Cooperative Vehicle Information Delivery Scheme for ITS Networks with OFDM Modulation Techniques

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***Abstract*— Vehicular Ad Hoc Networks (VANETs) are new technologies that offer many opportunities to wide range interesting services. Safe driving applications in Intelligent Transport System (ITS) are major applications of VANETs. In the high-speed mobility environment of VANETs, failure transmission due to change of vehicle positions, fluctuation of channel condition and blocking by large vehicles may decrease reachability of vehicle information messages for safety usage. In this paper, we focus on an OFDM transmission technology, which is employed in IEEE 802.11p for ITS networks. In the proposed scheme, some vehicles forward a same OFDM signal at almost same instance, which is less than a guard interval period. Therefore, vehicles can demodulate some same OFDM signals from different vehicles, and can obtain path diversity effect through some different vehicles. This paper also proposes a new media access control scheme to achieve the proposed transmission technology. The proposed media access control scheme is based on carrier sense multiple access (CSMA). Meanwhile, some forwarder vehicles can select the same random back-off period autonomously to synchronize transmission timing. As the results, the proposed scheme can achieve the high delivery ratio of vehicle information messages and reduce transmission delay. Finally, we consider vehicle movements, channel fluctuation due to fading and blocking due to large-size vehicle in computer simulations. The numerical results show that the proposed scheme can achieve the high delivery ratio with the short delay even if actually real environment, which considers fast movement, blocking, fading, is evaluated in the simulations. Moreover, we clarify that our scheme has high scalability in case of increasing of vehicles.**

***Keywords*— VANET, ITS networks, OFDM, Media access control, Vehicle information**

I. Introduction

Vehicular ad-hoc networks (VANETs) have been focused recently for building Intelligent Transportation Systems (ITS) [1], [2]. In VANETs, many vehicles construct a temporal network autonomously to communicate each other. VANETs have special attributes that differentiate it from the other types of networks such as mobile ad hoc networks (MANETs) [3], [4], [5]. Especially, the mobility patterns of vehicles in VANETs are more restrictive due to road structures. Therefore, almost all vehicles can only communicate with front and backward vehicles. In the conventional works, many routing protocols have been proposed to achieve effective data dissemination. These protocols are classified into some categories such as pure ad-hoc routing, position-based routing, and broadcast routing.

In MANETs, several routing protocols have been proposed and are still applicable for VANETs. Ad-hoc On-demand Distance Vector (AODV) [6] and Dynamic Source Routing (DSR) [7] are well-known routing protocols for general purpose mobile ad-hoc networks. Meanwhile, VANETs differ from MANETs by their dynamic change of network topology. In conventional studies, most pure ad-hoc routing protocols suffer from highly dynamic nature of vehicle mobility and tend to have low communication throughput due to poor route management performance [8].

Position-based routing employs routing strategies that use geographical information obtained from on-board navigation systems because movement of vehicles is restricted in just bidirectional movements constrained along roads and streets [9]. Most position-based routing algorithms are based on forwarding decision upon location information [10], [11], [12]. Additionally, some protocols consider the connectivity to construct reliable routes [13], [14]

Broadcast routing is frequently used for delivering advertisements and announcements in VANETs [15]. The simplest way is flooding, in which each vehicle re-broadcasts packets to all of its neighbors. Flooding performs relatively well for a small number of vehicles [16], [17]. However, it suffers from broadcast storm problems when the number of vehicle in networks increases because a lot of redundant messages are rebroadcasted and many collisions occur in networks [18]. Some schemes for the broadcast storm problems have been proposed in ad hoc networks [19], [20]. However, the investigation about the broadcast storm problems is not enough to be considered in VANETs [21].

Meanwhile, the IEEE 802.11p, intended for vehicular communication, has drown attention recently [22], [23]. The IEEE 802.11p also employs carrier sense multiple access (CSMA) mechanisms as medium access control techniques. Therefore, vehicles first listen to channel and transmit data packets if the channel has been free for a certain period. Hence, several transmissions are performed when we employ broadcast

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routing, and these transmissions cause long delay and packet collisions.

The physical layer of the IEEE 802.11p employs Orthogonal Frequency Division Multiplexing (OFDM) as modulation techniques. The OFDM has been focused for high-speed data transmission in wireless LAN, cellular systems and etc. OFDM signals are multipath robust due to low symbol rates and addition of a guard interval (GI) to an OFDM symbol [24]. Therefore, multipath reflections that have a delay spread less than the guard interval period can be demodulated with no inter-symbol interference (ISI). This characteristic is used for Single Frequency Networks (SFN) in television broadcast systems [25]. In SFN, the same OFDM signal is transmitted from some fixed antenna towers, which exist in different places. In order to demodulate multiple OFDM signals without ISI, reception timing of these OFDM signals should be less than the guard interval period. Therefore, high accuracy transmission timing control is required at transmitters.

Authors consider that the concepts of SFN can apply to vehicular networks. Meanwhile, vehicular networks have some different characteristics from television broadcast systems. First different characteristic is fast movement of vehicles. Therefore, physical relationship between vehicles is always changing, and forwarding vehicles are almost changing according to the physical locations. Therefore, autonomous transmission timing control mechanisms are required to achieve the concepts of SFN in vehicular networks. If we can achieve this concept, vehicles can obtain path diversity effect. As the results, communication performance will be improved without additional wireless resource.

In this paper, we focus on cooperative multiple transmission schemes similar to SFN for vehicular networks to improve transmission performance and to reduce transmission delay. Then, we propose a new vehicular network with cooperative transmission mechanisms. In the proposed vehicular network, neighbor vehicles select the same random delay period for collision avoidance autonomously, and forward the same OFDM signal at same instance according to the selected random delay period. Vehicles can demodulate the received OFDM signals without ISI when the arrival timing of each OFDM signals is confined to the guard interval period of the OFDM signals. Moreover, we assume the different sizes of vehicles in the computer simulations. Then, we evaluate the proposed scheme in the more actual wireless environment. The numerical results show that the proposed scheme can achieve the high delivery ratio with the short delivery delay.

II. System Model

In this paper, we intend to achieve data dissemination of vehicle information messages in specific area near a vehicle. Then, we employ broadcast communication to simplify transmission mechanisms to reduce end-to-end delay. In the almost all studies of ad-hoc networks, only one signal is transmitted by only one node. Therefore, more wireless resource is required to achieve path diversity effects because some nodes transmit the same signal at different timing. As the result, it is well known that broadcast storm problems occur.

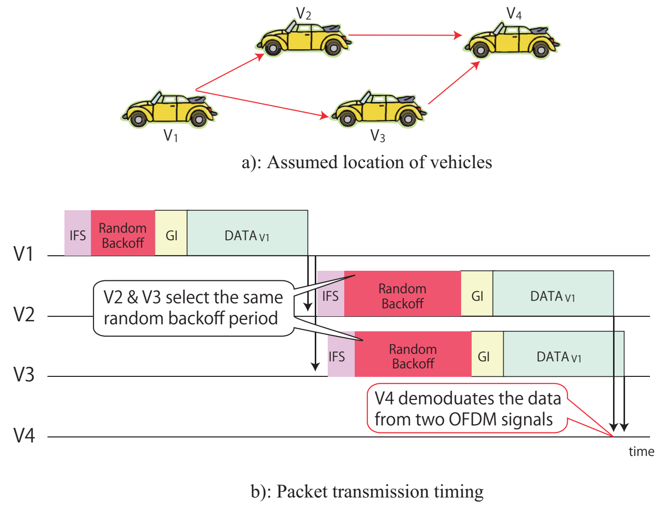

Fig. 1. Overview communication.

Meanwhile, some vehicles transmit the same OFDM signal simultaneously in the proposed scheme. Therefore, transmission period of the proposed scheme equals to that of the single signal transmission. Hence, our scheme can achieve path diversity effects without additional consumption of wireless resource. Additionally, vehicles re-broadcast the received packets of vehicle information messages when the vehicles exist in delivery area of the source vehicle that transmits the received packets.

Figure 1 shows the overview communication of the proposed scheme. Figure 1 a) shows the assumed location of four vehicles, and Fig. 1 b) shows the packet transmission timing. In the assumptions, the vehicle V_1 transmits its own vehicle information message to neighbor vehicles V_2 and V_3 by broadcasting. In order to demodulate two signals without intersymbol interference at the vehicle V_4, the two signals from the vehicles V_2 and V_3 must arrive during the guard interval period. Hence, the vehicles V_2 and V_3 should select the same random back-off value. Then, these two vehicles forward the same OFDM signal at almost same instance. As the results, the vehicle V_4 receives the two same signals from V_2 and V_3, and obtain the path diversity effect.

It is known that wireless channel in vehicular networks is assumed to be fading environments. In fading environments, only one wireless link may not be enough to achieve reliable communication. Additionally, some broadcast based protocols have been considered to achieve safety applications, which im-

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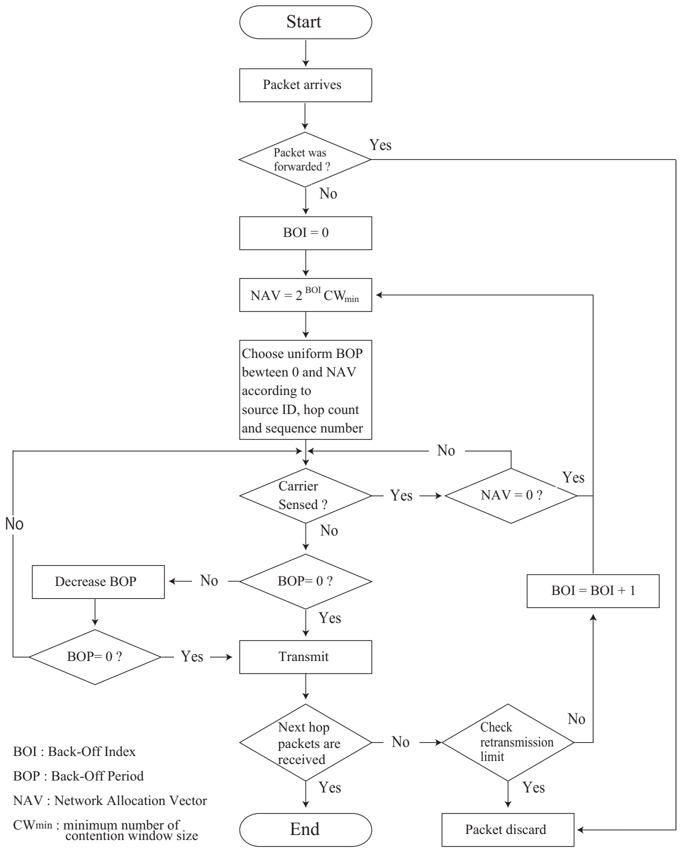
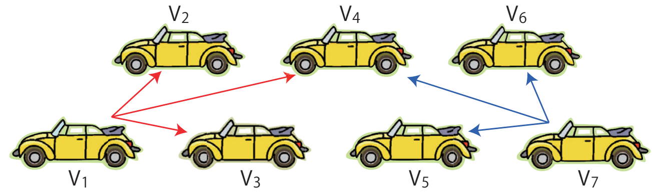


Fig. 2. Flowchart of media access control.

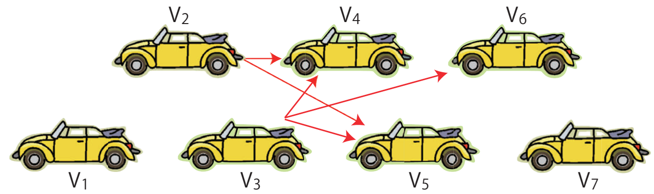
prove vehicle safety on the roads. Meanwhile, the transmission period of the proposed scheme equals to that of conventional CSMA mechanisms. Therefore, the proposed scheme can reduce transmission delay with performance improvement.

The proposed scheme employs the source ID, the hop count information and the sequence number of data packets for controlling transmission timing. Therefore, prior negotiation process is not required to start forwarding of data packets. Then, the proposed scheme can also be employed for collision avoidance systems in crossroads.

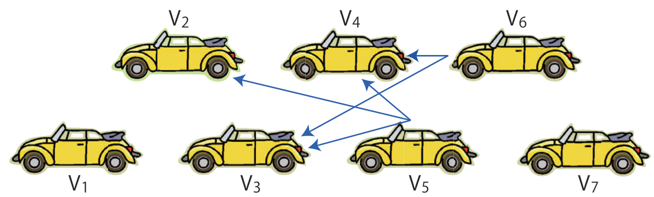
Figure 2 shows the flowchart of the proposed media access control scheme. The proposed scheme is extended mechanisms of CSMA/CA. In general CSMA mechanisms, random back-off periods are selected randomly at each node. Therefore, nodes have different random back-off periods, and transmit a packet at different timing to avoid packet collisions. In the proposed scheme, vehicles that transmit the same OFDM signal have to select the same random back-off period autonomously. Moreover, we assume that the proposed scheme should be processed in preference to schemes for single path transmission because interruption due to other transmission of packets damages performance of the proposed scheme. The procedures of the proposed scheme are described as follows.



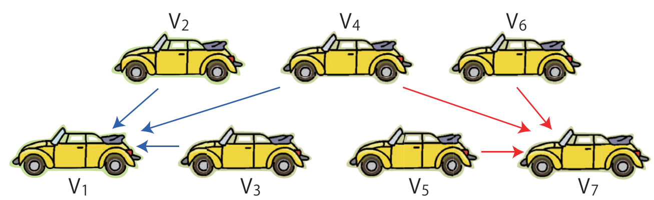
a): First hop communication from V1 & V7



b): Second hop communication from V1



c): Second hop communication from V7



d): Third hop communication from V1 & V7

Fig. 3. Example of transmission procedures.

- The procedures start when vehicles receive a packet from neighbor vehicles.
- Vehicles confirm the packet forwarding history to avoid redundant forwarding.
- Vehicles initialize the Back-Off Index (BOI) that determines the Network Allocation Vector (NAV), where CW_{min} is the minimum number of contention window size.
- Vehicles calculate the new NAV according to the initialized BOI value. The NAV denotes the interval period for the back-off period (BOP). In the general CSMA mechanisms, the BOP is selected randomly with uniform distribution.
- Vehicles generate a random value with the source ID, the hop count information and the sequence number of data packets for each node as random seeds. Hence, vehicle

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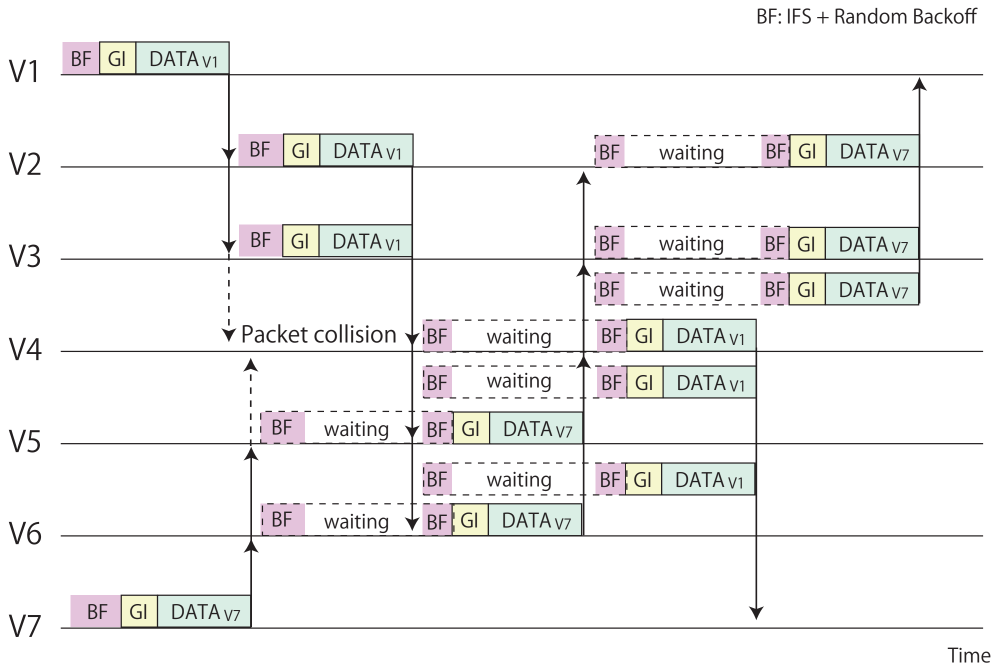

Fig. 4. Example of packet transmission timing.

can obtain the unique random value according to the source ID, the hop count information and the sequence number of data packets. Therefore, some vehicles that forward the same OFDM signal can select the same random back-off periods. As the results, the proposed scheme can synchronize the transmission timing of some forwarding vehicles autonomously. Moreover, vehicles can obtain transmission opportunities randomly because the random back-off period is generated randomly.

- Vehicles sense channel status. If the channel status is busy, vehicles check the NAV value and retry channel sensing. If the channel status is idle, vehicles check the BOP value.
- If the BOP value does not equal to zero, vehicles decrease the BOP value and wait for transmission timing. If the BOP value equals to zero, vehicles start to transmit the OFDM signal.
- After transmission of the OFDM signal, vehicles sense the channel to confirm transmission of the same data packet transmitted by next hop vehicles.
- When vehicles receive the same data packet of the transmitted OFDM signal, the procedures end. If not, vehicles check the retransmission limit of data packets to avoid continuous retransmission. Then, vehicles increase the BOI value to extend the NAV period to reduce collision probability, and try to retransmit the OFDM signal.

III. Operation examples

Figures 3 show the example transmission procedures. Figure 4 shows the packet transmission timing of the proposed schemes. In these figures, both the vehicle V_1 and the vehicle V_7 transmit the packets of their own vehicle information messages to the whole seven vehicles at almost same instance. Each procedure is described as follows.

- Figure 3 a) shows the first hop communication. Therefore, the vehicle V_1 and the vehicle V_7 transmit the packets. Vehicles V_2, V_3 and V_4 receive the signal of the packet from the vehicle V_1. Vehicles V_4, V_5 and V_6 receive the signal of the packet from the vehicle V_7. Therefore, vehicles V_2 and V_3 receive the packet from the vehicle V_1, and vehicles V_5 and V_6 receive the packet from the vehicle V_7. Meanwhile, the vehicle V_4 cannot receive the packets from the vehicle V_1 nor the vehicle V_7 because the two signals from the vehicles V_1 and V_7 conflict at the vehicle V_4.
- Figure 3 b) shows the second hop communication from the vehicle V_1. In this example, the selected random back-off value of the vehicles V_2 and V_3 is assumed to be less than that of the vehicles V_5 and V_6. Therefore, the vehicles V_2 and V_3 transmit the same signal at first. These two signals arrive at the vehicles V_4, V_5 and V_6. Then, these vehicles demodulate the two received signals. Meanwhile, the vehicles V_5 and V_6 resume the back-off process after the transmission from the vehicles V_2 and V_3 is completed.

- Figure 3 c) shows the second hop communication from the vehicle V_7. The vehicles V_5 and V_6 transmit the same signal. The vehicles V_2, V_3 and V_4 receive the two signals, and demodulate them.
- Figure 3 d) shows the third hop communication. In this example, the selected random back-off value for the vehicle information message of the vehicle V_1 is assumed to be less than that for the vehicle V_7. Therefore, the vehicles V_4, V_5 and V_6 transmit the same signal from the vehicle V_1 firstly, and the vehicles V_2, V_3 and V_4 also transmit the same signal from the vehicle V_7 secondly. Hence, the vehicle V_1 receives the packet from the vehicle V_7, and the vehicle V_7 receives the packet from the vehicle V_1.

IV. Numerical Results

To evaluate the proposed scheme, we performed computer simulations with network simulator QualNet [26]. Qualnet is the well-known wireless network simulation software that considers the more actual wireless environment. Therefore, the simulator considers packet errors due to low signal-to-interference and noise power ratio (SINR), channel fluctuation due to fading, blocking by large-size vehicles. The results are an average of 10 trial simulations. Our proposed scheme intends to achieve data dissemination of vehicle information messages for safe driving systems. Therefore, we employ broadcast communication to deliver the vehicle information messages in delivery area. In the simulations, the delivery area is set to 1000 [m] from a source vehicle. It is known that broadcast communication suffers from packet collisions when many vehicles exist in a communication area. Therefore, we considered 50 vehicles for small number of vehicles and 300 vehicles for large number of vehicles. We assumed that the road shape is the loop line with the radius equals to 1500 [m] and 2 lanes. Each vehicle is located randomly on the road, selecting the velocity between 90 [km/h] and 110 [km/h] randomly. Therefore, the distribution of vehicle velocity is uniformly between 90 [km/h] and 110 [km/h] The vehicle runs on the inside lane principally and keeps an inter-vehicular distance as 100 [m]. If there is no vehicle on the outside lane, the vehicle moves to the outside lane from the inside lane to overtake a forward vehicle. After overtaking, the vehicle moves to the inside lane if there is no vehicle on the inside lane. In the simulations, the passings occur according to the Table I.

The feature of this paper is also to consider the effect of large-size vehicles. Hence, we define the large-size vehicle ratio (LVR) that means the ratio of the large-size vehicles and the standard-size vehicles. When the large-size vehicle ratio is set to 0, all vehicles are standard-size vehicles. Meanwhile, we assumed that large-size vehicles are rectangular solids.

TABLE I

Average number of passings.

Number of vehicles	50	100	150	200	250	300
Number of passings	23	27	36	59	185	249

TABLE II

Simulation parameters.

Simulator	QualNet
Simulation time	150 [s]
Simulation trial	10 [times]
Number of vehicles	50 – 300 [vehicles]
Vehicle velocity	90 – 110 [km/h]
Size of vehicle information message	100 [Byes]
Transmission interval	200 [ms]
Communication device	IEEE 802.11p
Transmission rates	6 [Mbps]
Transmission power	19 [dBm]
Channel frequency	5.9 [GHz]
Antenna gain	0 [dB]
Antenna type	Omni directional
Antenna height	1.5 [m]
Propagation path loss model	Free Space
Wireless environment	Rayleigh fading
Road shape	Circle with radius = 1500 [m]
Number of lanes	2 [lanes]

If the rectangular solid is overlapped with the straight line between two standard-size vehicles, these two vehicles cannot communicate due to blocking. Additionally, a free space propagation model is used as the wireless propagation model. To consider channel fluctuation due to movement, rayleigh fading according to 100 [km/h] is assumed in the simulations.

The final purpose of this study is to fuse vehicle information delivery networks and communication networks for several network applications. Therefore, we employ IEEE 802.11p, which is a future communication device for ITS networks. In the simulations, the transmission range is about 285 [m], packet errors are determined due to the received signal-to-interference and noise power ratio (SINR). The size of a vehicle information message is 100 [Byte], and is transmitted with 5 [packets/s].

Our scheme is one of the broadcast communication methods. Therefore, we employ the probabilistic flooding scheme in comparison. The flooding probability is assumed to be 50, 75, and 100 [%]. Meanwhile, retransmission of vehicle information messages is not performed in order to evaluate the proposed scheme and flooding mechanisms fairly. Simulation parameters are shown in detail in Table II.

Figure 5 shows the area delivery ratio of vehicle information messages with the large-size vehicle ratio equals to 0 [%]. In this study, we define that the area delivery ratio is the message received ratio for vehicles in the delivery area. From

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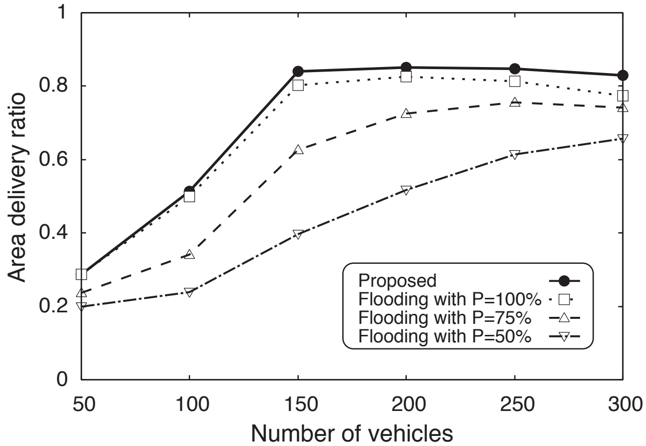

Fig. 5. Area delivery ratio (LVR=0).

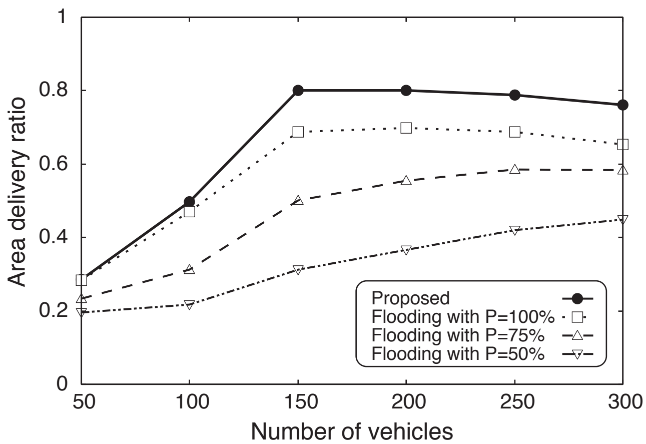

Fig. 6. Area delivery ratio (LVR=0.2).

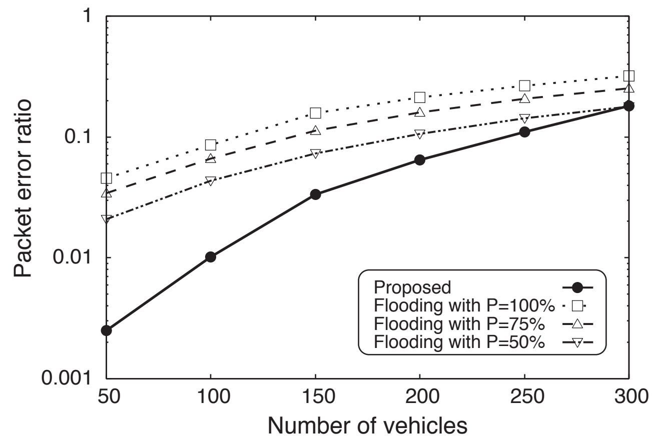

Fig. 7. Packet error ratio (LVR=0).

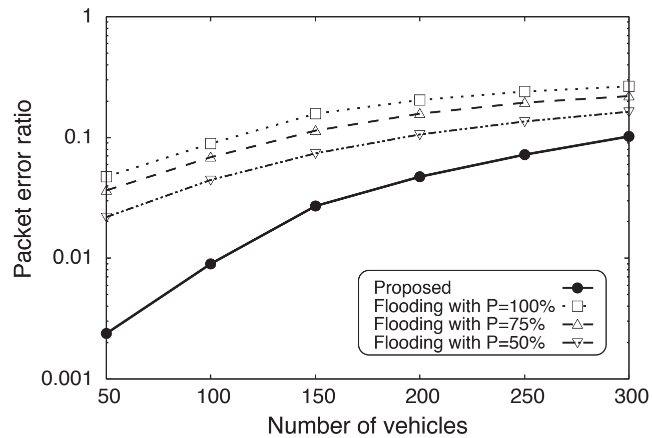

Fig. 8. Packet error ratio (LVR=0.2).

the results, we can find that our proposed scheme can achieve the highest delivery ratio. The performance of the full flooding scheme degrades when the number of vehicles increases. This reason is that broadcast storm problems tend to occur when the number of vehicles increases. Meanwhile, the delivery ratio of the probabilistic flooding scheme degrades when the flooding probability decreases. Especially, it degrades much when the value of the flooding probability is set to low. This is because several vehicles are required to forward vehicle information messages when there are a small number of vehicles on the road. Additionally, the performance of the every mechanism degrades when the number of vehicles is set to 50 or 100. The reason is that there are not enough vehicles to forward vehicle information messages in the delivery area.

Figure 6 shows the area delivery ratio of vehicle information messages with the large-size vehicle ratio equals to 20 [%]. Therefore, blocking due to large-size vehicles is considered in this condition. From the results, the proposed scheme can keep the high delivery ratio, which is almost same as that of Fig. 5. On the contrary, the performance of the flooding scheme degrades compared with Fig. 5. This reason is that the proposed scheme can obtain the multi-path diversity effect. Therefore, our scheme has resistance to blocking.

Figure 7 shows the packet error ratio of vehicle information messages with the large-size vehicle ratio equals to 0 [%]. From the results, the proposed scheme can reduce the packet error ratio compared with the flooding schemes. The reason is that the proposed scheme can demodulate some same OFDM signals. Therefore, vehicles tend to obtain better condition OFDM signals even if condition of OFDM signals degrades due to fading or blocking. Meanwhile, the packet error ratio increases with increasing in the number of vehicles. This is because interference signals also increase according to increasing in the number of transmitted packets.

Figure 8 shows the packet error ratio of vehicle information messages with the large-size vehicle ratio equals to 20 [%]. From the results, we can find that the packet error ratio is improved compared with Fig. 7. This is caused by large-size

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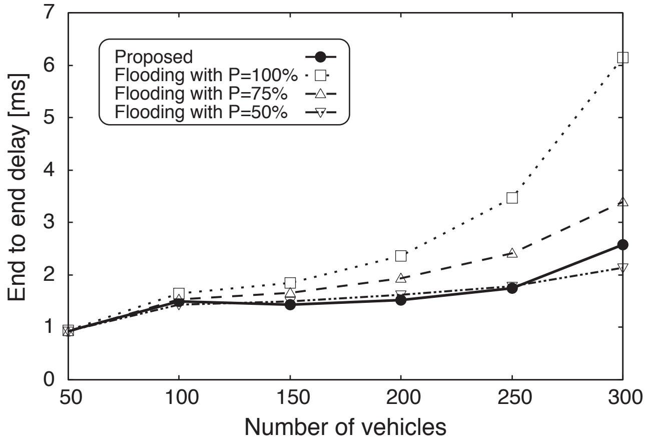

Fig. 9. End-to-end delay (LVR=0).

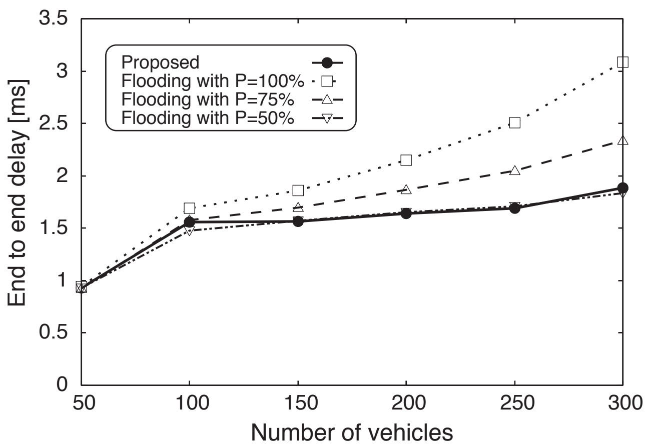

Fig. 10. End-to-end delay (LVR=0.2).

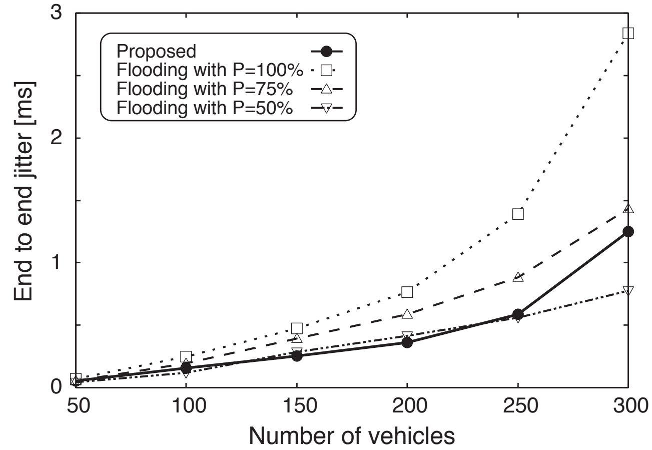

Fig. 11. End-to-end jitter (LVR=0).

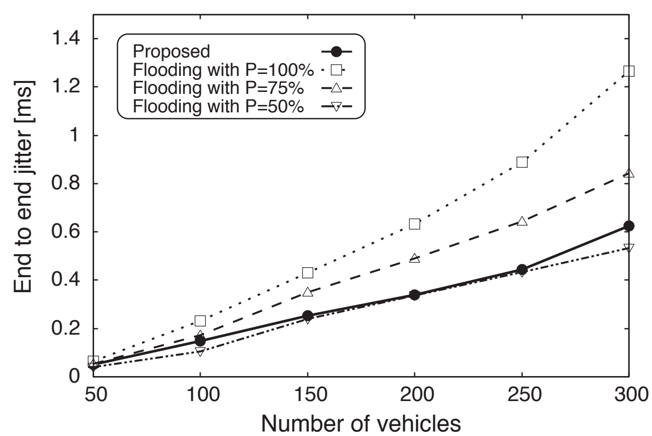

Fig. 12. End-to-end jitter (LVR=0.2).

vehicle can also block interference signals. Hence, SINR is improved due to reduction of interference power.

Figure 9 shows the end-to-end delay performance with the large-size vehicle ratio equals to 0 [%]. The delay period starts when a source vehicle transmits a vehicle information message, and ends when the vehicle information message is received at a vehicle in the delivery area. Therefore, the accurate delay of each vehicle is different due to the positions of the vehicles. Therefore, the delay performance averages delays of each vehicle in the delivery area. From the results, we can find that the proposed scheme can reduce the delay to the halves of the full flooding scheme. The reason is that vehicles transmit the same OFDM signal simultaneously in the proposed scheme. Hence, vehicles tend to obtain packet transmission opportunity according to reduction of consumed wireless resource. In road safety applications, delay is the most important factor to achieve collision avoidance and control of traffic flows. Moreover, our scheme can reduce the increasing amount of delay according to the increasing in the number of vehicles. Hence, our scheme has scalability for number of vehicles.

Figure 10 shows the end-to-end delay performance with the large-size vehicle ratio equals to 20 [%]. The results show that the proposed scheme can reduce the delay performance compared with Fig. 9. The reason is that blocking by large-size vehicles improves frequency reuse performance. Then, vehicles tend to obtain packet transmission opportunities due to reduction of reception signals.

Figure 11 shows the end-to-end jitter performance with the large-size vehicle ratio equals to 0 [%]. From the results, we can find that the proposed scheme can also reduce the jitter to the halves of the full flooding scheme. Moreover, the proposed scheme can keep low jitter performance even if the high area delivery ratio is maintained.

Figure 12 shows the end-to-end jitter performance with the large-size vehicle ratio equals to 20 [%]. The results show that the proposed scheme can reduce the jitter performance due to the same reason in the delay performance.

V. Conclusion

In this paper, we have focus on characteristics of OFDM communication that vehicles can demodulate some same OFDM signals in guard interval period. The proposed scheme offers the autonomous media access control scheme that some vehicles can transmit the same signal at same instance. Moreover, we have employed the proposed media access control scheme and the broadcast mechanism to achieve data dissemination of vehicle information messages. From the results, our scheme can keep the high message delivery ratio and the low end-to-end delay even if fast movement of vehicles, blocking by large-size vehicles and channel fluctuation due to fading are considered. In the actual communication environment, it is important to support these mixed factors for real safe driving systems. Meanwhile, we can provide required quality in communication if we employ the forward error correction (FEC) to recover the packet losses. Considering all these results mentioned above, the proposed scheme could be one of new fundamental schemes for achieving ITS.

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