Autonomous Decentralized Radio Resource Management Strategy for Inter-vehicle Communications

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I. Introduction

In recent years, intelligent transport systems (ITS) for safe, comfortable and efficient transportation have been investigated and many kinds of technologies have been developed[1]-[3]. Especially, inter-vehicle communications are expected to play an important role in ITS. If acceleration, braking or steering information can be transmitted to other drivers, then most of traffic accidents might be avoided. In inter-vehicle communications for ITS, network topology may change randomly and rapidly at unpredictable times because vehicle positions are always changed. Therefore, centralized control by a base station is not feasible, and autonomous decentralized control is required.

Spread spectrum access scheme for inter-vehicle communications may offer not only communication capability but also range finding function[4]. However, solution for near-far problem needs transmission power control. On the other hand, time division access scheme[5]-[7] needs no complex transmission power control because of high orthogonality among communication channels.

In time division access scheme, assignment of carrier frequencies and time slots is one of the most important issues. One possible assignment scheme is to give the same carrier frequency to a group of neighboring vehicles and a unique time slot to each vehicle in order to avoid interference. For this purpose, a new protocol is required, which makes a vehicle group sharing the same carrier frequency.

In this paper, an autonomous decentralized vehicle-grouping protocol is proposed. In this protocol, each vehicle uses a free time slot of a carrier frequency with the strongest received signal power. When stronger power is detected in another carrier frequency, carrier frequency switching is carried out. If the vehicle fails to find a free slot, vehicle exchanges the carrier frequency and time slot with the nearest vehicle. The performance of this protocol is evaluated in terms of link outage probability by computer simulations.

II. Vehicle-grouping Protocol

a. Vehicle Group

In time division access scheme, the transmission performance is seriously degraded if the same carrier frequency and the same time slot is used by any neighboring vehicle. In order to avoid such collision, neighboring vehicles are grouped to share the same carrier frequency and assigned a unique time slot, as shown in Fig. 1. Of course, carrier frequency can be reused in groups at a safe distance apart so as to guarantee no or minimal interference among the vehicle groups.

b. Transmitter and Receiver

A vehicle is assumed to have one transceiver TR_1 and two receivers R_2 and R_3 as shown in Fig. 2. In the assigned time slot, TR_1 transmits a packet and in the other time slots receives the signals from other vehicles at the assigned carrier frequency f_p. If a vehicle is at the edge of its own group, information from the neighboring group of carrier frequency f_q is important for safety driving. Therefore the receiver R_2 is employed, and accepts packets at carrier frequency f_q.

At the same time, TR_1 and R_2 measure the maximum received power $P_{\max1}$ and $P_{\max2}$ in a frame, respectively. The receiver R_3 measures the maximum received signal power $P_{\max3}$ among all carrier frequencies except for f_p and f_q. The relation $P_{\max1} > P_{\max2} > P_{\max3}$ holds if there is no fading.

c. Proposed Protocol

Frequency and Time Slot Modification

For simplicity, we do not consider the effects of fading. Only the signal attenuation due to path loss is considered. The path loss is assumed to be equal to free space loss. First, the procedure of carrier frequency change is described as follows. Let us first consider that a vehicle of frequency f_p approaches a vehicle of f_q. The relation between received signal powers becomes $P_{\max1} < P_{\max2}$. Then, as shown in Fig. 3(a), TR_1 and R_2 change the carrier frequencies from f_p to f_q and from f_q to

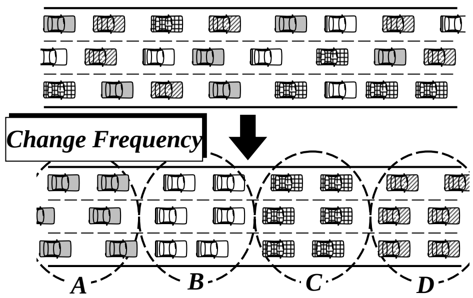

Figure 1 : Neighboring vehicles are grouped to share the same carrier frequency and to have a unique time slot.

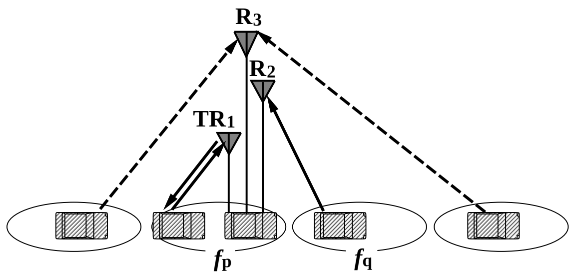

Figure 2 : Transceiver TR_1 for communication at f_p, receiver R_2 for receiving at f_q, and receiver R_3 for scanning.

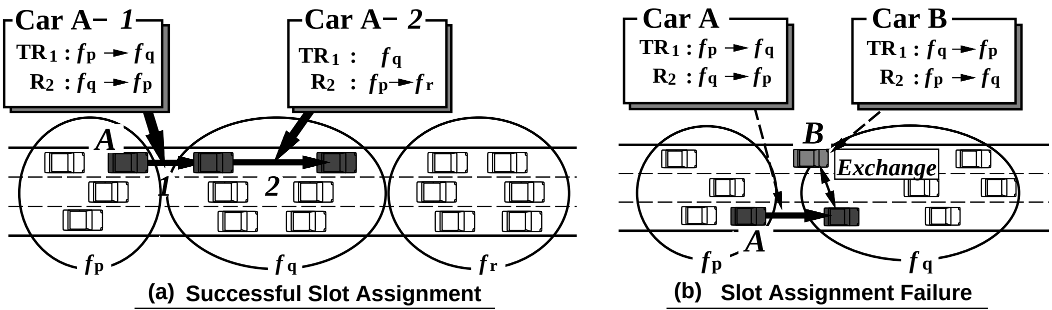

Figure 3 : Proposed vehicle grouping protocol.

f_p, respectively. This frequency change may cause a neighboring vehicle another frequency switching to f_q, which results in slot shortage. Therefore, the concept of trigger distance is introduced in order to prevent such chain reaction. The carrier frequency switching can be allowed only if the distance between these two vehicles is less than the trigger distance, as shown in Fig. 4. Larger values of trigger distance allow vehicles quick frequency switching and grouping while smaller values of trigger distance improve the link outage probability by reducing the chain reaction. The distance between vehicles is estimated from the received signal power of R_2. The carrier frequency switching is issued at the end of the frame.

Next, the procedure of time slot assignment is described as follows. After the carrier frequency switching, the vehicle searches for the available time slot in the previous frame. If a time slot is available, it is assigned to the vehicle. A permission parameter p_{slot} is introduced to reduce the probability of collision due to the contention. If the vehicle fails to get a time slot, it only switches the carrier frequency and has to continue to search for an alternative time slot in the next frame.

When a vehicle runs through a group as shown in Fig. 3(a), the received signal power from a vehicle group of f_r becomes large and $P_{\mathrm{max}2} < P_{\mathrm{max}3}$ will be detected. Then the carrier frequency of R_2 is switched to f_r and the vehicle can receive information from the nearest neighboring group by R_2.

Frequency and Time Slot Exchanging

In the modification procedure, the number of vehicles in a group is not controlled in any manner. If the number of vehicles in a group exceeds that of time slots in a frame, some of vehicles fail to get time slots. To avoid such failure, a frequency and time slot exchanging procedure is employed, which can limit the number of vehicles accommodated in a group. If a vehicle cannot get a time slot by using the modification procedure due to excess number of vehicles in a group, then carrier frequency change process is stopped and a new procedure is employed. In this procedure, the carrier frequency and transmission time slot of the vehicle A are exchanged with those of the vehicle B as shown in Fig. 3(b). The exchanging command is transmitted to the vehicle B at the moment when the vehicle A overtakes the vehicle B, which is detected by observing the received signal power. The vehicle A changes the carrier frequency immediately after transmitting the command. In the vehicle B, the carrier switching is carried out provided that the signal-to-interference ratio (SIR) of the received command is above the threshold.

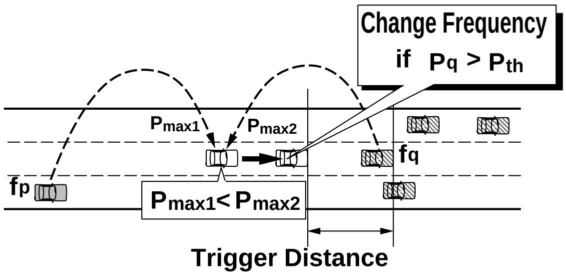

Figure 4 : Trigger distance.

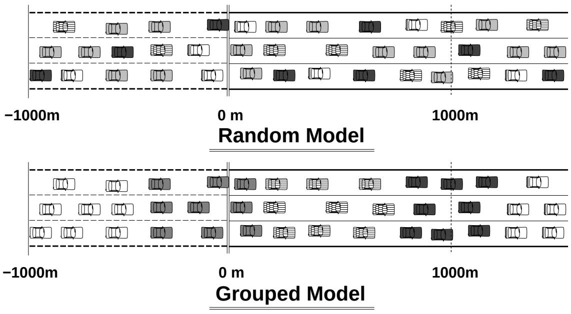

Figure 5 : Grouped model and random model.

III. Performance Evaluation

a. Simulation Parameters

In the computer simulations, 5, 10 and 20 carrier frequencies and 20 time slots in a frame are assumed. The length of a time slot is 1 msec. The channel is assumed as AWGN channel. Communication range is 250 m from the transmitting vehicle. Packets are received successfully if SIR is above 12 dB. Each vehicle can get a free time slot for transmission with permission probability $p_{slot} = 0.3$. The speed of vehicles follows a Gaussian distribution of mean 100 km/h with 10 km/h standard deviation. The time duration between the vehicles follows an exponential distribution of mean 3.0 sec. The road has 3 lanes with the width of 3.5 m. In the simulations, two models are taken into consideration: random model and grouped model. The random model is that each new vehicle uses a random carrier frequency and a random time slot initially as shown in Fig. 5. The performance of the proposed protocols is evaluated in random model. To compare with the random model, grouped model is assumed. In this model, carrier frequencies and time slots are ideally assigned to each vehicle group initially.

b. Link Outage

In order to evaluate the performance of this protocol, the link outage probability is investigated. Link outage probability P_{out} is the ratio of the total number of vehicles that received a packet successfully to the total number of all vehicles in communication area of the transmitting vehicle. The results of computer simulations are shown in Figs. 6, 7, 8 and 9.

Figure 6 shows the link outage probability without any carrier frequency change. In this case, high link outage probability is obtained in the random model. Most of the packets cannot be received since every vehicle is assigned random carrier frequency. In the grouped model, the link outage probability is increasing as the vehicles are running. Without carrier frequency change, vehicle groups cannot be maintained. We can see from Fig. 6 that the outage probability with 5 frequencies is better than the others in both the random model and the grouped model.

On the other hand, as compared with the performance without carrier frequency change as shown in Fig. 6, much lower outage probability is achieved by the proposed protocol owing to the carrier frequency change, as shown in Figs. 7, 8 and 9. In the random model, the link outage probability converges to less than 0.1 at the end of the road. As for the trigger distance, the link outage probability with trigger distance 250 m converges more rapidly than with trigger distance 9 m.

In the random model, the link outage probability curves with the 10 and 20 carrier frequencies, as shown in Figs. 8 and 9, converge slower than that with 5 frequencies shown in Fig. 7. On the other hand, in the grouped model, the link outage probability with the 10 and 20 carrier frequencies is less than 0.05, which is lower than that with 5 frequencies. The difference between the performance with the 10 and 20 carrier frequencies is small.

IV. Conclusion

An autonomous decentralized vehicle-grouping protocol for inter-vehicle communications is proposed in this paper. This protocol can make a vehicle group sharing the same carrier frequency and having different transmitting time slot for each vehicle. The link outage probability can be much improved by the proposed vehicle-grouping protocol. This protocol ensures good link outage probability for ITS inter-vehicle communications.

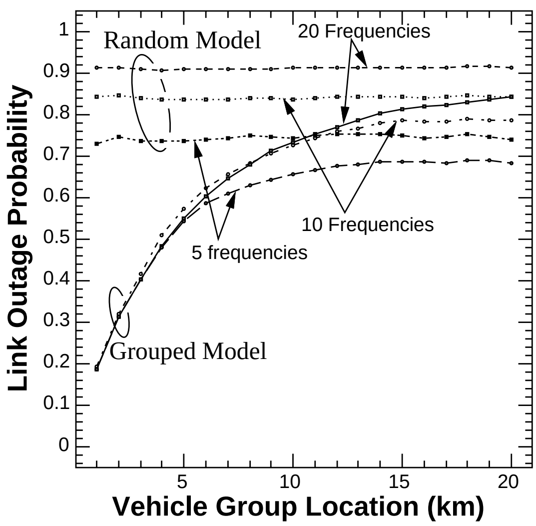

Figure 6 : Link outage probability without carrier frequency change.

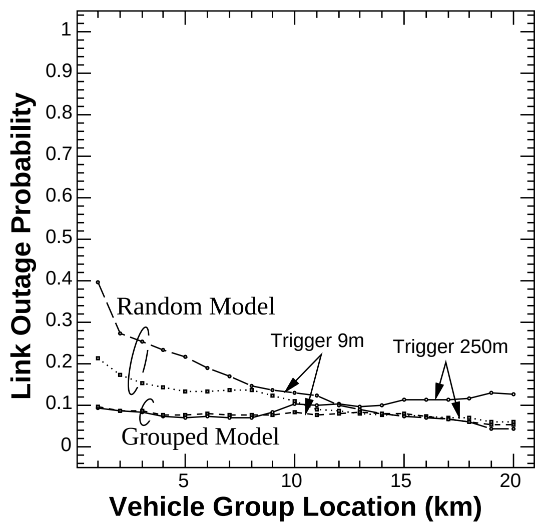

Figure 7 : Link outage probability of proposed protocol with 5 frequencies.

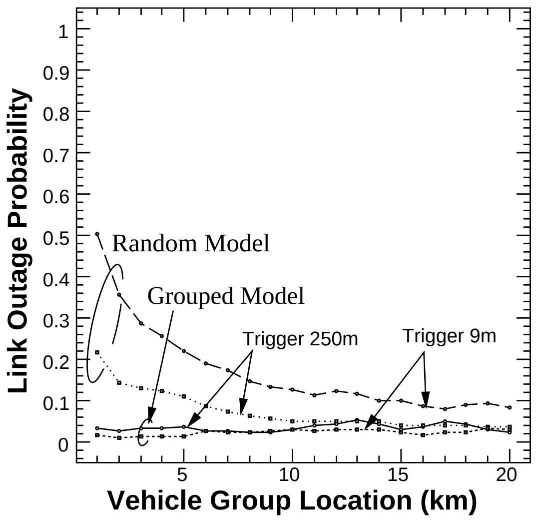

Figure 8 : Link outage probability of proposed protocol with 10 frequencies.

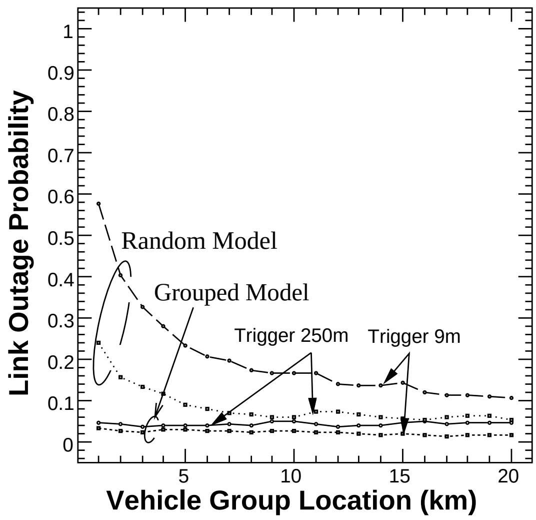

Figure 9 : Link outage probability of proposed protocol with 20 frequencies.

Acknowledgement

The authors would like to thank Telecommunication Advancement Organization of Japan for the financial support.

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