INVITED PAPER

Fast-response inter-vehicle communications

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Safe driving support is one of the most attractive and important applications of an inter-vehicle communication systems. Real-time and reliable exchange of status information on such as vehicle location, speed, sudden braking etc., among vehicles, is a key to offering prompt warnings to drivers in order to avoid fatal traffic accidents.
We have proposed a novel media access control (MAC) scheme based on code division multiple access (CDMA) technology, which offers fast response and high packet delivery ratio to meet the above requirements. This scheme is inherently robust to the hidden terminal problem and significantly outperforms the conventional MAC scheme, CSMA/CA, in the environment with high vehicle density. This paper introduces the proposed scheme, performance evaluation by simulation, and prototyping for field experiment. It also mentions future studies.

1. Introduction

More than 100 years have already passed since Carl Benz invented the gasoline automobiles. Automobiles have become an essential part of our dairy lives today. However, serious problems such as humans' death due to traffic accidents, loss of time due to traffic congestion and environmental pollution due to CO_2 emission, essentially remain unsolved.

Inter-vehicle communications that promptly exchanges status information such as on the vehicle location, speed, sudden braking etc. are expected to reduce the traffic accidents such as collisions among vehicles, and to reduce humans' death.

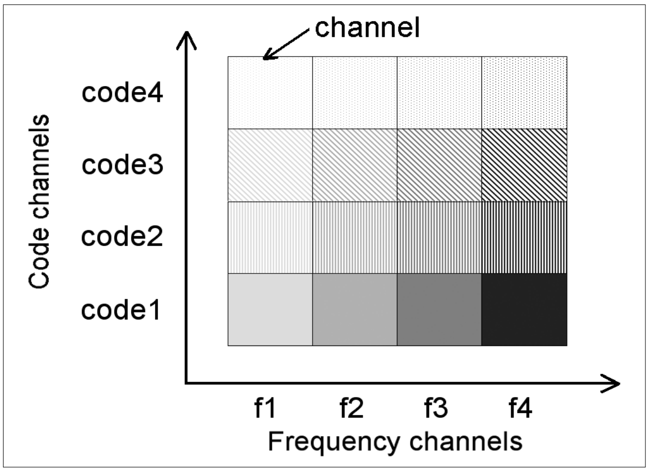
For inter-vehicle communications, much research [1-8] has been carried out and standardizations are now in process. Especially, IEEE is now going to standardize as 802.11p. Also in Japan, ITS Info-communications Forum, under the Ministry of Internal Affair and Communications of Japan, is now in the process to standardize specifications of inter-vehicle communication focusing on safe driving [9].

Communication schemes adopted in the most of the researches and the standardization on inter-vehicle communications, are based on the conventional media access control (MAC), i.e. carrier sense multiple access/collision avoidance (CSMA/CA) [10], which is popularly used in wireless LANs.

However, CSMA/CA has a limit in transmission delay and packet delivery ratio, due to its control scheme based on the carrier sensing. For satisfying challenging requirements on supporting safe driving, we have proposed a new scheme called "Multi-carrier Multi-code Spread ALOHA (MM-SA)", which is based on code division multiple access (CDMA) [11] technology. This scheme significantly reduces the transmission latency to millisecond order and improves the packet delivery ratio among vehicles [12-17]. It also has inherent robustness to the increase of vehicle density as well as to the hidden terminal problem [18].

This paper introduces our research on novel communication technologies for safe driving, using wireless ad hoc network, that promptly exchanges the status information on the vehicles such as on the vehicle location, speed, sudden braking etc. The later parts of this paper consist of the following sections: Section 2 introduces the communication scheme of MM-SA; Section 3 shows the performance evaluation by computer simulation; Section 4 refers to the prototyping to evaluate the performance in actual environment. Finally, we summarize future studies.

Figure 1. Example of Communication Channel Structure in MM-SA



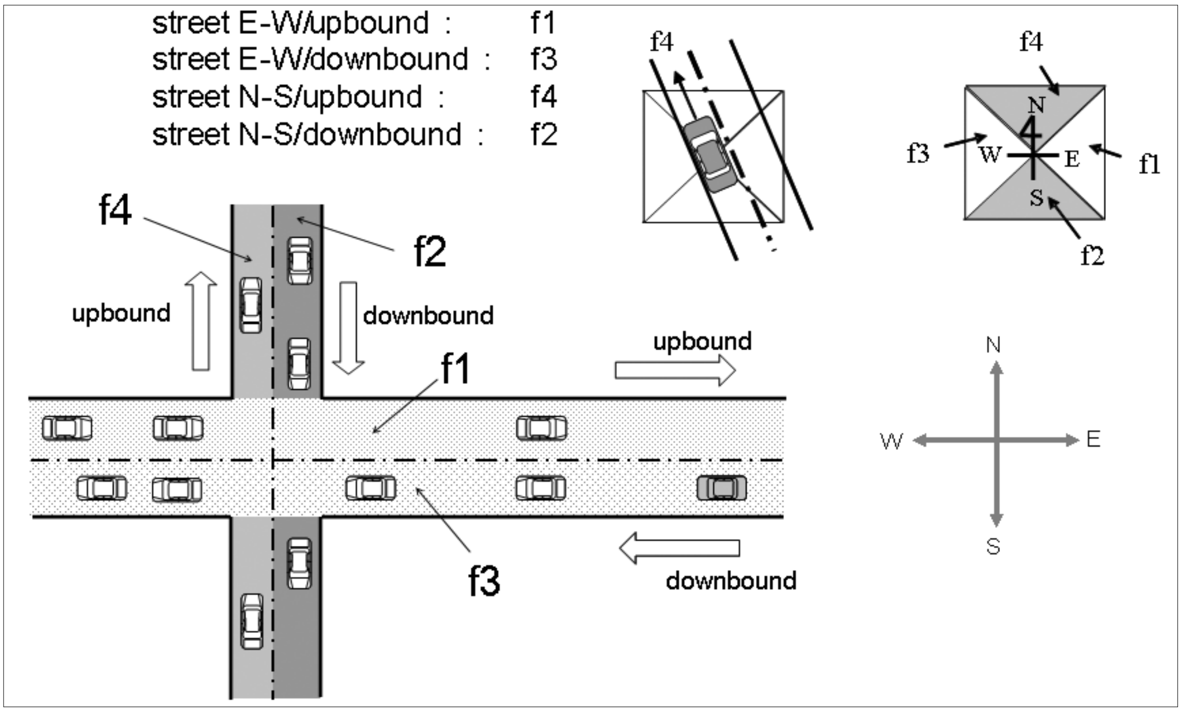


Figure 2. Frequency channel assignment example

2. Communication scheme of MM-SA

2.1 Features of MM-SA

MM-SA has the advantages of both FDMA (frequency division multiple access) and CDMA (code division multiple access). It allows prompt and reliable communication, even under the condition of high vehicle traffic density, by means of multiplexing in frequency channel domain and spreading code domain as shown in *Fig. 1*. Transmitted packet can be recovered regardless of packet collisions by using spreading code. Communication traffic is diffused to multiple frequencies.

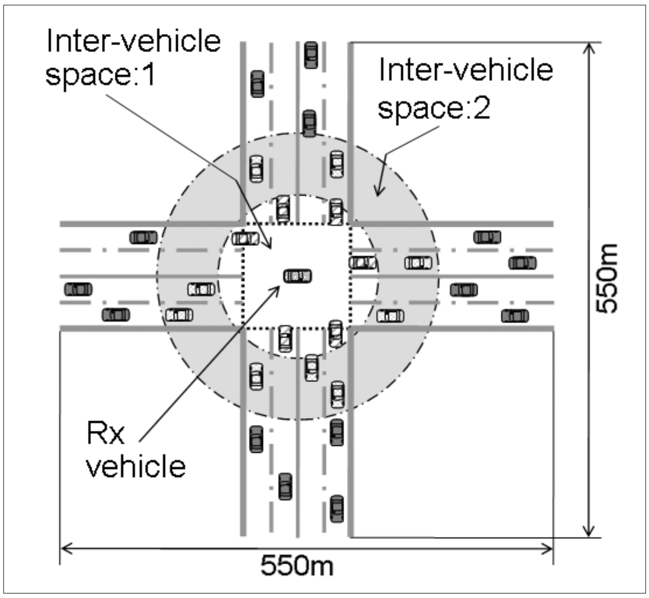
In the MM-SA, in order to reduce signal interference from other vehicles, frequency channel is autonomously determined by a vehicle itself, according to the vehicles' moving direction detected by GPS. Specifically, as shown in *Fig. 2*, assuming that four frequency channels are available, the moving direction in ±45° around the north is mapped to a channel, e.g., f3, and the moving direction in ±45° around the west is mapped to a channel, e.g., f2, and so forth.

However, this is the simplest case. In actual roads and intersections, topology or geometry of them is more complicated and in some cases, the same frequency channel may unfortunately be assigned to different roads. In such cases, frequency channels are determined by an additional control mechanism such as priority control etc.

2.2 Basic communication characteristics of CSMA/CA and CDMA

Basic communication characteristics of CSMA/CA and CDMA on which MM-SA scheme is based, for a single frequency channel (4.096 MHz bandwidth) in 5.8 GHz band, which are allocated for ITS wireless communications, are compared using Qualnet network simulator [19]. The parameters of CSMA/CA scheme are tuned to the specification defined by ITS Info-communications Forum. Transmission power (10 mW) and modulation type (π/4 shift QPSK) of CDMA are the same as the ones of CSMA/CA. The sensitivity levels of CSMA/CA and CDMA are -94.41 and -94.5 dBm, respectively. Spreading factor in CDMA is 7 and the contention window in CSMA/CA takes value from 1 to 256.

Figure 3. Simulation topology



Performance comparison targets the topology illustrated in *Fig. 3*, where vehicles are uniformly distributed on a 2-lane per direction. In the simulation, each vehicle (Tx nodes), except the one in the center of the intersection (Rx node), periodically generates status message of 140 bytes. Message generation cycle is 100 msec that are considered to be adequate for keeping track of surrounding vehicles' status. *Table 1* shows the comparison on the average delay for different number of Tx nodes. *Fig. 4* shows average packet delivery ratio vs. inter-vehicle space, which indicates the relative position of Tx node to Rx node.

The number of Tx vehicles	100	200	300	400	500
CSMA/CA [ms]	4.9	72.4	133	168	193
CDMA [ms]	1.9	1.9	1.9	1.9	1.9

Table 1. Comparison in packet transmission delay

From Table 1 and Fig. 4, CSMA/CA obviously suffers from performance degradation in terms of transmission delay and packet delivery ratio, when the number of vehicles increases. The hidden terminal problem will further degrade the performance.

In the CDMA, while vehicles experience difficulty in receiving data from far vehicles, due to the near-far effect [20] which is the typical characteristic of CDMA, this feature enables prompt and reliable information exchange among near vehicles, without being affected by the number of vehicles. This implies that the degradation of the performance due to hidden terminals is quite small. In inter-vehicle collision avoidance, prompt and reliable information exchange among near vehicles is very important rather than that among far vehicles.

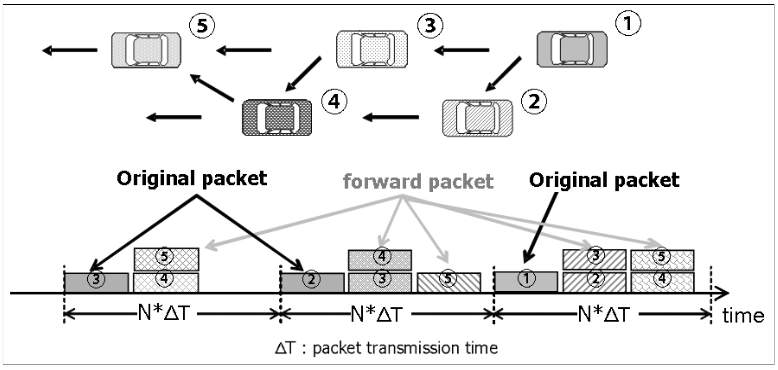
2.3 Packet forwarding scheme of MM-SA

In MM-SA, in order to enable vehicles to be aware of existence of far vehicles, packet forwarding scheme is adopted. In general, broadcast or flooding for packet forwarding causes, as known as the broadcast storm problem [21]. In order to avoid this problem, we have adopted the following strategies.

(1) To limit forwarding packets over a limited area determined by the vehicle's location (e.g. 100m in front and 10m in sides)?
(2) Not to forward packet with duplicated and/or outdated information.
(3) To adequately schedule packet transmissions, as illustrated in *Fig. 5*.

The key point of this scheduling is the control of vehicles'packet transmission time, in such a way that vehicles concurrently transmitting their own messages be located as far as possible from each other. This objective can be achieved by having each vehicle to generate its original message N*ΔT later than the message generation time at its adjacent vehicle in front. Here, ΔT is the packet transmission time and N is an integer constant. In our experience, N=3.

Figure 5. Packet forwarding scheme of MM-SA



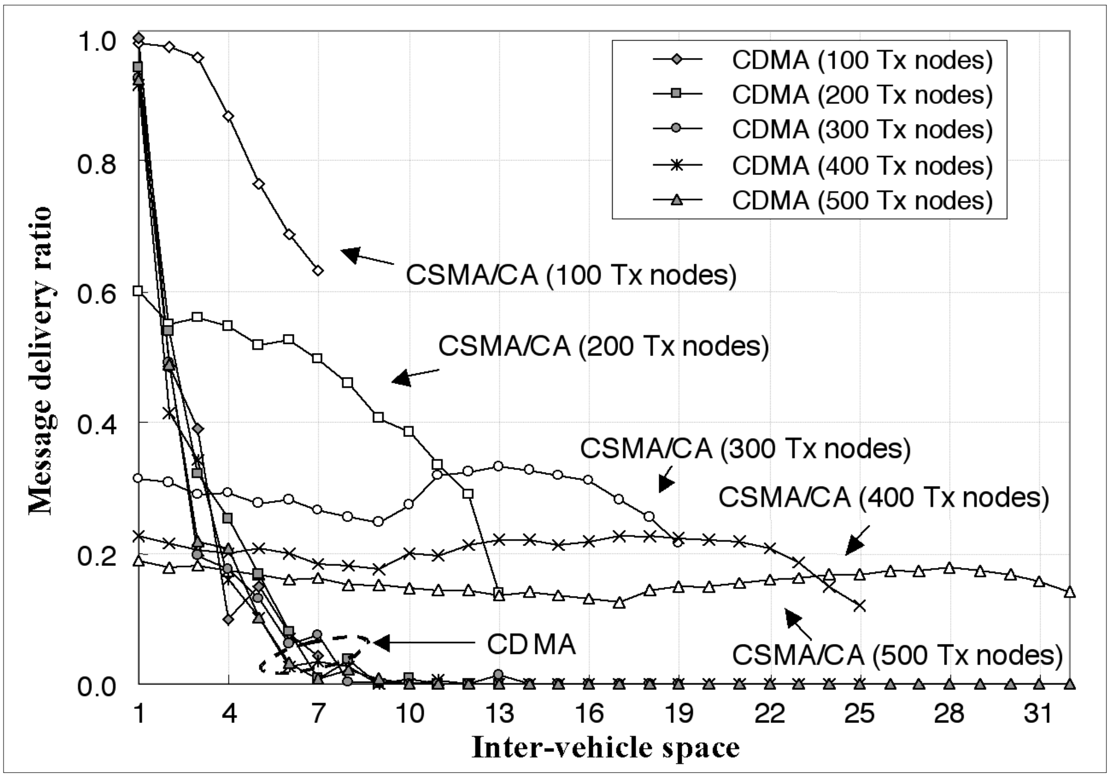


Figure 4. Comparison in packet delivery ratio

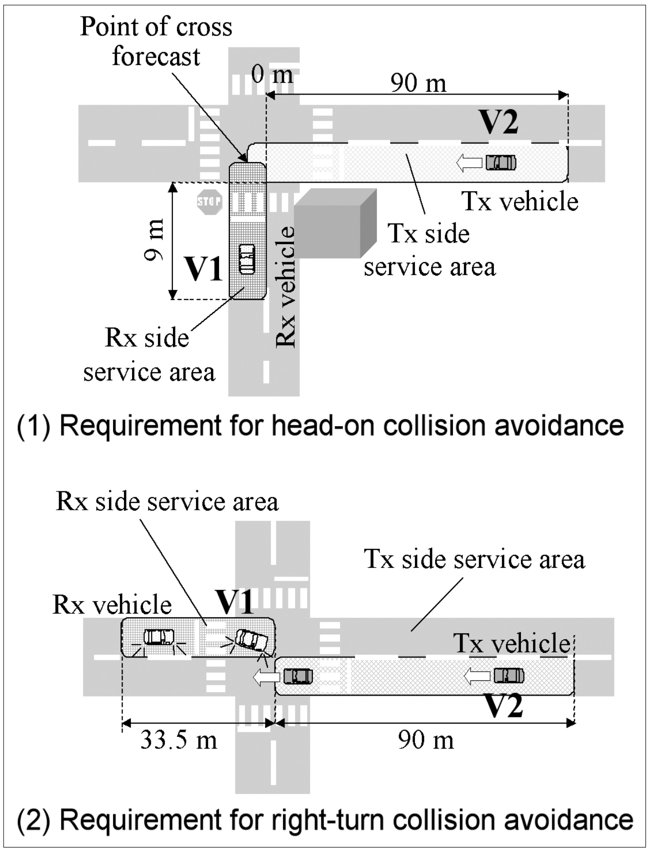
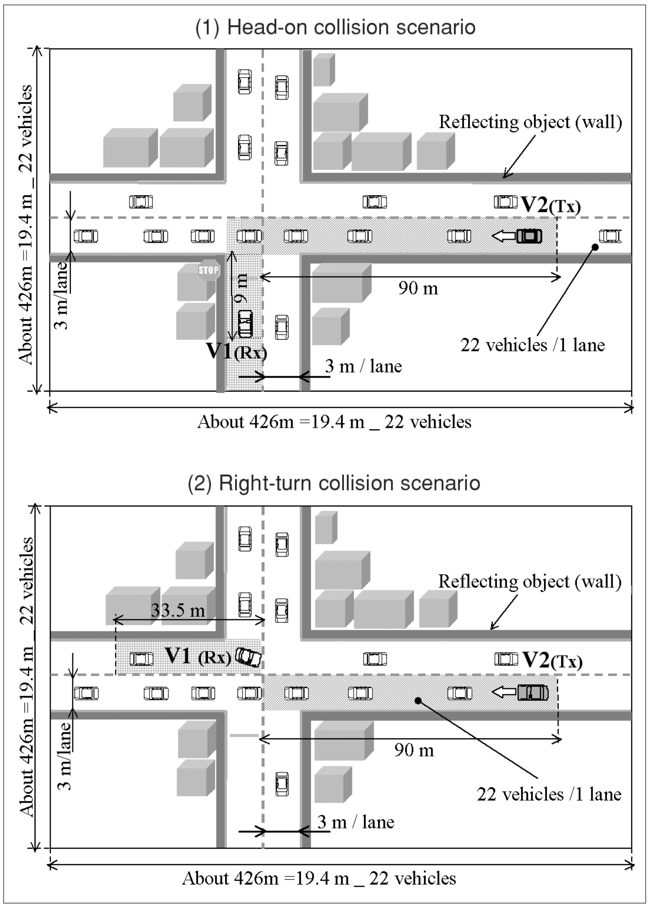


Figure 6.
Collision scenarios and ASV requirements

Figure 7.
Simulation conditions



3. Performance evaluation

3.1 Evaluation strategy

In Japan, the Advanced Safety Vehicle (ASV) program [22] assisted by automotive manufacturers and the Ministry of Land, Infrastructure, Transport and Tourism, has been defining the communication requirements for various safe driving scenarios. Among the scenarios, an especial emphasis has been put on intersection collisions that cause a large number of fatalities in each year. Some of the major scenarios of fatal traffic accidents are a head-on collision and a right-turn collision at an intersection. The performance of the MM-SA is evaluated, comparing with the CSMA/CA by simulation, in case of those collision scenarios based on the ASV requirements.

3.2 Collision Scenarios and ASV requirements

Fig. 6 (1) shows the head-on collision scenario. A vehicle V1 is going into an intersection and a vehicle V2 is going straight through the intersection. In this scenario, the driver of V1 can not recognize V2, which is blinded by a building at the corner. *Fig. 6 (2)* shows the right-turn collision scenario. In Japan, a vehicle must keep left on roads. A vehicle V1 is going to make a right-turn at an intersection and a vehicle V2 is going straight and through the intersection. In this scenario, the driver of V1 can not recognize V2, blinded by a large vehicle such as bus waiting to right-turn on the opposite direction.

In both collision scenarios, ASV requires that the message of V2 has to be received at V1 with larger than 80% of packet delivery ratio within 100ms from any location of V2, in the service area (Tx side service area) in the figures.

3.3 Simulation Conditions

Fig. 7 shows the simulation conditions. In the simulation, four frequency channels (4.096 MHz bandwidth for each) in 5.8 GHz band are used for channel allocation to roads. Locations of all the vehicles, other than V1 and V2, are determined randomly. Total number of vehicles around an intersection is 88. The inter-vehicle distance is 19.4 meter on average, assuming vehicles'speed of 70 km/h. Each vehicle periodically generates status message of 140 bytes with the period of 100 msec. It is assumed that there are walls along with both road sides, which represent buildings.

By simulations using Qualnet network simulator, the received power characteristic, the end-to-end packet delivery ratio and transmission delay from the vehicle V2 are measured at V1.

3.4 Received power characteristic in case of non-line-of-sight

Fig. 8 shows received power characteristic in head-on collision scenario, which is the case of non line-of-sight, by a simulation. In the simulation, ray-tracing is used for radio propagation model. The graph shows the

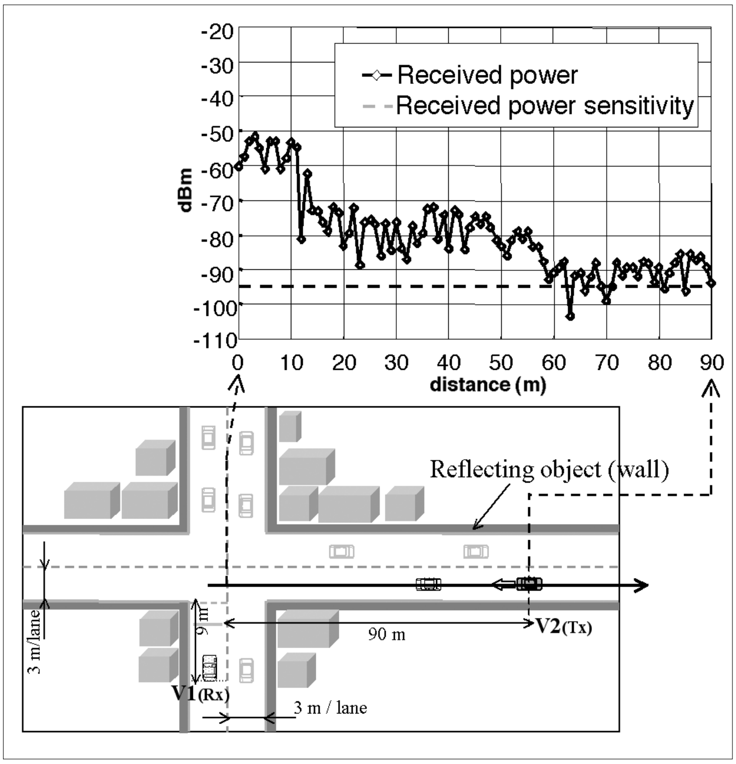


Figure 8.
Received Power Characteristic

estimated signal strength of V2 received at V1, where the horizontal axis is location of V2 in the service area. In the figure, signal strength of V2 is partially below the sensitivity level. Obviously, neither MM-SA nor CSMA/CA schemes can satisfy the ASV requirements. This results that the packet forwarding is necessary, so that a vehicles' message can be disseminated over the service area.

3.5 Simulation results

Fig. 9 shows the packet delivery ratio and the end-to-end transmission delay in case of head-on collision avoidance. For fair comparisons, the frequency channel assignment rule and packet forwarding scheme of the MM-SA are also applied to CSMA/CA. The results show that in 88-vehicle scenario, the MM-SA achieves approximately 100% of packet delivery ratio and shows better performance than CSMA/CA, and also achieves significantly smaller end-to-end transmission delay (at most 4 msec). On the other hand, in CSMA/CA scheme, the end-to-end delay is much larger, taking approximately 20 to 80 ms.

Fig. 10 shows the packet delivery ratio and the end-to-end transmission delay in case of right-turn collision avoidance. The MM-SA also shows better performance.

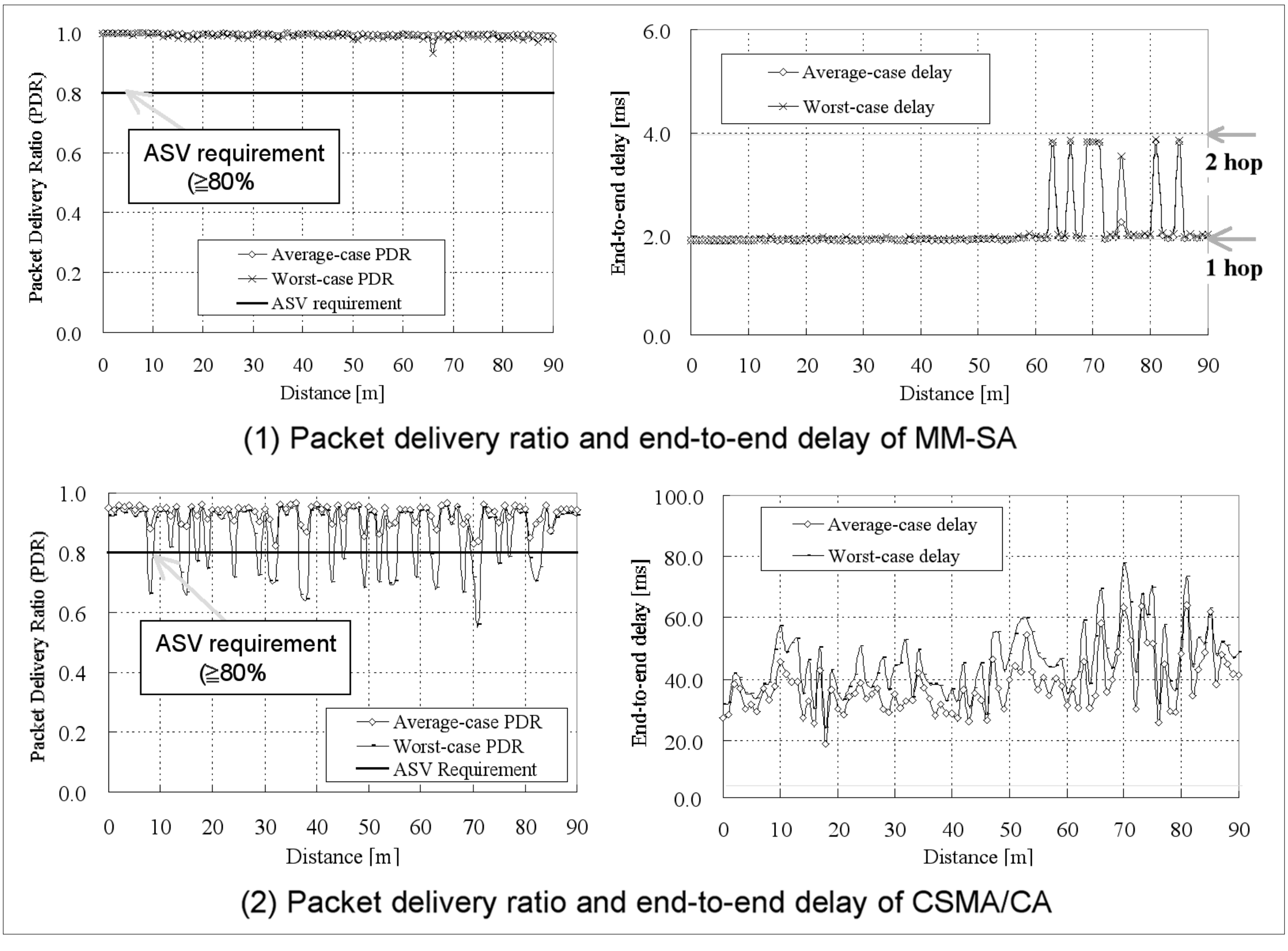


Figure 9.
Simulation results in case of head-on collision avoidance

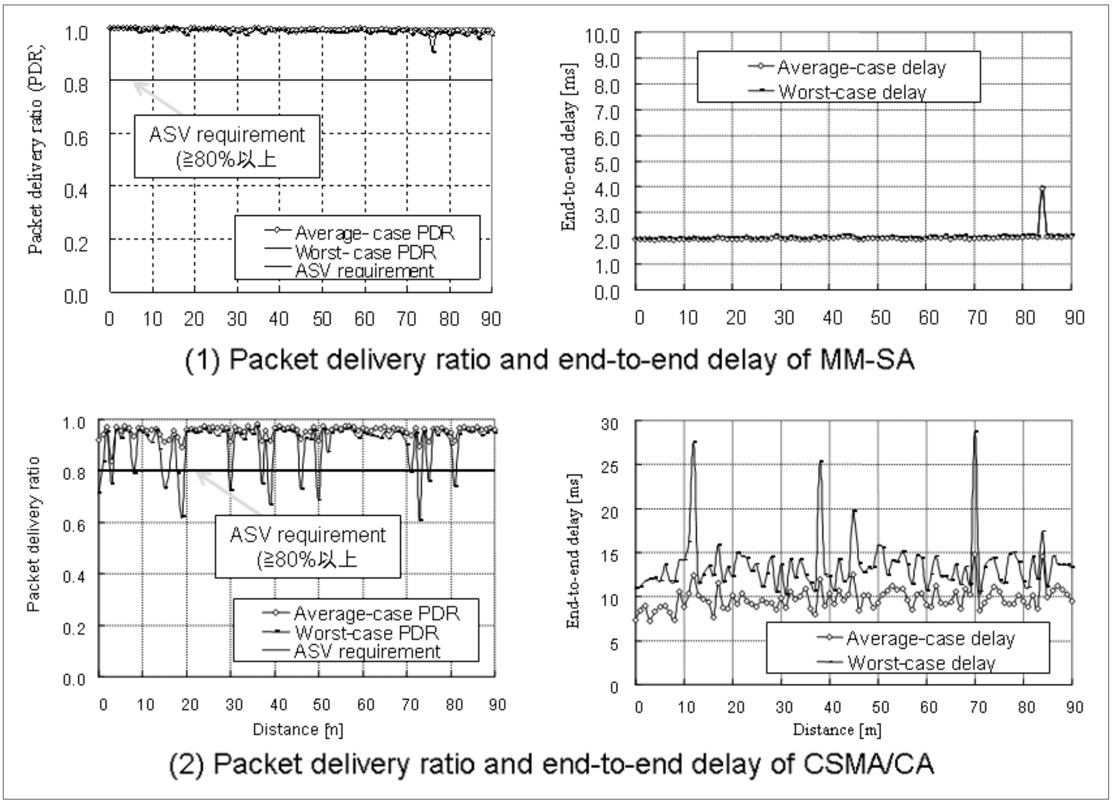


Figure 10. Simulation results in case of right-turn collision avoidance

4. Prototyping and field experiments

4.1 Prototype System

In addition to the evaluation of MM-SA scheme by simulation above, we have developed the prototype system shown in *Fig. 11. Table 2* shows the specification of the system. All the core technologies of MM-SA such as spread spectrum, frequency control, packet forwarding and transmission scheduling are implemented in the system. The system achieves the forwarding delay inside the system below 1 msec.

Figure 11. Prototype systems of MM-SA onboard unit

Table 2. Specification of Prototype Systems of MM-SA

Parameter	Specification
Frequency	5780, 5790, 5820, 5830MHz
Chip Rate	2.048Mcps
Bit Rate	585kbps
Spreading Factor	7
Modulation	π/4-shift QPSK
Data Detection	differential detection

4.2 Field experiments

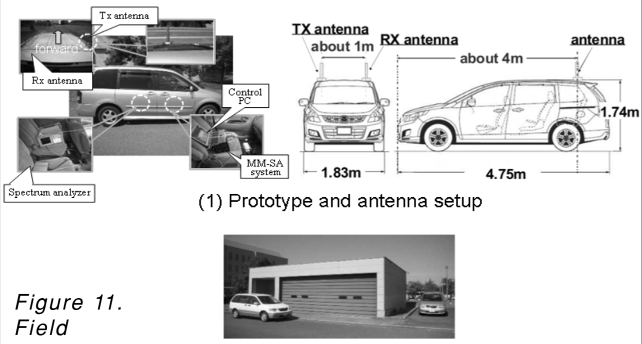
We are carrying out the field experiment, in order to evaluate the system performance in actual environment as shown in *Fig. 12*. Communication performance usually depends on the radio propagation environment, which significantly changes due to the surrounding obstacles and weather conditions. In this experiment, we measured the radio propagation and packet error rate characteristics under the non line-of-sight condition and the line-of-sight condition. The obtained data will be reflected to the computer simulation to improve its accuracy and reliability.

5. Conclusion

For inter-vehicle communications to assist safe driving, we have developed a novel scheme "MM-SA," which is based on CDMA technology, achieving fast response in millisecond order and highly reliable transmission of vehicle's status information.

We evaluated the effectiveness of MM-SA scheme by computer simulation based on Japanese ASV requirements, comparing with the existing and popularly used media access control, CSMA/CA. CSMA/CA suffers from performance degradation in terms of transmission delay and packet delivery ratio, when the number of vehicles increases and can not satisfy the ASV requirements. We also implemented the prototype system based on MM-SA and are carrying out the field experiment, to evaluate the system performance in actual environment.

In order to further make sure the effectiveness of MM-SA scheme, we plan to do the followings:



(1) Prototype and antenna setup

(2) Experiment at an intersection

Figure 11. Field experiments

(1) Field experiment on actual roads.
(2) Further performance evaluation in scalability (in larger numbers of vehicles) and in the other accident scenarios, comparing with the performance of IEEE 802.11p.
(3) Comparison with the other channel access schemes, e.g. timing synchronized CSMA and Distributed TDMA etc.

From the evaluations so far, we are convinced that MM-SA scheme is quite suitable for safe driving support by inter-vehicle communications.

Acknowledgments

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References

[1] Motegi S., Horiuchi H., “Relay control for data dissemination of spontaneous vehicular networks,” IEEE ITS Telecommunications, pp.1098–1101, 2006.
[2] Kremer K., “Vehicle density and communication load estimation in mobile radio local area networks (MR-LANs),” IEEE VTC’92, pp.698–704, 1992.
[3] Goldsmith A., “Wireless communications,” Cambride UniP, 2005.
[4] Tonguz O.K., Wisitpongphan N., Parikh J.S., Bai F., Midalige P., Sadekar V.K., “On the broadcast storm problem in ad hoc wireless networks,” IEEE BROADNETS, pp.1–11, 2006.
[5] Briesemeister L., Schafers L., Hommel G., “Disseminating messages among highly mobole hosts based on inter-vehicle communication,” IEEE VTC 2005, Vol.1, pp.423–428, June 2006.
[6] Campelli L., Cesana M., Fracchia R., “Directional broadcast forwarding of alarm messages in VANETs,” IEEE WONS2007, pp.72–79, January 2007.
[7] Yu S., Cho G., “A selective flooding method for propagating emergency messages in vehicle safety communications,” IEEE ICHIT2006.
[8] Korkmaz G., Ekici E., Ozguner F., “An efficient fully ad-hoc multi-hop broadcast protocol for inter-vehicular communication systems,” IEEE ICC2006, pp.423–428, June 2006.
[9] ITS Info-communications Forum, “Guideline of the inter-vehicle communications system using 5.8 GHz: RC-005,” *http://www.itsforum.gr.jp/Public/J7Database/index.html*
[10] ANSI/IEEE Std 802.11, “Wireless LAN mediun access control (MAC) and physical layer (PHY) specifications (1999).”
[11] Glodsmith A. “Wireless communications,” Cambride UniP, 2005.
[12] Shagdar O., Ohyama T., Shirazi M.N., Yomo H., Miura R., Obana S., “Safety Driving Support using CDMA Inter-Vehicle Communications,” The Journal of Inf. Proc., Vol.18, pp.1–15, January 2010.
[13] Yomo H., Shagdar O., Ohyama T., Miamoto M., Condo Y., Hasegawa J. Sakai T., Miura R., Obana S., “Development of a CDMA Inter-vehicle Communications System for Driving Safety Support,” IEEE Wireless Communications, Vol. 16, No. 6, December 2009.
[14] Shagdar O., Ohyama T., Shirazi M.N., Tang S., Suzuki R., Miura R., Obana S., “Message Dissemination in Inter-Vehicle CDMA Networks for Safety Driving Support,” IEEE VTC2009, April 2009.
[15] Yomo H., Miyamoto M., Shagdar O., Ohyama T., Shirazi M.N., Miura R., Obana S., “Supporting Safety Driving with Inter-Vehicle CDMA Networks under Realistic Accident Scenarios,” IEEE ICC, Vehicular Networking & Applications Workshop, June 2009.
[16] Yomo H., Miyamoto M., Shagdar O., Ohyama T., Shirazi M.N., Miura R., Obana S., “Performance of CDMA and CSMA Based Inter-Vehicle Networks for Safe Driving,” ITS World Congress 2009, September 2009.
[17] Shirazi M.N., Tang S., Shagdar O., Suzuki R., Obana S., “Performance Evaluation of Safety Applications over CDMA Vehicular Ad Hoc Networks,” ITS World Congress, November 2008.
[18] Toh C.K., “Ad Hoc Mobile Wireless Networks – Protocols and Systems,” PRENTICE HALL, 2002.
[19] Qualnet simulator, *http://www.scalable-networks.com*
[20] Andrews J.F., Weber S., Haenggi M., “Ad Hoc networks: to spread or not to spread ?,” IEEE Comm. Magazine, Vol.4, pp.84–91, 2007.
[21] Sze-Yao Ni, et al., “The Broadcast Storm Problem in a Mobile Ad Hoc Network,” MOBICOM ’99, pp.151–162, August 1999.
[22] ASV Programm, *http://www.mlit.go.jp/jidosha/anzen/01asv/index.html*