

Research Article

Optimization Design and Performance Analysis of Improved IEEE802.11p MAC Mechanism Based on High Mobility of Vehicle

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The high-speed movement of vehicles is the core factor affecting the rapid development of vehicular ad hoc network (VANET), especially the impact of vehicle mobility on data access and transmission performance. However, the classic IEEE802.11p data access and transmission protocol are still used in the multi-hop VANET under the highway system, which is adopted in the low-speed environment. Therefore, the impact of vehicle movement on the performance of the existing network is analyzed theoretically, and it is found that the network performance will be greatly reduced with the increase of vehicle speed. In order to improve the network performance in high-speed environment, an improved network access transmission protocol is proposed. Through Markov modeling, the analytic expressions of system delay, throughput, and packet loss rate are obtained. Finally, the effectiveness of the improved mechanism is verified by comparing the simulation results of two mechanisms.

1. Introduction

As the core technology foundation of intelligent transportation system, vehicular ad hoc network (VANET) plays an important role in optimizing traffic management, automatic driving, and avoiding traffic accidents. However, in the vehicles' high-speed mobile scene, the characteristics of large coverage and maximum speed up to 120 km/h undoubtedly put forward higher requirements for the compatibility and anti-Doppler performance, so it is very necessary to explore and optimize VANET based on high-speed mobile of vehicles.

Considering the convenience of deployment, open structure, and low cost, a multi-hop VANET which combines the existing Long-Term Evolution (LTE) network with IEEE 802.11p is adopted in this paper, as shown in Figure 1. The vehicle network is composed of cluster structure, and multiple vehicles form a sub-cluster, which is managed by the LTE base station Node B. Each cluster will select a vehicle as the cluster head (VH), then other vehicles communicate

with VH via IEEE 802.11p protocol, and VH will package all information of its cluster and transmit it to the corresponding Node B via LTE technology.

This network architecture avoids the transmission of useless information, so it reduces the throughput of LTE. For example, VH can choose not to send the information when its member has the same orientation and speed. VH can also use aggregate compression algorithm to save more bandwidth. On the basis of this framework, vehicle control will become more perfect, not only obtains the operating status of vehicles, but also masters the environment through sensors, radar, or GPS. However, it is a challenging task to collect such huge information, which requires the network protocol that can transmit information quickly and efficiently, so the QoS performance is required to be very high.

How to make random access and maintain good access performance is the primary problem to be solved of VANET in high-speed mobile environment. However, on the highway, the speed of vehicles and network topology are changing rapidly, and then the delay cannot be guaranteed.

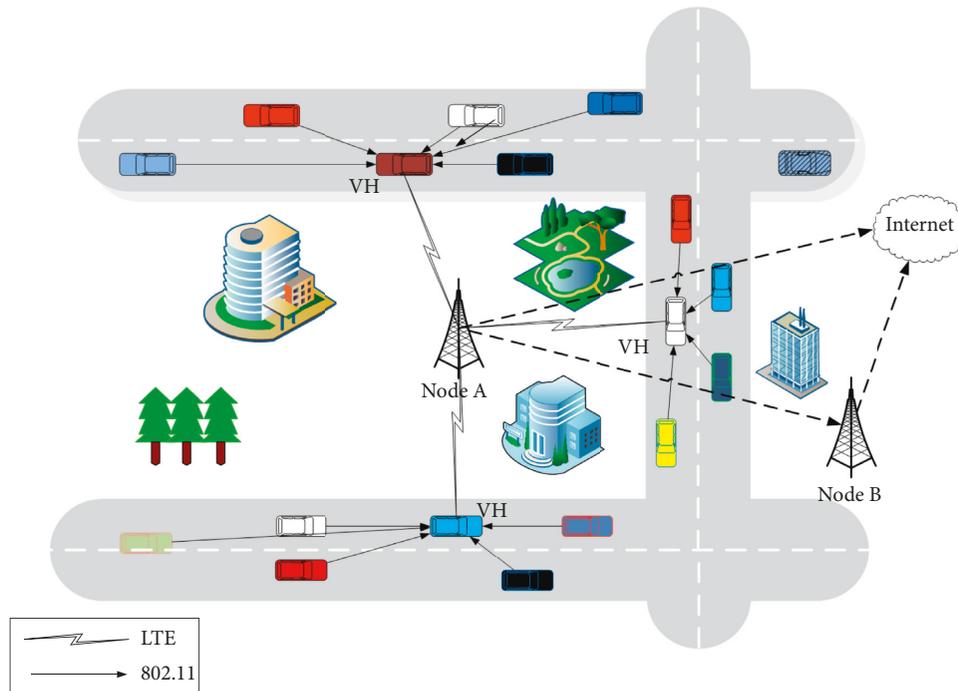


FIGURE 1: A multi-hop VANET structure.

At the same time, due to the high-speed movement of vehicles, the existing wireless access strategy cannot be well applied to VANET. In addition, compared with the general communication system, the communication time limit in VANET system is stricter than that in general static or low-speed wireless communication. Therefore, the wireless access strategy in VANET system needs to save all time and resources to improve the effective throughput.

2. Related Work

High mobility of vehicle can cause rapid topology changes. In [1], Saeed Tarapiah et al. compare many different routing protocols based on the various common metrics. However, the comparison has been done by using simulation tool NS2 instead of theoretical analysis. A Greedy Traffic Light and Queue-aware Routing (GTLQR) protocol is proposed in [2] to alleviate the packet loss caused by vehicle clustering at the intersection. In [3], the authors propose a fog computing-based content transmission scheme with collective filtering in edge of vehicles. But they only consider minimizing the latency in file downloading. In device-to-device mobile caching (DMC) networks, literature [4] proposes a completely distributed transmission algorithm based on signal-to-generating interference ratio (SGIR) to eliminate overhead for signaling and feedback. However, it only takes advantage of short distance transmission and ignores the mobility of the devices.

In [5], Hayder Amer et al. propose a noncooperative game approach to control congestion where the vehicles behave as selfish players requesting high data transmission rates. In [6], the authors propose a Bayesian-based Receiver Forwarding Decision (BRFD) scheme to mitigate the

broadcast storm problem incurred by interest packets in Named Data Network (NDN)-VANET.

The basic access method of IEEE 802.11p MAC is distributed coordination function (DCF) [7]. Designing MAC protocol is difficult for VANETs due to high mobility, and the different influences of MAC protocol on VANETs are reviewed in [8–11]. The authors of [12] describe a vehicle-to-vehicle (V2V) communication system to enable vehicles to drive in platoons. In [13], Shao et al. studied the connectivity characteristics and present a connectivity-aware MAC protocol for platoon-based VANETs. However, with a further increase in connectivity probability, the throughput will decrease. In [14], Felipe Cunha and Leandro Villas discuss the protocol stack of this type of network and provide a qualitative comparison between most common protocols. The authors of [15] propose the concept of Car2X to implement the communication between car to new physical infrastructure, consisting of cables, sensors, and many types of devices. A mathematical communication model is proposed in the high-speed IPV6 vehicle network in [16]. A data packet transmission algorithm for dynamical vehicle nodes is designed. In [17], Peng et al. introduce an IEEE 802.11p-based communication model for multiplatooning scenarios and present a probabilistic performance analysis. The author of [18] studies the vehicle communication network in the intelligent transportation system and uses OPNET Modeler software to build a vehicle movement model when the vehicle is running at low speed. A novel OFDMA-based Efficient Cooperative MAC (OEC-MAC) protocol is proposed under heavy traffic scenarios in [19] for VANETs. The authors of [20] present an enhanced TDMA-based cooperative MAC protocol called EVC-TDMA, to reduce the dropping rate and improve the throughput.

Jia and Dong of [21] design a consensus-based controller for the cooperative driving system (CDS) considering (intelligent) traffic flow, in order to investigate how the vehicular communication affects the features of intelligent traffic flow. The author of [22] proposes to use the hybrid VLC/RF (visible light communication/radio frequency) structure in VANET. And a distributed topology control (TC) algorithm is proposed to handle the TC game. Literature [23] investigates the resource allocation and interference management based on clustering mechanism in the device-to-device (D2D) communications under-laying VANETs aiming to optimize resource utilization efficiency. In [24], Mario Miler et al. develop a model for validating traffic accident locations which used a Volunteered Geographic Information (VGI) dataset, to estimate the correct location of traffic accidents.

The future of wireless ad hoc network will face the challenge to combine high-speed mobile vehicular communications with the present Internet infrastructure to provide multiple services. However, most of the literature only studies the impact of vehicle movement on network topology and data forwarding, less on data access and transmission. Obviously, the high-speed moving vehicles will cause the Doppler frequency shift of the channel and then affect the access and transmission of data. So, this paper focuses on the impact of vehicle movement on data access and transmission. Through the analysis of existing mechanisms, this paper proposes an improved mechanism to adapt to the high-speed mobile environment and make contributions to improving the quality of communication service.

3. The Existing Design of MAC Mechanism in High-Speed Mobile Environment

In IEEE802.11p protocol, DCF allows wireless stations to access the channel through competition. DCF protocol is widely used in low-speed scenarios; that is, once the site successfully accesses the channel, it can successfully transmit packets, so node competition is the main problem in low-speed scenarios. However, the high-speed movement of vehicles leads to severe fading and rapid changes of wireless channel. Under this condition, even if the vehicle site successfully accesses the channel, the data packet will fail to transmit. This happens a lot, especially at high speed. Therefore, in the high-speed mobile environment, in addition to node competition, channel transmission error is also one of the key factors affecting the system access mechanism.

When the channel transmission error occurs, then the sending station did not receive the confirmation message. According to the existing DCF protocol, the sender releases the channel occupation and enters the backoff phase where the size of window will be increased (see Figure 2). It is worth noting that the increase of window size is to

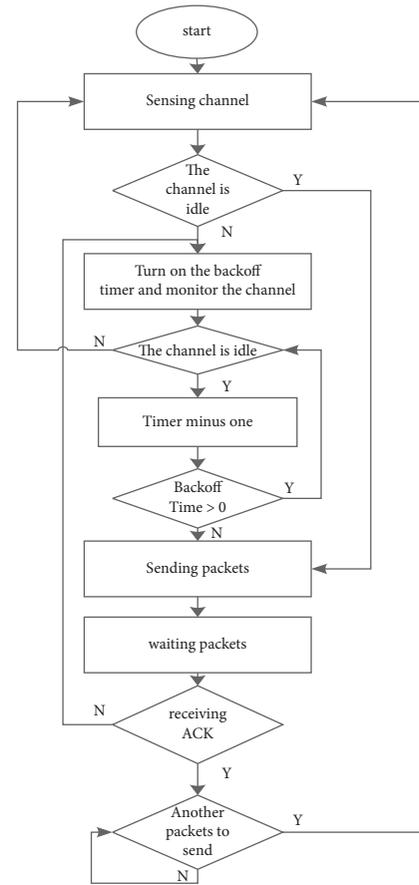


FIGURE 2: Flowchart of station access.

reduce the competition between nodes, but it does not change at this time. Therefore, the operation will increase the delay and waste the time. Secondly, there is little theoretical analysis on the impact of data retransmission on system performance. Therefore, this paper first investigates the impact of channel transmission error on the classical mechanism's performance in the environment of high-speed vehicle movement.

The two-dimensional vector is used to describe the whole transmission process of the system. Figure 3 shows the Markov state

$$\{s(t) = i, b(t) = k\}, \quad (1)$$

transition process, where $s(t) = i$ is the number of backoff and $b(t) = k$ is the value of the backoff delayer. In the low-speed mobile environment, the packet error rate is 0, but in the high-speed mobile environment, the packet error rate p_e is greater than 0. So, the station enters the backoff state in two cases: station conflict and no station conflict but data transmission error. Then, the transfer probability of Markov state is as follows:

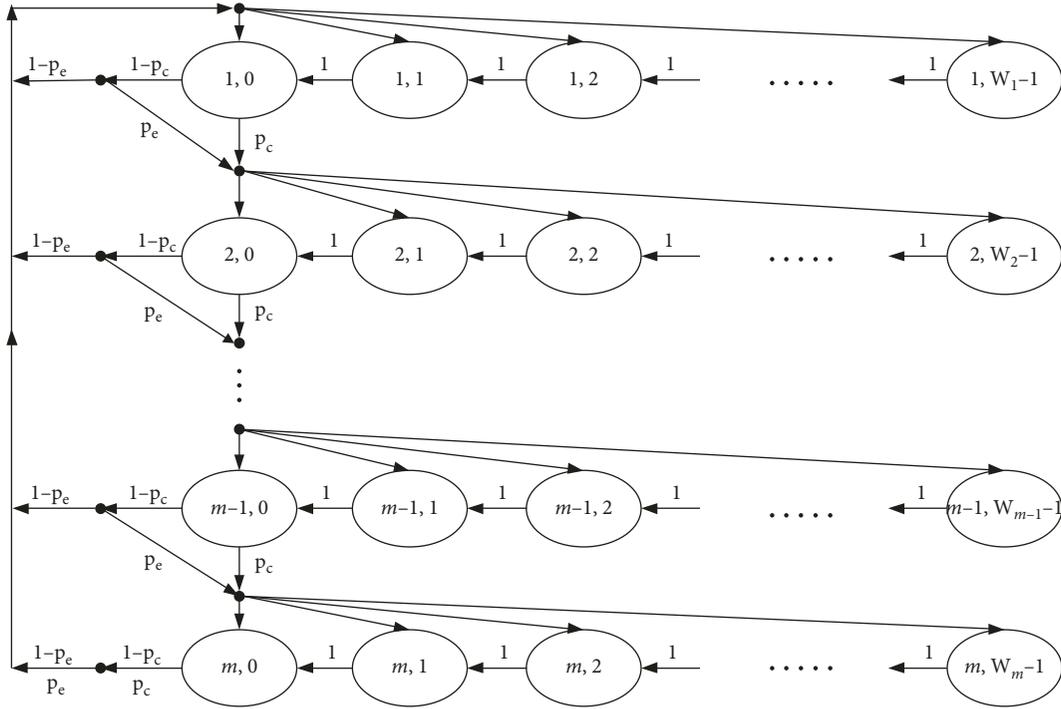


FIGURE 3: The Markov state of the existing mechanism.

$$P_0(i, k|i-1, 0) = \frac{p_c + (1-p_c)p_e}{W_i}, 1 \leq i \leq m, 0 \leq k \leq W_i - 1,$$

$$P_0(0, k|i-1, 0) = \frac{(1-p_c)(1-p_e)}{W_0}, 1 \leq i \leq m, 0 \leq k \leq W_1 - 1,$$

$$P_0(i, k-1|i, k) = 1, 1 \leq i \leq m, 1 \leq k \leq W_i - 1,$$

$$P_0(0, 0|m, k) \frac{1}{W_0},$$

(2)

where $W_i = 2^i W_0$ and W_0 is the minimum window size.

In high-speed mobile environment, when the delayer returns to 0, if there is no conflict between the node and others, it is divided into two cases. Case 1, when the channel transmits, the node starts to transmit new packets when the correct packets had been transmitted; otherwise, the node enters the backoff state with the size of window plus 1. Let

$$b_{i,k} = \lim_{t \rightarrow \infty} P_0\{s(t) = i, b(t) = j\}, \quad (3)$$

be the stationary distribution of the chain. By imposing the normalization condition,

$$1 = \sum_{i=0}^m \sum_{k=0}^{M_{i-1}} b_{i,k} = \sum_{i=0}^m \sum_{k=0}^{M_{i-1}} \frac{W_i - i}{W_i} b_{i,0} = \frac{b_{0,0}}{2} \left[W \left(\sum_{i=0}^{m-1} (2p_x)^i + \frac{(2p_x)^m}{1-p_x} \right) + \frac{1}{1-p_x} \right]. \quad (4)$$

It can be obtained

$$b_{0,0} = \frac{2(1-2p_x)(1-p_x)}{(1-2p_x)(W+1) + p_x W(1-(2p_x)^m)}. \quad (5)$$

At the same time, the main performance of the existing mechanism is as follows.

The station transmission probability in a randomly chosen slot time is

$$\tau = \sum_{i=0}^m b_{i,0} = \frac{2(1-2p_x)}{(1-2p_x)(W+1) + p_x W(1-(2p_x)^m)}, \quad (6)$$

and the probability that there is at least one transmission in the considered slot time is

$$p_c = 1 - (1-\tau)^n, \quad (7)$$

where n is the number of the stations.

The successful probability that a transmission occurs on the channel is

$$P_s = (1-p_x) \sum_{i=0}^m b_{i,0}. \quad (8)$$

The average number of backoff is

$$N_b = \sum_{i=0}^m \sum_{k=0}^{W_i} i b_{i,k}, \quad (9)$$

and it increases with the number of conflict and data retransmission.

The average backoff delay of the system is

$$T_b = p_x \sum_{i=0}^m b_{i,0} \frac{W_i}{2}. \quad (10)$$

The total delay of successful transmission is

$$T = T_{PHY} + T_b + T_{tr}, \quad (11)$$

where T_{PHY} is the delay of physical layer and T_{tr} is the transmission delay of data packet.

System throughput is defined as the amount of data successfully transmitted per unit time, which is an important indicator of system performance. And the system throughput is

$$\eta = \frac{E(P)}{T}. \quad (12)$$

In order to directly obtain the impact of high-speed vehicle movement on data transmission, the performance is analyzed numerically, where the packet error rate is $[0,0.7]$. It is worth noting when p_e is equal to 0, which represents low-speed environment. Here, the increasing speed of vehicle is expressed by the increase of p_e .

Figure 4 describes the relationship between the average number of backoff and system parameters. As can be seen from the figure, the average number of backoff increases with the increase of packet error rate p_e . This is because another conflict data transmission error will increase the number of backoff. At the same time, the average number of backoff is proportional to the collision probability and the maximum backoff orders, which is consistent with the system characteristics of the vehicle low-speed circumstances.

Figure 5 describes the relationship between the delay and the system parameters. It can be seen from this figure that the delay increases with the increase of packet error rate p_e , which indicates that the more higher the vehicle speed, the bigger the packet error rate, the longer the delay. When p_e increases from 0.1 to 0.7, the system delay increases by 600%. Therefore, how to reduce the system delay is one of the key factors to improve the system quality of service (QoS) in the high-speed mobile environment.

Figure 6 shows the relationship between throughput and system parameters. It can be seen from the figure that the throughput decreases with the increase of packet error rate p_e , which means that the faster the vehicle moves, the lower the system throughput. When p_e changes from 0.1 to 0.7, the system throughput decreases from 0.14 to 0.05, which decreases by nearly 64%. It is very terrible for the system.

Figure 7 analyzes the relationship between packet loss rate and system parameters. It can be seen from the figure that the packet loss rate increases with the packet error rate. Since the number of backoff increases due to the packet error

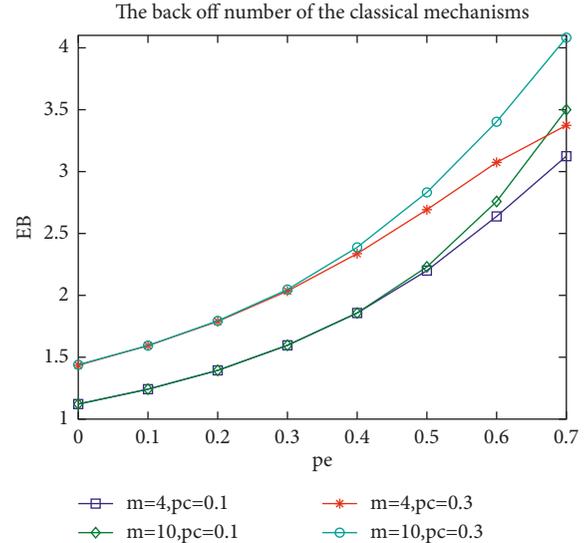


FIGURE 4: E(B) of the classical mechanism.

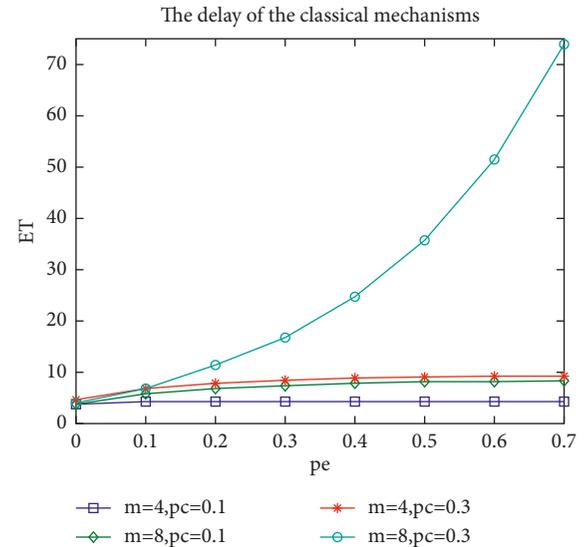


FIGURE 5: E(T) of the classical mechanism.

rate, the system discards the packets when the number of backoff increases to maximum. At the same time, when p_e increases from 0.1 to 0.7, the packet loss rate increases significantly, from 0 to 0.4, which is 400%. The large increase of packet loss rate seriously affects the system performance. Therefore, reducing the system packet loss rate means slowing down the increase of number of backoff, and how to slow down it is the core task of this paper.

To sum up, in high-speed mobile environment, the existing IEEE802.11p scheme will prolong the delay, increase packet loss rate, waste communication resources, and inhibit the improvement of system performance. Therefore, a new scheme needs to be proposed to adapt to high-speed mobile station. At the same time, the influence of channel data transmission on system access performance could be discussed in high-speed mobile environment.

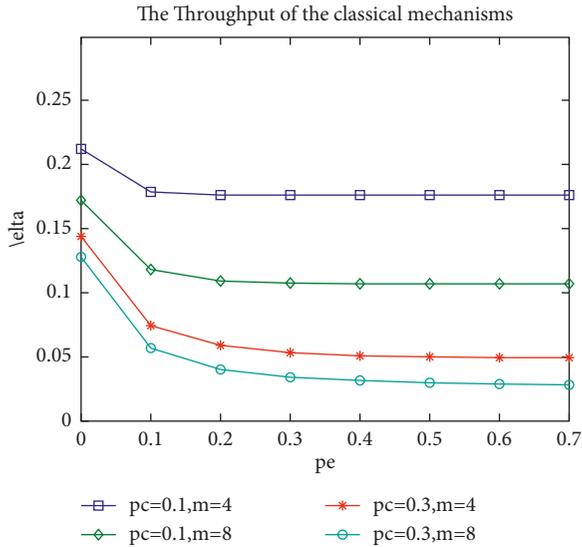


FIGURE 6: η of the classical mechanism.

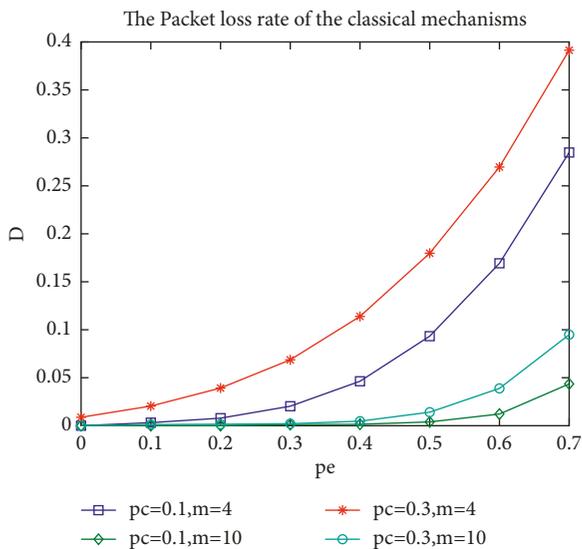


FIGURE 7: Loss of the classical mechanism.

4. Optimization Design of IEEE802.11p Mechanism Based on High-Speed Mobile

Through the analysis of the third part, the existing IEEE802.11p mechanism does not consider the impact of high-speed movement vehicle. In order to solve this problem, based on the high-speed mobility of vehicle, the IEEE802.11p mechanism is optimized. For high-speed mobile vehicle, the transmission failure of packets is caused by poor channel conditions, and the competition does not change in order to solve the above contradiction, as shown in Figure 8.

- (1) The station still enters into the backoff state. One goal is to avoid a vest of the time resources, and the other goal is to leave the time to other stations with

lower mobile speed and better communication conditions.

- (2) The backoff window remains the same size because the node contention does not increase. This is obvious that reducing the size of the backoff window can effectively reduce the system transmission delay and improve the system transmission efficiency.

As shown in Figure 9, it is supposed that there are always packets to be transmitted. The vehicle node first senses the channel; if the channel is idle for DIFS, the backoff delayer would be activated. Then, the station enters into backoff state, and the size of the backoff window is the minimum W_{\min} . When the backoff delayer decreases to 0, the station tries to access the channel. Then, the operation is divided into three cases. The first case is that the station fails to access the channel, and the station enters the backoff state with increased window size. In the second case, the station is successfully connected to the channel, the data are successfully transmitted, and then the station enters into the backoff state with the minimum window size. In the last case, if the station accesses the channel successfully but the data fail to be transmitted, the site enters the backoff state with invariant window size. When the number of backoff reaches the maximum number m , the station discards the failed packet.

The optimized mechanism has the following advantages:

- (1) The high-speed mobility of the vehicle is fully considered, which makes the optimized IEEE802.11p protocol suitable for the VANET.
- (2) According to the characteristics of the channel in high-speed mobile environment, the optimization scheme distinguishes the competition and channel conditions. According to the station access and channel transmission, the optimized IEEE802.11p protocol is proposed.
- (3) When the channel fails to transmit data, the station enters the backoff state with invariant window size, so as to effectively improve the channel utilization resources.
- (4) The backoff window size does not increase after the channel transmission failure. This is a reasonable operation because that the competition does not change.
- (5) The optimized IEEE802.11p protocol can effectively reduce the transmission delay and improve the transmission efficiency of the system.

Next, we theoretically verify the effectiveness of the proposed mechanism.

5. Performance Evaluation of IEEE802.11p Mechanism in High-Speed Mobile Environment

In order to facilitate the performance analysis of the optimized mechanism, the analysis of existing IEEE802.11p mechanism is modified.

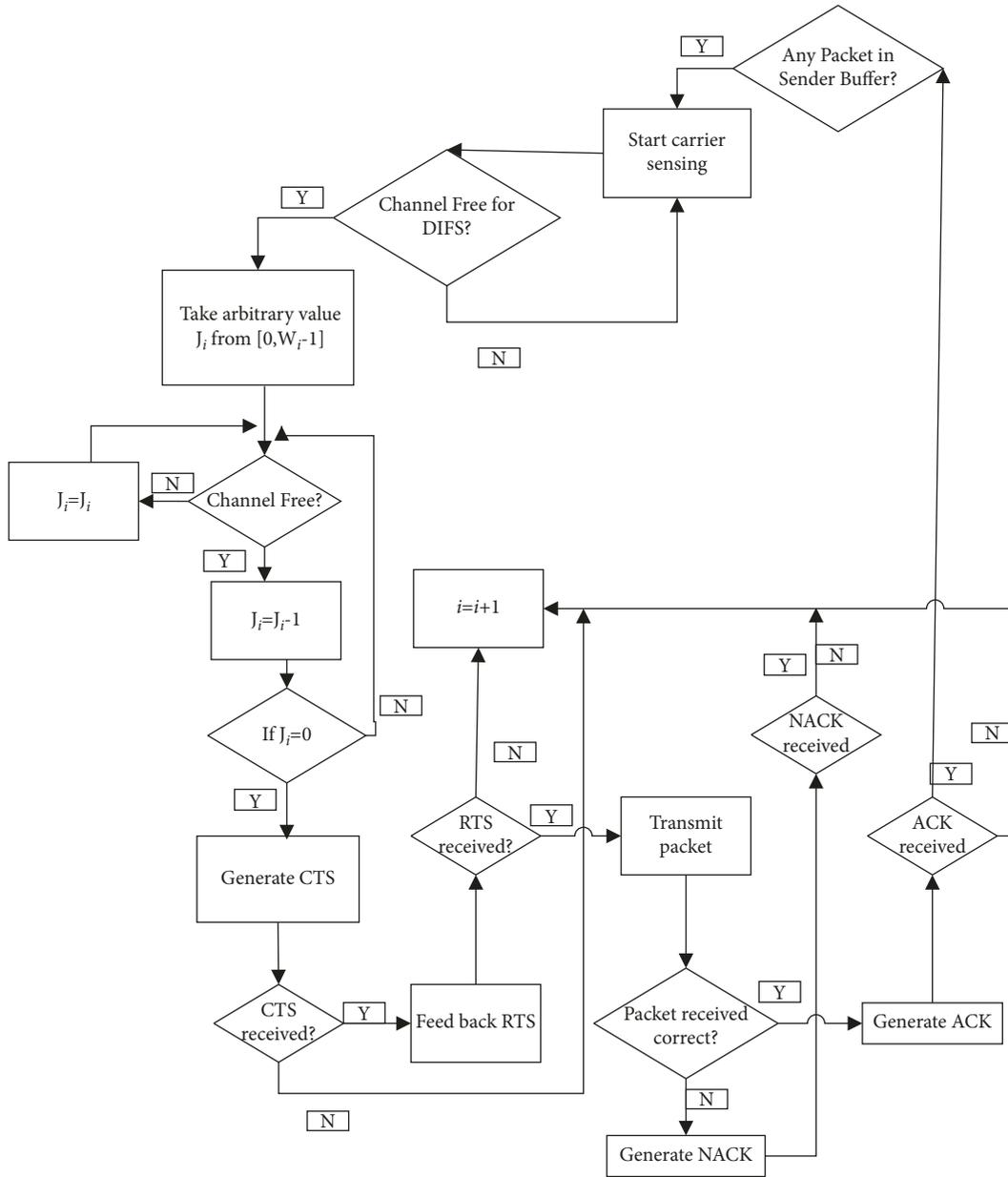


FIGURE 8: Flowchart of improvement mechanism.

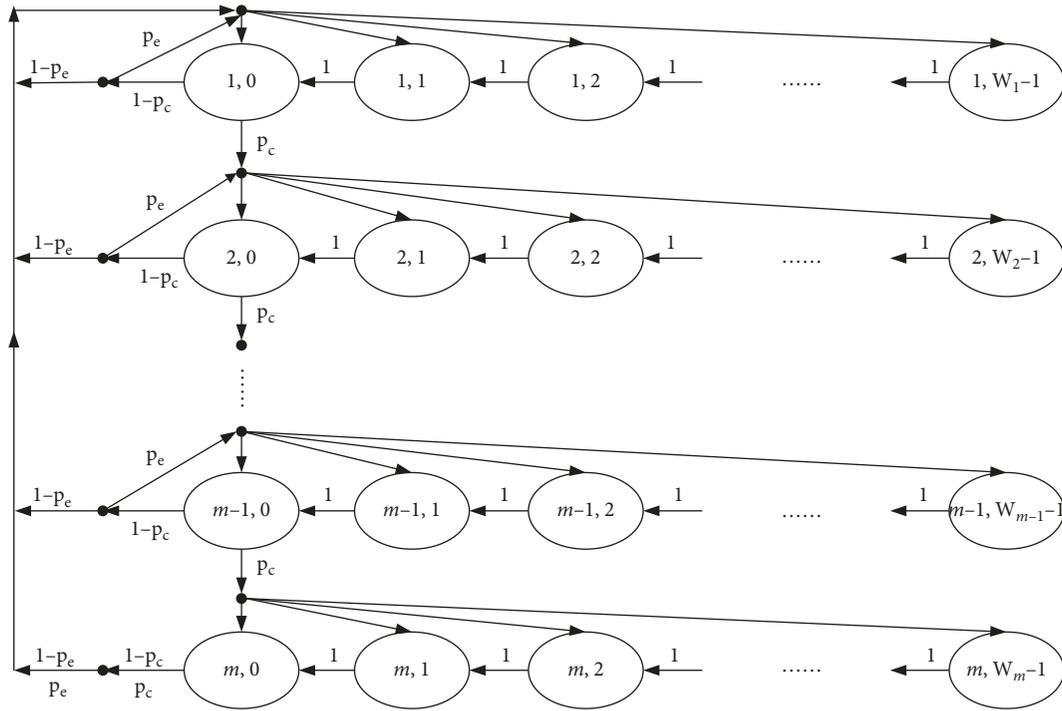


FIGURE 9: The Markov state of the proposed mechanism.

The optimization mechanism is analyzed as follows. The Markov state transition diagram is given as shown in Figure 9.

$$\begin{aligned}
 P_0(i, k|i-1, 0) &= \frac{p_c}{W_i}, 1 \leq i \leq m, 0 \leq k \leq W_i - 1, \\
 P_0(i, k|i, 0) &= \frac{(1-p_c)p_e}{W_i}, \\
 P_0(0, k|i-1, 0) &= \frac{(1-p_c)(1-p_e)}{W_0}, 1 \leq i \leq m, 0 \leq k \leq W_1 - 1, \\
 P_0(0, k|0, 0) &= \frac{(1-p_c)p_e}{W_0}, \\
 P_0(i, k-1|i, k) &= 1, 1 \leq i \leq m, 1 \leq k \leq W_i - 1, \\
 P_0(0, 0|m, k) &= \frac{1}{W_m}.
 \end{aligned}
 \tag{13}$$

At the same time, the state transition probability $b_{i,k} = \lim_{t \rightarrow \infty} P_0\{s(t) = i, b(t) = j\}$ is as follows.

$$b_{i,0}p_c = b_{i+1,0}p_y, i = 1, 2, \dots, m-1, \text{ Where, } p_y = p_c + (1-p_c)(1-p_e).
 \tag{14}$$

So, $b_{i,0} = (p_z)^i b_{0,0}$, $i = 1, 2, \dots, m-1$, where $p_z = p_c/p_y$.

$$\begin{aligned}
 p_c b_{m-1,0} &= (1 - p_c) b_{m,0}, \text{ and } b_{m,0} = \frac{p_c}{(1 - p_c)(1 - p_e)} b_{m-1,0} = \frac{p_c}{(1 - p_c)(1 - p_e)} (p_z)^{m-1} b_{0,0} b_{m,0} \\
 &= \frac{p_c}{(1 - p_c)(1 - p_e)} b_{m-1,0} = \frac{p_c}{(1 - p_c)(1 - p_e)} (p_z)^{m-1} b_{0,0} \\
 b_{i,k} &= \frac{W_i - k}{W_i} (b_{i-1,0} p_c + (1 - p_c) p_e b_{i,0}) \\
 &= \frac{W_i - k}{W_i} b_{i,0} = \frac{W_i - k}{W_i} (p_z)^i b_{0,0}, \\
 i &= 1, 2, \dots, m - 1, k = 0, 1, \dots, W_i - 1, \\
 b_{0,k} &= \frac{W_i - k}{W_i} [(1 - p_c)(1 - p_e) + (1 - p_c) p_e b_{0,0}] \tag{15} \\
 &= \frac{W_i - k}{W_i} \cdot p_y b_{0,0}, \\
 k &= 0, 1, \dots, W_0 - 1, \\
 b_{m,k} &= \frac{W_i - k}{W_i} (p_c b_{m-1,0} + (1 - p_c) p_e b_{m,0} + p_c b_{m,0}) \\
 &= \frac{W_i - k}{W_i} (1 + p_c) b_{m,0} = \frac{W_i - k}{W_i} (1 + p_c) (p_z)^m b_{0,0}, \\
 k &= 0, 1, \dots, W_m - 1.
 \end{aligned}$$

When the channel transmits error packets, the node enters the backoff state with invariant window size. Similarly, the performance index of the optimization mechanism is obtained as follows:

- (1) The access probability of the system is

$$p_{\text{mac}} = \sum_{i=0}^m b_{i,0}. \tag{16}$$

- (2) The average backoff order of the system is

$$N_b = \sum_{i=0}^m \sum_{k=0}^{W_i} i b_{i,k}. \tag{17}$$

- (3) The average backoff delay of the system is

$$T_b = (1 - p_c)(1 - p_e) \sum_{i=0}^m b_{i,0} \frac{W_i}{2}. \tag{18}$$

- (4) The total delay of successful transmission is

$$T = T_{\text{PHY}} + T_b + T_{tr}. \tag{19}$$

- (5) System throughput is

$$\eta = \frac{E(P)}{T}. \tag{20}$$

However, the above method lacks specific description of retransmission phenomenon; that is, the index of channel retransmission times and retransmission delay cannot be obtained.

So, the following Markov process is used to analyze the proposed mechanism. Let the two-dimensional Markov process

$$\{B(t) = i, N(t) = n\}, \tag{21}$$

represent the state of the sender at slot t , i denotes the number of backoff, and n denotes the number of retransmissions ($n \leq i$). The new Markov state is shown in Figure 10.

And the state transition probability $R_{i,k} = \lim_{t \rightarrow \infty} P_0\{B(t) = i, N(t) = n\}$ is as follows:

$$R_{i,n} = \binom{i}{n} p_c^{i-n} (1 - p_c)^n p_e^{n-1} (1 - p_e). \tag{22}$$

From the steady-state probability, the following indexes can be obtained:

- (1) The probability P_s that a transmission occurring on the channel is successful is

$$P_s = R_{0,0}. \tag{23}$$

- (2) The average delay of the system is

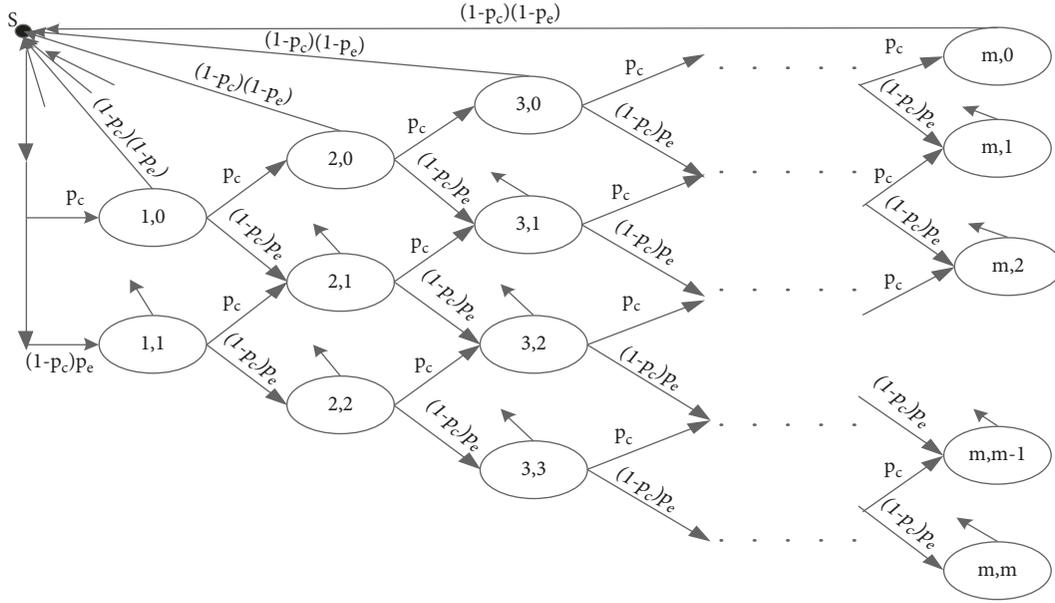


FIGURE 10: The new Markov state of the proposed mechanism.

$$E(T) = \sum_{i=1}^m \sum_{n=1}^i (1 - p_c)(1 - p_e)R_{i,n} \left(\sum_{t=1}^i \frac{W_t + 1}{2} + nT_s \right). \tag{24}$$

(3) Average packet loss rate of the system is

$$D = \sum_{n=0}^m (p_c - (1 - p_c)p_e)R_{m,i}. \tag{25}$$

(4) The average access times of the system are

$$E(B) = \sum_{i=0}^m \sum_{n=0}^i iR_{i,n}. \tag{26}$$

(5) The average number of retransmissions is

$$E(N) = \sum_{i=0}^m \sum_{n=0}^i nR_{i,n}. \tag{27}$$

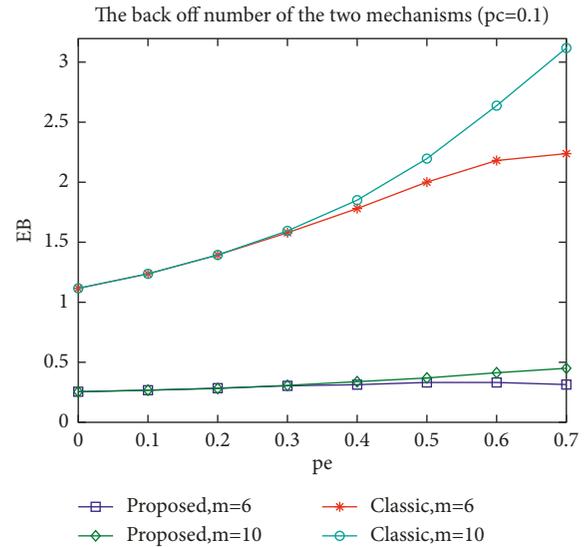


FIGURE 11: E(B) of two mechanisms (pc = 0.1).

6. Performance Simulation and Evaluation of the System

In order to verify the superiority of the proposed mechanism, we conduct a numerical analysis. In the numerical simulation, considering a saturated network, the following parameters were set: $p_c \in [0, 0.9]$, $P_e \in [0, 0.9]$, $m \in [1, 16]$

Figures 11 and 12 show the comparisons of the average number of backoff of the two mechanisms. From the two pictures, the number of backoff of the improved mechanism is much smaller than that of the classical mechanism. Taking Figure 11 as an example, when p_e increases from 0.1 to 0.7 ($m = 10$, $p_c = 0.1$), the number of backoff increases from 0.5 to 1, but that of the classical mechanism increases from 0.5 to 3.2, which means that the number of backoff decreases by

68.7%. Therefore, the faster the vehicle moves, the greater the error rate p_e , the better the improved mechanism.

At the same time, the number of backoff is inversely proportional to the maximum number of backoff and collision probability. It is obvious that the number of backoff increases with the maximum. Similarly, as the number of nodes increases, the probability of collision increases, the times of collisions increase, and the number of backoff increases.

Figures 13 and 14 show the comparison of the average data transmission delay under the two mechanisms. It can be seen from the figure that the proposed mechanism greatly reduces the data transmission delay. Taking Figure 13 as an example, when p_e changes from 0.1 to 0.7 ($m = 10$), the delay changes from 4 to 5.6, but the delay of classical mechanism

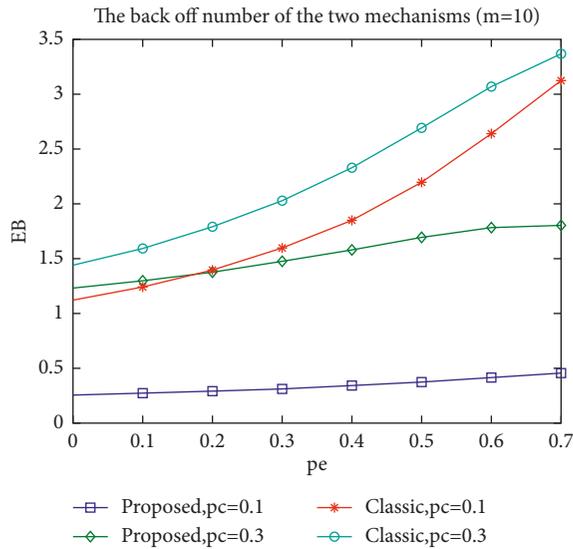


FIGURE 12: E(B) of two mechanisms ($m = 10$).

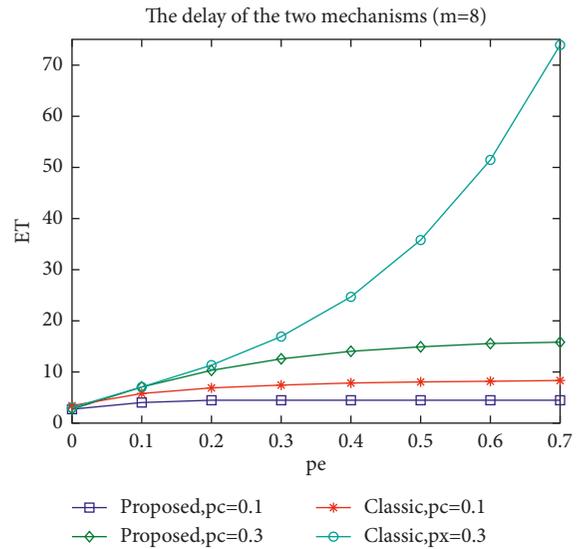


FIGURE 14: E(T) of two mechanisms ($m = 8$).

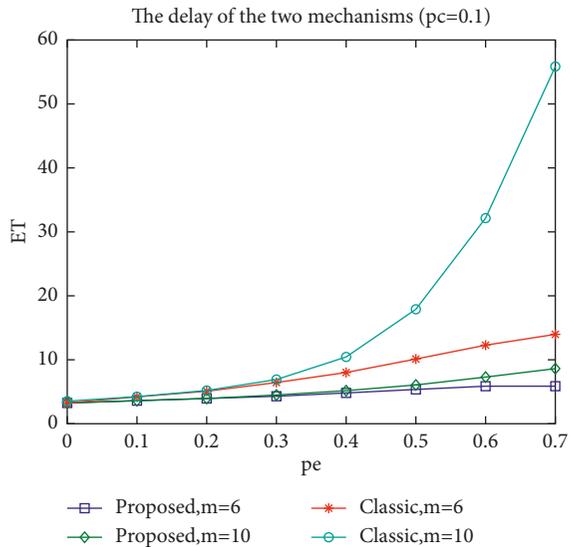


FIGURE 13: E(T) of two mechanisms ($pc = 0.1$).

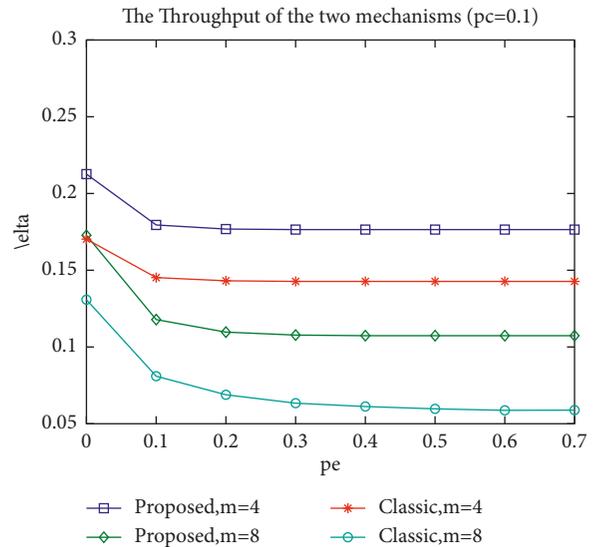


FIGURE 15: η of the two mechanisms ($p_c = 0.1$).

changes from 4 to 57, which means that the average delay is reduced by 90.2%. Under the original mechanism, when the error rate is large, the number of backoff increases and the backoff delay increases exponentially. However, in the proposed mechanism, the backoff window size remains the same. Therefore, in the high-speed mobile environment, the faster the vehicle moves, the greater the error rate, and the more time-saving the proposed mechanism.

At the same time, it can be seen from the two figures that the data transmission delay increases the maximum number of backoff and collision probability. The proposed mechanism only changes the size of the backoff window before retransmission.

Figures 15 and 16 compare the throughput of the two mechanisms. According to the graph, the throughput is much higher than that of the classical mechanism. For example, when p_e increases from 0.1 to 0.7 ($m = 4$), the

throughput decreases by 17% from 0.21 to 0.175, while the throughput of the classical mechanism decreases by 20% from 0.175 to 0.14. In other words, the proposed mechanism not only improves the system throughput, but also reduces the impact of packet error rate on throughput.

In the classical mechanism, both conflict and data retransmission can increase the number of backoff, while the proposed mechanism distinguishes the two situations. Figure 17 analyzes the relationship between the retransmission times and system parameters of the proposed mechanism. According to Figure 17, it is obvious that the retransmission times increase with the packet error rate because the maximum number of backoff and collision probability directly affect the successful data transmission rate and indirectly affect the retransmission times. Therefore, the retransmission times are directly proportional to the maximum number of backoff and inversely proportional

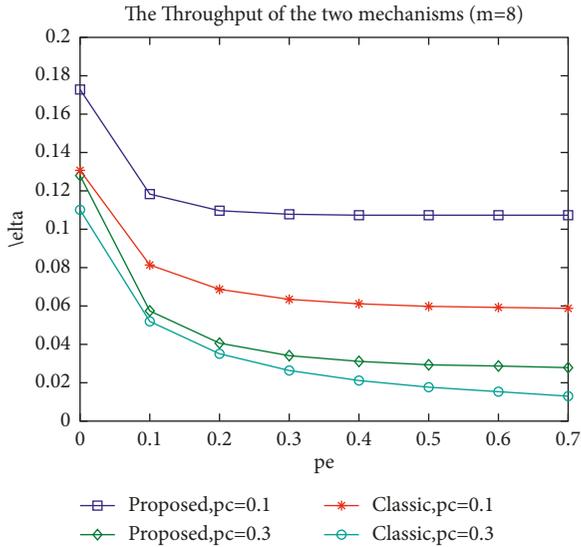


FIGURE 16: η of the two mechanisms ($m = 8$).

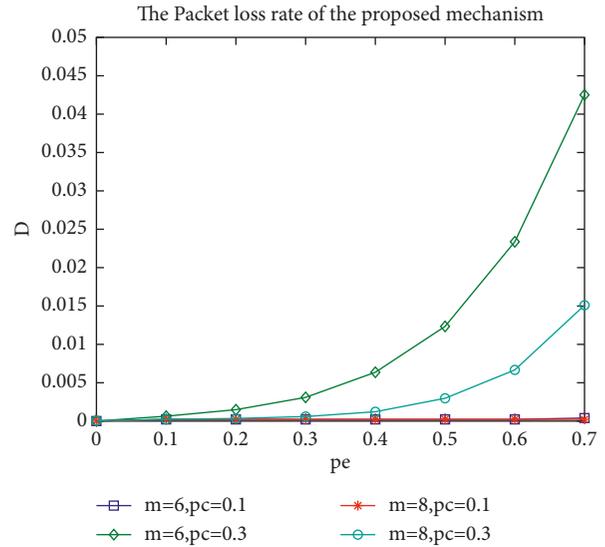


FIGURE 18: Loss of the proposed mechanism.

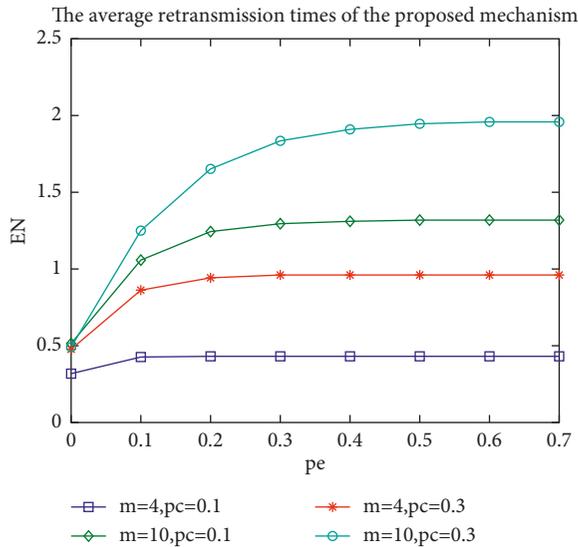


FIGURE 17: EN of the proposed mechanism.

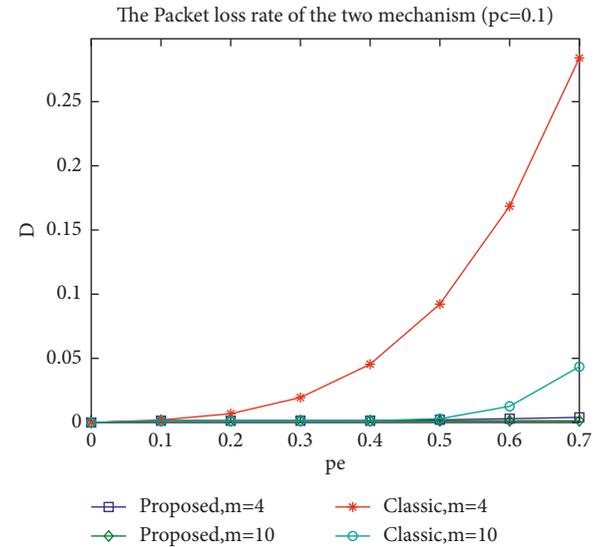


FIGURE 19: D of the two mechanisms ($p_c = 0.1$).

to the collision probability. The larger the maximum number of backoff, the more successful the access times and retransmission times. However, the higher the collision probability, the less the access times and retransmission times.

Figure 18 describes the relationship between packet loss rate and system parameters. It can be seen from the figure that the packet loss rate increases with the packet error rate. At the same time, by comparing the curves of ($p_c=0.1, m=6$) and ($p_c=0.3, m=6$), it can be seen that the collision probability is the key factor affecting the packet loss rate. On the other hand, when the packet error rate increases from 0.1 to 0.7, the packet loss rate increases from 0 to 0.043 ($m=6$), but the packet loss rate increases from 0 to 0.015 ($m=6$), which shows that increasing the maximum number of backoff can effectively reduce the packet loss rate, but also increase the system delay.

Figures 19 and 20 show the comparison of packet loss rates under the two mechanisms. It can be seen from the figure that the packet loss rate is much lower than that of the classical mechanism. For example, when the packet error rate increases from 0 to 0.7 ($m=4$), the packet loss rate of the proposed mechanism increases from 0 to 0.001, but the classical mechanism increases from 0 to 0.045.

From the above pictures, the results of the study are summarized below. First, the proposed mechanism can greatly improve the system performance, such as reducing the packet loss rate, reducing delay, and improving the throughput. Secondly, in the high-speed mobile environment, the faster the moving speed of vehicles, the better the proposed mechanism. Third, the proposed mechanism improves the competitiveness by changing the backoff decision, but does not destroy the system fairness. Fourth, in the proposed mechanism, the setting of the maximum

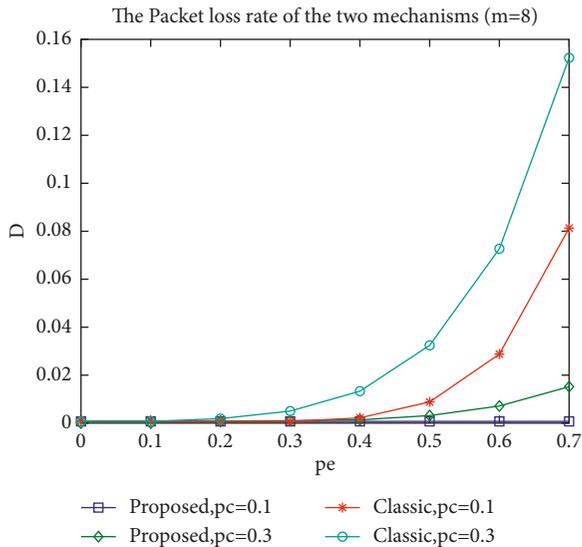


FIGURE 20: Loss of the two mechanisms ($m = 8$).

number of backoff is contradictory to reducing the packet loss rate and the transmission delay. However, how to optimize the maximum number of backoff is the main content of our follow-up work.

To sum up, compared with the shortcomings of the classical mechanism in high-speed mobile environment, the proposed mechanism greatly improves the system performance and guarantees the network QoS by comprehensively considering the impact of high-speed vehicle movement on data transmission.

7. Conclusion

The high-speed movement of vehicles is the core factor affecting the rapid development of VANET, especially the data transmission performance. In order to study the data transmission performance in high-speed mobile environment, this paper first analyzes the impact of vehicle movement on network performance under the classical protocol which is often used in low-speed mobile scenarios. According to the simulation results, the network performance will decline significantly with the increase of vehicle speed. In order to improve the network performance, the vehicle moving-based protocol is proposed. Through introducing Markov modeling, the analytical expressions of system delay, throughput, and packet loss rate are obtained. Finally, the effectiveness of the improved mechanism is verified by comparing the simulation results of two mechanisms. At the same time, the simulation results show that, with the increase of vehicle speed, the system performance under the proposed mechanism is also declining, but the decline is slow compared with the original mechanism. In the high-speed mobile environment, the proposed mechanism provides technical guidance and theoretical support for data transmission of the VANET, which has important significance.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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