

Article

ASMAC: An Adaptive Slot Access MAC Protocol in Distributed VANET

Shi-Yuan Han *  and Chang-Yue Zhang

Shandong Provincial Key Laboratory of Network Based Intelligent Computing, University of Jinan, Jinan 250022, China; zhang_cyue@163.com

* Correspondence: ise_hansy@ujn.edu.cn; Tel.: +86-531-8276-6503

Abstract: The media access control (MAC) protocol is responsible for channel resource sharing and conflict management in the communication process in VANET, which is of great significance for ensuring efficient and reliable communication. The existing MAC protocol with fixed time slot allocation cannot solve the problem of time slot resource exhaustion or waste when the traffic density is unbalanced. In this paper, we propose an adaptive time slot access MAC protocol in distributed VANET (ASMAC). ASMAC adapts the access time slot according to the driving direction of the vehicle and the traffic density ratio to improve the time slot access efficiency. In the ASMAC protocol, the frame is divided into several time slots based on TDMA, and the time slots in a frame are divided into two time slot sets according to the driving direction. The vehicle selects a time slot access corresponding to the time slot set. When the vehicle finds that there is no accessible time slot in the time slot set, it accesses the available time slot in the reverse time slot set to improve the efficiency of time slot access. In this paper, the analysis and simulation results of highway and four-way intersection scenarios are given and the validity of the ASMAC protocol is verified by comparing with the VeMAC and SAMD protocols.

Keywords: VANET; medium access control; TDMA; slot access



Citation: Han, S.-Y.; Zhang, C.-Y.

ASMAC: An Adaptive Slot Access MAC Protocol in Distributed VANET. *Electronics* **2022**, *11*, 1145. <https://doi.org/10.3390/electronics11071145>

Academic Editor: Robin Braun

Received: 18 February 2022

Accepted: 3 April 2022

Published: 5 April 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

An intelligent transportation system (ITS) plays an increasingly prominent role in alleviating traffic congestion and reducing traffic accidents [1]. By integrating with existing communication technologies, it ensures the safety and reliability of the information transmission during vehicle driving and that it happens in real time. As the information-bearing platform of ITS, the vehicular ad hoc network (VANET) [2] realizes the sharing of vehicle position, speed, direction and other information through wireless communication technology to ensure the efficient traffic safety and other information transmission [3]. The VANET is composed of vehicles equipped with wireless communication equipment and RSUs fixed on the road. The VANET architecture is shown in Figure 1 [4]. It mainly broadcasts information through V2V and V2R to support various applications such as road safety information, traffic management and network entertainment [5]. The media access control (MAC) protocol in a VANET plays a decisive role in channel resource sharing and conflict management during the communication process, which is of great significance to ensure the reliability of communication and that it occurs in real time [6]. However, the characteristics of short transmission distance between vehicles on the road, rapid movement of nodes and frequent changes in network topology can easily lead to many problems such as hidden terminals, exposed terminals, access collisions and merging collisions in mobile ad hoc networks. The traditional MAC protocol cannot meet the current needs of a VANET, so it is necessary to design new MAC protocols to improve the fairness and reliability of wireless channel access.

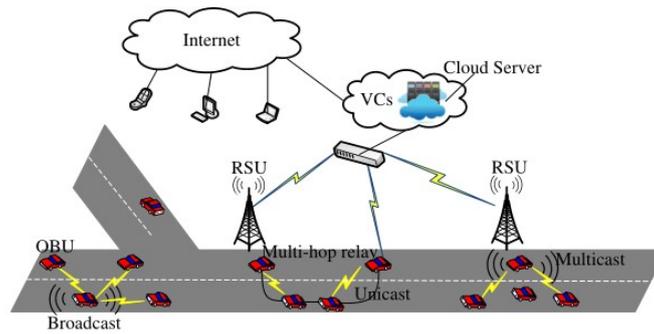


Figure 1. The structure of a VANET.

A binary backoff rule is proposed in the standard MAC protocol IEEE802.11p [7], and nodes transmit data when the channel is idle through competition. When there are multiple vehicles sending data at the same time, it is easy to cause collisions and transmission failures. All colliding nodes cannot receive data packets and have to reaccess the channel, which causes a large access delay [8]. In addition, since IEEE802.11p does not have a request to send/clear-to-send mechanism [9] during packet broadcast, the problem of hidden terminals can easily happen.

In order to make up for the deficiencies of IEEE802.11p, some contention-free MAC protocols based on frequency division multiple access (FDMA), code division multiple access (CDMA) and time division multiple access (TDMA) have been proposed to improve the data transmission rate in a VANET [10,11]. In the MAC protocol based on FDMA, there are technical problems such as frequency synchronization and Doppler effect when the communication vehicles need to be synchronized to the same channel frequency [12], so FDMA technology is not suitable for a VANET. In the MAC protocol based on CDMA, vehicles in the same communication range share the same frequency channel for multichannel communication through the pseudo-random noise code of the unique code sequence [13]. This method is too complex for the implementation of protocols suitable for real traffic scenes requiring high reliable transmission [14]. Neither of the above two MAC protocols can meet the strict quality of service (QoS) requirements in a VANET. Therefore, TDMA-based MAC protocols have been proposed in recent years. In TDMA-based MAC protocols, multiple vehicles use the same frequency channel resources to communicate without interference from neighbor vehicles. The main idea of the TDMA protocol is to divide the time into several identical frames, then divide the frames into a fixed number of time slots, and assign time slots to each vehicle node to transmit information to effectively avoid the problem of hiding and exposing terminals when nodes compete for time slots. Currently, there are two scheduling schemes for MAC protocols based on the TDMA mechanism, one is centralized TDMA and the other is distributed TDMA. In the MAC protocol of centralized TDMA [15–20], time slots are centrally allocated by the selected central vehicles or roadside RSUs equipment. The centralized MAC protocol requires the support of a large number of RSUs, which has high requirements for channel and high resource consumption.

The distributed TDMA-MAC protocol does not require intermediate nodes to allocate time slots for competing vehicles within the vehicle communication range, but randomly selects time slots from unused time slots to send information by listening to the time slot occupancy of neighboring vehicles. In the VeMAC [21–23] protocol, the time slots in a frame are divided into three sets of time slots L, R and F, and the beacon is broadcast by dividing disjoint time slot sets for vehicles traveling in the opposite direction and the RSU to reduce transmission collisions. In the DTDMA protocol proposed in [24], the data traffic is divided into multiple access categories, and a more complex random access strategy is also developed. In VeMAC and DTDMA, a random selection strategy has been adopted when the vehicle accesses the time slot, which can effectively solve problems of concurrent access channel. However, due to the fixed size of the time slot division in one frame, the scalability of vehicle accessing the time slot is so poor that is not enough to deal with the

time slot access in extreme cases. When the node density is higher or lower, it will cause more collisions or waste of time slot resources. In the MoMAC protocol [25], L and R are further divided into smaller subsets. When the vehicle changes its driving lane, the occupied time slot also changes. Thus, the MoMAC protocol is too complicated to achieve good results. Based on VeMAC, a near-conflict-free reserved MAC protocol (CFR-MAC in [26]) has been proposed. In this protocol, vehicle nodes select the time slot they want to occupy and broadcast the information of reserving the time slot. However, the delay of time slot reservation becomes longer with the increase of node density and whether the time slot is successfully reserved can only be known after one frame. In the SAMD protocol [27], a time slot reservation allocation scheme based on vehicles' moving direction is proposed. SAMD is a hybrid protocol, which combines TDMA and CSMA/CA mechanism to divide the time slots in a frame into RS and CS time slot sets. Then, the RS set is divided into two sets based on vehicles' driving direction and the time slots are dynamically divided according to the number of vehicles in different driving directions. The ratio of the number of time slots in two sets on RS is equal to the ratio of the traffic density in the opposite direction. In this way, the allocation of the left and right time slot sets can be dynamically adjusted. The nodes in the CS time slot set compete to acquire time slots and to reserve time slots on the service channel to send non-safety information. The SAMD protocol improves the scalability of the protocol by dynamically dividing time slots. However, due to the fast speed of vehicles and frequent changes in network topology, there may be hidden terminal problems between vehicles when dynamically adjusting time slots. The BMA protocol is also optimized based on the VeMAC protocol in [28], which is different from dividing time slots according to driving direction in VeMAC. In BMA, the time slots in a frame are firstly divided into high-density areas and low-density areas according to the vehicle density, and then each density area is divided into two time-slot groups with the median value of the node speed as the critical value. When multiple vehicles have access collision or merge collision, the vehicle node with the largest difference from the median speed in the same density area occupies the time slot.

This paper proposes an adaptive slot access MAC protocol (ASMAC) in a distributed VANET to solve the problem of slot depletion or waste caused by more or less vehicle nodes in a fixed divided slot set under unbalanced traffic density. In the ASMAC protocol, time slots are divided into two sets and vehicles select the corresponding time slot to access according to their driving direction, which effectively avoids collisions between vehicles traveling in the opposite direction. During the driving process, when there are no available time slots in the time slot set due to the large number of vehicle nodes, the vehicle is allowed to obtain the available time slots in the reverse time slot set according to the size of the time slot index. In this way, the adaptive access of time slots is realized. For the collision problem during driving, one vehicle node is selected to continue to occupy the time slot according to the driving speed and direction of the vehicle, while the other vehicles reselect the time slot to access. Thus, it can improve the slot access rate and reduce collisions between vehicles. Compared with the VeMAC and SAMD protocols, the experimental results show that the ASMAC protocol has a higher packet reception rate and lower number of collisions.

The framework of this paper is as follows: In Section 2, we describe the system model. Section 3 introduces the design of the ASMAC protocol. We analyze the performance of the ASMAC protocol in Section 4, and in Section 5, simulation experiments are carried out to evaluate the performance of the ASMAC protocol. Finally, we summarize the work of this paper.

2. System Model

In this section, we introduce the system model of the ASMAC protocol, which includes the protocol direction, slot division, neighbor table and slot array. Single-channel communication is used in the ASMAC protocol. Each vehicle is equipped with signal transceiver equipment and a GPS device. Through these devices, the vehicle can determine its basic driving status information such as position, speed and driving direction, and it

communicates with neighboring vehicles by receiving or sending wireless signals. Based on TDMA, the time is divided into frames and then the frames are divided into time slots. Each vehicle occupies a time slot and periodically broadcasts the occupancy information of time slot and driving status information.

In the ASMAC protocol proposed in this paper, the VANET is composed of vehicles traveling in opposite directions on a two-way traffic road. The directions in ASMAC are defined according to the driving direction of the vehicle in the GPS, as shown in Figure 2 [21]. Among them, vehicles traveling from east or west to north are called forward vehicles, and vehicles traveling from east or west to south are called reverse vehicles. Vehicles in two directions are defined as two sets: the forward-driving vehicles are the set D_F and the reverse-moving vehicles are the set D_R . Since the relative speed between vehicles traveling in opposite directions is relatively large, collisions are more likely to occur. Therefore, the time slot is divided according to the two sets of vehicles' traveling directions, which can effectively avoid the collision problem between vehicles traveling in opposite directions.

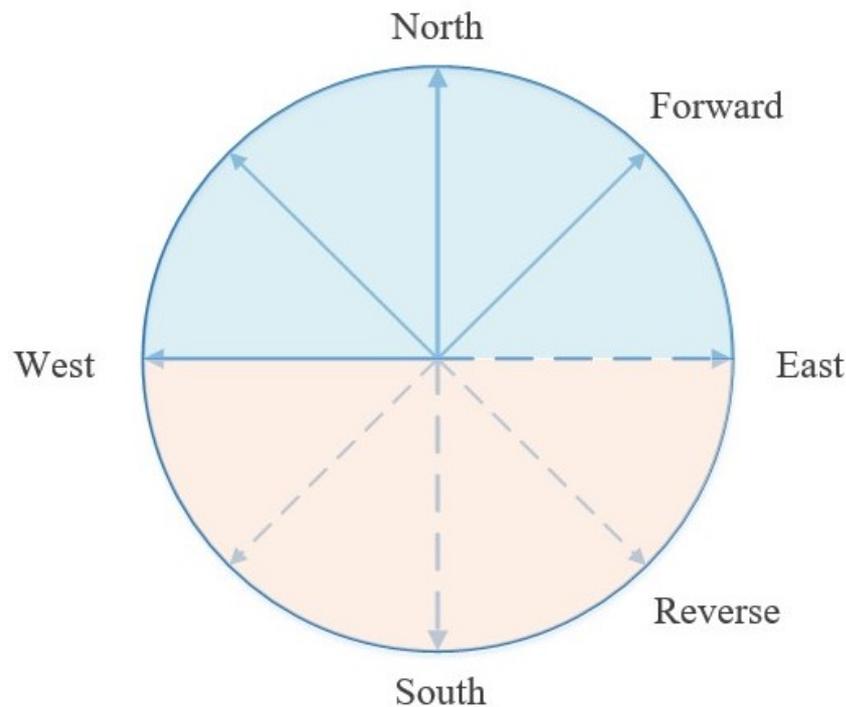


Figure 2. The directions of vehicle movement.

The frame is divided into n time slots based on TDMA, and each time slot is numbered S_i ($i = 1, 2, \dots, n$). Let us divide each frame into two time slot sets D_F and D_R , which are, respectively, associated with the forward-driving vehicle and the reverse-driving vehicle sets. The former time slot set is allocated to the forward-driving vehicles, and the latter time slot set is allocated to the reverse-driving vehicles, as shown in Figure 3. Since the vehicles equipped with GPS can realize the synchronization between vehicles through a 1PPS signal, vehicle nodes can determine the time slot number of the current time slot at any time. Furthermore, it periodically broadcasts the driving status information and slot usage information through the occupied time slot.

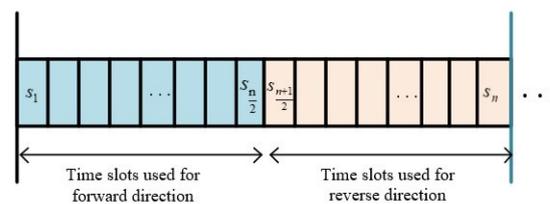


Figure 3. The time slot in a frame is divided into two time slot sets.

In order to facilitate the distributed information transmission, the following definitions are made to ensure that vehicle x can maintain communication with vehicle nodes within a two-hop communication range:

- $N_o(x)$: a collection of all vehicle node IDs within the communication range of vehicle x ;
- $N_i(x)$: the set of all vehicle IDs that vehicle x can communicate with through the intermediate one-hop neighbor node;
- $T_u(A)$: the time slot occupancy set of nodes within the two-hop communication range of vehicle x .

3. ASMAC Protocol

3.1. Preliminaries

Based on TDMA technology, the synchronization between vehicles is achieved through GPS devices and each vehicle node needs to acquire a time slot in a frame in the channel for data transmission. After a node obtains a time slot, it occupies the time slot for data transmission in subsequent frames until it voluntarily gives up or collisions occur. The one-hop set (OHS) is formed within the communication range of the vehicle. If there is an overlap between two OHS sets, the union of the two OHS neighbor sets is called a two-hop neighbor set (THS). As shown in Figure 4, the one-hop neighbor of x is w and the one-hop neighbor of w is x and y , so that x , y are two-hop neighbor vehicles of each other. The vehicle node can communicate with all vehicle nodes within the THS communication range. Therefore, the time slot occupancy information of all nodes within the THS communication range can be known. Here we also define a neighbor table to record the information of vehicle nodes within the THS communication range. The fields in the neighbor table are: *vehicle ID, driving direction, driving speed, location, time slot number*. Furthermore, vehicles update their neighbor table according to the received information of neighbor nodes after each frame. All vehicle nodes in the THS select different time slots to transfer data according to the information from their neighbor table. If more than one vehicle uses the same time slot, there will be a collision, resulting in the failure of information transmission between vehicles. As shown in Figures 4 and 5, two types of collisions may occur on a time slot: access collision and merge collision. The access collisions occur when vehicles access a time slot and the merge collisions occur between moving vehicles. Access collision refers to the collision that occurs when two or more vehicles in the same THS acquire a same time slot at the same time. As shown in Figure 4 [22], if vehicles x and y within the two-hop communication range want to access the same time slot to transmit data, vehicles x and y simultaneously send the occupied time slot signal and an access collision occurs between the vehicles at this time. Access collisions occur when vehicles access time slots, while merge collisions occur between vehicles that have acquired time slots. When the distance between vehicles occupying the same time slot on the road is gradually shortened to within the two-hop communication range due to acceleration or deceleration, a merge collision occurs, such as in Figure 4, where vehicles x and z occupied the same time slot. At the beginning, the two vehicles are outside the two-hop communication range of each other. With the change of speed of the two vehicles, the distance between x and z gradually shortens to the two-hop communication range so a merge collision occurs between the two vehicles.

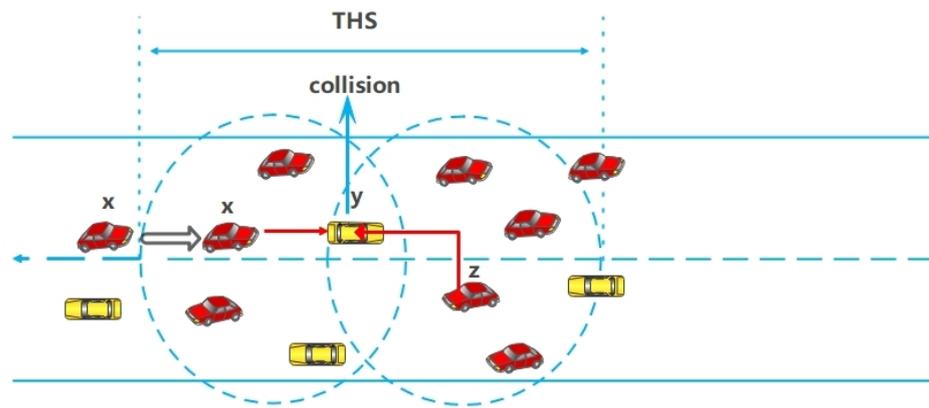


Figure 4. Vehicle communication in balanced traffic flow scenario.

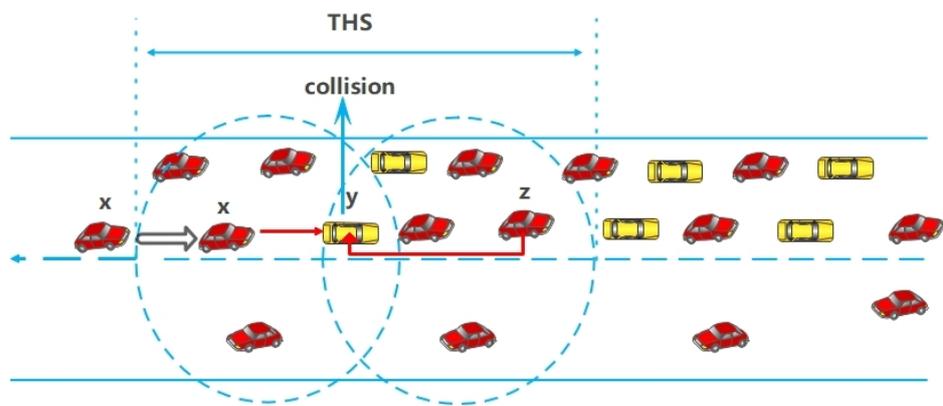


Figure 5. Vehicle communication in unbalanced traffic flow scenario.

3.2. Time Slot Access

When a vehicle node transmits data on a channel, the header of each datagram should include the node x 's one-hop neighbor set $N_o(x)$ and the time slot usage information of all vehicle nodes $y \in N_o(x)$. Suppose a newly joined vehicle A has just started up and needs to acquire a time slot to transmit information. First, vehicle A listens for a continuous frame of time (it may not be the same frame). Then, it can obtain the one-hop neighbor set $N_o(A)$ and time slots usage of each node $i \in N_o(A)$. Similarly, node $i \in N_o(A)$ can acquire and broadcast time slots usage information of vehicle node $z \in N_o(i)$, so that vehicle A can know the time slot usage set $T_u(A)$ of vehicle nodes in the two-hop neighbor. At the end of each time slot, all vehicle nodes update their one-hop neighbor set and the usage information of time slots within the two-hop communication range.

Based on the $T_u(x)$, the time slot set in which node x can determine the available time slots in a frame is called $U_T(x)$. According to the driving direction of the vehicle, the time slot s in available time slots in the corresponding time slot set is selected as the transmission time slot. The beacon frame occupying the time slot s is sent out to indicate that the time slot is to be occupied. Vehicle node x can successfully obtain the time slot s when there are no other nodes within its two-hop communication range trying to obtain the time slot. Otherwise, an access collision will occur between the nodes. The handling of collisions between vehicles is explained in Section 3.3.

The node selects the time slot access according to its driving direction. For the vehicle traveling in the forward direction, it selects the time slot S_{min} with the smallest time slot number in the D_P part of $U_T(x)$ to access. Similarly, when a vehicle traveling in the opposite direction accesses a time slot, the time slot S_{max} with the largest time slot number in the D_N part of $U_T(x)$ is selected for access.

Through the neighbor table, the vehicle node can obtain the number of nodes in each driving direction and the time slot occupancy within the two-hop communication range. When the number of vehicles in the two directions differs greatly, there will be insufficient time slots on the side with more nodes and the side with fewer vehicles causes the problem of wasting time slot resources. Thus, an adaptive time slot access method is proposed to solve the above problems. Firstly, a threshold m ($m \geq 1$) is set to represent the ratio of the number of vehicles on both sides. The number of forward vehicles is represented by n_F and the number of reverse vehicles is represented by n_R ; here, we assume that $n_F \geq n_R$ and there will be two cases:

$$\begin{cases} \frac{n_F}{n_R} \leq m, \\ \frac{n_F}{n_R} \geq m \end{cases} \quad (1)$$

When the ratio of the number of vehicles traveling in the forward direction to the number of vehicles traveling in the reverse direction is less than the m , it can be considered that the number of vehicles in the two directions is relatively balanced. Vehicles access the available time slots in the corresponding time slot set according to the direction of travel.

When the ratio of the number of vehicles in the two driving directions is greater than m , it can be considered that the number of vehicles traveling in the forward direction is much larger than the number of vehicles traveling in the reverse direction. Therefore, it is indicated that the traffic flow is unbalanced at this time. In this case, if vehicle c in the forward moving vehicle accesses the time slot, when c traverses the time slot set D_p , it finds that no time slot can be accessed in the time slot set. Let vehicle c traverse the available time slot of part D_N from $S_{\frac{n+1}{2}}$ and select the time slot with the smallest available time slot number for access.

3.3. Collision Elimination

According to the neighbor table, the vehicle node can know the driving state information of all vehicles in the two-hop neighbor set, such as direction, position, speed, acceleration and slot occupancy. In Section 3.1, we have introduced two possible collisions between vehicles.

3.3.1. Access Collision Elimination

When multiple vehicles access the same time slot at the same time, the processing method of the existing MAC protocol is basically to make all vehicles accessing the same time slot abandon the current competing time slot and reselect a time slot randomly among the available time slots. This inevitably leads to higher collision probability and a waste of time slot resources. In ASMAC, it is assumed that there are two vehicles A and B competing for the same time slot i at the same time. According to the vehicle driving state information in the neighbor table, the driving direction and speed of the vehicle can be obtained. There are two situations: vehicles traveling in the same direction compete for the same time slot and vehicles traveling in the opposite direction compete for the same time slot.

When vehicles A and B are traveling in the same direction, the vehicle with the higher speed is selected to access the time slot by comparing the speeds of vehicle A and B, while the other vehicle is reassigned to the time slot.

When the driving directions of vehicles A and B are different and the ratio of the traffic density in the two driving directions is greater than the threshold m , the difference in the traffic density in the two directions is large. The vehicle on the side with the smaller traffic density is selected to connect to a time slot. This is due to the fact that on the lanes with less density, the distance between nodes is farther and the network topology changes rapidly, so the vehicles need more time slots to communicate.

3.3.2. Merge Collision Elimination

A merge collision occurs when vehicles occupying the same time slot travel within two-hop communication range of each other. Assuming that two vehicles A and B occupy the same time slot and $V_A > V_B$, the distance between the two vehicles is $Dist > 2R$ (R is the vehicle communication radius). There will be a merge collision between vehicles A and B. When a collision is detected, the vehicle with a higher speed is selected to continue to use the time slot and other vehicles reselect to access the time slot. Here, vehicle A continues to use this time slot, while vehicle B reaccesses an available time slot. This is because the vehicle network topology with high speed changes frequently, and time slots are more needed to transmit safety related information.

4. The ASMAC Protocol Analysis

4.1. Time Slot Acquisition

In this section, the probability of a node acquiring a time slot on the channel is analyzed. We consider there are K contending nodes, each of which needs to acquire a time slot on the channel. A relevant model is established to obtain the number of nodes that obtain a time slot in n frames and the probability that a node obtains a time slot in n frames. We make the following assumptions before proceeding with the analysis:

- All vehicles competing for time slots are in the same THS, so $T_u(x)$ and $U_T(x)$ are the same;
- The THS of all competing vehicles will not change;
- All vehicle nodes in the THS will update $T_u(x)$ and $U_T(x)$ according to the information received from the neighbor nodes at the end of each frame;
- All competitors know whether the access time slot is successful at the end of each frame.

Assuming that the initial number of available time slots in a frame is N , S_n is the number of nodes that can successfully obtain time slots in n frames. S_n is a discrete-time Markov chain [23] with the following transition probabilities:

$$p_{ij} = \begin{cases} \frac{X(j-i, K-i, N-i)}{(N-i)^{K-i}}, & 0 \leq i \leq K-i, i \leq j \leq k \\ 1, & i = j = k \\ 0, & \text{others} \end{cases} \quad (2)$$

where $X(u, k, w)$ represents the total number of time slots obtained by u nodes in k contending nodes, when there are w available time slots, $X(u, k, w)$ is calculated as follows:

$$X(u, k, w) = \begin{cases} C_u^k A_u^k ((w-u)^{k-u} - \sum_{i=1}^{k-u} X(i, k-u, w-u)), & 0 \leq u \leq k \\ A_u^w, & u = k \\ 0, & u > k \end{cases} \quad (3)$$

Let X_n denote the number of nodes that successfully obtain time slots, and the probability of all vehicle nodes successfully obtaining time slots within n frames is:

$$p(X_n = K) = P_{1, K+1}^n \quad (4)$$

The average number of nodes that successfully obtain time slots in n frames is calculated as:

$$a_n = \sum_{i=0}^k iP(X_n = i) \quad (5)$$

The probability of each node successfully obtaining a slot is as follows:

$$P = \frac{a_n}{K}. \quad (6)$$

Compared with VeMAC and SAMD, the ASMAC protocol divides the time slots in the frame into two sets and does not divide a part of the time slots separately for infrastructure or competitive communication. Therefore, the number of available time slots of vehicles is large, and the probability of successful time slot access will be large.

4.2. The Number of Collisions

It is assumed that there are N time slots in each frame within n frame time and K vehicles access time slots. In order to ensure the reliability of communication, each vehicle needs to be allocated a time slot, so $N > nK$ must be satisfied. For any time slot, we assume that p represents the probability that at most one vehicle occupies the time slot, then:

$$p = \left(1 - \frac{K}{N}\right)^{n-1} \left(1 - \frac{K}{N}(1+n)\right). \quad (7)$$

The probability of collision in a time slot is $1 - p$, that is, two vehicles access this time slot at the same time. Let $P(i)$ be the probability of collision of i time slots in N time slots, then:

$$P(i) = C_N^i (1-p)^i p^{N-i}. \quad (8)$$

Let \bar{V} denote the average number of collisions, that is:

$$\bar{V} = \sum_{i=1}^{\frac{nK}{2}} i \times P(i). \quad (9)$$

In the VeMAC and SAMD protocols, when vehicles collide with a time slot, the collided vehicle abandons the current time slot and reselects a new available time slot to access. That is to say, the number of available time slots in the channel is reduced, while the number of vehicles competing for time slots is be reduced, which reduces the time slot access probability and increases the collision probability of vehicle access time slot. In our ASMAC protocol, if there is a collision between vehicles, one of the vehicle nodes is selected to continue to use the time slot according to the speed of the vehicles and the other vehicles reselect the available time slot access. It can effectively reduce the collision probability during time slot access and avoid the waste of time slot resources.

5. Simulation Experiment and Results

In this section, the proposed protocol is simulated to evaluate the protocol performance. We use NS3 and SUMO to build the simulation environment and simulate the road vehicle communication environment, in which the traffic scenes of two-way traffic and four-way traffic lanes are included. Each direction is composed of two two-way lanes. The length of each lane is set as 1000 m and 800 m, respectively, and the communication radius R is set as 100 m. Vehicles travel at a uniform speed with normally distributed speed and have the same probability when choosing the direction of travel at the intersection. For the convenience of simulation, we assume that the vehicle broadcasts the message in the ideal wireless channel, ignoring the influence of other factors and the only factor that causes the error of the message broadcast is the collision during the transmission process. The simulation parameters are shown in Table 1.

Table 1. Simulation parameters.

Parameter	Highway	Intersection
Street Length	1000 m	800 m
Direction	2	4
Speed	60 km/h–100 km/h	30 km/h–50 km/h
Number of Nodes	150–400	40–200
Frame Size	0.1 s	0.1 s
Number of Slots	80	80
Transmission Range	100 m	100 m

The first simulation scenario was a two-way highway with vehicles traveling at different speeds, generating the same number of vehicles in each direction. The second simulation scenario was an intersection with four traffic roads. A range of 40–200 vehicles were randomly generated in each direction. The size of each packet was set to 512 B and the transfer rate was 12 Mbps. The performances of the three protocols were studied under equilibrium traffic density and nonequilibrium traffic density.

First, the traffic scene of a two-way expressway and a four-way intersection under balanced traffic flow were simulated using the packet acceptance rate and the number of collisions (total number of access collisions and merge collisions) generated during driving as the evaluation indicators. Figure 6 shows the results of the number of collisions and packet reception rate under different number of competing vehicles in the simulation process of a two-way highway. From the results in the figure, it can be seen that as the number of competing vehicle nodes increases, the number of collisions increases in all three protocols. When the number of competing vehicles is set to 200, the number of collisions in the ASMAC is reduced by 58.3%, 44.1% and 38.3% compared with the VeMAC, SAMD and BMA protocols, respectively. When the number of competing vehicles is 400, the number of collisions in the ASMAC protocol is reduced by 65.2%, 40.9% and 29.7%. This is because some time slots in VeMAC and SAMD are divided into RSU and reserved for time slots, which leads to the reduction of available time slots. Therefore, with the increase of the number of nodes competing for available time slots, a larger number of time slot access collisions occurs. With the BMA protocol, BMA divides the time slot set into two time slot groups through the median value of speed. However, when the time slot group is selected according to the vehicle speed, there are multiple vehicles with the same speed causing access collision, resulting in low data acceptance rate. In Figure 6a, the packet reception rate of the four protocols gradually decreases with the increase of the number of vehicle nodes, but the packet reception rate of the ASMAC protocol is always higher than that of VeMAC, SAMD and MBA. Because the occurrence of collisions also affects the reception rate of data, the higher the number of collisions and the lower the reception rate of data packets.

Simulations were performed in a four-way traffic scenario to evaluate the performance of the ASMAC protocol. As in the two-way traffic scenario, the same number of vehicles were generated in each direction to evaluate the number of collisions and packet reception rates for different vehicle node numbers. The simulation results are shown in Figure 7.

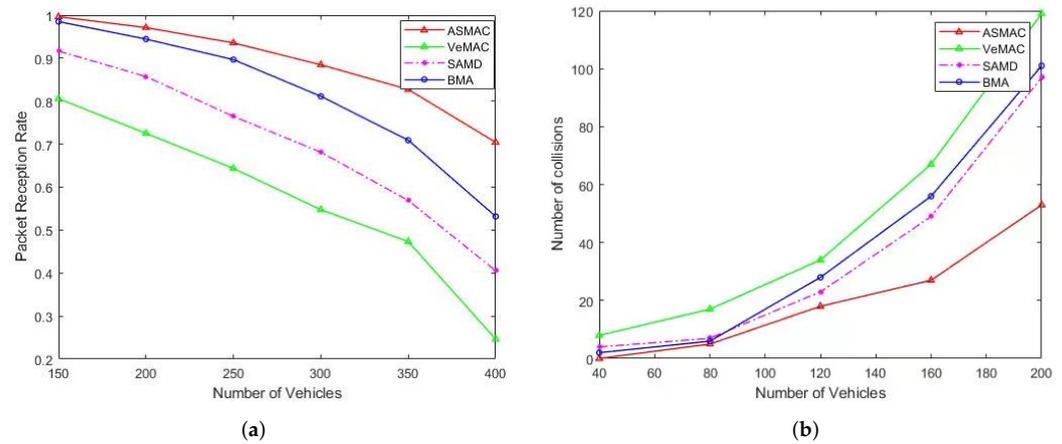


Figure 6. Packet reception rate and the number of collision on highway. (a) Packet reception rate. (b) Collisions.

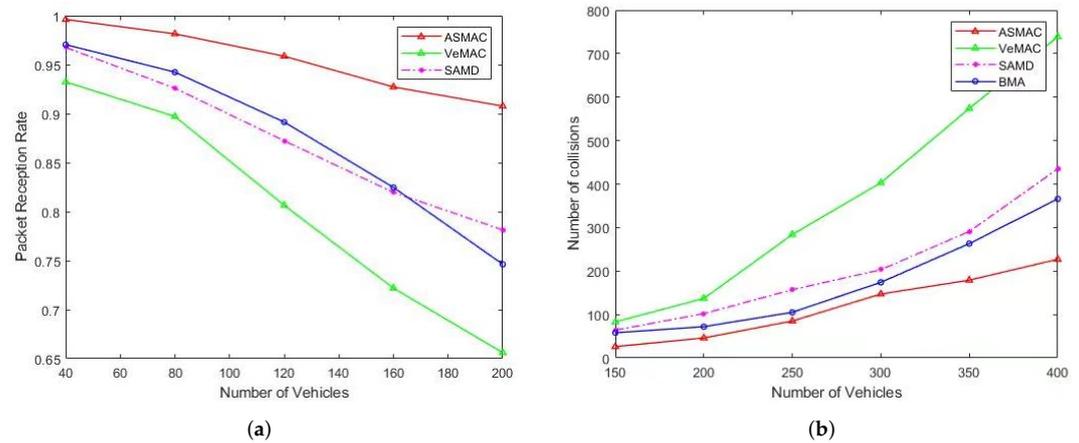


Figure 7. Packet reception rate and the number of collision on highway. (a) Packet reception rate. (b) Collisions.

From the simulation results, it can be seen that the performance of ASMAC, VeMAC, SAMD and MBA in the four-way traffic scenario is degraded compared to that of the two-way traffic scenario. When there are 200 vehicles, the number of collisions of the ASMAC protocol is 55.4%, 45% and 47% lower than the VeMAC, SAMD and MBA protocols. This is because the number of vehicle nodes increases at four-way intersections. After turning and lane changing, the vehicle needs to reacquire the time slot, resulting in an increase in time slot access collision. At the intersection, the number of merging collisions also increases, which seriously affects the performance of the MAC protocol. The SAMD and BMA protocols cannot process the vehicle in case of collision, which reduces the packet acceptance rate. In the same environment, the number of collisions of ASMAC protocol is always less than that of the VeMAC and SAMD protocols. The more vehicles, the better the performance of ASMAC.

In this paper, the performance of the three protocols in the case of unbalanced traffic flow density was studied. Firstly, we defined a parameter r representing the traffic density ratio, which represents the ratio of the number of vehicles on the sparse side to the number of vehicles on the dense side. When $r = 1$, it means that the number of vehicles on both sides is in a balanced state, while smaller r values indicate a greater difference between the number of vehicles on both sides. The cases where the total number of generated vehicles is 200, 400 and 600 were simulated, respectively, and the reception rate of data packets was tested by using different r values. Figures 8–10 shows the packet reception rate when the

number of vehicles is 200, 400 and 600, respectively. From the simulation results, it can be seen that different traffic density ratios have a greater impact on the VeMAC protocol than on the ASMAC, SAMD and MBA protocols. When the number of vehicles is set to 200 and r is set to 0.2, the packet reception rate in the ASMAC protocol is 11.6%, 7.1% and 5.2% higher than that in the VeMAC, SAMD and MBA protocols. When we increased the number of vehicles to 600 and r was set to 0.2, the packet reception rate of ASMAC protocol increased by 12.8%, 13.7% and 8.5%. This is because the fixed time slot division in the VeMAC protocol makes the access collision probability higher on the side where the vehicles are denser, while the time slot resources of one sparse vehicle is wasted, resulting in a lower data packet reception rate. In the SAMD protocol, the number of left and right time slots can be dynamically divided according to the ratio of the number of nodes in the driving direction, which can effectively improve the time slot access rate. However, due to the rapid movement of vehicle nodes, it is easy to cause the merge collisions of vehicles in the opposite direction, resulting in an increase of the number of collisions. In the MBA protocol, when the node density on one side is high, the difference in vehicle speed is small. Thus, it is very easy for multiple vehicles with the same speed to compete and collide in the same time slot. In the ASMAC protocol, the vehicle on the dense side is allowed to access the time slot with the smallest time slot number in the reverse time slot set when there is no available time slot in the time slot set. In case of collision, one of the vehicles is selected to continue to use the time slot according to the driving speed. The vehicle-adaptive access to time slots improves the time slot access efficiency and avoids the waste of time slot resources.

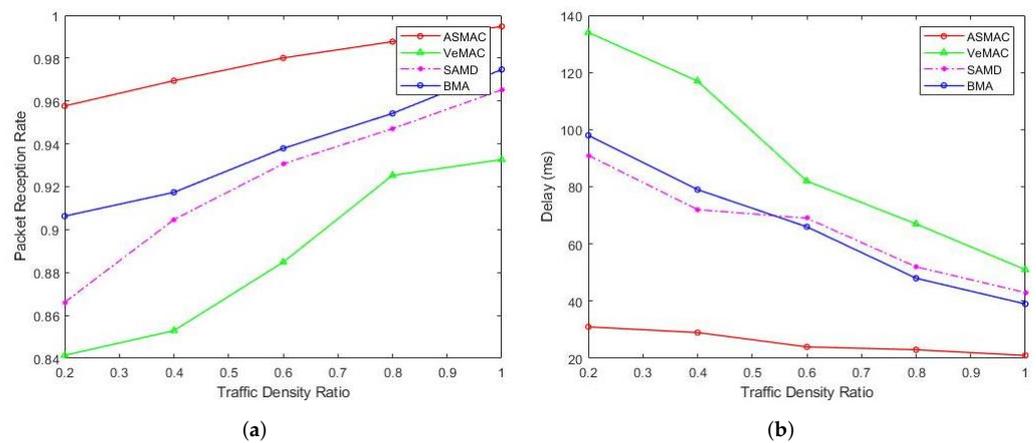


Figure 8. (a) Packet reception rate and (b) delay under different traffic density ratios when the number of vehicles is 200.

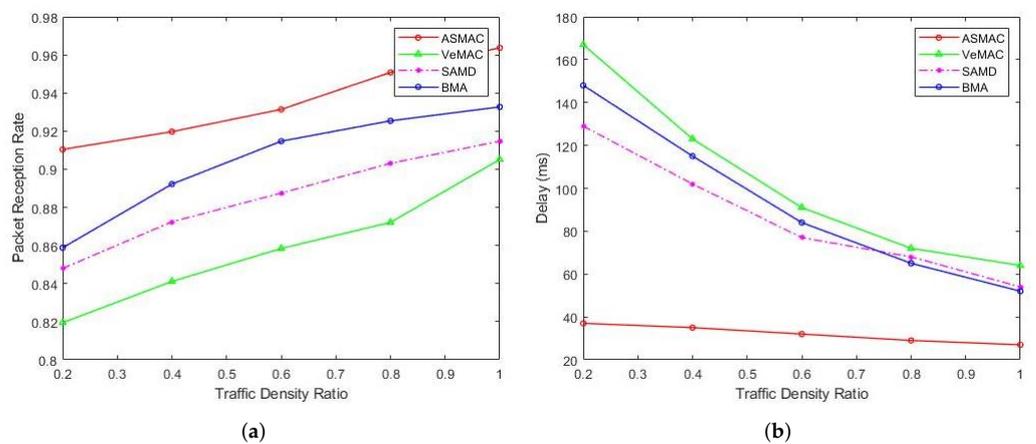


Figure 9. (a) Packet reception rate and (b) delay under different traffic density ratios when the number of vehicles is 400.

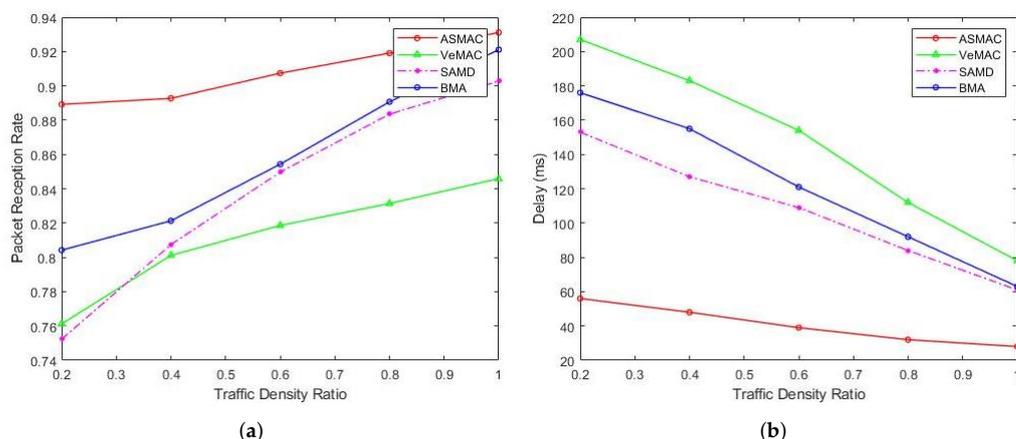


Figure 10. (a) Packet reception rate and (b) delay under different traffic density ratios when the number of vehicles is 600.

6. Conclusions

In this paper, we proposed an adaptive slot access MAC protocol (ASMAC) in a distributed VANET to solve the problem of slot depletion or waste caused by more or less vehicle nodes in the fixed divided slot set in VeMAC, under unbalanced traffic density. Learning from the idea of dynamic division according to vehicle nodes from the SAMP and BMA protocols, the ASMAC protocol optimizes the method of vehicle access time slot and the processing of vehicle collisions. Vehicles select the time slot access according to the sequence of time slots and the size of the traveling speed. Compared with other protocols, it improved the time slot access rate and reduced the number of collisions. The simulation results also proved the validity of the ASMAC protocol.

In the ASMAC protocol proposed in this paper we considered how to improve the access efficiency of the time slot and reduce the collision problem between vehicles by letting the vehicle adaptively access the time slot. Further research is needed in future work on the reliability of the protocol communication process.

Author Contributions: Conceptualization, S.-Y.H.; methodology, S.-Y.H.; writing—original draft preparation, C.-Y.Z.; writing—review and editing, S.-Y.H. and C.-Y.Z.; supervision, S.-Y.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China under Grants 61903156 and 61873324, the Natural Science Foundation of Shandong Province for Key Project under Grant ZR2020KF006, "New 20 Rules for University" Program of Jinan City under Grant No. 2021GXRC077, the Natural Science Foundation of Shandong Province under Grant ZR2019MF040, the University Innovation Team Project of Jinan under Grant 2019GXRC015, the Higher Educational Science and Technology Program of Jinan City under Grant 2020GXRC057, and the State Scholarship Fund of the China Scholarship Council.

Acknowledgments: This research was supported by the National Natural Science Foundation of China under Grants 61903156 and 61873324, the Natural Science Foundation of Shandong Province for Key Project under Grant ZR2020KF006, the State Scholarship Fund of the China Scholarship Council, and University Innovation Team Project of Jinan under Grants 2019GXRC015.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Helfert, M.; Krempels, K.H.; Klein, C. Smart cities, green technologies, and intelligent transport systems. In *Communications in Computer and Information Science*; Springer: Berlin/Heidelberg, Germany, 2015.
2. Sam, D.; Raj, V.C. VANETs-A Platform for the Future Intelligent Transport System (ITS). *Asian J. Inf. Technol.* **2014**, *13*, 38–45
3. Hu, J.; Huang, J.; Lv, W.; Zhou, Y.; Wang, J.; He, T. CAPS: Coding-Based Adaptive Packet Spraying to Reduce Flow Completion Time in Data Center. *IEEE/ACM Trans. Netw.* **2019**, *27*, 2338–2353. [[CrossRef](#)]

4. Ma, M.; Liu, K.; Luo, X.; Zhang, T.; Liu, F. Review of MAC Protocols for Vehicular Ad Hoc Networks. *Sensors* **2020**, *20*, 6709. [[CrossRef](#)] [[PubMed](#)]
5. Dot, H.S. Vehicle Safety Communications Project Task 3 Final Report. 2005. Available online: <https://rosap.ntl.bts.gov/view/dot/3925> (accessed on 7 February 2022).
6. Huang, J. Motion Prediction Based TDMA Protocol in VANETs. *Electronics* **2020**, *9*, 1792. [[CrossRef](#)]
7. Hassan, M.I.; Vu, H.L.; Sakurai, T. Performance Analysis of the IEEE 802.11 MAC Protocol for DSRC Safety Applications. *IEEE Trans. Veh. Technol.* **2011**, *60*, 3882–3896. [[CrossRef](#)]
8. Zhu, W.; Gao, D.; Foh, C.H.; Zhao, W.; Zhang, H. A Collision Avoidance Mechanism for Emergency Message Broadcast in Urban VANET. In Proceedings of the 2016 IEEE 83rd Vehicular Technology Conference (VTC Spring), Nanjing, China, 15–18 May 2016.
9. Raviglione, F.; Malinverno, M.; Feraco, S.; Avino, G.; Casetti, C.; Chiasserini, C.F.; Amati, N.; Widmer, J. Experimental assessment of IEEE 802.11-based V2I communications. In Proceedings of the 18th ACM Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, & Ubiquitous Networks, Alicante, Spain, 22–26 November 2021.
10. Hadded, M.; Muhlethaler, P.; Laouiti, A.; Zagrouba, R.; Saidane, L.A. TDMA-based MAC Protocols for Vehicular Ad Hoc Networks: A Survey, Qualitative Analysis and Open Research Issues. *IEEE Commun. Surv. Tutor.* **2015**, *17*, 2461–2492. [[CrossRef](#)]
11. Hadded, M.; Zagrouba, R.; Laouiti, A.; Muhlethaler, P.; Saidane, L.A. An optimal strategy for collision-free slots allocations in Vehicular Ad-hoc NETWORKS. In *Vehicular Ad-Hoc Networks for Smart Cities*; Springer: Singapore, 2015.
12. Ferdous, H.S.; Murshed, M. Ad hoc operations of enhanced IEEE 802.11 with multiuser dynamic OFDMA under saturation load. In Proceedings of the IEEE Wireless Communications and Networking Conference, Cancun, Mexico, 28–31 March 2011.
13. Inoue, T.; Nakata, H.; Itami, M.; Itoh, K. An analysis of incident information transmission performance using an IVC system that assigns PN codes to the locations on the road. In Proceedings of the IEEE Intelligent Vehicles Symposium, Parma, Italy, 14–17 June 2004.
14. Shagdar, O.; Ohyama, T.; Shirazi, M.N.; Yomo, H.; Miura, R.; Obana, S. Safety Driving Support Using CDMA Inter-Vehicle Communications. *IPSI J.* **2010**, *18*, 1–15. [[CrossRef](#)]
15. Ahizoune, A.; Hafid, A.; Ali, R.B. A contention-free broadcast protocol for periodic safety messages in vehicular Ad-hoc networks. In Proceedings of the IEEE Conference on Local Computer Networks, Denver, CO, USA, 10–14 October 2010.
16. Sharafkandi, S.; David, H.C.D. A new MAC layer protocol for safety communication in dense vehicular networks. In Proceedings of the IEEE Local Computer Network Conference, Denver, CO, USA, 10–14 October 2010; pp. 637–644.
17. Almalag, M.S.; Olariu, S.; Weigle, M.C. TDMA cluster-based MAC for VANETs (TC-MAC). In Proceedings of the IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM), San Francisco, CA, USA, 25–28 June 2012; pp. 1–6.
18. Zhang, R.; Cheng, X.; Yang, L.; Shen, X.; Jiao, B. A Novel Centralized TDMA-Based Scheduling Protocol for Vehicular Networks. *IEEE Trans. Intell. Transp. Syst.* **2015**, *16*, 411–416. [[CrossRef](#)]
19. Lin, L.; Hu, B.J.; Wei, Z.; Wu, C. A collision-predicted TDMA MAC protocol in centralized vehicular network. In Proceedings of the IEEE International Conference on Communication Technology, Chengdu, China, 27–30 October 2017.
20. Cao, S.; Lee, V.C. A novel coordinated medium access control scheme for vehicular ad hoc networks in multichannel environment. *IEEE Access* **2019**, *7*, 84333–84348. [[CrossRef](#)]
21. Omar, H.A.; Zhuang, W.; Li, L. VeMAC: A novel multichannel MAC protocol for vehicular ad hoc networks. In Proceedings of the IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS), Shanghai, China, 10–15 April 2011; pp. 413–418.
22. Omar, H.A.; Zhuang, W.; Li, L. VeMAC: A TDMA-based MAC protocol for reliable broadcast in VANETs. *IEEE Trans. Mob. Comput.* **2012**, *12*, 1724–1736. [[CrossRef](#)]
23. Omar, H.A.; Zhuang, W.; Abdrabou, A.; Li, L. Performance evaluation of VeMAC supporting safety applications in vehicular networks. *IEEE Trans. Emerg. Top. Comput.* **2013**, *1*, 69–83. [[CrossRef](#)]
24. Hadded, M.; Laouiti, A.; Zagrouba, R.; Muhlethaler, P.; Saidane, L.A. A Fully Distributed TDMA based MAC Protocol for Vehicular Ad Hoc Networks. Ph.D. Thesis, Inria Paris Rocquencourt, Paris, France, 2015.
25. Lyu, F.; Zhu, H.; Zhou, H.; Qian, L.; Xu, W.; Li, M.; Shen, X. MoMAC: Mobility-Aware and Collision-Avoidance MAC for Safety Applications in VANETs. *IEEE Trans. Veh. Technol.* **2018**, *67*, 10590–10602. [[CrossRef](#)]
26. Zou, R.; Liu, Z.; Zhang, L.; Kamil, M. A near collision free reservation based MAC protocol for VANETs. In Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC), Istanbul, Turkey, 6–9 April 2014; pp. 1538–1543.
27. Chen, C.; Chen, L.; Qiu, T.; Wang, Z.; Pei, Q. A Slot Assignment Scheme based on Moving Directions of Vehicles in the Internet of Vehicles. In Proceedings of the International Symposium on Wireless Personal Multimedia Communications (WPMC), Chiang Rai, Thailand, 25–28 November 2018.
28. Wu, C.; Hu, B.J.; Wei, Z.H.; Lin, L. An adaptive TDMA scheduling strategy based on beacon messages for vehicular ad hoc network. In Proceedings of the International Conference on Communication Software and Networks (ICCSN), Guangzhou, China, 6–8 May 2017; pp. 255–261.