Reduction of Intersymbol Interference in DS-CDMA IVC
Based on Location-Oriented Code Allocation

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Abstract
In an inter-vehicle communication (IVC) system using OFDM (Orthogonal Frequency Division Multiplexing) modulation and a CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) scheme as a MAC (Media Access Control) protocol, the performance is degraded by hidden terminals. IVC using DS-CDMA (Direct Spread-Code Division Multiple Access) has been researched to remedy this problem. However, when this method is applied, there is a concern about the degradation of communication characteristics due to intersymbol interference. This intersymbol interference is divided into two types: (1) different intersymbol interference and (2) same intersymbol interference. In this paper, it is shown that each interference can be reduced by using two proposed methods, improving the communication characteristics.

1. Introduction
Recently, ITS (Intelligent Transportation Systems) has been widely developed to solve problems such as automobile congestion, traffic accidents, and environmental problems. To realize a safer traffic environment, it is necessary to improve the communication characteristics of IVC, which allows more immediate communication without using a base station. In current communication standards for IVC (IEEE 802.11p, ARIB STD-T109), CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) is used as a modulation scheme for MAC and OFDM [1,2]. However, when these standards are used, there is a fear of degrading communication characteristics due to the hidden terminal problem[3]. IVC using DS-CDMA (Direct Spread-Code Division Multiple Access) has been researched to reduce the effects of this problem[4,5]. However, when this method is used, there is a concern about degradation of communication characteristics due to intersymbol interference. This intersymbol interference is divided into two types: (1) different intersymbol interference and (2) same intersymbol interference. To reduce each interference, a spreading code in which different codes are orthogonal and the slotted ALOHA scheme with code sensing to improve the MAC layer are proposed in this paper. In this paper, a three-lane highway was assumed and evaluated by computer simulation.

2. Communication Model
2.1 DS-CDMA IVC scheme
A DS/SS modulation scheme is used in the DS-CDMA scheme[6]. By using the DS-CDMA scheme, it is possible to use the slotted ALOHA, which is a MAC protocol suitable for real-time communication. This is an advantage of IVC, where real-time communication is required in an emergency. However, as the number of communication users increases in the DS-CDMA system, the received signal is subjected to interference from other signals using different spreading sequences and the performance degrades. Therefore, in this paper, this interference is eliminated by using two spreading codes in which different codes are orthogonal.

2.2 Hadamard codes
Hadamard codes are orthogonal with other Hadamard codes when they are synchronized[7]. Hadamard codes that can be constructed from Hadamard matrices are orthogonal. A $M$th order Hadamard matrix can be generated as following.

$$H_M = \begin{bmatrix} H_M^{W} & H_M^{W^2} \\ H_M^{W^2} & -H_M^{W} \end{bmatrix} \tag{1}$$

The autocorrelation and cross-correlation values of Hadamard codes are shown in Figs. 1 and 2, respectively (length of codes $M=32$[chips]).

In Figure 1, the autocorrelation of Hadamard codes has several peak values in one period. In Figure 2, the cross-correlation values of Hadamard codes always are lower than the highest peak value of the autocorrelation. However, the cross-correlation values of Hadamard codes are orthogonal at a period of 32. Therefore, by using Hadamard codes in DS-CDMA IVC, the effects of intersymbol interference can be reduced and communication characteristics are expected to improve.
2.3 Zero-padding Gold codes

Zero-padding Gold codes are made by adding 0 to the end of Gold sequences. As a result, zero-padding Gold codes are orthogonal with other zero-padding Gold codes when they are synchronized. The autocorrelation and cross-correlation values of zero-padding Gold codes are shown in Figs. 3 and 4, respectively (length of codes \( M = 32 \) chips).

In Figure 3, the autocorrelation of Zero-Padding Gold codes has the highest peak value when the time difference becomes a cycle of 32. A similar characteristic is also observed for Gold codes. In Figure 4, cross-correlation values of zero-padding Gold codes also have a similar characteristic to that of Gold codes. However, the cross-correlation values of the zero-padding Gold codes are orthogonal at a period of 32. Therefore, by using zero-padding Gold codes in DS-CDMA IVC, the effects of intersymbol interference can also be reduced and communication characteristics are expected to improve.

2.4 Slotted ALOHA scheme with code sensing

In this section, the communication characteristics are further improved by the slotted ALOHA scheme with code sensing that reduces the same intersymbol interference. If the users who acquired the same spreading code transmit the packet in the same slot timing, the same intersymbol interference occurs. Therefore, as shown in Figure 5, we propose a method of controls so that vehicles with the same spreading code do not transmit signals at the same time[4].

\[
W = (12 - x) \times 3.2 [\mu s] \tag{2}
\]

The transmission status of another user is detected using the transmitted spreading code before transmitting the packet. At this time, if no other vehicle is transmitting using the same spreading code, the status is “idle”. On the other hand, if another vehicle is transmitting with the same spreading code, the status is “busy”. When detecting the “idle” status, the user transmits a packet. When the “busy” status is obtained, the transmission of the packet is postponed. After that, the transmission status is detected again using the control bit at the next slot timing. From Figure 5, User2 and User3 acquire the same spreading code. At this time, assuming that User2 has 12 bits as control bits and User3 has 6 bits, User2 has a wait time of 0 [\mu s] and User3 has a wait time of 19.2 [\mu s] from Eq.(2). Therefore, User3 performs packet transmission with this waiting time. Therefore, the slotted ALOHA scheme with code sensing can reduce the same intersymbol interference in the same slot.
3. Simulation Model

3.1 Location oriented PN code allocation

The location-oriented PN code allocation scheme is one of the schemes that solve the problem of PN code allocation. To realize the CDMA system, a scheme to allocate a unique PN code to each user is necessary. If unlimitedly long PN codes are used, it may be possible to assign a unique PN code to each vehicle in the world. Since a safety application requires real-time communication, the use of an unlimitedly long PN code is not suitable. Therefore, it is necessary to optimize the length of the PN code within the specific communication area, and several schemes have been researched. In this paper, the method of allocating PN codes on the road periodically is assumed[4].

![Figure 6: Example of PN code allocation](image)

Each vehicle determines the PN code used for data transmission based on its own location. An example of PN code allocation in a three-lane straight road is shown in Figure 6. The road is divided into small areas. PN codes are appropriately allocated to the small areas. In Figure 6, 30 different PN codes are allocated every \( Y \) [m] in each lane and an equivalent allocation pattern is repeated every \( X \) [m]. The number \( \# k \) shown in each divided small area indicates the PN code number allocated to this area. Each vehicle detects the PN code allocated to the area and transmission is performed using the assigned PN code. The location of each vehicle was assumed to be that estimated by GPS. If there is an error in the vehicle position estimated by GPS, the probability of acquiring a spreading code different from the spreading code obtained from the original position becomes high, which may deteriorate communication characteristics. Therefore, in this paper, we consider the position estimation error by GPS. Assuming that the vehicle position estimation error by GPS has an error on the circumference around the vehicle with a normal distribution, the standard deviation was changed from \( \sigma = 0 \) [m] to \( \sigma = 7.5 \) [m] in 2.5 [m] steps.

3.2 Simulation parameters

In this paper, it is assumed that the road is straight with a length of 1000 [m] and a lane width of 5 [m]. The velocities of vehicles on lanes 1, 2, and 3 are 60 [km/h], 80 [km/h], and 100 [km/h], respectively. The density of vehicles ranges from 10 [vehicles/km] to 200 [vehicles/km], and the communication range is 50 [m] and 100 [m]. The simulation parameters, which are based on ARIB STD T-109 [1], are shown in Table 1. In the PN code allocation, the repeat width \( X \) is determined as a function of the communication distance. All PN codes are allocated to the road so that code overlap does not occur.

### Table 1: Simulation parameters

| Shape of Road       | Straight Road |
|---------------------|---------------|
| Evaluation Length   | 1000 [m]      |
| Width of Lane       | 5 [m]         |
| Primary Modulation  | BPSK          |
| Secondary Modulation| DS/SS         |
| Spreading Code      | Hadamard Codes (length : 32 [chip]) |
|                     | Zero-Padding Gold Codes (length : 32 [chip]) |
| PN Code Allocation  | Oriented PN Code Allocation |
| MAC                 | Slotted ALOHA, |
|                     | Slotted ALOHA with Code Sensing |
| Carrier Frequency   | 760 [MHz]     |
| Chip Rate           | 10 [Mchip/s]  |
| Packet Size         | 800 [bits]    |
| Packet Length       | 2.56 [ms]     |
| Transmission Interval| 11 [ms]      |
| Transmission Power  | 10.0 [mW]     |
| Propagation Model   | Two-wave Rice Model |
| Noise               | AWGN(-103.8 [dBm]) |

4. Simulation Results

4.1 PER performance

Figures 7 and 8 show the PER performance of DS-CDMA IVC plotted against the density of vehicles on the road. For comparison, the results obtained using Gold codes are also shown. In this paper, PER is defined as

\[
\text{PER} = \frac{P_{\text{error}}}{P_{\text{all}}} \tag{3}
\]

where \( P_{\text{error}} \) denotes the number of packets with an error of more than 1 [bit] after decoding error correction and \( P_{\text{all}} \) denotes the number of packets that have been received. As shown in the figures, by using orthogonal codes rather than Gold codes, a different intersymbol interference is reduced. However, when \( \sigma \) [m], representing the position estimation error by GPS, is considered, the influence of this value on the PER characteristic increases with decreasing communication range. This is because when the communication range is narrow, the unit area width \( Y \) [m] (Figure 6) decreases, which affects the error by GPS and the receiving vehicle obtains an incorrect spreading code. Therefore, by using the slotted ALOHA scheme with code sensing, the same intersymbol interference is reduced, and the communication characteristics are further improved.
4.2 Comparison of spreading codes

From Figure 9, showing a comparison of the amount of interference between different codes per user when using Hadamard and Zero-Padding Gold codes, zero-padding Gold codes have a higher interference power than Hadamard codes. From this, the amount of interference using zero-padding Gold codes is larger than that using Hadamard codes, and the communication characteristics are worse than those observed using Hadamard codes as shown in Figures 7, 8.

5. Conclusion

We discussed the reduction in intersymbol interference for DS-CDMA IVC systems. As shown by computer simulation, by using orthogonal codes, a different intersymbol interference is reduced and PER performance as a function of vehicle density is improved. Moreover, PER performance can be further improved by using the slotted ALOHA scheme with code sensing. Also, in this study, even though both Hadamard and Zero-Padding Gold codes are orthogonal, using Hadamard codes in DS-CDMA IVC systems is more effective than using Zero-padding Gold codes.

References

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