of passengers. In the USA, the Federal Communication Commission (FCC) [3] established the Dedicated Short Range Communications service (DSRC) in 2003. The DSRC [4] radio technology is defined in the frequency band of 5.9 GHz a total bandwidth of 75 MHz. This band is divided into seven 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 not only reserved for the network management messages, but is also used to transmit messages of high priority messages. The six SCHs are dedicated to data transmission.

Communication uses beacon messages (current status, aggregate data, and emergency messages). If several vehicles simultaneously broadcast messages, then a collision occurs. It is important to avoid collisions on the CCH in order to ensure a fast and reliable delivery of safety messages. To provide a QoS and reduce collisions on the CCH, we introduce an adaptive slot allocation strategy (ASAS) that takes into account the specificity of VANET networks. The strategy proposed operates at the CHs which are the 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 slot reservation, we ensure an efficient utilization of the time slots and thereby decrease the rate of merging collisions [5] and hidden node collisions caused by vehicles moving in opposite directions.

The rest of this paper is organized as follows. Section 2 reviews related work on MAC protocols in VANETs. Section 3 sets out the challenges of TDMA based MAC solution deployment. Sections 4 and 5 describe the system and the network model, respectively. We give a detailed description of ASAS in Sect. 6. Conclusion and perspectives are presented in Sect. 7.

2 Related Work

Various MAC protocols have been proposed for VANETs based, either on contention-based medium access method CSMA/CA such as IEEE 802.11p [6], or on contention-free medium access schemes using time division multiple access

(TDMA), such as AD-HOC MAC [7], VeMAC [5], or on hybrids of these two methods such as DMMAC [8].

The IEEE 802.11p [6] recently designed by TGp Task Group of IEEE [9] improves the standard IEEE 802.11 to support VANETs. This standard improves QoS by offering different message priorities. The prioritization is achieved by using the Enhanced Distributed Channel Access EDCA [6] technique. However, the IEEE 802.11p standard is a contention-based MAC methods that cannot provide a bound on access delays, which is critical for high priority safety applications [10].

VeMAC [5] is a contention-free medium access control protocol recently proposed for VANETs. The protocol implements multichannel TDMA mechanisms, which reserve disjoint sets of time slots in the CCH for vehicles moving in opposite directions and for road side units (RSU). In VeMAC, each node has two transceivers; the first one is always tuned to the CCH whereas the second one can be tuned to any service channel. The assignment of time slots to vehicles on the CCH is performed in a distributed way in which each vehicle randomly acquires an available time slot, and the assignment of time slots on the SCHs is performed by the service providers in a centralized way. However, the size of each VeMAC packet transmitted by a vehicle on the CCH is large (Vehicle ID, current position, set of one-hop neighbors, and the time slot used by each node within the one-hop neighborhood), which increases the overhead of the VeMAC protocol on the CCH. In addition, its random slot assignment technique is inefficient due to the appearance of free slots.

The proposal in [8] is called 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 consists of time slots, and 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 uses CSMA/CA as its channel access scheme. During the CRP, vehicles negotiate and reserve the network resources on SCHs for non-safety applications. However, the simulation model used to evaluate DMMAC fails to take into account the RSU, velocity variation, joining/leaving of vehicles, and bidirectional traffic. Moreover, it was limited to the case of a straight highway scenario with a number of slots smaller than the maximum number of vehicles in the network, meaning that the number of time slots available is always sufficient for the number of vehicles involved.

Problems

The first aim of MAC protocols for VANETs is to ensure that each vehicle the time to send messages without collisions. TDMA is a method that can be used to assign one-time slot to each active vehicle. We study below the challenges of MAC solution in VANETs focusing particularly on the TDMA techniques.

3.1 Distributed TDMA Slot Allocation

When a distributed scheme is used to allocate a time slot, two types of collision on time slots can occur [11]: access collisions between vehicles trying to allocate the same available time slots, and merging collisions between vehicles using the same time slots.

Access collision [5] occurs when two or more vehicles within the same two-hop neighborhood set attempt to access the same available time slot. This problem is likely to happen when a scheme way is used to allow the vehicle to reserve a time slot.

Merging collision [11] is a basic problem for mobile ad-hoc networks, this problem occurs when two vehicles in different two-hop sets using the same time slot become members of the same two-hop set due to their mobility. Generally in VANET, merging collisions are likely to occur in the following cases:

- Vehicles moving with different speeds,
- Vehicles moving in opposite directions,
- There is an RSU installed along the road.

3.2 Centralized TDMA Slot Allocation

When a centralized scheme is used to allocate a time slot, an inter-cluster interference problem can arise. There are two types of inter-cluster interference [12]: One-Hop neighboring Collision and Hidden Node Collision.

One-hop neighboring collision (OH-Collision) occurs when a time slot is used by two neighboring vehicles belonging to neighboring clusters. Figure. 1 shows an example of an OH-collision situation when vehicle CM-31 in cluster III and vehicle CG-45 in cluster IV are using the same time slot. Since CM-31 and CG-45 are within transmission range of each other, then a collision will occur at vehicle CM-31 and CG-45.

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 Fig. 1 when vehicle CM-31 in cluster III and vehicle CM-44 in cluster IV are using the same time slot. Since these two vehicles are outside transmission range of each other, a collision will occur at vehicle CG-45 of cluster IV.

4 Network Model

A VANET network in a highway environment consists of a set of vehicles moving in opposite directions on two roads, each road having two lanes. The vehicles belong to self-organized groups called “clusters.” In each cluster, there are three different vehicle states: CH, cluster member (CM), and cluster gateway (CG).

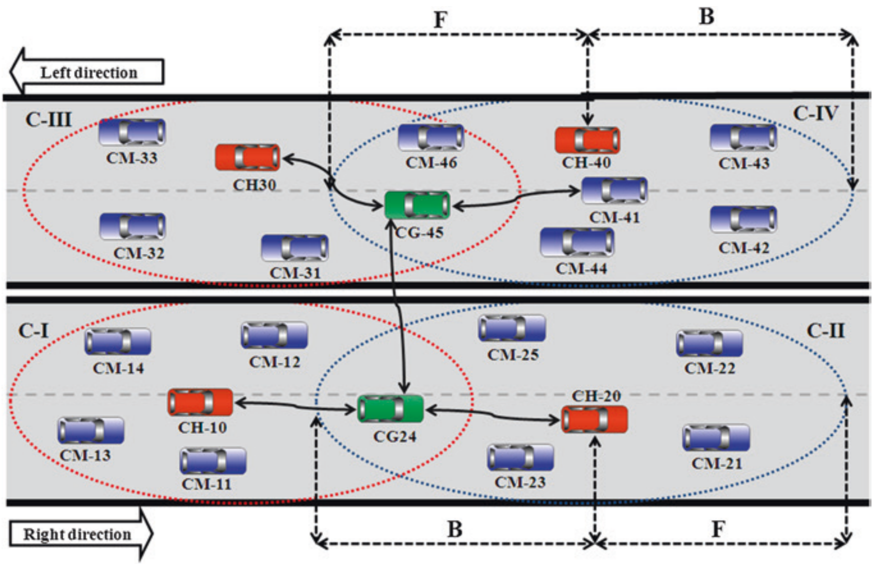

Fig. 1 Network model

Sometimes, there is another state named undecided state (US) that is used for the initial state of a vehicle. All CMs and CGs are within one hop communication range of the CH, see Fig. 1.

Each cluster has two sets of vehicles: F (Front) and B (Behind).

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

Let C_i be a cluster of size m with its cluster head CH_i defined by the position (x, y, z).

$$F_i = \{V_{i,1 \le i \le m}(x', y', z'), x' \ge x\}$$

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

After the clusters have been set up and the cluster heads have been elected as shown in Fig. 1, each cluster head maintains a local TDMA MAC frame. 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 other time slots.

5 System Model

A vehicle is said to be moving in a left (right) direction if it is currently heading in any direction from North/South to West (East), as shown in Fig. 1. Based on this definition, if two vehicles are moving in opposite directions on a two-way road, it

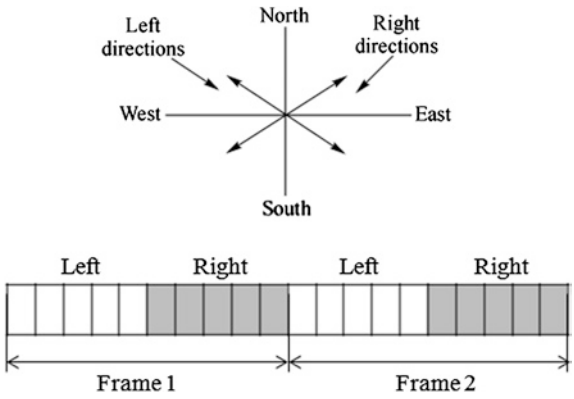

Fig. 2 Partitioning each frame into two sets: *left* and *right*

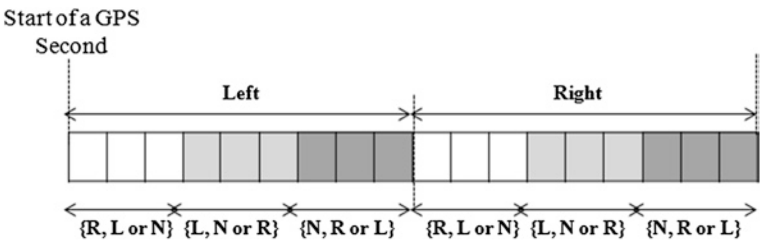

Fig. 3 Partitioning of each set into *R*, *L* and *N*

is certain that one vehicle is moving in a left direction while the other vehicle is moving in a right direction [5]. The access time is partitioned into frames and each frame is partitioned into two sets of time slots: *Left* and *Right*, as shown in Fig. 2. The *Left* set is associated with vehicles moving in left directions, while the *Right* set is associated with vehicles moving in right directions.

In ASAS, 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 Fig. 3.

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

6 ASAS Description

The ASAS protocol is based on a 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 strategy is centralized in stable cluster heads that continuously adapt to a highly 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 requests from the vehicles in their HELLO messages, which are used by the cluster head to calculate the 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.

6.1 Cluster Formation

Clustering is the process that divides all the vehicles in a network into organized groups called clusters. Several algorithms such as [13] and [14] have been proposed for cluster formation that take into account the specific characteristics of VANETs. We propose a cluster formation algorithm based on information of the vehicles' 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 the 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 1 km), we can decide whether two vehicles can be grouped into the same cluster.

Cluster head election Initially, all vehicles are in the USA. To divide the network into clusters, each vehicle broadcasts its current state "position, speed" to notify its presence to its one-hop neighbors. Then, based on the received messages each vehicle can build its one-hop neighboring list. To determine the most stable CH, the election of a cluster head is based on the following function. The elected cluster head is a vehicle which has the minimum average distance to the other vehicles in the cluster, the closest speed to the average speed and the maximum number of neighboring vehicles.

$$F(i) = \alpha \left(\sum_{j \in N(i)} d(P_i, P_j) \right) / n_i + \beta \left(\sum_{j \in N(i)} |V_i, V_j| \right) / n_i - \sigma \times n_i$$

where

$$\begin{cases} n_i\text{: Number of vehicles within one} - \text{hop range of vehicle } i \\ d(P_i, P_j)\text{: Euclidean distance between vehicles } i \text{ and } j \\ |V_i, V_j|\text{: Velocity differences between } i \text{ and } j \\ N_i\text{: The set of one hop neighbors of vehicle } i \\ \alpha, \beta, \sigma\text{: The weight coefficients, } \alpha + \beta + \sigma = 1 \end{cases}$$

The vehicle that has the minimum value of F is elected as the CH. All the vehicles that are within transmission range of the CH become CMs and are not allowed to participate in another cluster head election procedure until it becomes necessary.

$$\begin{cases} \text{CH} = \{i/F(i) = \text{Min}(F(j), \forall j \in N(i))\} \\ \text{CM} = \{j, \forall j \in N(i) \text{ and } j \neq i\} \end{cases}$$

Once the cluster head has been elected, it starts to periodically broadcast invite-to-join ITJ message to its one-hop neighbors. If a CM receives an ITJ message from another neighboring CH moving in the same direction, it will attempt to get the attention of the CH by sending to it a request-to-join (RTJ) message. Upon the receipt of an ACK message from CH, the corresponding vehicle will switches from CM state to cluster gateway state CG.

Cluster Maintenance In VANETs, a vehicle can join or leave a cluster at any time. These two operations will have only local effects on the topology of the cluster if the vehicle is a CM. However, if the vehicle is the CH before leaving the cluster, it must hand over the responsibility to one of the very close CMs. The first reason for that is to keep the cluster organized as a "one-hop cluster with two sets of vehicles F and B" even if the current CH leaves. The second reason is to avoid using the re-clustering algorithm and thus no re-clustering overhead is generated when the cluster head leaves the cluster. Then, the current CH will order the CM to switch to CH and switch its own state to CM.

When the CH receives an ITJ message from another neighboring cluster head moving in the same direction, only one of them will keep its CH responsibility while the other will switch to CM. The CG between two clusters becomes a CM of the new cluster and each CM of the cluster whose CH will become a CM will switch to CM if it receives an ITJ message from the new CH and will switch to US otherwise. Selecting the cluster head when two clusters merge is done according to the function defined in Sect. 6.1.

6.2 TDMA Slot Assignment Mechanism

In this study, we assume that each vehicle is equipped with a positioning system, e.g., global positioning system (GPS), which can provide an accurate real-time three-dimensional position (latitude, longitude and altitude), direction, velocity, and exact time. The synchronization between vehicles can be performed by using GPS timing information.

We also assume that the TDMA frame consists of k time slots and each frame is divided into two sets of time slots of size $k/2$, see Fig. 3. The first and the second sets are used by vehicles moving in right and left directions, respectively. However, if a vehicle moving in a right/left direction detects that no free time slot is available for vehicles moving in that direction, then it will request a time slot normally reserved for vehicles moving in the opposite direction. This technique is used to mitigate the merging collision problem. We also assume that each cluster

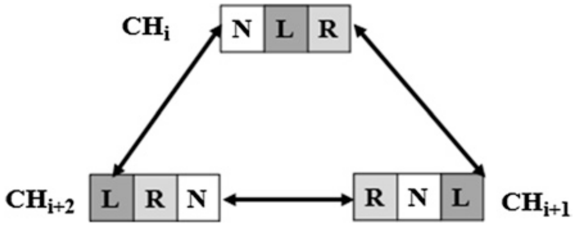

Fig. 4 Distribution of three time slots subsets

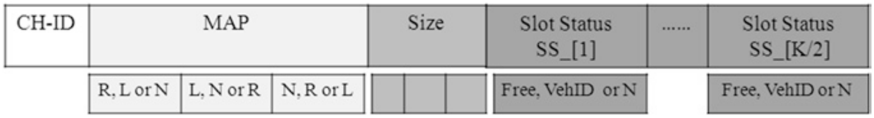

Fig. 5 Frame information

head CH maintains two sets of vehicles, F and B, and each of which is divided into three subsets of time slots *L*, *R*, and *N*.

To avoid inter-cluster interference, the allocations of the time slot subsets are different between neighboring clusters (as shown in Fig. 4).

TDMA Slot Reservation In this section, we provide a detailed description of our TDMA slot allocation strategy. When a vehicle *V* needs to access the network, it first sends a reservation request to the cluster head CH for a periodic time slot. When the CH receives the reservation request and depending on the vehicle position, it determines whether the current time slot belongs to the *L* or *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 neighboring clusters. The CH can obtain the MAP information of the neighboring cluster heads through the cluster gateways CGs. 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 neighboring cluster heads via its CGs (see Fig. 5). This FI contains the following fields:

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 the cluster head's 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 slot reservation techniques based on FI broadcasts where each vehicle must determine the set of time slots used by all the vehicles within its two-hop neighborhood in order to acquire a time slot.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	10	13	14		11	12			N	N	N	N												
2	21	22			N	N	N	N	20	23	24	25												
3													30	32	33		31				N	N	N	N
4													41	42	43		N	N	N	N	40	44	45	46

Fig. 6 An example of slot assignment

In our reservation technique, the CH discovers the available slots while requiring less overhead than the other techniques. Moreover, the CH also knows all the time slots which are likely to cause a collision at the transmission channel (i.e., N set). As shown in Fig. 6, especially in the frame information of cluster head number 2 (FI-2), there are two available time slots for new vehicles moving ahead of the cluster head and the reservation of any time slot whose identifier belongs to [5…8] may cause a collision. When all the slots in the L or R subsets are busy, the CH must communicate with its two neighboring cluster heads to reserve a time slot in the N set for new vehicles respectively belonging to the F or B set.

Property 1 For each cluster C_i:

- $\forall k \in R_i$, if $\exists x \in B_i$ such that $\mathrm{FI}_i\_SS[k] = x$, thus it is certain that vehicle x can transmit during slot k without intra-cluster and inter-cluster interference from another vehicle.
- $\forall k \in L_i$, if $\exists x \in F_i$ such that $\mathrm{FI}_i\_SS[k] = x$, thus insuring that the vehicle x can transmit during slot k without intra-cluster and inter-cluster interference from another vehicle.

Property 2 For each cluster C_i:

- $\forall x \in B_i, \exists k \in R_i$ such that $\mathrm{FI}_i\_SS[k] = x \Leftrightarrow |B_i| \leq \mathrm{FI}_i\_Size[R]$.
- $\forall x \in F_i, \exists k \in L_i$ such that $\mathrm{FI}_i\_SS[k] = x \Leftrightarrow |F_i| \leq \mathrm{FI}_i\_Size[L]$.

where $|B_i|$ and $|F_i|$ are respectively the number of vehicles in the B_i and F_i set.

Otherwise, if $|B_i| > \mathrm{FI}_i\_Size[R](|F_i| > \mathrm{FI}_i\_Size[L])$, i.e., there are vehicles that cannot acquire a time slot, because all the slots in R_i or L_i are busy, in this case the CH_i will communicate with neighboring cluster heads to allocate time slots to these vehicles by shortening the length of N_i and increasing the length of R_i or L_i. Then, the cluster head CH_i, must update its frame information FI_i and transmit this frame to its two neighboring cluster heads CH_{i-1} and CH_{i+1}.

Time slots are allocated according to the vehicle's movement and position. 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 provides an efficient broadcast service for the successful delivery of real-time safety information.

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

Dynamically reallocating slots In VANETs especially in a highway environment, the number of vehicles is not equally distributed in each direction. Thus, the ratio between the two slot sets *Left* and *Right* should be adjusted according to the vehicle density. We use the algorithm presented in [15] to adjust the ratio of the two slot sets. In order to describe the ratio adjustment algorithm, the following notations are introduced and valid for a specific moment in time t and for a specific cluster head n.

$N^n(t)$	The current CMs of cluster head n
$S^n(t)$	The frame length of the cluster head n, i.e., the number of time slots of each frame of cluster head n
$S_d^n(t)$	The number of time slots reserved for the direction d of the cluster head n, i.e., *Left* or *Right* set
$\rho\text{max}, \rho\text{min}$	The maximum threshold and minimum threshold, which is a ratio between the number of vehicles in the cluster and the number of slots

Initially we suppose the number of vehicles in each direction to be equal. The density of vehicles changes as the vehicles move and we reach the conditions expressed in (1), see below. We need to adjust $S_d^n(t)$ to come back to the conditions expressed in (1).

$$\begin{cases} \frac{N^n(t)}{S_d^n(t)} > \rho\text{max} \text{ or } \frac{N^n(t)}{S_d^n(t)} < \rho\text{min} \\ \frac{N^n(t)}{S_d^n(t)} < \rho\text{max} \text{ and } \frac{N^n(t)}{S_d^n(t)} > \rho\text{min} \end{cases} \quad (1)$$

The cluster head n sends its neighboring cluster heads, through the cluster gateways a proposal to redistribute the number of the *Left* or *Right* slots in the FI. If the neighboring clusters head agree to the proposal, the new slot allocation scheme will be adopted by the neighboring cluster heads that have the same frame length in the next time frame. Each cluster head must save information about how the slots are allocated and periodically sends it in the FI.

7 Performance Evaluation

In this section, we evaluate the effect of transmission range and speed variation and we carry out a comparison of ASAS with the DMMAC and VeMMAC protocols.

7.1 Simulation Setup

We did several tests to evaluate the performance of ASAS under various realistic conditions. We used VanetMobiSim [16] to create a mobility scenario and we used a JAVA simulation, using the JDK compiler.

Table 1 The average and the standard deviation of the speed

μ (km/h)	σ (km/h)
80	20
100	30
120	35

Table 2 System parameters for simulation

Parameter	Value
Highway length	2 km
Directions	2
Lanes each way	2
Lane width	5 m
Transmission range/Scenario	{150, 350, 550, 750, 1,000} m
Slots/ABS frame	50
Slots for right direction	25
Slots for left direction	25
Slot duration	1 ms
Simulation time	120 s
Number of vehicles/Scenario	60

7.2 Mobility Scenarios and Simulation Parameters

The mobility scenarios implemented for the highway are with two-way traffic and different density levels in each direction, see Fig. 3. The vehicles are moving at different speeds (Table 1) and have different transmission ranges. During simulation time, each vehicle moves at a constant speed, and the number of vehicles on the highway remains constant. Table 2 summarizes the simulation parameters .

7.3 Performance Metrics and Simulation Results

We evaluate our MAC protocol using the following performance metrics:

- MR-Collision rate: the 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 DMMAC and VeMAC, the IC-collision rate is defined as the rate of collision between the adjacent sets of two-hop neighboring vehicles that is moving in the same direction.

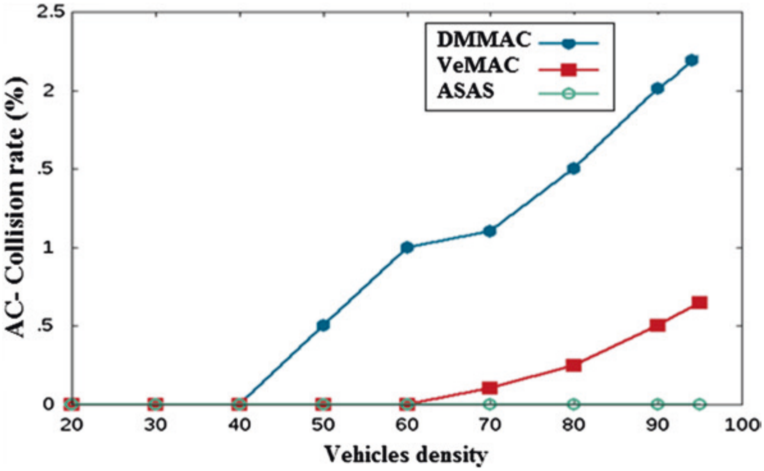

Fig. 7 The access collision rate as a function of vehicle density

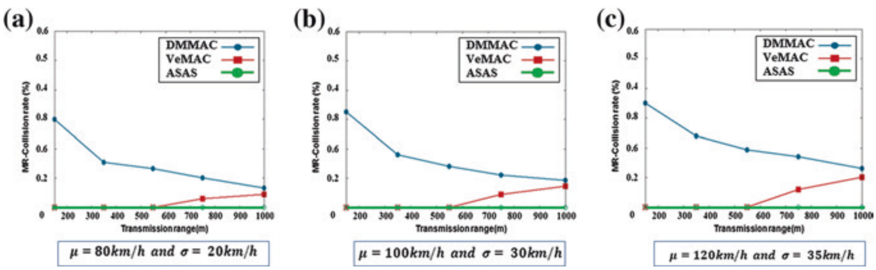

Fig. 8 The merging collision rate as a function of transmission range

Due to the highly 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. Therefore, it creates stable clusters and keeps the current clusters as stable as possible.

The rate of access collisions under different traffic load conditions is shown in Fig. 7. We note that no access collisions generated by ASAS in contrast to both the DMMAC and VeMAC protocols. The reason is that the assignment of time slots to vehicles is performed by the cluster heads in a centralized manner. The VeMAC protocol generates a higher rate of access collisions than ASAS, especially for a high traffic load but the rate is significantly lower than that generated by the DMMAC protocol. These results show the effectiveness of the ASAS technique.

In Fig. 8, the *x*-axis represents the transmission range, while the y-axis represents the merging collision rate of the vehicles. Figure 8a, b, c shows the rate of merging collisions for DMMAC, VeMAC, and ASAS. It is clear that merging

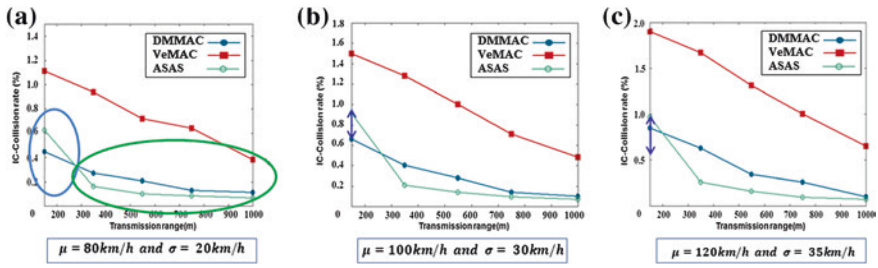

Fig. 9 The inter-cluster collision rate as a function of transmission range

collisions are entirely eliminated for ASAS as it its merging collision rate is always equal to zero for all velocities and transmission range values. Indeed, ASAS allocates disjoint 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. We can see that the ASAS protocol performs even better when the average speed becomes higher and thus the average speed has no impact on the performance of ASAS.

Figure 9 shows the rate of IC-Collisions for the DMMAC, VeMAC, and ASAS protocols. It is clear that ASAS shows a lower rate of IC-Collisions than both DMMAC and VeMAC. The figure shows that the IC-Collision rate is reduced by 50 % compared to VeMAC and by 5–15 % compared to DMMAC. The reason is that ASAS strictly assigns disjoint sets of time slots to vehicles moving behind and ahead of the cluster head. Thus, the protocol decreases collisions between neighboring clusters, which decreases the rate of Inter-cluster collisions compared to the other 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 conclude that ASAS can operate successfully under the DSRC architecture because the transmission range in DSRC is equal to 1,000 m. However, we note that if the transmission range is low (less than 250 m) the DMMAC protocol performs slightly better than ASAS. This is due to the large number of clusters which increases the rate of inter-cluster collisions. We can also see that the ASAS performs even better when the average speed is higher.

8 Conclusion and Future Work

This paper proposes an ASAS for cluster-based TDMA for VANETs in which the assignment of time slots to vehicles is performed by the cluster heads in order to avoid any access collision problems. ASAS can adapt to different traffic conditions because it has a stable clustering technique that provides stable clusters with less overhead. From the experimental 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 and 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, speed scenarios 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 performance of ASAS in a city scenario and the effect of RSUs on the performance of ASAS. In addition, the dynamic adjustment of the length of the three subsets will be scrutinized. We plan to extend ASAS to support multichannel operation and a reliable broadcast on the control and service channels. We also plan to evaluate ASAS for unicast transmission mode both through simulations and analysis. In addition, we will carry out an experimental comparison with other existing broadcast protocols such as the IEEE 802.11p standard that operates with a DSRC architecture.

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