

# A Frame Collision Reduction Method for Safety Message Broadcasting in IEEE1609.4/IEEE802.11p based VANETs

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## **Abstract**

Vehicular ad hoc network (VANET) is a dedicated network to connect vehicles without any centralized administration or infrastructure. The wireless access in vehicular environments (WAVE) protocol leveraging IEEE 1609/802.11p is widely implemented for VANETs. However, in congested traffic situation, the performance of the WAVE system degrades significantly due to serious collision, especially for safety related broadcast services on the control channel (CCH) interval due to the inherent drawback of its collision avoidance mechanisms called carrier sense multiple access with collision avoidance (CSMA/CA). In this paper, we propose a method that can decrease the number of frame collisions in CCH with a few modifications to the IEEE 802.11p protocol. In the paper, vehicles still employ CSMA/CA to compete for the channel access opportunity. However, by taking advantage of periodicity of synchronization interval, a two-state switching scheme introducing two new inter frame space (IFS) is proposed to reduce the number of competing vehicles substantially and as a result, the collision probability is significantly decreased. The simulation results demonstrate the superiority of the proposed method in packet collision rate.

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**Keywords:** Vehicular ad hoc network(VANET), wireless access in vehicular environments (WAVE), IEEE 802.11p, carrier sense multiple access with collision avoidance (CSMA/CA), collision reduction

## 1. Introduction

A wireless ad hoc network is a decentralized wireless network, which does not rely on an infrastructure, such as access points (APs). One special type of mobile ad hoc network, which is known as VANET, is a wireless network supporting moving vehicles, and has been an important component of dedicated short range communication (DSRC). A VANET typically consists of a set of vehicles combining communication facilities called on-board unit (OBU) and a set of stationary units along the roads called road side units (RSU) [1]. The latter can connect together via satellite, cellular networks or local area network (LAN), and provide access to Internet [2]-[5]. The main purpose of a VANET is to provide vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. Based on these two types of communications, VANET mainly supports three types of applications: safety applications, infotainment services and traffic management applications [6]. Both Europe and the United States have allocated a 75MHz spectrum in the 5.9 GHz band for DSRC. The DSRC spectrum is further divided into seven 10 MHz channels as shown in Fig. 1 [1]: six service channels (SCH) for non-safety related applications and one control channel (CCH) in the middle of the allocated spectrum for safety and control messages [1].

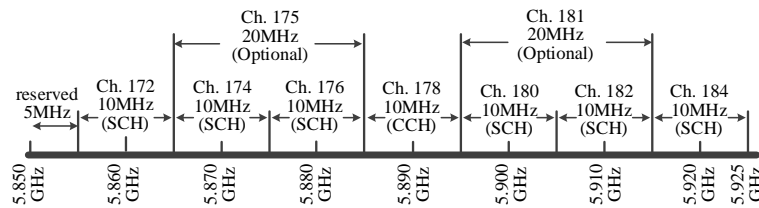


Fig. 1. FCC channel allocation for DSRC

Various medium access control (MAC) layer protocols have been proposed for VANETs. The WAVE standard proposed by IEEE, introduces the IEEE 802.11p and the IEEE 1609.4 protocol for MAC. As the upper layer, the IEEE 1609.4 offers an alternative scheme for a fixed 100 ms synchronization interval. In the first half cycle of the period, the CCH interval, all vehicles must switch to the control channel and monitor for safety messages and WAVE service advertisement (WSA) exchanges, while in the second half cycle of the period, the SCH interval, they switch to one of the SCHs to perform non-safety applications optionally [7]. The initial 4 ms of either interval is reserved for guard period, in which no transmission is allowed and the channel status is forced to be busy. Most of the high-priority safety applications for VANETs are based on one-hop broadcasting on CCH interval. For instance, for V2V communication based applications such as pre-crash sensing, blind spot warning and emergency electronic brake lighting, each vehicle periodically broadcasts information about its position, speed, direction and so on.

The IEEE 802.11p employs CSMA/CA mechanism to compete for the channel access opportunity, in which a random backoff process is imported to reduce the probability of frame collisions between nodes, i.e. OBUs and RSUs in a VANET. However, the probability of frame collision increases in proportion to the number of nodes. G. Bianchi modeled and analyzed the behavior of the CSMA/CA protocol using a discrete Markov chain in [8]. He

claimed that the system parameters such as the contention window (CW), inter-frame space (IFS) and the number of nodes strongly influence the system performance. Daein JEONG analyzed the distributed broadcasting performance of IEEE 802.11p which may be a perfect model for safety related application communication in the CCH interval [9]. His research revealed that more than 90% of frames collapse is a result of severe collision with 40 vehicles in communication range.

There have been many studies on the CSMA/CA mechanism to reduce the number of collisions. Loss differentiation of the pack error rate (PER) [10], idle time [11]-[13], transmission rate [14], and frame size [15] are performance metrics. Almost all these proposed methods need either obtaining the acknowledgement (ACK) or the RTS/CTS exchange to determine whether the transmission is successful, or adopt measures based on the result with management by an AP. Nevertheless, although these studies may have some efforts on the SCH interval, as most frames in the CCH interval are single hop broadcast frames with neither ACK nor RTS/CTS exchange, and no central administrator such as AP, these methods do not really work to reduce collisions in the CCH interval. In [16]-[17], mechanism of adjusting CW dynamically based on the estimated number of surrounding vehicles for broadcasting in CCH interval is particularly discussed. Unfortunately, as we will also discuss in Chapter 2, simply adjusting CW has limited effect on mitigating collisions.

Due to the inherent drawback of the CSMA/CA mechanism of IEEE 802.11p on CCH interval, there have been also studies on proposing novel MAC protocols instead of IEEE 802.11p. Among all these novel works, protocols implementing time division multiple access (TDMA) mechanisms are impressive [18]-[21]. Originating from RR-ALOHA [18], these protocols further divide the CCH interval into transmission period (TS) and reservation period (RS). Each node (unless slot assignment is saturated) is assigned a one- $\mu$ s contention free time slot in TS for safety message broadcasting, while the time slot assignment is negotiated in RS by mechanisms such as CSMA [19], space division multiple access (SDMA) [20], code division multiple access (CDMA) [21] or other methods. In [19], IEEE 802.11p CSMA mechanism is implemented in RS for channel reservation. In SDMA schemes [20], a vehicle's access decision is based on its location on the road. In [21], CDMA codes are applied in the MAC mechanism because of its robustness against noise and interference. In conclusion for TDMA based protocols, there would be no collisions for safety messages in TS because no contention exists. Nevertheless, the mechanism consumes large amount of extra message exchange for time slot reservation in RS, which lowers the throughput. Further, all these non-CSMA based novel protocols are complex to implement, and are not compatible with existing wireless communication protocols.

This paper proposed an improved method for safety message broadcasting in CCH based on the IEEE 802.11p, which combines high efficiency of the CSMA/CA and low collision rate of the TDMA. In the 802.11p, all OBUs and RSUs compete for channel access opportunity simultaneously when the channel becomes vacant. This induces a large amount of competing nodes, which lead to a high probability of collision. In our proposed method, most communicating nodes are arranged in a TDMA-like scheme to avoid competition, while the rest still compete for channel under the conventional CSMA/CA but with lower superiority. The mechanism reduces the number of competing nodes significantly, therefore, reduces the probability of collision. With a few modifications to IEEE 802.11p protocol, the proposed method is easy to be implemented and is compatible with existing facilities.

The remainder of this paper is organized as follows. Section 2 describes the conventional IEEE 802.11p. Section 3 describes the mechanism of the proposed method. Section 4 presents evaluation results based on simulations. Section 5 concludes this paper.

## 2. The Conventional IEEE802.11p

### 2.1 System model

In this section, we evaluate the broadcasting performance of the MAC protocol defined in the IEEE 802.11p considering two important metrics: packet loss probability and transmission delay. First, we describe the CSMA/CA mechanism introduced in the IEEE 802.11p briefly as following. A node has to ensure that the channel has been idle before transmission. If the channel is idle, the node can transmit immediately. Otherwise, the node has to defer until the medium is determined to be idle without interruption for a period of time equal to a distributed inter-frame space (DIFS), and then perform a backoff procedure by setting a counter randomly selected from  $[0, W-1]$ , where  $W$  is the size of the contention window (CW). The counter decreases if the channel is idle for an entire time slot. When the counter is decreased to zero, the node is allowed to access the channel [22]. Collisions will happen if more than one competing nodes are randomized with the same backoff counter value.

In our VANET model, all nodes, which include RSUs and OBUs, are supposed to transmit only broadcast frames in the CCH interval. At the beginning of each CCH interval, each node is supposed to have one frame to broadcast for safety reasons. Since the guard interval is defined as medium busy to prevent multiple nodes from attempting to transmit simultaneously upon channel switching, all vehicles need to defer for a DIFS and backoff before transmission. Any frame is valid for only one CCH interval, and would be dropped and considered as a failed transmission if expired in our analytical model. Perfect channel condition is assumed for simplicity. The communication links are symmetric, and each node in the VANET has the same and fixed communication range.

### 2.2 Packet Loss Probability in CCH interval

We define  $T_s$  as the duration of a successful transmission in  $\mu s$ . According to Section 18 of [22], we have

$$T_s = T_h + \frac{L}{R} + DIFS \quad (1)$$

where  $T_h$  is the duration of physical layer convergence procedure (PLCP) in  $\mu s$ ,  $L$  the packet length in bits, and  $R$  the data rate in Mbits/s. Since events occur on a CCH interval based on a discrete slotted time scale, the useful duration  $T$  of a CCH interval measured in slot times is defined as

$$T = (T_{CCH} - T_g - \frac{L}{R}) / \sigma \quad (2)$$

where  $T_{CCH}$  is the duration of the CCH interval,  $T_g$  the guard time, and  $\sigma$  the duration of one time slot. Frames cannot be transmitted during the guard interval, or if the residual time before the end of the CCH interval is shorter than  $\frac{L}{R}$ , otherwise the transmission would not be

completed due to the mandatory channel switching.

The probability  $P(l, n, w, k)$  ( $1 \leq l \leq w$  and  $1 \leq k \leq n$ ), modeled through a Bernoulli process and computed in [23], represents the probability that  $n$  vehicles in the system generate the broadcast message at the beginning of a CCH interval, and acquired backoff counters from a contention window of  $w$  time slots by randomizing,  $(l-1)$  slots have passed before the first transmission attempt, and  $k(k < n)$  vehicles transmit in the  $l$ th slot.

$$P(l, n, w, k) = \left(1 - \frac{l-1}{w}\right)^n \binom{n}{k} \left(\frac{1}{w-l+1}\right)^k \left(1 - \frac{1}{w-l+1}\right)^{n-k} \quad (3)$$

Define  $L(w, n)$  as the mean number of collapsed broadcast messages because of accessing the channel simultaneously. The closed-form expression of  $L(w, n)$  is derived as (4):

$$L(w, n) = \sum_{l=1}^w \left\{ \frac{P(l, n, w, 1) \cdot L(w-1, n-1) + \sum_{k=2}^n P(l, n, w, k) [k + L(w-l, n-k)]}{\sum_{k=2}^n P(l, n, w, k) [k + L(w-l, n-k)]} \right\} \quad (4)$$

Based on (3) and (4), starting from  $L(W, N)$ , all the possible numbers could be recursively computed. Consequently, the probability of packet loss can be computed as:

$$P(W, N) = \frac{L(W, N)}{N} \quad (5)$$

We analyzed the packet loss probability of different network conditions by calculating (5) with different  $W$  and  $N$  values. The results reveal that the CSMA/CA mechanism is even unacceptable on most occasions. For example, with the default  $W$  of 16 time slots which is defined in IEEE 802.11p, even in a slightly crowded situation of 10 vehicles,  $P(16, 10)$  is about 52.31%, meaning that almost half of the safety-related broadcast messages are dropped because of collision. In a generally crowded situation with 30 vehicles in communication range,  $P(16, 30)$  reaches 81.20% and is completely unacceptable for safety concerns. Even with  $W=64$ ,  $P(64, 30)$  is reduced to 39.95%, which is still unacceptable for safety concerns.

### 2.3 Transmission Delay in CCH interval

We evaluate the transmission delay by computing the mean maximum time to complete broadcast message transmission for all vehicles during a CCH interval. Without acknowledgement mechanisms for broadcast messages, each broadcast message transmits only once regardless of success or failure. Thus,

$$T(w, n) = \sum_{l=1}^w \sum_{k=1}^n P(l, n, w, k) [T_s + T(w-l, n-k)] \quad (6)$$

We compute (6) under the condition of  $T_s=458\mu s$ , i.e. 500-byte payload and 12-Mbps bit rate to analyze the performance of transmission delay. The results reveal the high collision rate problem from another aspect compared to section 2.2. For example,  $P(16, 20) = 5.375$  ms, however  $T_s \times 20 = 13.16$  ms, meaning that with the best randomization of the CW, only 8 of 20 frames may be transmitted correctly. The time summed for all vehicles to complete broadcasting is much shorter than it needs to have when vehicles do transmission simultaneously with heavy collisions. Even with  $W=64$ ,  $P(64, 20)=7.663$ ms, there are no more than 11 out of 20 frames can transmit without collision.

## 2.4 Analysis of Key Improvement

For safety message broadcasting on the CCH interval, in consideration of the fact that there is neither acknowledgement exchange nor central administrator, optimizing  $W$  and  $N$  as revealed in equation (5) is the only way to reduce the collision rate of the CSMA/CA mechanism. From the analysis in Sections 2.2 and 2.3, we can conclude that a larger value of  $W$  does some improvement on lowering the collision rate, but is inefficient and inconspicuous. The main reason of high collision rate is the high quantity of competing vehicles, which is the key of improvement.

Let's investigate key difference of MAC arrangement between wireless local area network (WLAN) and VANET. In a WLAN, MAC always starts a transmission procedure immediately when a message is required to be sent by the upper layer. However, for a safety related broadcast message, the life time of which is as long as the entire CCH interval. Although every vehicle is obliged to broadcast its own state in each CCH interval, it's unnecessary for all vehicles to compete for channel simultaneously at the end of the guard time. However, according to IEEE 802.11p, vehicles have to do so. If vehicles do not start competition together, instead, from discrete points in the CCH interval, the amount of competing vehicles  $N$  may be lowered significantly. In the example provided by Fig. 2, although all the three vehicles get a "four" for backoff counter value, no collision occurs because they are arranged into a TDMA like pipeline, and  $N$  is reduced to 1, thus no competition exists in fact. The challenge is how to arrange and maintain the pipeline. We extended this idea, and proposed a new method as discussed in Section 3.

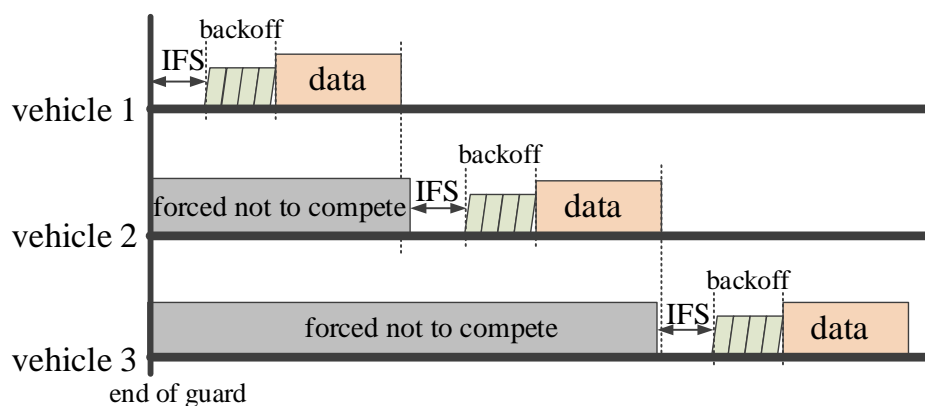


Fig. 2. Staggered channel competition

## 3. Adaptive Method

In this section, we propose an adaptive method to reduce the collision rate on CCH interval, with a few modifications to the IEEE 802.11p. The basic operation flow is discussed in Section 3.1 and 3.2. Section 3.3 discussed the operation under different collision situations.

Fig. 3 illustrates the proposed method, each time slot in the CCH interval is given an identical integer serial number starting from digit "1". If the duration of CCH is not dividable by a time slot, the remainder is also assigned a serial number.

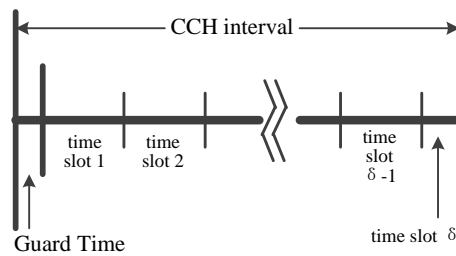


Fig. 3. Serial number for time slots in CCH interval

We assume that every node has and only has one broadcast frame to transmit. If a node needs to transmit multiple frames, it must keep multiple threads for every frame using our proposed method. For simplicity, we do not discuss the situation with multiple frames in this paper.

The paper proposes two new IFSs named CW included IFS (CW-IFS) and silent IFS (SI-IFS). For the former one, the usage is similar to DIFS but the duration equals to the sum of  $W$  time slots and a DIFS. SI-IFS is a period in which a node monitors the channel while it is forced to refrain from any transmission. The details of the two new IFSs will be further discussed in the following sections of Chapter 3.

### 3.1 Operation for OBUs

Any OBU node in a VANET is assigned either one of the following two states: Acquiring Time Slot (ATS) or Occupying Time Slot (OTS). A node is at ATS state when powering up. Before transmitting any frames, an ATS state vehicle should wait until the channel is idle for a CW-IFS seconds, then begin the legacy backoff procedure to obtain channel access opportunity. If the node succeeded in the competition, besides executing the frame transmission, it also sets its own state to OTS, and stores the time slot serial number of the channel that is detected vacant. If the node failed in the competition, it remains in the ATS state, and performs the CW-IFS and backoff procedure to obtain channel access opportunity again. Fig. 4 shows a simple example of three vehicles at ATS state competing for channel access. The guard time is not shown for simplicity. Vehicle 1 succeeded in competing and moved to OTS state first with storing time slot 1. When transmission is done, it starts deferring for SI-IFS immediately. Then vehicle 2 and vehicle 3 obtained the channel access privilege and moved to OTS state successively, with storing time slot  $i$  and  $j$  respectively.

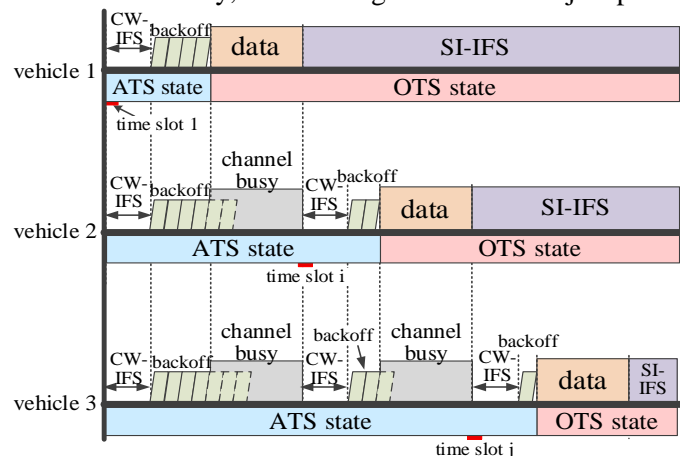


Fig. 4. ATS state vehicle operations

Before performing any transmission, an OTS state node should defer for a SI-IFS first, which lasts from the end of message transmission to the stored time slot in the next CCH interval. At the beginning of the stored time slot, if the channel is busy, the node continues monitoring the channel until it is vacant and stores the new time slot. After confirming that the channel is free, the node begins the DIFS deferring and backoff procedure as defined in the IEEE 802.11p. If the node succeeded in obtaining the channel access opportunity, it remains in the OTS state and sends the frame. When the transmission is done, it starts the SI-IFS deferring immediately. If failed in channel competition, the node sets its own state to ATS, and begins the channel access procedure for ATS nodes. Fig. 5 reveals the state movement chart between OTS and ATS state.

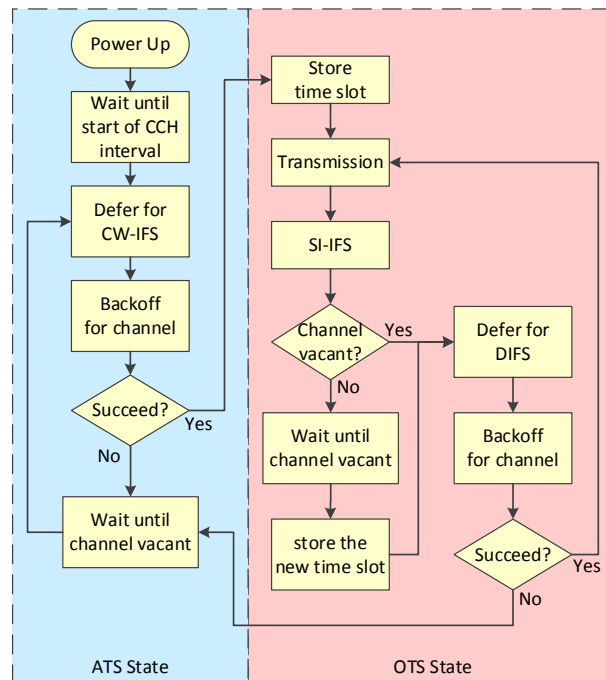


Fig. 5. Transition between ATS and OTS state

Fig. 6 shows the next CCH interval of Fig. 4. Once new ATS state vehicle enter the communication range. As shown in Fig. 6, vehicle 1 stored time slot 1, it starts deferring from the beginning of the CCH interval. Vehicle 2 and vehicle 3 keep monitoring and receiving frames silently, until the stored time slot comes. When time slot  $i$  comes, the channel is detected to be free, thus vehicle 2 starts the DIFS deferring procedure immediately. On the other hand, at the beginning of time slot  $j$ , vehicle 3 detects the channel to be still busy, so it has to wait until the channel to be vacant, and then obtain channel access opportunity. Vehicle 4, the ATS state vehicle, keeps competing for the channel, but has no possibility to win, because CW-IFS equals to the sum of DIFS and W time slots, which is greater than the maximum possible defer time for OTS state vehicles. Fig. 6 indicates that vehicle 1, 2 and 3 do not compete for channel access but their channel usage ratios are not lowered. In the next coming CCH interval, all the four vehicles are in a pseudo-TDMA pipeline to access the channel without competing with each other.



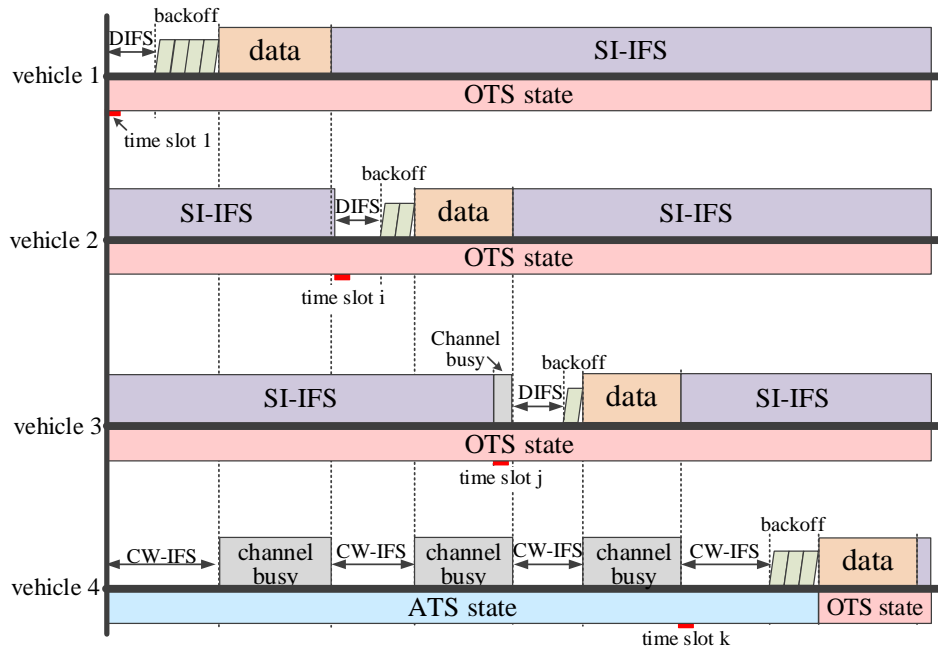


Fig. 6. OTS state vehicle operations

### 3.2 Operation for RSUs

The two-state operations are effective for OBUs because the topology of moving vehicles are relatively stable, thus the topology of competing nodes varies slowly. Some cluster based MAC protocols [24]-[26] are proposed based on the phenomenon. For RSUs, the proposed two-state operations are not compatible, because RSUs do not move and do not form clusters with OBUs. Storing the time slot that the RSU succeeded in getting channel in the previous CCH does not have the expected effect, because the topology of competing nodes within communication range in each CCH interval varies substantially. Considering that only a few RSUs exist in the communication range of an OBU cluster, RSUs are always in the ATS state in our proposed method regardless of package delivery results.

### 3.3 Collision Analysis

The main element of frame collision is undoubtedly the collisions between all ATS state nodes, because they always compete simultaneously on channel vacant. Here we would further discuss collision between a vehicle in ATS state and a vehicle in OTS state, and vehicles in OTS state.

Fig. 7 presents another possible result of the example discussed in Fig. 6. Let us suppose that the data length for vehicle 1 was 500 bytes in the previous CCH interval, and is 100 bytes in the interval shown in Fig. 7. The duration of 400-byte difference makes the medium becoming vacant 266.7 $\mu$ s before time slot i according to eq. (1), which is longer than the duration of CW-IFS. As a result, vehicle 4 finishes CW-IFS deferring and starts backoff when vehicle 1 is still in SI-IFS. As shown in Fig. 7, vehicle 4 succeeds in competing with vehicle 1 even before vehicle 1 finishes deferring for DIFS.

Let us define  $\Delta T$  as the time difference for a vehicle to finish transmitting in the between

two adjacent CCH intervals. If  $\Delta T > CW\text{-IFS} + \sigma \times W - \text{DIFS}$ , the ATS state vehicle would achieve the transmission privilege before competition begins. If  $0 \leq \Delta T < \sigma$ , the ATS state vehicle would have no chance to succeed. With  $\sigma \leq \Delta T \leq CW\text{-IFS} + \sigma \times W - \text{DIFS}$ , the vehicles in ATS state would compete with the vehicles in OTS state, and collisions may occur. The competition is still compliant to the distribution discussed in Section 2. However, because competitions are dispersed within the whole CCH interval, the number of competing vehicles is reduced substantially, and the collision rate is much lower than the IEEE 802.11p protocol. If no vehicle in ATS state exists,  $\Delta T$  would be completely idle that may lower the system throughput.

If  $\Delta T < 0$ , which means the frame is longer than the one in the previous CCH interval, the competition may occur between vehicles in OTS state, for example vehicle 2 and vehicle 3 in Fig. 6. Fortunately, similar to the situation of competitions between vehicles in ATS and OTS state, the collision rate is not high because of few competing vehicles.

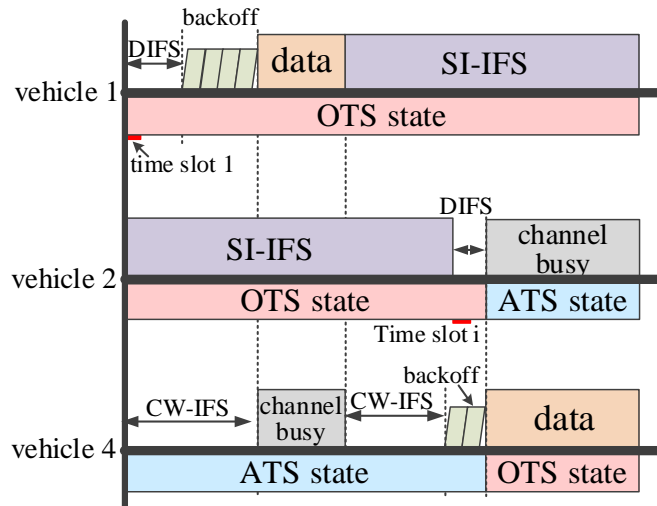


Fig. 7. ATS vs OTS state vehicle competition

#### 4. Performance Analysis

We have conducted extensive simulations to validate the performance of the proposed method, the IEEE 802.11p and a typical TDMA based protocol proposed by Lin Zhang in [14] for comparison. In Lin Zhang's proposed protocol, the synchronization interval is still 100 ms, but the duration duty of CCH and SCH interval is flexible.

The simulation parameters are listed in Table 1. in detail.

Table 1. Simulation parameters

Channel Bandwidth[MHz]	10
Modulation Type	OFDM
Transmission Rate [Mbits/s]	12
Preamble Length[ $\mu$ s]	32
PLCP Header Length[ $\mu$ s]	8

slot time[ $\mu$ s]	13
SIFS[ $\mu$ s]	32
DIFS[ $\mu$ s]	58
W[time slots]	15
communication range[km]	1
Data Payload[bytes]	200-800
Synchronization Period[ms]	100
Guard Period[ms]	4
CCH Period[ms]	46
SCH Period[ms]	46
RSU density [RSUs/km]	3
OBU density [OBUs/km]	1-90
Simulation Time[s]	100

We conducted simulations with vehicle density ranging from 1 veh/km up to 90 veh/km. As discussed in Section 3.3, the variation of payload size causing  $\Delta T$  has an effect on the performance of our proposed method, we did our simulation with four sets of payload conditions: one fixed size payload condition of 500 bytes, and three random size payload condition in an uniform distribution of three different ranges. For IEEE 802.11p and TDMA, we only did the condition of fixed 500 bytes, because payload size does not affect the performance.

#### 4.1 Packet Delivery Ratio

**Fig. 8** shows the probability of successful packet delivery within one frame in the CCH interval. [200,800] means a randomized payload size uniformly distributed from 200 to 800 for the proposed method, and vice versa for [300,700], [400,600] and [500,500]. In our proposed method, we suppose that there are always two new joining ATS state vehicles in each CCH interval. As for the IEEE 802.11p MAC, the success ratio decreases rapidly as traffic density increases. When the vehicle amount is more than 10 within the communication range, more than half of frames is lost due to serious collision. As for our proposed method, opposite to the IEEE 802.11p, the delivery ratio raises slowly with the increase of vehicle density when the latter is less than 60 veh/km. This is because the collisions are mainly between ATS state nodes including new joining vehicles and RSUs as they compete for channel simultaneously once the channel becomes vacant. With the increase of vehicles in OTS state within communication range, the ratio of non-OTS state site lowers, so the whole package delivery ratio rises. When the vehicle density is higher than 60 veh/km, the delivery ratio drops sharply. The reason is an amount of vehicles failed in competition for obtaining the channel access opportunity until the end of the CCH interval so the frame is expired and dropped. The simulation result also reveals that the wider distribution of packet length causes lower delivery ratio, but not severely. The delivery ratio is higher than 90% in most conditions. In the TDMA based protocol, more than 99% of messages are transmitted successfully when the vehicle density is lower than 20 veh/km. With the increasing of vehicles, the delivery ratio drops down to 81% gently. This is because broadcast is reliable in the reserved time slot, the collision occurs only in reservation period. Owing to the flexible duration of CCH interval, expiration rate is lowered at the cost of short duration of SCH interval.

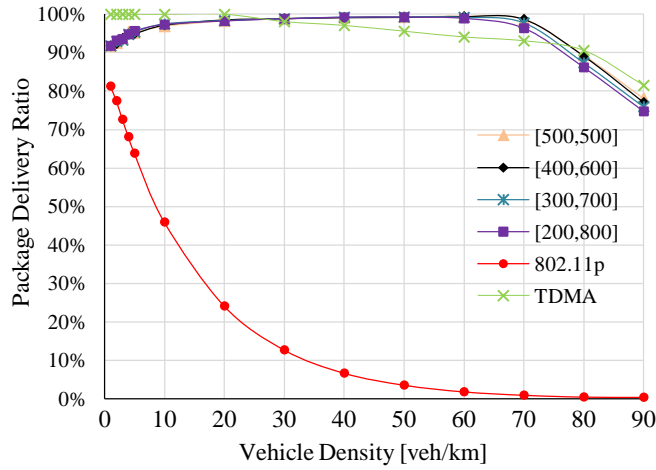


Fig. 8. Package Delivery Ratio

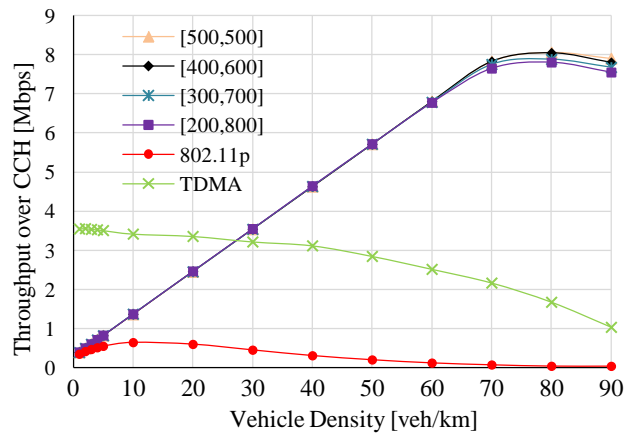


Fig. 9. Throughput over CCH

## 4.2 Data Throughput

Data throughput is one of the superiority comparing to TDMA based methods, because our method does not need extra message negotiation for channel access timing. Fig. 9 shows the data payload performance on CCH interval. The throughput of our proposed method reveals a linear increase with the increase of vehicle density until 70 veh/km. This is because we supposed that each vehicle has only one message for broadcasting in a CCH interval, and when the vehicle density is low, the CCH interval keeps idle after all vehicles have finished transmitting. When the vehicle density is higher than 70, the throughput increases slowly and finally drops down gently, because the channel usage is saturated, and messages begin to be lost because of expiration and collision. Thanks to the flexibility of CCH interval in the TDMA based method, the throughput maintains a stable but reducing value above 3 Mbps, which is higher than our proposed one, when the vehicle density is less than 30 veh/km. However, due to the tremendous cost for RS period especially in high vehicle density condition with high collision rate, the throughput declines rapidly, on the contrary to our proposed method. The IEEE 802.11p does not achieve a good performance due to its inherent shortage of high collision rate.

### 4.3 Data Delay

To evaluate the data delay in the CCH interval, we measured the total time from the beginning of the CCH interval to the time when the last site finishes message broadcasting. Fig. 10 shows the result. For the TDMA based protocol, every vehicle is assigned a time slot of one ms regardless of the package length, thus the time for all vehicles to complete broadcasting is linearly proportionate to vehicle density. According to Equation (1), a frame of 500 bytes consumes 458  $\mu$ s, so the rest 542  $\mu$ s of the 1 ms time slot is idle and wasted. When the vehicle density is higher than 60 veh/km, the TDMA protocol becomes unpractical, because taking RS into account, nearly no time is left for SCH interval. For our proposed method, thanks to the high efficiency inherited from the IEEE 802.11p, the total time cost is only 65% of the TDMA based protocol in average. As analyzed in Section 3.3, a wider frame length distribution causes lower channel efficiency. The total time cost of condition with payloads uniformly distributed within 200 to 800 is about 1.2 times of the one with fixed 500-byte payloads. When the vehicle density is higher than 60 veh/km, the channel usage begins to saturate, and the time cost closed at the 46ms, which is the duration of CCH interval excluding the 4ms guard time. The statistics of IEEE 802.11p appears to be lower than that of the TDMA and our proposed method, nevertheless, the reason is that most of the packets are lost due to serious collision. According to Equation (6), on the worst condition, every possible value within  $[0, W]$  is selected as contention windows, so the limit value of Equation (6) will be  $T_{limit}=(T_s+T_{slot})\times W$ . With our simulation parameters,  $T_{limit}=7.536$ ms, which equals to the minimum time cost for 16 messages. In Fig. 10, when vehicle density is higher than 40 veh/km, the total time cost almost equals to  $T_{limit}$ , meaning that, up to 16 vehicles may have transmitted their messages correctly, the rest all collapsed.

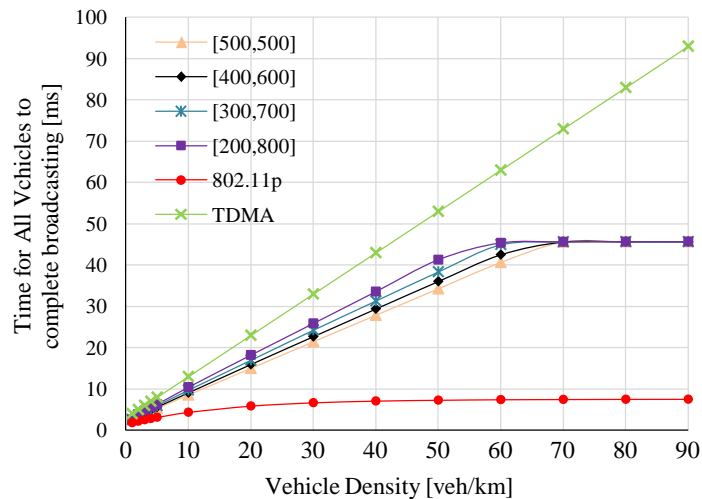


Fig. 10. Time Cost for Completing Broadcasting

Table 2 summarizes the performances from our proposed scheme, the IEEE 802.11p, and TDMA. It suggests that the proposed scheme is superior.

**Table 2.** Performance Comparison

	<b>This work</b>	<b>IEEE 802.11p</b>	<b>TDMA</b>
Package Delivery Ratio	high	low	high
Data Throughput	high	low	medium
Data Delay	medium	short	long

## 5. Conclusion

In this paper, we propose a novel method for VANET to reduce the collision rate of message broadcasting on CCH interval. By involving a two-state based mechanism and two new IFS, the periodicity of synchronization interval is better utilized, and most nodes are arranged into a TDMA-like scheme without extra negotiation. As a result, nodes avoid competing simultaneously from the beginning of the CCH interval, thus the amount of competing site is greatly reduced, which is the most important factor causing collision. The proposed method is compatible with the existing IEEE 802.11p WAVE network because no extra frame is needed, and it has only a slight impact on the existing CSMA/CA mechanism. Simulation results have revealed that when vehicle density is high than 30 veh/km, our proposed method has better performance than the TDMA based protocols in terms of package delivery ratio and channel usage rate.

## References

- [1] IEEE Std. 1609.0, "IEEE Guide for Wireless Access in Vehicular Environments (WAVE) Architecture," 2013. [Article \(CrossRef Link\)](#).
- [2] Car 2 Car Communication Consortium, "CAR 2 CAR Communication Consortium Manifesto – Overview of the C2C-CC System," August 2007. [Article \(CrossRef Link\)](#).
- [3] Liang Zhou, "Mobile Device-to-Device Video Distribution: Theory and Application," *ACM Transactions on Multimedia Computing, Communications and Applications*, vol.12, no.3, pp.1253-1271, 2015. [Article \(CrossRef Link\)](#).
- [4] D. Wu, L. Zhou, Y. Cai "Social-aware rate based content sharing mode selection for D2D content sharing scenarios," *IEEE Transactions on Multimedia*, vol.19, pp.2571-2582, 2017. [Article \(CrossRef Link\)](#).
- [5] L. Zhou, "QoE-Driven Delay Announcement for Cloud Mobile Media," *IEEE Transactions on Circuits and Systems for Video Technology*, vol.27, pp.84-94, 2017. [Article \(CrossRef Link\)](#).
- [6] P. Papadimitratos, A. de la Fortelle, K. Evenssen, R. Brignolo, S. Cosenza, "Vehicular communication systems: Enabling technologies, applications, and future outlook on intelligent transportation," *IEEE Communication Magazine*, vol.47, pp. 84-95, 2009. [Article \(CrossRef Link\)](#).
- [7] IEEE Std. 1609.4, "IEEE Standard for Wireless Access in Vehicular Environments (WAVE) -- Multi-channel Operation," 2010. [Article \(CrossRef Link\)](#).
- [8] G. Bianchi, "Performance analysis of the IEEE 802.11 distributed coordination function," *IEEE Journal on Selected Areas in Communications*, vol.18, no.3, pp.535-547, March 2000. [Article \(CrossRef Link\)](#).
- [9] Daein JEONG, "Performance Analysis of Distributed Broadcasting in IEEE 802.11p MAC Protocol," *IEICE Transactions Communications*, Vol. E98-B, No.6 June 2015. [Article \(CrossRef Link\)](#).
- [10] H.Ma and S.Roy, "Contention Window and Transmission Opportunity Adaptation for Dense IEEE 802.11 WLAN Based on Loss Differentiation," in *Proc. of Communications, 2008. ICC '08. IEEE International Conference on*, pp.2556-2560, May 2008. [Article \(CrossRef Link\)](#).

- [11] M.Heusse, F.Rousseau, R.Guillier, and A. Duda, "Idle sense: an optimal access method for high throughput and fairness in rate diverse wireless LANs," in *Proc. of SIGCOMM 2005*, pp.121-132, 2005. [Article \(CrossRef Link\)](#).
- [12] Q. Yu, Y. Zhuang, and L. Ma, "Dynamic contention window adjustment scheme for improving throughput and fairness in IEEE 802.11 wireless LANs," in *Proc. of GLOBECOM 2012*, pp.5074-5080, 2012. [Article \(CrossRef Link\)](#).
- [13] J. Lv, X. Zhang, X. Han, and Y. Fu, "A Novel Adaptively Dynamic Tuning of the Contention Window (CW) for Distributed Coordination Function in IEEE 802.11 Ad hoc Networks," in *Proc. of Convergence Information Technology, 2007. International Conference on*, pp.290-394, 2007. [Article \(CrossRef Link\)](#).
- [14] R. Oliverira and I. Koutsopoulos, "Maximum-Throughput Access Control in Wireless LANs Through Max-Weight-Inspired Policies," *IEEE Transactions on Vehicular Technology*, vol.59, no.6, pp.3036-3046, July 2010. [Article \(CrossRef Link\)](#).
- [15] J. Zhu, B. Metzler, X. Guo, and Y. Liu, "Adaptive CSMA for Scalable Network Capacity in High-Density WLAN: A Hardware Prototyping Approach," in *Proc. of INFOCOM 2006. 25th IEEE International Conference on Computer Communications. Proceedings*, pp.1-10, April 2006. [Article \(CrossRef Link\)](#).
- [16] Y. Bouchaala, P. Muhlethaler, O. Shagdar, N. Achir, "Optimized Spatial CSMA for VANETs: A Comparative Study using a Simple Stochastic Model and Simulations Results," *Consumer Communications & Networking Conference (CCNC), 2017 14th IEEE Annual*, pp. 293-298, 2017. [Article \(CrossRef Link\)](#).
- [17] Giorgia V. Rossi, Kin K. Leung, "Optimised CSMA/CA Protocol for Safety Messages in Vehicular Ad-Hoc Networks," in *Proc. of Computers and Communications (ISCC), 2017 IEEE Symposium on*, pp. 689-696, 2017. [Article \(CrossRef Link\)](#).
- [18] Ruilin Liu, Yong Xiang, Yanqing Yang, "MARR-ALOHA: A mobility adaptive variety of RR-ALOHA for vehicular ad-hoc networks," in *Proc. of Consumer Electronics, Communications and Networks (CECNet), 2012 2nd International Conference on*, pp.3304-3309, 2012. [Article \(CrossRef Link\)](#).
- [19] Lin Zhang, Zishan Liu, Rui Zou, Jinjie Guo, Yu Liu, "A scalable CSMA and self-organizing TDMA MAC for IEEE 802.11 p/1609.x in VANETs," *Wireless Personal Communications*, vol.74, pp.1197-1212, January 2014. [Article \(CrossRef Link\)](#).
- [20] Hassan Aboubakr Omar, Weihua Zhuang, "VeMAC: A TDMA-Based MAC Protocol for Reliable Broadcast in VANETs," *IEEE Transactions on Mobile Computing*, vol.12, pp.1724-1736, 2013. [Article \(CrossRef Link\)](#).
- [21] H. Nakata, T. Inoue, M. Itami, K. Itoh, "A study of inter vehicle communication scheme allocating PN codes to the location on the road," in *Proc. of Proceedings of the 2003 IEEE International Conference on Intelligent Transportation Systems*, pp. 1527-1532, vol.2. [Article \(CrossRef Link\)](#).
- [22] IEEE Std. 802.11, "IEEE Standard for Local and Metropolitan Area Networks Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," March 2012. [Article \(CrossRef Link\)](#).
- [23] Claudia Campolo, Alexey Vinel, Antonella Molinaro, and Yevgeni Koucheryavy, "Modeling Broadcasting in IEEE 802.11p/WAVE Vehicular Networks," *IEEE Communications Letters*, vol.15, No.2, pp.199-201, February 2011. [Article \(CrossRef Link\)](#).
- [24] Khalid Abdel Hafeez, Lian Zhao, Jon W.Mark, Xuemin(Sherman) Shen, and Zhisheng Niu, "Distributed Multichannel and Mobility-Aware Cluster-Based MAC Protocol for Vehicular Ad Hoc Networks," *IEEE Transactions on Vehicular Technology*, vol.62, No.8, pp.3886-3902, October 2013. [Article \(CrossRef Link\)](#).
- [25] Mengying Ren, Lyes Khoukhi, Houda Labiod, Jun Zhang, Veronique Veque, "A new mobility-based clustering algorithm for vehicular ad hoc networks (VANETs)," in *Proc. of Network Operations and Management Symposium (NOMS), 2016 IEEE/IFIP*, April 2016. [Article \(CrossRef Link\)](#).

- [26] Raghavendra Pal, Nishu Gupta, Arun Prakash, Rajeev Tripathi, “Adaptive Mobility and Range Based Clustering Dependent MAC Protocol for Vehicular Ad Hoc Networks,” *Wireless Personal Communications*, pp.1-16, August 2017. [Article \(CrossRef Link\)](#).



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