Performance Evaluation of DS-CDMA IVC Based on Location-Oriented Code Allocation and Performance Improvement Using SIC in Urban Environment

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Abstract

In ARIB STD T-109, the inter-vehicle communication (IVC) systems are based on the carrier sense multiple access/orthogonal frequency division multiplexing (CSMA/OFDM) scheme. However, there is concern that communication performance is degraded owing to hidden terminals. On the other hand, to reduce this effect, research has been conducted on simultaneous communication using direct spread-code division multiple access (DS-CDMA). However, when this method is applied in urban environment where there are many reflections and diffractions, there is concern regarding the degradation of communication performance by interference waves. In this paper, the performances of DS-CDMA IVC with various forms of primary modulation are compared and the performance of DS-CDMA IVC with successive interference canceller (SIC) is evaluated to reduce the effects of interfering waves.

1. Introduction

In recent years, research and development on intelligent transport systems (ITS) that utilize information and communication technology in transportation systems that realize the movement of people and things have been conducted worldwide. Among them, it is strongly desired to use the IVC, by which real-time information between vehicle systems, such as safe driving support systems and automatic driving systems, is exchanged. In ARIB STD-T109, which is the current IVC standard, a communication scheme using carrier sense multiple access/collision avoidance (CSMA/CA) as media access control (MAC) and orthogonal frequency division multiplexing (OFDM) for modulation is defined[1]. However, in CSMA/OFDM (OFDM with CSMA/CA), there is concern that communication performance is degraded owing to the hidden terminal problem[2].

As a scheme for reducing the effects of this problem, research has been conducted on the IVC using direct spread-code division multiple access (DS-CDMA). DS-CDMA IVC enables simultaneous communication by assigning different spreading codes to each user. However, when this method is applied in an urban environment where there are many reflections and diffractions, there is concern regarding the degradation of communication performance by interference waves. Therefore, in previous research, the communication performance of DS-CDMA IVC has been researched in the urban environment[3]. In addition, DS-CDMA IVC has the problem that the communication performance is degraded by the near-far problem and intersymbol interference. Therefore, in order to reduce the effects of interference, DS-CDMA IVC using successive interference canceller (SIC) has been studied when quadrature-phase-shift keying (QPSK) is used for primary modulation and spreading codes are randomly assigned[4]. On the other hand, a location-oriented code allocation scheme has been studied to solve the problem of spreading codes allocation for straight roads[5]. In this paper, the communication performance of DS-CDMA IVC based on location-oriented code allocation in an urban environment and the SIC scheme is evaluated.

2. Communication Model

2.1 DS-CDMA IVC scheme

A DS/SS modulation scheme is used in DS-CDMA[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 for IVC where real-time communication is required in case of emergency. However, in the DS-CDMA system, as the number of communication users increases, the performance of the received signal degrades owing to the effects of interference from other signals using different spreading sequences; this is called multiple access interference (MAI). In addition, the near-far problem also degrades the performance because a signal with high reception power causes strong interference of low-power signals. These problems occur because the spreading sequences are not in a perfect orthogonal relationship. Therefore, in this
paper, the SIC scheme is used to solve these problems.

2.2 Successive interference canceller (SIC)

The block diagram of the receiver is shown in Fig. 1.

![Block diagram of receiver with SIC](image)

Figure 1: Block diagram of receiver with SIC

In the receiver, the correlations between the received signal, \( y(t) \), and the spreading sequences using the matched filter bank are calculated to detect the spreading code \( k \) that maximizes the correlation \( B^{(k)} \). \( B^{(k)} \) is expressed by the following formula.

\[
B^{(k)} = \sum_{p=-\infty}^{\infty} y(t - pT_s) C^{(k)}(p) \tag{1}
\]

where, \( k \) denotes the spreading code number, \( T_s \) denotes the symbol duration time, \( C^{(k)} \) denotes the spreading sequence that consists of 1 and -1, and \( p \) denotes the chip number of the spreading sequence. If it is assumed that \( B^{(k)}/N \) obtained by normalizing \( B^{(k)} \) by the sequence length, \( N \), is resampled and its despread narrow band signal, \( s^{(k)} \), was obtained, the replica signal, \( y^{(k)}(t) \), is expressed as the following formula.

\[
y^{(k)}(t) = \sum_{p=-\infty}^{\infty} \frac{|B^{(k)}|}{N} s^{(k)}(t - pT_s) C^{(k)}(p) \tag{2}
\]

Then, the replica signal is subtracted from the received signal by the following formula.

\[
y'(t) = y(t) - y^{(k)}(t) \tag{3}
\]

By repeating (1) to (3), the influence of MAI and the near-far problem can be reduced and the desired signals can be retrieved.

3. Simulation Model

3.1 Location-oriented code allocation

In DS-CDMA IVC, it is necessary to assign a spreading code to each user. The length of spreading codes is limited, and thus spreading codes must be efficiently assigned to each vehicle. In this paper, the scheme of allocating spreading codes on the road in every unit area distance, \( Y'[m] \), and repeating an equivalent allocation pattern in every, \( X[m] \), is used. An example of spreading codes allocation in a two-lane road is shown in Fig. 2.

![Example of spreading code allocation](image)

Figure 2: Example of spreading code allocation

In the previous study, it was shown that communication performance is improved by narrowing the unit area width, \( Y'[m] \), in the case of high vehicle density [7]. Within 50[m] from the center of the intersection, where vehicle spacing is likely to be narrower, \( Y \) and \( X \) are 5[m] and 40[m], respectively. On the other hand, more than 50[m] from the intersection, \( Y \) and \( X \) are 10[m] and 80[m], respectively.

3.2 Propagation model

In the urban environment, the radio wave propagation becomes complicated owing to reflection and diffraction from structures such as buildings. Therefore, the propagation characteristics due to multipaths change greatly depending on the surrounding environment in an urban area. In this paper, 3-dimensional ray tracing is used as the propagation model[3]. The simulation parameters in ray tracing are shown in Table 1.
horizontal direction are randomly placed waiting for traffic lights. In this paper, the reception point is set as shown in Fig. 3 on the road model, such that the hidden terminal problem occurs.

The density of vehicles is in the range from 5/[km/lane] to 40/[km/lane] at intervals of 5/[km/lane]. The simulation parameters, which are based on ARIB STD T-109, are shown in Table 2.

Table 2: Simulation parameters

| Parameter | Value |
|-----------|-------|
| Primary Modulation | BPSK, QPSK, 16QAM, 64QAM |
| Packet Size | 80[bits] |
| Spreading code | Gold sequence (length: 31) |
| MAC | Slotted ALOHA |
| Packet Length | 6.0[ms], 3.1[ms], 1.5[ms], 1.0[ms] |
| Number of Slots | 16, 33, 66, 99 |
| Bandwidth | 8.3[MHz] |
| Career Frequency | 760[MHz] |
| Transmission Power | 1[dBm] |
| Minimum Sensitivity | -98.5[dBm] |
| Error Correction Code | Convolution Code (constraint length = 7, code rate = 1/2) |
| Code Decision Algorithm | Soft Viterbi |
| Transmission Interval | 100[ms] |
| Noise | -104.6[dBm] |

4. Simulation Results

4.1 PER performance

Figure 4 shows the PER performance of the DS-CDMA IVC random assignment of code and DS-CDMA IVC based on location-oriented code allocation against the number of vehicles on the road. In this paper, PER is defined as the following formula.

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

\[ P_{\text{error}} \] denotes the number of packets that have over 1[bit] of error after decoding error correction and \( P_{\text{all}} \) denotes the number of packets that have been received. The result is that DS-CDMA IVC based on location-oriented code allocation in an urban environment has same performance of random assignment. From the results, DS-CDMA IVC based on location-oriented code allocation can be efficiently allocated in urban environment. In comparison with each primary modulation, it is shown that the PER performance is improved by using a higher-order primary modulation. This is probably because a higher-order primary modulation can provide more slots by decreasing the packet length. As an exception, the PER performance using the 64 quadrature amplitude modulation (QAM) scheme has not been improved. The signal point spacing of the 64QAM scheme is narrower than others. Therefore, it is considered that this is because DS-CDMA IVC is susceptible to noise and interference when using the 64QAM scheme.

4.2 Performance improvement using the SIC scheme

Figure 5 shows the PER performance of DS-CDMA IVC using the SIC scheme and not using the SIC scheme against the number of vehicles on the road. Spreading codes are assigned by the location-oriented code allocation scheme. As
shown in the figure, DS-CDMA IVC using the SIC scheme in a 16QAM scheme shows better PER performance than those with other primary modulation, regardless of the vehicle density. In addition, when the SIC scheme is not used, DS-CDMA IVC using the 64QAM scheme has better PER performance than that using the QPSK scheme. On the other hand, the PER performance of DS-CDMA IVC with SIC using the 64QAM scheme is worse than that with SIC using the QPSK scheme. This is because, as mentioned in the previous subsection, 64QAM is susceptible to noise and interference and it is difficult to reduce the effect of interference using the SIC scheme. However, the PER performance is improved by using the SIC scheme in any primary modulation.

5. Conclusions

We evaluated DS-CDMA IVC based on location-oriented code allocation in an urban environment. It was also shown that the higher-order primary modulation leads to better performance because it allows for more slots, but is more susceptible to noise and interference. There is the same trend in this case when using the SIC scheme. However, the PER performance is much improved by using the SIC scheme.

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