Viterbi-based Decoding Algorithm for DBO-CSS

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요 약

본 논문에서는 DBO-CSS 신호의 차분검출을 위한 비터비 알고리즘을 이용한 최대신호 에너지 검출(maximum signal energy detection) 알고리즘을 제안한다. 차분복호에 의한 신호대 잡음비 열화를 감소시키기 위하여 본 논문에서는 "코릴레이션 메트릭"이라는 에너지 누적 메트릭을 제안하고 이를 비터비 알고리즘의 모든 스테이트에 적용하도록 수정하였다. 제안한 알고리즘은 기존의 블록복호에 기반한 DBO-CSS 차분 복호 알고리즘과 비교하여 BER = 10^{-5} 에서 약 2.5dB의 SNR 성능향상을 가져옴을 실험을 통하여 확인하였다.

ABSTRACT

Differential detection algorithm for DBO-CSS based on maximum signal energy detection (MSED) using viterbi algorithm is proposed. In order to mitigate SNR degradation caused by differential decoding, a modified viterbi algorithm with so called correlation metric (CM) in every state is proposed. It is shown that the performance gain of the proposed algorithm when compared with that of the conventional differential detection with the block decoding algorithm is about 2.5dB at BER = 10^{-5}.

키워드

viterbi, DBO-CSS, differential decoding

Ⅰ. Introduction

Recently, as the concept of ubiquitous is generalized, a lot of candidates for the terminals of sensor network have appeared by many engineers. As a standard for the candidates of the terminals, IEEE802.15.4a group selected two communication methods in October 2006. One of both methods is IR-UWB and the other is ISM DBO-CSS as they have been announced in [1].

As described in the name DBO-CSS (Differentially Bi-Orthogonal Chirp Spread Spectrum), DBO-CSS spreads differentially encoded bi-orthogonal codes with chirp signals as in [2-3]. Bi-orthogonal code table $\boldsymbol{C}$ is described in [1]. Because the DBO-CSS is designed for WPAN(wireless personal area network), it adopts differential modulation method which can be modulated and demodulated with very simple hardware in order to meet the requirements of WPAN; that is low-power consumption and low complexity.

But, inherently, the BER performance of differential demodulation method is worse than that of differentially encoded coherent demodulation method. When the application systems need high performance receiver, therefore the algorithms to enhance the BER performance, such as DF-DPD(decision feedback differential phase detection) in [3] and viterbi-DD(viterbi differential detector) in [4], are usually used to minimize the performance gap between differential and coherent demodulations.

However, in case of the DBO-CSS which decodes bi-orthogonal code using differentially demodulated data, it is difficult to get performance enhancement with DF-DPD and viterbi-DD these two methods make hard decision results, because the hard decision degrades the coding gain of bi-orthogonal code. To solve the hard decision problem and to improve the BER performance, we propose a new decoding algorithm.

Ⅱ. Proposed Architecture

Although the DBO-CSS is proposed for low power consuming and small sized sensors, the servers which collect information from distributed sensors with very low SNR must have high performance receiver exactly to decode in such a bad communication conditions.

Viterbi algorithm is a well known algorithm which can make maximum likelihood detection, and it is used in many applications. In this paper we have modified the viterbi algorithm to get maximum likelihood detection in DBO-CSS decoding.

1) Correlation metric (CM)

Because the DBO-CSS transmits the differentially modulated signals after bi-orthogonal coding, the receivers for DBO-CSS generally perform differential demodulation first and bi-orthogonal decoding next, in the reverse order of transmitter. In this case, the DF-DPD and the viterbi-DD algorithms can be considered to reduce the performance gap between differential and coherent demodulations. But, because such algorithms make outputs as hardly decided bits, the SNR gain of entire DBO-CSS system can not be earned.

In this paper, we intended to perform bi-orthogonal decoding first and then differential demodulation next in order to maintain bi-orthogonal coding gain. Differential modulation of in-phase and quad-phase can not maintain the bi-orthogonal relations as in figure 1.

So, the total number of receivable code set is 4^4=256,because the possible digits in every position are 4 as{1, −1, j, −j}. Among these code sets, there are inseparable code sets when signal phases are rotated by the wireless channel. For example, the code {1,1,1,1} is inseparable with the code {−1, −1, −1, −1} rotated by π radian, so that the number of code sets which we can distinguish are 256/4 = 64. Such 64 correlation results are assigned to 64 states, and we call them as correlation metric (CM). Eq. (1) describes all possible code sets which can be transmitted and (2) describes the correlated results of the received signal r with all possible code sets.

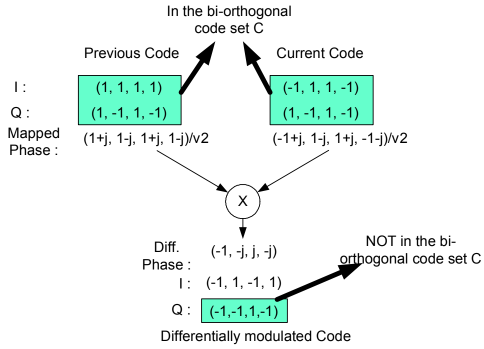


Fig.1. Case of non-biorthogonal differential code

$$S_{i,k} = \begin{cases} 1 & if\ k=0 \\ j^{floor(i/16)} & if\ k=1 \\ j^{floor(i/4)} & if\ k=2 \\ j^{i} & if\ k=3 \end{cases},\quad \text{where } j=\sqrt{-1} \qquad (1)$$

$$CM_{i,j} = \sum_{k=0}^{3} S_{i,k}^{*} \cdot r_{j,k} \qquad (2)$$

where i is a state number, j is a stage number, k is a chirp number, S is reference signal, and r is received signal.

The objective of CM is not in getting direct bi-orthogonal coding gain, but in mapping code energy to a value as the first step to get the full coding gain.

2) Branch metric (BM)

The correlated values, CMs, of i-th stage are multiplied by that of (i-1)-th stage in order to get differential phase between i-th and (i-1)-th stages. Because the branches which connect the states of (i-1)-th stage and those of i-th stage can be linked when the differential codes between the (i-1)-th stage codes and the i-th stage codes are in the bi-orthogonal code table ***C***, the branch metric (BM) can be calculated according to (3) and (4). Because $I_{j,k}$ in(3) can pick out branches which have bi-orthogonal relation, we can get the undegraded bi-orthogonal coding gain

$$I_{j,k} = \begin{cases} 1, & \mathrm{Re}\{S_{j,0}\cdot S^*_{k,0}, S_{j,1}\cdot S^*_{k,1}, S_{j,2}\cdot S^*_{k,2}, S_{j,3}\cdot S^*_{k,3}\}\in \mathbf{C} \\ & \text{and } \mathrm{Im}\{S_{j,0}\cdot S^*_{k,0}, S_{j,1}\cdot S^*_{k,1}, S_{j,2}\cdot S^*_{k,2}, S_{j,3}\cdot S^*_{k,3}\}\in \mathbf{C} \\ 0, & else \end{cases} \quad (3)$$

$$BM_{i,j,k} = CM_{i,j}\cdot CM^*_{i-1,k}\cdot I_{j,k} \quad (4)$$

where i is current stage number, j the state number of i−th stage, k the state number of (i−1)−th stage. To get rake receiver gain in multipath channel, (4) can be modified as (5).

$$BM_{i,j,k} = \left(\sum_{l=1}^{L} CM_{i,j,l}\cdot CM^*_{i-1,k,l}\right)\cdot I_{j,k} \quad (5)$$

where L is the number of fingers, and $CM_{i,j,l}$ is an l−th finger's CM of j−th state in i−th stage.

3) Path metric (PM)

The selection process to find out optimal path is performed as shown in (6). The proposed algorithm selects the path whose signal energy is a maximum, because the BM has signal energy with differential phase information.

$$PM_{i,j} = \max_k\left\{PM_{i-1,k} + \max(|re(BM_{i,j,k})|, |im(BM_{i,j,k})|)\right\} \quad (6)$$

where $re(x)$ means the real value of x and $im(x)$ the imaginary value of x. Further processes to decode bits such as tracing back are not described in this paper, because these processes do not affect system performance, the objective of this paper is the BER and the PER performance enhancements.

Ⅲ. Simulation Results

We now present some simulation results to allow for comparisons with the conventional approach and the coherent detection of coherently encoded bi−orthogonal code. Conventionally, DBO−CSS can be detected by the series of processes; that is, the matched filtering, the differential demodulation, the bi−orthogonal demapping and the decoding. And, in order to make a reference, the coherently encoded bi−orthogonal coding method (CEBCM) with the code table ***C*** as the model in figure 2 is simulated. Conventional detector model is shown in figure 3.

We simulated in AWGN channel and the diffuse multipath channel [5]. We assume that the transceivers are synchronized perfectly, and that DAC and ADC have the infinite precision with each other. In PER simulation, 10,000 packets are simulated and each packet has 100Byte transmit data. Simulation result of PER performance in AWGN is shown in figure 4. As shown in figure 4, about 2.5dB of required SNR can be reduced in the proposed method. Figure 5 shows the simulation results of the diffused channel in [5]. As we can see in these figures, the PER and the BER of the proposed algorithm is saturated at lower error rate than that of the conventional algorithm.

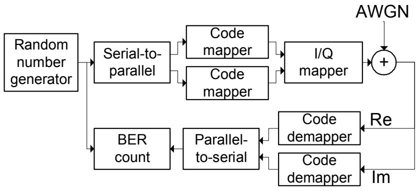


Fig.2. Simulation model of CEBCM

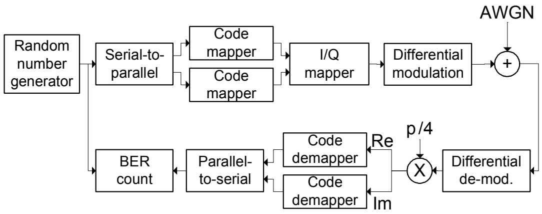


Fig. 3. Simulation model for conventional DBO−CSS detector

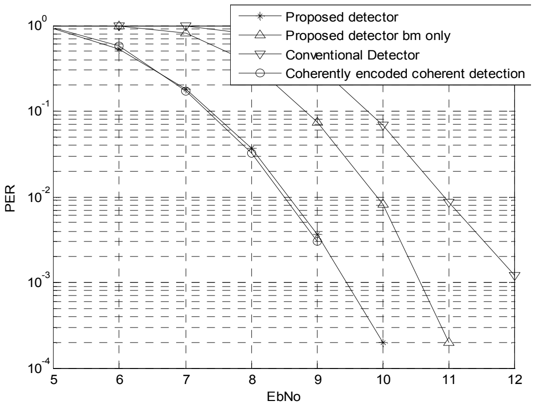
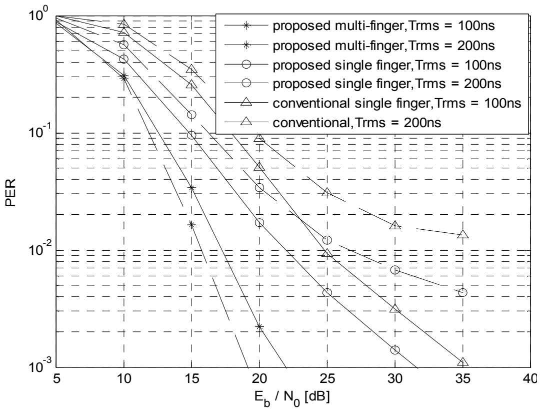
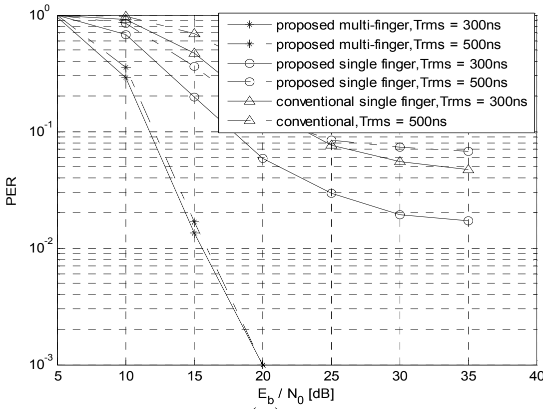


Fig. 4. PER Performances in AWGN channel



(a)



(b)

Fig.5. Performance in diffused multipath channel (a) PER when Trms = 100 and 200ns (b) PER when Trms = 300 and 500ns

Ⅴ. Conclusions

In this paper, we presented a new decoding algorithm for DBO-CSS which is one of the standards of IEEE802.15.4a. Frankly speaking, the hardware complexity of the proposed algorithm would be huge if we implement it on ASIC. But, if we implement the receiver by using embedded processor, the hardware complexity problem can be solved. Since the data rate of DBO-CSS is very low, the processor can afford to the computational complexity.

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