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# Application-based Performance Evaluation of Wireless Access in Vehicular Environment using Broadcast Protocol

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***Abstract*— V2V (Vehicle to Vehicle) is recently seen as a very promising technology to avoid accidents and to relieve traffic congestion in transportation. DSRC (Dedicated Short Range Communication) is the most polular communication technology that could be used in V2V system. To figure out what extent DSRC could support typical V2V applications, this paper proposed a performance evaluation method. Firstly, we use cellular automata model to generate the spatial distribution of the vehicles. Then we simulated the procedure of V2V message propagation both as physical and MAC layer of DSRC. Compared with most of the analysis model, hidden terminal issue was taken into consideration as well. Based on the vehicles distribution and the message propagation procedure, we conducted an application-oriented performance evaluation of DSRC based on a typical application, namely FCW (Forward Collision Warning). Simulation results show that communication performance could not meet the need of safety related application under some circumstances, promotions should be fulfilled to guarantee the reliability of V2V applications.**

***Index Terms*— V2V,DSRC,CSMA/CA,application-oriented**

## I. INTRODUCTION

V2V (Vehicle to Vehicle) is considered one of the most promising technology to be applied in transportation system to address the traffic problems. Assisted by V2V system which aims to realize all time information sharing among vehicles, pedestrians and infrastructures, drivers could react more correctly and quickly by getting full aware of the traffic environment state around [1].

DSRC (Dedicated Short Range Communication) is a kind of communication technology that can function well in vehicular environment. To realize the full utilization of this technology, some standardization organizations around the world have been working on the standards of DSRC for years. The most pervasively adopted standard is WAVE (Wireless Access in Vehicular Environment), including IEEE 802.11p and IEEE 1609.x family of standards, which was set up by IEEE (Institute of Electrical and Electronics Engineers). The protocol stack of WAVE is shown in Fig. 1 [2].

The Networking Service of WAVE consists of Data Plane and Management Plane. Data Plane is composed of network layers from physical layer to transport layer. Above LLC layer, WSMP (WAVE Short Message Protocol) substitutes transport layer and network layer. WSMP is a protocol for rapid exchange of messages in a rapidly varying radio frequency environment where low latency is also an important objective. An application can send messages directly to LLC layer through WSMP. Management Plane includes a set of management functions required to provide networking services.

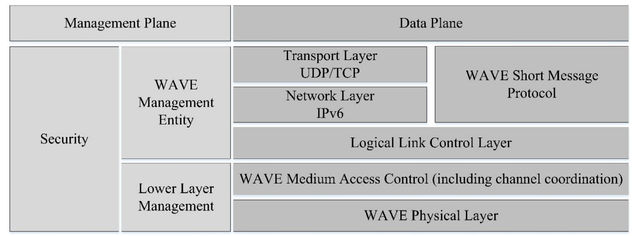


Fig. 1. WAVE protocol stack

Communication lays the foundation of the entire V2V system, so the reliability of communication is very important. Although WAVE protocol stack adopts a lot of methods to improve the reliability of DSRC, the performance of WAVE still needs to be studied. [3] presented a model to analyze the latency when the probability of message correctly being delivered is $\alpha$. [4] analyzed the system performance of opportunistic vehicular content dissemination, studied the influence of mobility model and communication range. [5] proposed an analytical model for the throughput of EDCA (enhanced distributed coordinated access). [6] studied the performance of 802.11p in Vehicular Traffic Congestion Control. [7] and [8] proposed analytical models to evaluate the performance of Vehicular Ad Hoc Networks, taking collision and hidden terminal activities into consideration.

Some other works focus on the study of the communication performance by real world test. [9] conducted experiments to compare the performance of 802.11n and 802.11p in a V2X system. [10] conducted experiments in a typical urban expressway, and evaluated the performance of 802.11p under both Line-of-Sight and Non-Line-of-Sight circumstances. [11] implemented a V2X system based on 802.11p and 4G in Beijing and evaluated the communication performance. [12], [13], [14], [15] also conducted experiments using different devices at different places and scenarios to evaluation the communication performance of DSRC in real world environment.

In this paper, we study the communication performance of 802.11p in tense traffic flow, and present how collision

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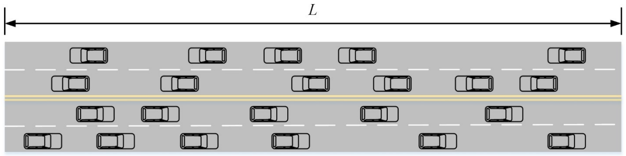


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Fig. 2. Road segment with length $L$

and hidden terminal activities brought by vehicle distribution influence the communication performance. Based on the results, we propose an application-oriented method to evaluate the communication performance.

Later in Section 2, we introduce the network model we used to analyze the performance of WAVE. Simulation configurations are shown in Section 3. Section 4 presents the simulation results. In section 5, to illustrate the reliability more distinctly, we proposed an application-based model to evaluate the communication performance. Section 6 concludes this paper.

## II. NETWORK MODEL

### A. Node Distribution

In vehicular environment, vehicles travel along the roads, so the position distribution is quite different from that in normal MANET (Mobile Ad hoc NETwork). The distance between nodes affects the channel quality a lot, thus affecting the performance of communication. In this paper, we focus on the performance on a road segment with certain length L, as shown in Fig. 2.

We use a simplified Poisson process to simulate the entry of vehicle to the road segment as follow:

$$\begin{cases} P\left[N(t+\triangle t)-N(t)=1\right]=\lambda\triangle t, \\ P\left[N(t+\triangle t)-N(t)\geq 2\right]=0, \end{cases} \tag{1}$$

Where:
$N(t)$ is the number of vehicles arriving before time t;
$P(A)$ is the probability of event A happening;
$\lambda$ is the parameter of Poisson process.
Once a vehicle enters the segment, it keeps at a constant speed.

### B. Physical Layer Model

In this paper, we use communication radius model which is a simplest and most pervasively used model, which can be written as:

$$P(r)=\begin{cases} 0, r\leq R \\ 1, r>R \end{cases} \tag{2}$$

Where:
$P(r)$ is the probability of successful communication between two vehicles at a distance of r;
$R$ is the communication range.

802.11p uses the same MAC protocol with 802.11 standard family, that is CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance). The process of CSMA/CA is illustrated in Fig. 3.

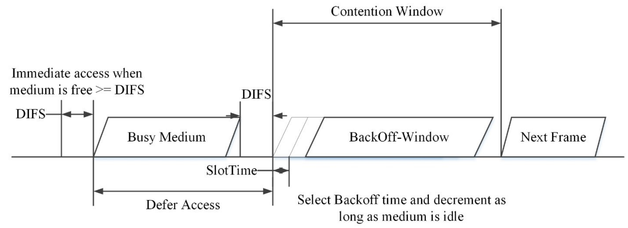


Fig. 3. Basic access method of CSMA/CA

When a communication station has a packet to transmit, it senses the medium first. When the medium is sensed idle for a period of time called DIFS (Distributed Inter-Frame Space), the station transmits the packet immediately. If other stations are using the medium, the medium would be sensed busy. In case of medium busy, the station senses the medium for a period time of DIFS. If the medium stays idle for DIFS, the backoff procedure would be invoked for the station. At the beginning of the backoff procedure, the station shall set its backoff timer to a random time as equation (3) shows:

$$BackoffTime=Random()\times aSlotTime \tag{3}$$

In (3), the random value is a Pseudo-random integer drawn from a uniform distribution between 0 and CW-1 (Contention Window), and aSlotTime is a value related to PHY characteristic. During the backoff procedure, the bakcoff time decrement by aSlotTime if the medium stays idle for aSlotTime. If the medium is determined to be busy at any time during a backoff slot, the backoff procedure is suspended. Then the station senses the medium for a period time of DIFS. If the medium stays idle for DIFS, the backoff procedure resumes. If the medium is idle when the backoff time reaches 0, the transmission commences immediately. If the medium is busy at this time, the CW increases according to an exponential increase rule until it reaches aCWmax.

In the process of unicast, some mechanisms are designed to ensure the packet delivered correctly, such as ACK (acknowledgement) and RTS/CTS (Request to Send/Clear to Send). However, in case of broadcast, no such measures are taken, which makes the communication more unreliable.

## III. SIMULATION SETUP

### A. Generation of Traffic Flow

First in the simulation, we generated traffic flow according to the model in 2.A. As is shown in Fig. 2, the road is composed of 4 lanes, each lane has an independent flow of vehicles, namely no lane change behavior. The length of the road is 3 km. The velocity of each vehicle when it entered the road is initially set as 5 m/s, the maximum of velocity in the simulation is 20 m/s.

In the following simulation processes, we choose a certain time after 200s, using the location distribution of all the

TABLE I
PHYSICAL AND MAC LAYER PARAMETERS

| Parameter | Value |
|---|---|
| Channel Bit Rate | 12Mbps |
| SIFS | 32 $\mu$s |
| DIFS | 58 $\mu$s |
| aSlotTime | 13 $\mu$s |
| aCWmax | $2^5 \times 15$ |
| aCWmin | 15 |
| Max backoff stages number | 5 |
| Packet buffer size | 150000 bytes |

vehicles at that time. Velocity is also taken into consideration in the following analysis.

### B. Propagation Process

Broadcast is studied in this work, which means there are no ACK or RTS/CTS. Firstly, we assume that each vehicle attempts to transmit a packet of 100 bytes every 100 ms, if a new packet arrives before the last packet finish transmitting, it is buffered until the buffer is full. The transmission cycle and packet length are in accordance with the definitions in [18], [19].

To make the simulation results more reliable, some physical layer and MAC layer parameters are set according to real network devices, as is shown in TABLE I.

Due to the distribution of vehicles and communication range, not all the vehicles could communicate with one another. So we use a vector of flags ChannelBusy to indicate the channel state correspondingly. For each vehicle on the road, only the vehicles in its communication range would interfere the transmission. So every time we check and update the transmission state of a vehicle, firstly, we find all the vehicles among its communication range. Then we take all the vehicles in this area into account to simulate the CSMA/CA process.

In this work, hidden terminal problem is also taken into consideration. Take the scenario in Fig. 4, Vehicle A and Vehicle B are beyond each others communication range, so when A is transmitting a packet, B probably starts another transmission, too. In this circumstance, some vehicles are both in the communication range of Vehicle A and Vehicle B, like Vehicle C. Taking Vehicle C as an example, if Vehicle A and Vehicle B transmit packets at the same time, the packets arrived at Vehicle C would interfere with one another, thus causing packet loss. Hidden terminal problem might result in very terrible communication performance in case of CSMA/CA. In the simulation, we assume that as long as one slot is interfered by hidden terminal, the entire packet is incorrect, regardless of error correcting code. Based on this assumption, we calculate the packet loss caused by hidden terminal, the results will be presented in the next chapter.

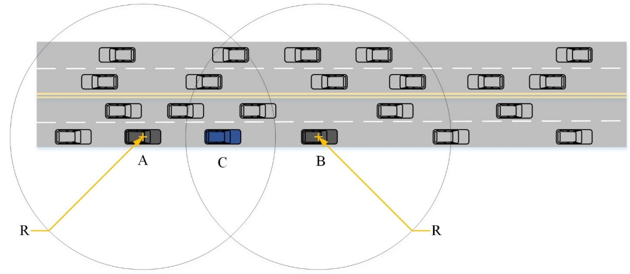


Fig. 4. Hidden terminal problem

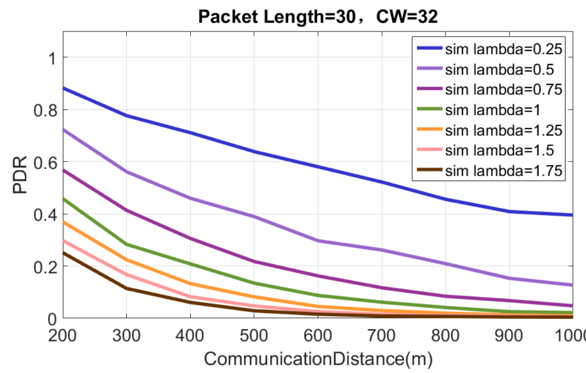


Fig. 5. Packet Deliver Rate caused by collision

## IV. SIMULATION RESULTS

We use 2 main metrics to indicate the performance of 802.11p, PDR (Packet Deliver Rate) and latency. In simulation, we assume that road has a certain length, so the vehicle at the beginning and end of the road would not be influenced by the vehicles ahead or behind it, which is not realistic. In the following analysis, we take a vehicle in the very middle of the road as a most representative example.

### A. PDR

The major factors that may affect the application layer packet rate are packet length, communication distance and traffic flow density. In this simulation, packet loss is caused by 2 factors: collision brought by CSMA/CA and signal interference brought by hidden terminal activities.

The packet deliver rate caused by collision is calculated according to equation (4):

$$pdr_c = \frac{N_{success}}{N_{send}} \tag{4}$$

Where:
$pdr_c$ is packet deliver rate caused by collision;
$N_{send}$ is the total number of packets to send;
$N_{success}$ is the number of the packets successfully sent;
In this simulation, we mainly study the influence of vehicle density, communication distance and packet length on. Packet length decides how many time slots the packet needs to finish transmitting. So when a packet starts to transmit at an idle slot, it will occupy more slots with larger

TABLE II

PDR CAUSED BY COLLISION

| vehicle density, communication distance | $pdr_c$ (different packet length) | | |
|---|---|---|---|
| | 10 slots | 20 slots | 30 slots |
| λ=0.25 , R=200 | 0.8820 | 0.8797 | 0.8824 |
| λ=0.75 , R=200 | 0.5706 | 0.5570 | 0.5681 |
| λ=0.25 , R=1000 | 0.3882 | 0.3887 | 0.3953 |
| λ=0.75 , R=400 | 0.3042 | 0.3059 | 0.3058 |
| λ=1 , R=400 | 0.2036 | 0.2058 | 0.2082 |
| λ=0.75 , R=600 | 0.1615 | 0.1627 | 0.1623 |
| λ=1 , R=500 | 0.1339 | 0.1384 | 0.1343 |
| λ=0.75 , R=300 | 0.1162 | 0.1172 | 0.1140 |
| λ=1 , R=900 | 0.0271 | 0.0250 | 0.0251 |

packet length. Without considering the hidden terminal activities, there is no relationship between packet deliver rate and packet length(see Table II). Fig. 5 shows simulation PDR under different vehicle density and communication distance, in which packet length is 30 slots and CW is 32. In this case, PDR will be reduced with the increase of communication distance and vehicle density. When vehicle density is more than 1.5 veh/s and communication distance is more than 700 m, PDR is basically 0.

The total PDR considering hidden terminal is calculated according to equation (5):

$$PDR = (1 - pdr_c) \sum_{i=1}^{n} p_{phy}(i) \frac{N_{error}(i)}{N_{receive}(i)} \tag{5}$$

Where:

$n$ is the number of vehicles within communication range;

$p_{phy}(i)$ is the physical packet deliver rate of vehicle $i$;

$N_{error}(i)$ is the number of packets received by vehicle $i$ which are incorrect due to being interfered by hidden terminals;

$N_{receive}(i)$ is the number of the packets vehicle $i$ receives;

Fig. 6 shows the PDR without hidden terminal activities(on the left) and the PDR considering hidden terminal activities(on the right). PDR will be lower considering hidden terminal in the same condition than PDR without hidden terminal. Considering hidden terminal, packet loss increases as packet length increases, because the more slots a packet occupies when transmitting, the more likely it is interfered by hidden terminals. Besides, hidden terminal activities is strongly related to the distribution of vehicles (see Tabel III). Table III shows simulation PDR under different packet length. We set communication distance to 500 m. As for CW, we fix it to 64. Higher vehicle density would cause larger number of hidden terminals and thus aggravating the packet loss. There is a huge difference between PDR considering hidden terminal and PDR without considering hidden terminal, especially in the case of low vehicle density. With the increase of the packet length, the difference is more obvious. It means that, hidden terminal under the CSMA/CA broadcast has a great influence on PDR.

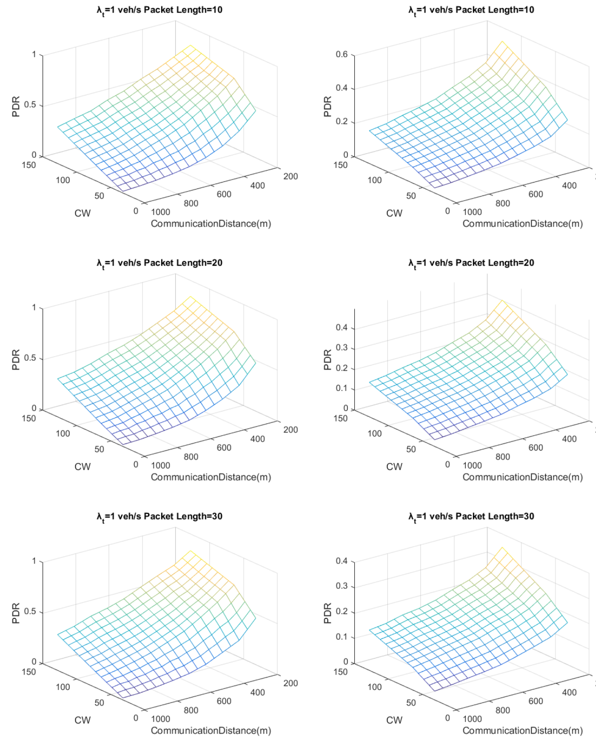


Fig. 6. PDR without hidden terminal activities (on the left) and PDR considering hidden terminal activities (on the right)

TABLE III

PDR CONSIDERING HIDDEN TERMINAL

| vehicle density | PDR (different packet length) | | |
|---|---|---|---|
| | 10 slots | 20 slots | 30 slots |
| λ=0.25 | 0.8035 | 0.4422 | 0.3382 |
| λ=0.5 | 0.6258 | 0.3092 | 0.2439 |
| λ=0.75 | 0.4723 | 0.2393 | 0.1990 |
| λ=1 | 0.3678 | 0.1929 | 0.1663 |
| λ=1.25 | 0.2865 | 0.1609 | 0.1430 |
| λ=1.5 | 0.2162 | 0.1293 | 0.1196 |
| λ=1.75 | 0.1684 | 0.1103 | 0.1052 |

### B. Latency

Latency is calculated according to equation (6):

$$t_{lat} = \frac{1}{m} \sum_{j=1}^{m} [t_f(j) - t_a(j) + t_{trans}] \tag{6}$$

Where:

$t_{lat}$ is the average latency;

$m$ is the total number of packets to send;

$t_f(j)$ is the time when packet $j$ finishes transmission;

$t_a(j)$ is the time when packet $j$ arrives at the sending buffer;

$t_{trans}$ is the signal transmission time, assuming that this is fixed to all the packets;

Fig. 7 shows the average latency. As the vehicle density increases, the latency increases, too. Because the increase

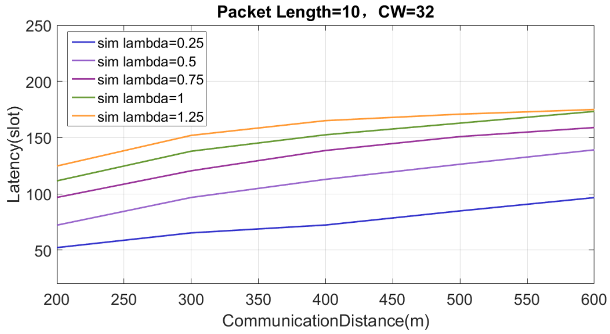


Fig. 7. Average latency

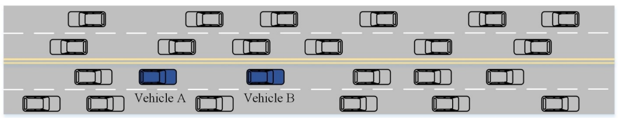


Fig. 8. Scenario of FCW

of vehicle density will cause increase of vehicle number in the communication distance, which means the competition is more intense, each node needs to wait more time to send packets. As the same, the increase of communication distance will also make the competition more intense.

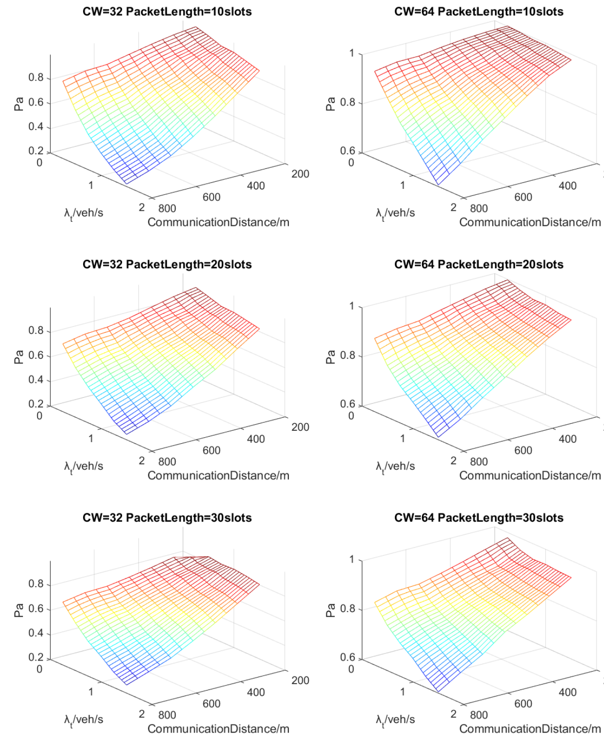


Fig. 9. FCW success probability

## V. APPLICATION-ORIENTED ANALYSIS

In section IV, we focus on the average PDR and latency to evaluate the communication performance of 802.11p. To make the results more distinct and comprehensive, we proposed an application-oriented method so that we could figure out what extent the communication performance support V2V applications.

In this paper, we take FCW (Frontal Collision Warning) as an example. Fig. 8 shows the scenario of FCW. Vehicle A travels after Vehicle B with a larger speed, it might crash into Vehicle B in case of drivers fault or distraction. In this scenario, we use V2V system to remind the drivers of the emerging danger. We assume $P_a$ to be the probability of that the application could function well. Obviously, $P_a$ is related to vehicles speed, location and PDR, latency. In the process of generation traffic flow and vehicle distribution, the NaSch model already takes safety into consideration, so in the simulation of traffic flow, crash is impossible. In reality, some unreasonable behaviors of drivers, like hard braking and suddenly lane changing, would cause traffic accidents, which could not be simulated in the model. So, in this part of analysis, we assume that the front vehicle decelerates suddenly with maximal acceleration.

Firstly, we use TTC (Time to Collision) to indicate the danger level. In the simulation, each vehicle has a TTC to its front vehicle, if its speed is more than its front vehicle, we choose the case with the minimum of TTC to see the system performance under the worst circumstance. We define $d_s$ as the safe distance, which means as long as the rear vehicle receives warning messages before two vehicles at a distance of $d_s$, the crash can be avoided. Then we have:

$$d_s = \frac{(v_{i+1} - v_i)^2}{2\mu g} + (v_{i+1} - v_i) \cdot t_r \tag{7}$$

Correspondingly, $t_s$ is defined as safe time interval, which means as long as the rear vehicle receives the warning message in a period of time shorter than $t_s$ from now on, the crash can be avoided, we have:

$$t_s = \frac{d_0 - d_s}{v_{i+1}} \tag{8}$$

Where:
$v_{i+1}$ is the speed of the rear vehicle;
$v_i$ is the speed of the front vehicle;
$t_r$ is the reaction time of the driver;
$d_0$ is the original distance between the two vehicles;
$\mu$ is friction coefficient;
$g$ is gravitational acceleration.
Then, $P_a$ is calculated as equation (9),(10):

$$P_a = 1 - [1 - PDR(k+1,k)]^m \tag{9}$$

$$m = \frac{t_s - t_l(k+1,k)}{T_{trans}} \tag{10}$$

Where:
$k$ is vehicle index in which case TTC is minimal;
$PDR(k+1,k)$ is the $PDR$ of vehicle $k+1$ sending packets to vehicle k;
$t_l(k+1,k)$ is the latency of vehicle $k+1$ sending packets to vehicle $k$;

$T_{trans}$ is the sending cycle;

In this scenario, $t_r$ is 1 s, $T_{trans}$ is 100 ms, $\mu$ is 0.6. To show the performance of V2V under worst condition, we calculate the minimal $P_a$ in the simulation considering hidden terminal. The result of worst condition is shown in Fig. 9.

When communication distance, vehicle density and packet length increases, $P_a$ decreases because of the decrease of PDR. And When CW increases, $P_a$ increase, too. When the vehicle density is 1.5 veh/s, communication distance is 800 m, CW is 32 and packet length is 30 slots, the $P_a$ may be not more than 30%, which is quite low when involving safety issues. Considering another general situation, the vehicle density is 0.5 veh/s, communication distance is 500 m, CW is 64 and packet length is 10 slots, the $P_a$ may be more than 90%, which can be accepted.

## VI. CONCLUSION

Different from former works, in this paper, we build an entire system to evaluate the performance, from vehicle distribution to typical V2V application. Firstly, we use cellular automata model to generate the traffic flow. Then based on this vehicle distribution, we conducted a simulation of CSMA/CA process, taking both collision and hidden terminal activities into consideration. Beside the average PDR and latency, we get the PDR and latency between any two vehicles. Then we proposed an application-oriented evaluation method to make the communication performance more distinct. Based on a model of FCW, we derived the success rate of FCW application, and provided numerical results.

Among the simulation results, we find that there is no relationship between PDR and packet length without considering hidden terminal. If considering hidden terminal, the conclusion is different that PDR decrease when packet length increase. And both PDR considering hidden terminal and without considering hidden terminal decrease when communication distance and vehicle density increase. As for latency, when vehicle density and communication distance increase, latency increases. There is no obvious relationship between latency and packet length.

## ACKNOWLEDGMENT

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## REFERENCES

[1] Rakouth H, Alexander P, Kosiak W, et al. V2X Communication Technology: Field Experience and Comparative Analysis[C]. Proceedings of the FISITA 2012 World Automotive Congress. Springer, Berlin, Heidelberg, 2013: 113-129.

[2] IEEE Standard for Information TechnologyłTelecommunications and Information Exchange Between SystemsłLocal and Metropolitan Area NetworksłSpecific Requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments, IEEE Std. 802.11p-2010, Jul. 2010.

[3] Li Y, Wang W, Duel-Hallen A. The latency of gaining -reliability for message dissemination in vehicle-to-vehicle networks[C]. Global Communications Conference (GLOBECOM), 2012 IEEE. IEEE, 2012: 5550-5555.

[4] Li Y, Wang Z, Jin D, et al. Collaborative vehicular content dissemination with directional antennas[J]. IEEE Transactions on Wireless Communications, 2012, 11(4): 1301-1306.

[5] Han C, Dianati M, Tafazolli R, et al. Analytical study of the IEEE 802.11 p MAC sublayer in vehicular networks[J]. IEEE Transactions on Intelligent Transportation Systems, 2012, 13(2): 873-886.

[6] Murali A, Bhanupriya K, Smitha S B, et al. Performance evaluation of IEEE 802.11 p for vehicular traffic congestion control[C]//ITS Telecommunications (ITST), 2011 11th International Conference on. IEEE, 2011: 732-737.

[7] Khabazian M, Aissa S, Mehmet-Ali M. Performance modeling of safety messages broadcast in vehicular ad hoc networks[J]. IEEE transactions on intelligent transportation systems, 2014, 14(1): 380-387.

[8] Khabazian M, Aissa S, Mehmet-Ali M. Performance modeling of message dissemination in vehicular ad hoc networks with priority[J]. IEEE Journal on Selected Areas in Communications, 2011, 29(1): 61-71.

[9] Chen X, Yao D. An empirically comparative analysis of 802.11 n and 802.11 p performances in CVIS[C]//ITS Telecommunications (ITST), 2012 12th International Conference on. IEEE, 2012: 848-851.

[10] Wang Y, Hu J, Zhang Y, et al. Reliability evaluation of IEEE 802.11p-based vehicle-to-vehicle communication in an urban expressway[J]. Tsinghua Sci Technol 2015; 20(4): 417-428.

[11] Liu Z, Liu Z, Meng Z, et al. Implementation and performance measurement of a V2X communication system for vehicle and pedestrian safety[J]. International Journal of Distributed Sensor Networks, 2016, 12(9): 1550147716671267.

[12] Teixeira F A, e Silva V F, Leoni J L, et al. Vehicular networks using the IEEE 802.11 p standard: an experimental analysis[J]. Vehicular Communications, 2014, 1(2): 91-96.

[13] Sukuvaara T, Ylitalo R, Katz M. IEEE 802.11 p based vehicular networking operational pilot field measurement[J]. IEEE Journal on Selected Areas in Communications, 2013, 31(9): 409-417.

[14] Bai F, Krishnan H. Reliability analysis of DSRC wireless communication for vehicle safety applications[C]//Intelligent Transportation Systems Conference, 2006. ITSC'06. IEEE. IEEE, 2006: 355-362.

[15] Meng Z, Liu Z, Gu X, et al. Guaranteed V2V QoS services implementation and field measurements in hybrid WAVE\LTE environments[C]//TENCON 2015-2015 IEEE Region 10 Conference. IEEE, 2015: 1-6.

[16] Nagel K, Schreckenberg M. A cellular automaton model for freeway traffic[J]. Journal de physique I, 1992, 2(12): 2221-2229.

[17] Mengkai S, Yi Z, Danya Y, Chang L. Application-Oriented Performance Comparison of 802.11p and LTE-V in V2V Communication System[J]. Tsinghua Sci Technol, accepted.

[18] Intelligent Transport System (ITS); Vehicular Communications; Basic Set of Applications; Definition, ETSI Std. ETSI ITS vers. 1.1.1/Tech. Rep. 102638, Jun. 2009.

[19] Vehicle safety applications, U.S. DOT IntelliDrive(sm) Project-ITS Joint Program Office, Washington, DC, USA, Tech. Rep., 2008.