VRCP: A MAC Protocol for Integrated Inter-Vehicle and Road to Vehicle Communications

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This paper describes a new MAC protocol for integrated inter-vehicle and road to vehicle communications called VRCP (Vehicle and Road-side Collaborative MAC Protocol) that achieve high performance in communications. The VRCP uses two channels. In the VRCP, RVC is used for both the access control of IVC and data communications. For the performance evaluations, the autonomous cruising traffic simulator considering the shadowing effect is employed to investigate in realistic traffic conditions. Simulation results show that the performances of the VRCP in the case of using RVC for access control of IVC and another case of using RVC for both the access control of IVC and data communication. In particular, the VRCP can achieve high performance by using RVC for compensate the data of IVC even in the shadowing conditions, compared to the conventional IVC by contention access scheme.

Keywords: *Inter-vehicle communications, Road to vehicle communications, Medium access control protocol*

1. Introduction

Intelligent transport systems (ITS) need the technologies such as communications, positioning, and human-machine interfaces to improve the safety, efficiency and convenience of traffic. Especially, it is important to get the information such as position, velocity and acceleration of surrounding vehicles for improving the traffic efficiency and traffic safety. Inter-vehicle communications (IVC) and road to vehicle communications (RVC) have been studied energetically as the means of exchanging such information [1-6].

To exchange the information among vehicles in intelligent systems such as advanced vehicle control and safety systems (AVCSS) or advanced cruise-assist Highway systems (AHS), communications achieving high performance is required. By using IVC, communications in ad hoc network is possible among vehicles having onboard unit without infrastructure. However the performance of such communications are degraded due to increase of communication traffic and shadowing effect in case of congestion. In case of RVC, communications with a centralized access control of base stations achieving high performance such as TDMA scheme or FDMA scheme can be realized. However, the communication area of such schemes is restricted within the area of base stations. So, many base stations must be set successively to communicate wide area with such schemes. This is so costly for infrastructure.

From these points of view, to communicate with high performance if the base stations are available and to share information among vehicles by communications even if the base stations are not available, it is expected of not using IVC and RVC independently but integrating IVC with RVC. There are some studies on medium access control (MAC) protocol integrating IVC with RVC until now [6][7].

On the other hand, the authors have been studied on using contention access schemes [8] for communications in ITS [9][10]. The contention access scheme can realize the decentralized exchanging of information easily, because such schemes can provide flexible access control against the network that terminal come in or departure frequently. There is no research on the MAC protocol integrating IVC with RVC using such schemes.

So in this paper, we propose a new MAC protocol called VRCP (Vehicle and Road-side Collaborative MAC Protocol) integrating IVC with RVC based on the non-persistent CSMA scheme that is traditional contention access scheme, and on TDMA scheme that can achieve high frequency efficiency.

This paper is described as follows. In section 2, the related works on integration of IVC and RVC is represented. VRCP is proposed in section 3. The performance evaluations of the VRCP by simulations are depicted in section 4. Then, the autonomous cruising traffic simulator [12] including shadowing model is used for the simulations. Final section 5 is conclusions.

2. On related works

There is some MAC protocols proposed so far to improve the performance of exchanging information among vehicles [6][7].

It is difficult to cooperate the channel access of each vehicle in IVC network, because almost of conventional such networks are decentralized ad hoc network. RVC can provide centralized channel access control with such network. In the I-Warp II [6], RVC is used for dynamic

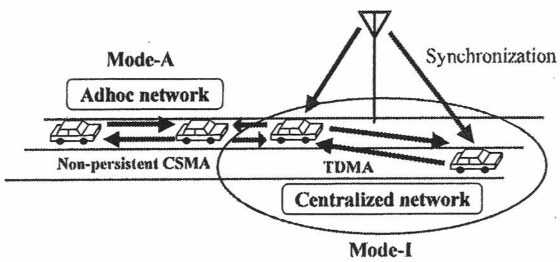


Fig. 1. Concept of the VRCP.

allocation of the code used in IVC based on the code division multiple access. Such scheme can improve the performance of IVC within the area of base stations. Furthermore, by such integrated scheme, IVC can be possible without base stations, because such scheme uses IVC mainly. However, this type of integrated scheme cannot avoid the inter-vehicle shadowing in IVC, because RVC is not used for data communications.

DRVC [7] is an integrated scheme based on the DSRC [12]. DRVC is the integrated scheme aiming at the effective use of onboard unit in the DSRC. In DRVC, RVC is used for the data communication to relay the information if IVC fail. However DRVC is applicable only within the area of base stations based on ARIB STD T-75 [12].

The VRCP we propose in this paper is the integrated scheme that uses both IVC and RVC mainly. For the point of how to use RVC, the VRCP uses RVC for both access control of IVC and data communications. Moreover, the VRCP can use in only IVC context, so the communication area is not restricted within the area of base stations.

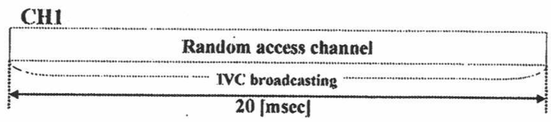
3. A proposal of the VRCP

VRCP is a MAC protocol for integrated IVC and RVC. The VRCP can use RVC for both access control of IVC and data communications. In this paper, the VRCP using RVC only for the access control of IVC is called the C-TYPE (Control type) VRCP. In the C-TYPE VRCP, IVC is available when the signal of base station cannot receive, and IVC achieving high performance by using RVC for the access control of IVC can be available within the area of base stations. On the other hand, the VRCP using RVC for both the access control of IVC and data communications is called CD-TYPE (Control and Data communication type) VRCP. CD-TYPE VRCP can use for C-TYPE VRCP, and can also use for compensating of data in IVC if the inter-vehicle shadowing occurs. It is not considered the case that RVC use only for the data communications.

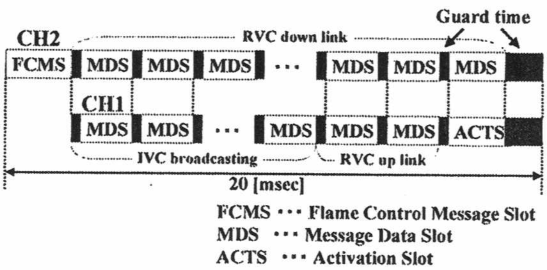
As shown in Fig. 1, the VRCP has two modes to change the access scheme according to the condition of signal from base stations. One is ad hoc mode (Mode-A) using the non-persistent CSMA scheme that is conventional contention scheme in the condition when the signal from the base stations cannot be received. Such scheme can provide the flexible access control with the decentralized ad hoc network without base stations. However, such scheme has a problem that the contention of access causes the collision of packets transmitted on the channel, and this problem causes the degradation of communication performance. In such schemes, the non-persistent CSMA scheme is expected for the access scheme of IVC. The validity of this scheme is investigated by a field test (Demo2000 [13]) in Japan. Another is infrastructure mode (Mode-I) using the TDMA scheme with centralized access control in the condition when the base stations are available. TDMA scheme achieve higher performance than contention access scheme. By changing these modes, C-TYPE of the VRCP is realized.

In the VRCP, two sets of channels (CH1, CH2) are used. In Mode-A, the CH1is used as a random access channel, and the CH2 is not used (see Fig. 2(a)). Each vehicle in Mode-A broadcasts their information to neighbors through the CH1 by the non-persistent CSMA scheme. On the other hand, both CH1 and CH2 are used in Mode-I as represented in Fig. 2 (b). In this mode, CH1 is divided into some message data slots (MDS) according to the flame control message broadcasted through CH2. The MDS are allocated to the vehicles based on the information broadcasted from base station through the flame control message slot (FCMS). Each vehicle in Mode-I broadcasts their information to neighbors through the MDS allocated by the base stations. In this way, a centralized IVC network is realized by the TDMA scheme among vehicles in Mode-I. CH2 is also used as data channel for exchanging information of vehicles suffering from inter-vehicle shadowing. For example, C+D-TYPE of the VRCP is realized when the base stations receive the information of IVC and broadcast the information through the CH2 as a data channel.

In the VRCP, the change of modes is decided whether the flame control message can receive or not. Fig. 3 shows the transition diagram about change of modes. When the flame control message from the base stations cannot be received, each vehicle in the Mode-A accesses the CH1 by the non-persistent CSMA scheme, (see Fig. 3 (a)). If this message is received, the vehicle tries to demand allocation of MDS to transit to the Mode-I through the activation slot (ACTS). Then, if the vehicle gets the MDS, this vehicle transits from Mode-A to Mode-I (Fig. 3(b)). Otherwise, the mode of the vehicle remains Mode-A (Fig. 3(c)). When the flame control message from the base stations can be received, each vehicle in the Mode-I downloads the such vehicle preserve the mode (Fig. 3(d)). Otherwise, the mode of such vehicle transits from Mode-



(a) Mode-A



(b) Mode-I

Fig. 2. Channel design for each mode in the VRCP.

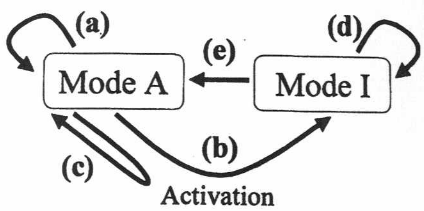


Fig. 3. Mode transition diagram in the VRCP.

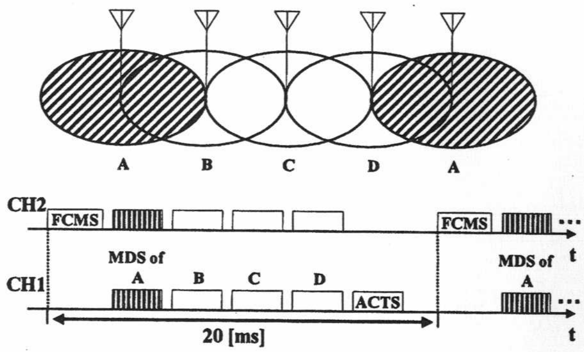


Fig. 4. Structure of TDMA sub-frame in Mode-I.

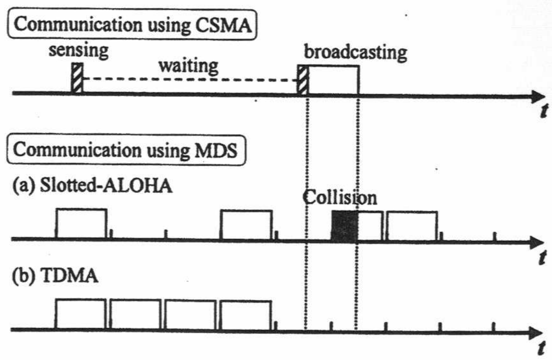


Fig. 5. A situation of both CSMA and MDS coexisting communications.

I to Mode-A (Fig. 3(e)). Such vehicle tries to broadcast by non-persistent CSMA scheme.

In the VRCP, it is assumed that the base stations are placed with overlapping half each other for the sake of continuous communication in RVC (see Fig. 4). For this assumption, to avoid overlapping MDS in each base station (A, B, C, and D in Fig. 4), the frame of TDMA is divided to four sub-frames reused every four base stations. Each base station has the information about the allocation of MDS renewed every frame, and share this information with each other to prevent MDS from overlapping. Therefore, IVC among vehicles in Mode-I is free from collision if the number of MDS is larger than the number of vehicles within the communication range of base stations. Moreover, periodical exchange of information among surrounding vehicles is realized, because each vehicle broadcast own information with the same MDS in every frame. This is particularly important for the intelligent systems such as AVCSS or AHS. The number of MDS depends on the frequency bandwidth the system use. The larger is the bandwidth, the larger is the number of MDS.

The VRCP has some situations that the communications both in Mode-A and in Mode-I are interfered. One of such situations is occurred at the boundary areas where the modes change from Mode-A to Mode-I or from Mode-I to Mode-A. Another situation is when the shadowing caused by heavy vehicles prevents vehicles from receiving the signal from base stations. There is also the other situation that the number of MDS is less

TABLE I
PARAMETERS IN SIMULATIONS

(a) Road parameters

Type	Highway
Road length	2 [km]
Road width	3.5 [m]
The number of lane	8

(b) Vehicle Parameters

	Length	Width	Height
Normal vehicle	4.0 [m]	1.7 [m]	1.4 [m]
Heavy vehicle	7.0 [m]	2.0 [m]	4.0 [m]

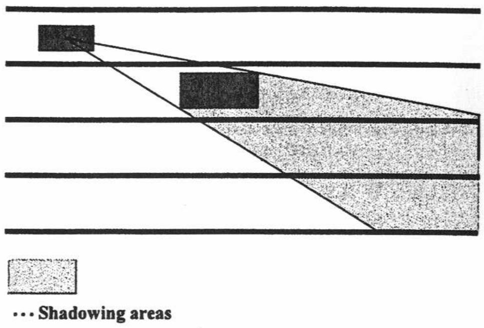
(c) Traffic Parameters

Vehicle density	10, 50, 100 [Veh./km/lane]
Heavy vehicle ratio	0, 0.2, 0.5, 0.8, 1.0

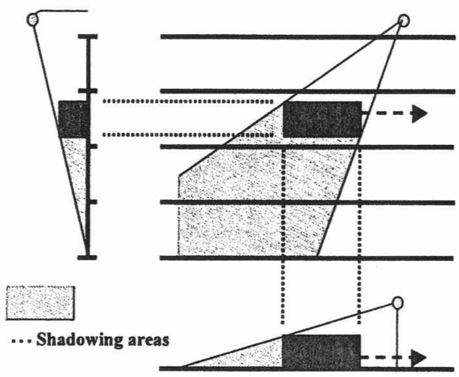
(d) Communication parameters

Packet length(data)		70 [Oct] (40 [Oct])
Communication cycle (frame length)		20 [msec]
Communication Range		100 [m]
Slot length		77 Oct
MAC	Mode-A	Non-persistent CSMA scheme
	Mode-I	TDMA scheme

than the number of vehicles within the network of the base stations. Under such situations, both the communication using CSMA and the communication using MDS are coexistent. Fig.5 shows such coexistent situations. In Fig.5, packets are transmitted when it is detected that the channel is free by carrier sense in the communication using the CSMA, whereas packets are transmitted immediately at the timing synchronized by a base station in the communications using MDS. In the communications using MDS, when the slotted-ALOHA is used (corresponding to the scheme that have no access control of IVC), MDS are allocated randomly as shown in Fig.5 (a). In this case, MDS used for transmission are distributed randomly and uniformly, so that the CSMA packets are overlapped with a high probability. Such a situation causes frequent packet collisions. On the other hand, if RVC is used for access control of IVC, TDMA can be used. In TDMA, MDS used for communications are gathered into a large part as shown in Fig.5 (b). CSMA packets can avoid this large part by carrier sense. Therefore, the CSMA packets and the TDMA packets are mutually almost separated, so that the probability of packet collisions is decreased. VRCP can use TDMA in Mode-I, since the whole or a part of RVC is used for access control of IVC. The influence of such situation on performance of the VRCP is discussed in later of this paper.



(a) Inter-vehicle shadowing area



(b) Road to vehicle shadowing area
Fig. 6 Definition of shadowing area.

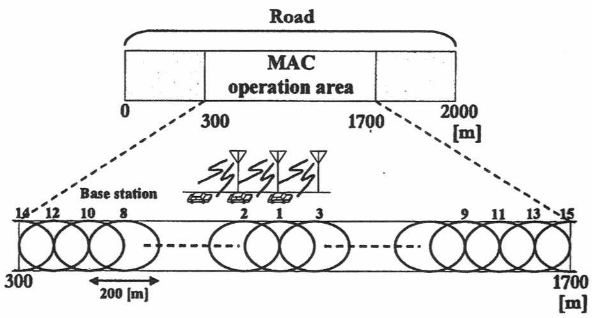


Fig. 7. Road model in simulations

4. Performance evaluations

In this section, performance of the VRCP is evaluated by simulations. The first, models of the simulator are described. The results of the simulations are shown later.

4.1. Simulation model and parameters

The simulator using for the evaluation in this paper is based on the autonomous cruising traffic simulator [11] that has been investigated so far is used. This is a microscopic simulator. In this simulator, it is supposed that each driver having different characteristics decide the behavior of the vehicle running in highway using information of neighbors in limited view autonomously. By including the communication model to this simulator, performance evaluation in the real traffic conditions can be possible. The manners of each vehicle are the same as ref. [11].

Table. 1 shows the parameters in simulations. In simulations, an eight-lanes highway road in which each lane is 3.5m wide, whose length is 2km is assumed. The simulations are carried out in vehicles' density is 10, 50, 100veh./km/lane. 100veh./km/lane correspond to the traffic congestion. The shadowing effect of both inter-vehicle and road to vehicle caused by heavy vehicles is also considered. The shadowing areas are defined as areas where the base station disappears from the vehicle's antenna geometrically as represented in Fig. 6. This antenna is to be centered on the roof. It is assumed that the application of the VRCP is share of information among vehicles in AVCSS. AVCSS aim at improvement of the safety performance of transportation systems using the communications. For example, a collision warning system is one of the typical AVCSS. Such a system predicts surrounding vehicle's future positions from the information such as position, velocity, and acceleration, and can warn to the driver if a possibility of collision is high [14]. Such a system needs the periodical exchange of vehicle's information among surrounding vehicles that exist within a communication range. DOLPHIN protocol [4] that was used in Demo2000 [13] also adopts the periodical communications. Therefore, the packet-traffic model used in this paper is based on that of the DOLPHIN protocol; i.e., packet length is 70 oct, and the transmission interval for each vehicle is 20 msec, as shown in Table. I (d).

As an evaluation index, the average packet loss rate is considered here. This is defined as the ratio of total lost packets number to total received packets number in all vehicles. If the transmitting packet receives successfully in all vehicles within the communication area, this packet is considered as success packet. In other words, the packet is considered as loss even when one vehicle of all vehicles within the communication area cannot receive the transmitting packet. Also, there is no consideration of characteristics of propagation such as fading caused by multi pass, that is, the packet is lost only when shadowing or collision occur.

The simulations are carried out in the model represented in Fig. 7. In this model, the area where VRCP operates is set from the point at 300m to the point at 1700m in the road whose length is 2km. The base stations are set up on the crush areas of highway. These stations cover the area both going up and down lane. The

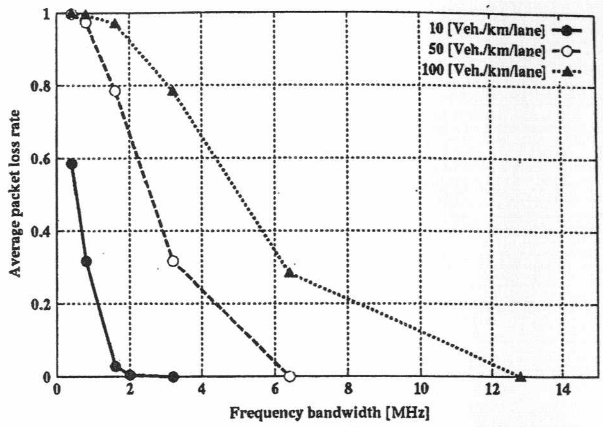


Fig. 8. Average packet loss rate versus frequency bandwidth of CH1 (The number of base stations is 15, no shadowing consideration)

number of base stations is variable from 1 to 15. If the number of base stations is 15, the whole area where the VRCP operates is completely in Mode-I when no shadowing occurs. This corresponds to the situation that all vehicles in this area communicate with each other by TDMA scheme. Conversely, if no base stations exist, the whole area where the VRCP operates is completely in Mode-A. This corresponds to the situation that all vehicles in this area communicate by non-persistent CSMA scheme.

4.2. Simulation results

4.2.1. Relation between frequency bandwidth and performance of the VRCP. In this paper, the VRCP is supposed to be applied to the communications for the AVCSS. So, the performance of exchange information among vehicles is most important. In addition, the required frequency bandwidth for RVC is varied for many applications, and it is difficult to decide. Therefore, we suppose that RVC is used for the access control of IVC to improve the performance of communication in Mode-I of the VRCP, and the frequency bandwidth of CH2 is not considered. In this investigation, only the frequency bandwidth of CH1 is considered.

As mentioned before, the performance of the Mode-I in the VRCP depends on the number of MDS allocated for the TDMA scheme. This is decided according to frequency bandwidth of the CH1. The larger the frequency bandwidth of CH1 is, the larger the number of MDS is. So, the required frequency bandwidth of the VRCP is investigated firstly. The number of base stations in this investigation is 15. There is also no consideration of shadowing effect. In such conditions, the modes of all vehicles are completely to be Mode-I in whole area MAC operates, that is, all vehicles use the TDMA scheme for communication. In the TDMA scheme, there are in theory no packet collisions if the number of MDS is larger than the number of vehicles in the network. Fig. 8 illustrates the average packet loss rate of the VRCP as

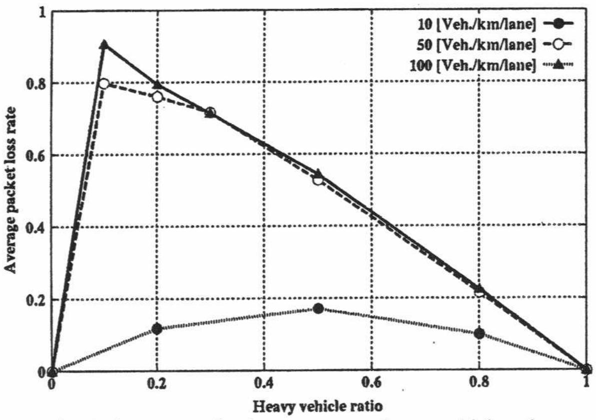


Fig. 9. Average packet loss rate versus heavy vehicle ratio (The number of base stations is 15,frequency bandwidth of CH1 is 25.6 [MHz])

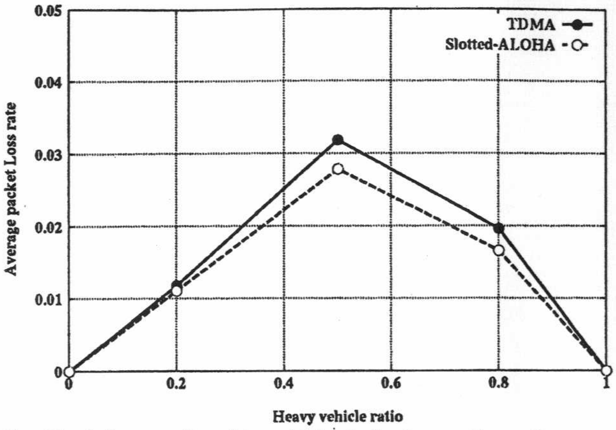
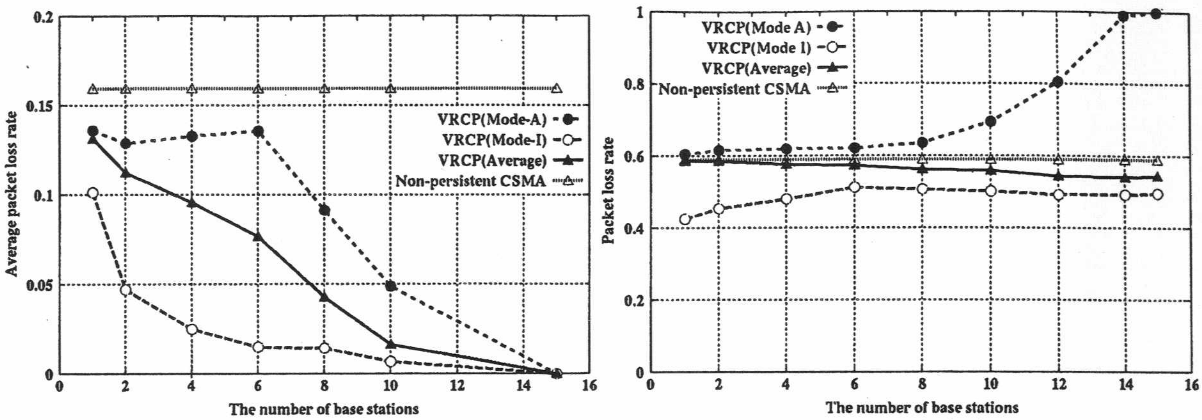


Fig. 10. Influence of road to vehicle shadowing on the performance (The number of base stations is 15,frequency bandwidth of CH1 is 25.6 [MHz])

frequency bandwidth when the vehicle's density is 10, 50, 100 veh./km/lane. The points in this figure represent the average packet loss rate when the frequency bandwidth is 0.4, 0.8, 1.6, 3.2, 6.4, 12.8MHz. Thus, the average packet loss rate is to be zero at the point of 3.2, 6.4, 12.8 MHz when the vehicle's density is 10, 50, 100 veh./km/lane respectively, because the number of MDS is larger than the number of vehicles in the network.. This result implies there are no collisions of packets by the TDMA scheme in these conditions. The required frequency bandwidth make the average packet loss rate to be zero is larger as the vehicle's density increase. The reason is that many MDS is required when the vehicle's density is high. In the investigation later, the frequency bandwidth of CH1 is set to 25.6MHz that is enough to allocate for vehicles even when the vehicle's density is 100veh./km/lane.

4.2.2. Influence of shadowing on the performance of the VRCP. So, the next investigation is about the influence of the shadowing on the performance of the VRCP. In this simulation, the number of base station is 15 and frequency bandwidth of CH1 is 25.6MHz. In Fig. 9and Fig. 10, the average packet loss rate of the VRCP is depicted as function of heavy vehicle ratio, when the vehicle' s density is 10, 50, 100veh./km/lane, and considering the shadowing. Note that in these figures the average packet loss rate is zero if the shadowing does not occur (corresponding to 0 or 1.0 in heavy vehicle ratio) as mentioned above. On the contrary, if the shadowing occurs, the average packet loss rate increases due to the shadowing. If the results of these figures are compared, inter-vehicle shadowing is particularly dominant in the whole influence. The influence of the inter-vehicle shadowing decreases as heavy vehicle ratio increase, because the number of normal vehicles suffering from shadowing decreases and the number of heavy vehicle not influenced by the shadowing increases. On the other hand, the influence of road to vehicle shadowing is small in the whole influence. However, there is a serious situation that such shadowing causes the interference of communications between in Mode-A and Mode-I, because the vehicle in Mode-I can be changed to Mode-A due to this shadowing even in the network within the area of base stations. Fig. 10 shows that the influence of this situation is largest when heavy vehicle ratio is 0.5. This figure also illustrated the comparison of the performance of the slotted ALOHA scheme and the TDMA scheme in Mode-I. This result shows that the TDMA scheme restrains the degradation of performance. The cause of this result is that the probability that the access of each scheme is divided each other is to be high due to the successive allocation of MDS according to the control of the base stations.

4.2.3. Performance evaluation of the C-TYPE VRCP. In this paper, the VRCP is proposed from premise that both IVC and RVC is integrated in the future. However, The RVC may use only for the access control of IVC when both communications develop without integration. Considering such development, the performance of the C-TYPE VRCP that use RVC only for the access control of IVC is evaluated in this section. Fig. 11 shows the performance comparison of the communication of the C-TYPE VRCP and conventional IVC by the non-persistent CSMA scheme in the cases that the shadowing is considered (Fig.11 (b)) or not (Fig.11 (a)). In this comparison, the frequency bandwidth of both CH1 and CH2 is set to 25.6MHz, and the vehicle density is set to 100veh./km/lane, and heavy vehicle ratio is set to 0.5. Then the frequency bandwidth of the single channel IVC by the non-persistent CSMA scheme is set to 51.2MHz to compare fairly with the VRCP that is a dual channel scheme. As shown in Fig. 11, the performance of the C-TYPE VRCP is improved as the number of base stations increase, whereas the performance of the IVC by the non-persistent CSMA scheme is constant without depending on the number of base stations. The performance



(a) No shadowing (b) Shadowing

Fig. 11. Performance comparison of the C-TYPE VRCP and the IVC by the Non-persistent CSMA scheme
(Frequency bandwidth of CH1 and CH2 is 25.6 [MHz], Frequency bandwidth of the non-persistent CSMA scheme is 51.2 [MHz],vehicle's density is 100 [veh./km/lane], heavy vehicle ratio is 0.5)

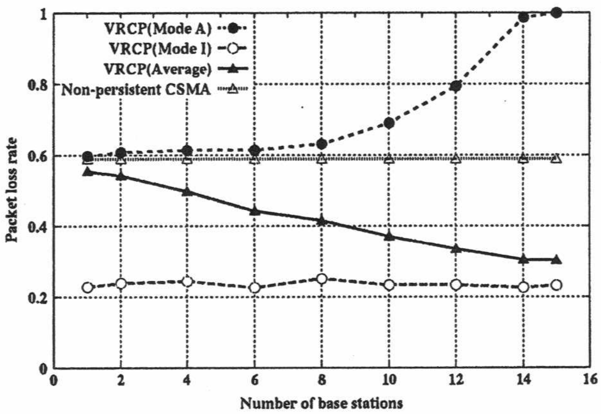


Fig. 12. Performance comparison of the CD-TYPE VRCP and the IVC by the Non-persistent CSMA scheme
(Frequency bandwidth of CH1 and CH2 is 25.6 [MHz], Frequency bandwidth of the non-persistent CSMA scheme is 51.2 [MHz],vehicle's density is 100 [veh./km/lane], heavy vehicle ratio is 0.5)

of the C-TYPE VRCP improves, since the communication by the TDMA scheme achieving high performance is dominant over the communication by the non-persistent CSMA scheme with the number of base stations increase. If the shadowing is not considered, the packet collisions do not occur when the whole MAC operating area of the VRCP is within the area of base stations, because all vehicle communicate each other by the TDMA scheme. Otherwise, the performance of the C-TYPE VRCP degrades, and the performance gain against the IVC by the non-persistent CSMA scheme also decreases, because the probability of failed communications is increased even in the Mode-I by the inter-vehicle shadowing.

4.2.4. Performance evaluation of the CD-TYPE VRCP. The VRCP can decrease the communication failure due to the inter-vehicle shadowing by using as the CD-TYPE scheme. In the VRCP, such scheme is realized by broadcasting the data through the CH2 that has the same frequency bandwidth as the CH1. By using such scheme, the communications between vehicles suffering from the inter-vehicle shadowing succeed if the road to vehicle shadowing does not occur. Fig. 12 illustrated the performance comparison of the communication of the CD-TYPE VRCP and conventional IVC by the non-persistent CSMA scheme. The parameters in this investigation are the same in the section 4.2.3. This result shows that the performance of the CD-TYPE of the VRCP is improved according to the effect of RVC data communications even when the shadowing occurs.

As shown in Fig.11 (b) and Fig.12, the performance of communications in Mode-A is worse than that of IVC using the non-persistent CSMA scheme. The reason is explained from situations of vehicles in Mode-A. There are two kinds of situations that vehicles communicate in Mode-A. One is the situation that there are no base stations within a vehicle's communication range of each vehicle. The other is that base stations exist within a vehicle's communication range, but the base station is hidden by heavy vehicle shadowing. In the former situation, communications performance of Mode-A is the same as that of IVC using the non-persistent CSMA scheme. On the other hand, in the latter situation, communications in Mode-A mean that one or more heavy vehicles exist around of the vehicle, and that inter-vehicle shadowing is likely to occur. Transmitting packets tend to be lost in such a situation. Moreover, packet collisions caused by coexistence of both Mode-A and Mode-I communications mentioned in Sec. 3, which does not occur in the IVC using the non-persistent CSMA scheme, occur in the latter situation. Therefore, the communication performance of Mode-A is worse than that of IVC using the non-persistent CSMA scheme. This performance difference between Mode-A and IVC using the non-persistent CSMA scheme become larger with increasing the number of base stations, because a ratio of vehicles under the latter situation to all the vehicles communicating in Mode-A increases. For instance, when the base stations cover the whole area (15 base stations in the simulations), all of the vehicles communicating in Mode-A are to be under the latter worse situation. As a result, the packet loss rate of Mode-A reaches 1.0 under such condition. However, even if such a condition occurs, communications between the vehicle and each surrounding vehicles are almost successful. Then, the safety among such vehicles is preserved. Average performance of VRCP upgraded with increasing the number of base stations, because a ratio of vehicles in Mode-A reduces and a ratio of vehicles in Mode-I increases. To improve the performance of communications in the vehicles suffering from both inter-vehicle and road to vehicle shadowing, multi hop IVC system must be considered. The investigation of such systems is further works.

5. Conclusions

In this paper, we propose a new MAC protocol, called VRCP, integrated inter-vehicle and road to vehicle communications. The VRCP has two modes changing access schemes and uses two channels. By using the VRCP, the vehicle uses the TDMA scheme for communications with RVC for access control of IVC within the area of the base stations, and uses the non-persistent CSMA scheme that is traditional decentralized access scheme when the signal from the base stations cannot receive. Moreover, RVC is used for data communications through the one of the channels when the base station is available. This makes possible the vehicle-road-vehicle communication even in the inter-vehicle shadowing conditions. VRCP is also available in the area where the signal from the base stations cannot receive.

The performance of the VRCP has been evaluated in the realistic traffic conditions by using the autonomous cruising traffic simulator including both the communication model and the shadowing model. From the simulation results, an influence of shadowing on the performance of the communications in the VRCP has been cleared. Also, the performances of the VRCP in the case of using RVC only for access control of IVC (C-TYPE) and another case of using RVC for both the access control of IVC and data communication (CD-TYPE) have been represented. In particular, the VRCP can achieve high performance even in the shadowing conditions by using RVC for compensate the data of IVC, compared to the conventional IVC by contention access scheme.

To achieve higher performance against severe shadowing conditions, it must be considered a multi-hop IVC system. This is the further works. Also, we have supposed that exchanging information in the AVCSS is only considered as RVC application in this paper. So an extension of the VRCP for such many application of RVC is also further works.

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