doi:10.3772/j.issn.1006-6748.2020.01.013

Decision-feedback subset aided multiple-symbol differential detection①

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Abstract

In view of the inaccuracy of the estimated symbols on the edge of the observation window, a decision-feedback subset aided multiple-symbol differential detection (MSDD) framework, dubbed DF-S-MSDD, is proposed in ultra-wideband impulse radio (UWB-IR) system with differential space-time block-code (DSTBC) modulation. Specifically, motivated by the decision-feedback aided MSDD (DF-MSDD), a subset of the decision-feedback symbols is selected, and the optimal symbols are preserved, and then all the remaining symbols are optimized. Furthermore, the simulations validate that the proposed DF-S-MSDD provides solid bit error-rate performance with a low complexity in UWB-IR system with DSTBC modulation.

Key words: multiple-symbol differential detection (MSDD), decision-feedback (DF), decision-feedback subset, ultra-wideband impulse radio (UWB-IR), differential space-time block-code (DSTBC)

0 Introduction

Coherent detection is capable of achieving performance improvement with accurate channel state information (CSI)[1]. However, collecting the perfect CSI is a demanding task. By contrast, the noncoherent receivers mitigate the problem of estimating CSI. Therefore, transmitted reference and differential detection get attention as noncoherent schemes in the single antenna system[2-4]. Unfortunately, there is a wastage of the transmit power with the transmitted-reference, and the differential detection leads to bit error rate (BER) performance loss because the current symbol is detected using a noisy template of the received signal[5,6]. Furthermore, multiple-symbol differential detection (MSDD) receives much research attention[7-9].

As a milestone for noncoherent detection, differential space time block-codes (DSTBC) becomes attractive[10,11], which is capable of improving the BER performance significantly compared to the single-antenna system. Furthermore, generalized likelihood ratio test based MSDD (GLRT-MSDD) and sphere decoding based MSDD have been conceived for the system[12]. However, the aforementioned MSDD algorithms impose exponentially increasing complexity with the number of the observation window. Thus, the GLRT-MSDD and the sphere decoding based MSDD are impractical when the number of the observation window increases. Decision-feedback based MSDD (DF-MSDD) represents the computationally efficient algorithm with a low complexity[13]. On the other hand, due to the inaccuracy of the estimated symbols on the edge of the observation window, there leaves a gap in terms of the BER performance between DF-MSDD and GLRT-MSDD.

Aiming to solve the problem of the performance loss caused by inaccurate detection on the edge of the DF-MSDD, in this work, a decision-feedback subset aided MSDD (DF-S-MSDD) is developed in the system with DSTBC modulation. More specifically, based on the DF-MSDD, a subset of decision-feedback symbols is employed, and the remaining symbols are optimized with GLRT-MSDD. The proposed DF-S-MSDD can simplify the classic exhaustive search as a detection with a lower computational complexity. Another benefit of the DF-S-MSDD is that, by getting rid of the inaccurate decision-feedback symbols on the edge of the observation window, it also enjoys a better BER performance when compared to the DF-MSDD. In general, the proposed DF-S-MSDD strikes an appealing performance-versus-complexity trade off.

It is worth emphasizing that the proposed DF-S-MSDD can be generalized in many noncoherent transmission with DSTBC modulation. Particularly, the ultra-wideband impulse radio (UWB-IR) signal contains lots of dense multi-paths components[14]. Therefore,

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① Supported by the National Natural Science Foundation of China (No. 61562058) and Lanzhou University of Technology Hongliu Excellent Youth Talent Support Program.

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Received on Jan. 9, 2019

using the optimal coherent detector will increase the difficulty and cost of system implementation. Thus, noncoherent schemes become inevitable in UWB-IR system. Relying on this technique, the system description and simulation experiments are discussed in the UWB-IR system with DSTBC modulation.

The structure of this paper is formulated as follows. The system description is offered in Section 1. In Section 2, the GLRT-MSDD and DF-MSDD are introduced. The proposed DF-S-MSDD is described in details in Section 3. Considering the practicability, the detection performance of the DF-S-MSDD is discussed by simulations in Section 4. Finally, conclusion is shown in Section 5.

Notations: lower-case (upper-case) boldface symbols represent vectors (matrices); $(\ )^{\mathrm{T}}$ and $\mathrm{Tr}(\ )$ denote the transpose and the trace of a matrix, respectively; $*$ stands for convolution; $\delta(t)$ represents the Dirac delta function.

1 System description

In this section, the multiple-input multiple output (MIMO) system description will be introduced for point-to-point UWB system with DSTBC modulation. The transmitter is equipped with $T(T > 1)$ transmit antennas, the receiver is equipped with $R(R > 1)$ receive antennas. At the transmitter, S denotes the date rate, TS bits map to $T \times T$ unitary matrices $\boldsymbol{C}_i$, which is the i-th information symbol. With the aid of differential encoding, the transmission symbol is given as

$$\boldsymbol{G}_{i+1} = \boldsymbol{G}_i \boldsymbol{C}_{i+1} \tag{1}$$

where, $i = 0, 1, \cdots, M-1$, and M denotes the total number of transmission symbols. The DSTBC information symbols are selected from a codeword set as $\boldsymbol{C}_i \in \boldsymbol{\Omega}$. $T \times T$ matrices $\boldsymbol{G}_i$ are transmitted from T transmit antennas in T successive intervals. It is noted that each codeword symbol employed has to be a unitary matrix. When the unitary matrices are designed according to the DSTBC codex of Refs[15-17], the proposed MSDDs are applicable to the system where the number of antennas is more than 2. In order to facilitate the encoding scheme, the transmit antenna is set to $T = 2$ in the following. Each DSTBC symbol maps onto the information-bearing DSTBC symbol[18], and it belongs to the set $\boldsymbol{\Omega} = \{\boldsymbol{C}^0, \boldsymbol{C}^1, \boldsymbol{C}^2, \boldsymbol{C}^3\}$. The corresponding rule for bits information and DSTBC symbols are given as follows. $00 \rightarrow \boldsymbol{C}^0 = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$, $01 \rightarrow \boldsymbol{C}^1 = \begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix}$, $10 \rightarrow \boldsymbol{C}^2 = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}$, $11 \rightarrow \boldsymbol{C}^3 = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$. The reference symbol is $\boldsymbol{G}_0 = \begin{pmatrix} 1 & -1 \\ 1 & 1 \end{pmatrix}$. The m-th row, n-th column entry of $\boldsymbol{G}_i$ is represented as $g_{m,2i+n-1}$ with $m = 1, 2$; $n = 1, 2$. For the m-th antenna, the transmitted signal is given by

$$s_m(t) = \sqrt{\frac{E_b}{2}} \sum_{i=0}^{M-1} \sum_{n=1}^{2} g_{m,2i+n-1} \omega(t - (n-1)T_f - iT_s) \tag{2}$$

where, t is time parameter, $\omega(t)$ represents the monocycle pulse with duration T_ω, T_f is the frame duration, the duration for transmitting a symbol is $T_s = 2T_f$, which indicates that 2 frames are needed to transmit one information symbol, E_b is the energy for transmitting one bit. To facilitate the demonstration, $j = 2i + n - 1$ is brought, and $g_{m,2i+n-1}$ is simplified as $g_{m,j}$ correspondingly. Then

$$\begin{aligned} s_m(t) &= \sqrt{\frac{E_b}{2}} \sum_{i=0}^{M-1} \sum_{n=1}^{2} g_{m,2i+n-1} \omega(t - (2i+n-1)T_f) \\ &= \sqrt{\frac{E_b}{2}} \sum_{j=0}^{2M-1} g_{m,j} \omega(t - jT_f) \end{aligned} \tag{3}$$

The channel impulse response between the m-th transmit antenna and the r-th $(1 \leqslant r \leqslant R)$ receive antenna is given by

$$h_{m,r}(t) = \sum_{l=1}^{L_{m,r}} \alpha_l^{m,r} \delta(t - \tau_l^{m,r}) \tag{4}$$

where, $L_{m,r}$ represents the total number of propagation paths, $\alpha_l^{m,r}$ and $\tau_l^{m,r}$ denote the path-gain and the delay of the l-th path, respectively. Correspondingly, the overall channel response between the m-th transmit antenna and the r-th receive antenna is formulated as

$$\rho_{m,r}(t) = \omega(t) \times h_{m,r}(t) = \sum_{l=1}^{L_{m,r}} \alpha_l^{m,r} \omega(t - \tau_l^{m,r}) \tag{5}$$

As a result, the received signal at the r-th receive antenna can be expressed as

$$\begin{aligned} y_r(t) &= \sum_{m=1}^{2} s_m(t) \times h_{m,r}(t) + n_r(t) \\ &= \sqrt{\frac{E_b}{2}} \sum_{m=1}^{2} \sum_{j=0}^{2M-1} g_{m,j} \rho_{m,r}(t - jT_f) + n_r(t) \end{aligned} \tag{6}$$

where $n_r(t)$ is the additive white Gaussian noise (AWGN), its mean is zero and power spectral density is $N_0/2$ with two-sided. To help understand and implement the proposed algorithms, the received signal from R receive antenna can be rewritten with matrix as

$$\boldsymbol{y}_i(t) = \begin{pmatrix} y_1(t + 2iT) & y_1(t + 2iT + T) \\ \vdots & \vdots \\ y_R(t + 2iT) & y_R(t + 2iT + T) \end{pmatrix} \tag{7}$$

The noncoherent transmission is designed under the the assumption, that the channel is constant during T symbols intervals[12]. Based on the assumption and the received signal in Eq. (7), MSDDs will be formulated in the UWB system with DSTBC modulation.

2 GLRT-MSDD and DF-MSDD

It is assumed that the number of the observation window is N DSTBC symbols. The target is how to detect $N-1$ information-bearing symbols jointly from the N received symbols. As such, the relationship is investigated between the information symbols C_i and the received symbols. Firstly, $N-1$ information symbols are expressed as the set $\mathbb{C} = [\boldsymbol{C}_1, \boldsymbol{C}_2, \cdots, \boldsymbol{C}_{N-1}]$. Furthermore, $\mathbb{C}$ will be detected from the received signal $\{y_r(t)\}$ of N observation window, where $0 < t \leqslant NT_s$. When $y_r(t)$ is obtained, the signal matrices will be combined with R received signal as Eq. (7). According to the GLRT criterion[8], $\mathbb{C}$ can be determined with Ref. [12].

$$\hat{\mathbb{C}} = \underset{\tilde{\mathbb{C}} \in \Omega^{N-1}}{argmax} \left\{ \sum_{\beta=1}^{N-1} \sum_{\gamma=0}^{\beta-1} \mathrm{Tr}\left[\left(\prod_{i=\gamma+1}^{\beta} \widetilde{\boldsymbol{C}}_i \right) \boldsymbol{Q}_{\beta,\gamma} \right] \right\} \quad (8)$$

where $\boldsymbol{Q}_{\beta,\gamma}$ is the correlation matrix received from R receive antenna, its entries are the correlation function of the β-th and the γ-th received signal expressed as

$$\boldsymbol{Q}_{\beta,\gamma} = \sum_{r=1}^{R} \left(\int_0^{T_i} \boldsymbol{y}_\beta^{\mathrm{T}}(t) \boldsymbol{y}_\gamma(t)\,\mathrm{d}t \right) \quad (9)$$

where T_i is the integration interval. By GLRT-MSDD in Eq. (8), $N-1$ consecutive symbols will be estimated according to the N received symbols. It can be seen that GLRT-MSDD in Eq. (8) is an exhaustive search algorithm. Inspired by the decision-feedback algorithm, instead of optimizing all the symbols over a observation window, the previous decision symbols are feedback and implemented into the GLRT-MSDD metric. For example, in the observation window of $[\widetilde{\boldsymbol{C}}_{\beta-N+1}, \cdots, \widetilde{\boldsymbol{C}}_{\beta-1}, \widetilde{\boldsymbol{C}}_\beta]$, the previous decision-feedback symbols, i. e., $[\hat{\boldsymbol{C}}_{\beta-N+1}, \hat{\boldsymbol{C}}_{\beta-N+2}, \cdots, \hat{\boldsymbol{C}}_{\beta-1}]$ are substituted into Eq. (8), then DF-MSDD is given by Ref. [11].

$$\hat{\boldsymbol{C}}_\beta = \arg \max_{\widetilde{\boldsymbol{C}}_\beta \in \Omega} \left\{ \sum_{\gamma=\beta-N+1}^{\beta-1} \mathrm{Tr}\left[\left(\prod_{i=\gamma+1}^{\beta-1} \hat{\boldsymbol{C}}_i \right) \widetilde{\boldsymbol{C}}_\beta \boldsymbol{Q}_{\beta,\gamma} \right] \right\} \quad (10)$$

According to the DF-MSDD given in Eq. (10), it is obvious that only a codeword symbol is detected in a observation window. Thus, when compared to the GLRT-MSDD, the computational complexity of DF-MSDD will be reduced significantly. On the other hand, it is pointed out that[19], the reliability of the estimated symbols in the middle of the observation window is higher than that at the edge. Thus, for the DF-MSDD, the error detection on the edge of the observation window results in performance loss. Therefore, DF-MSDD is modified, and DF-S-MSDD is proposed in the next section.

3 DF-S-MSDD in UWB system

In the GLRT-MSDD, $N-1$ information symbols can be estimated from the observation of N symbols; for the DF-MSDD, the previous $N-2$ estimated symbols are feedback, and then the last symbol is detected. In the following, the DF-S-MSDD will be formulated. For the DF-S-MSDD, the previou $N-2-\iota$ symbols are feedback, and the optimization is employed over the last $\iota+1$ symbols with GLRT-MSDD. Moreover, in order to reduce the performance loss caused by the inaccuracy at the edge of the observation, instead of returning all the $\iota+1$ decision symbols but only $\iota+1-\zeta$ symbols, and the remaining ζ detection symbols are discarded at the edge of the observation. Accordingly, the sampling architecture for the DF-S-MSDD is designed. Note that the observation window slides forward $\iota+1-\zeta$ symbol durations each time. The proposed sliding mechanism is particularly suitable for extracting the cross-correlation information among different blocks.

4 Simulations and analysis

In this section, Monte-Carlo simulations are carried out to validate the advantages of the proposed noncoherent transmission in the UWB system with DSTBC. The channel is given as the IEEE 802.15.3a CM2 model[16]. The monocycle waveform $\omega(t)$ is $\omega(t) = [1 - 4\pi(t/T_\omega)^2]\exp[-2\pi(t/T_\omega)^2]$, where the pulse duration is $T_\omega = 0.287$ ns. The frame duration is $T_f = 80$ ns, the maximum excess delay of the channel is chosen as $T_n = 40$ ns, where $T_f > T_n$ eliminates the inter-symbol interference. The transmit antenna is set to $T = 2$. Furthermore, when the receive antenna is $R = 1$, $\iota = 1$, $\zeta = 1$, the BER performance of the DF-S-MSDD is demonstrated. Specifically, as shown in Fig. 1, as the observation window increases from 5 to 10 and 20, the BER performance of the proposed DF-S-MSDD has been improving. When the size of observation window is $M = 10$, the SNR is 9 – 10, as shown in Fig. 2, the BER performance of the DF-MSDD is less than DF-S-MSDD about 0.3 dB. This is due to the accurate detection at the edge of the observation window for the DF-S-MSDD.

5 Conclusion

In contrast to the existing DF-MSDD in UWB system with DSTBC, the proposed DF-S-MSDD generates the performance gain by discarding the symbols at the

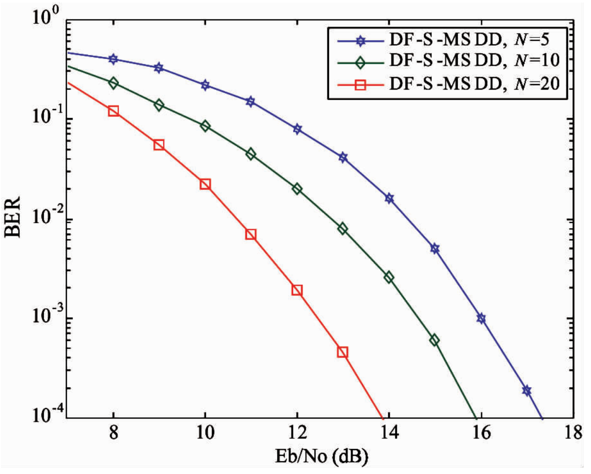

Fig. 1 BER performance of the proposed DF-S-MSDD in the UWB system with DSTBC

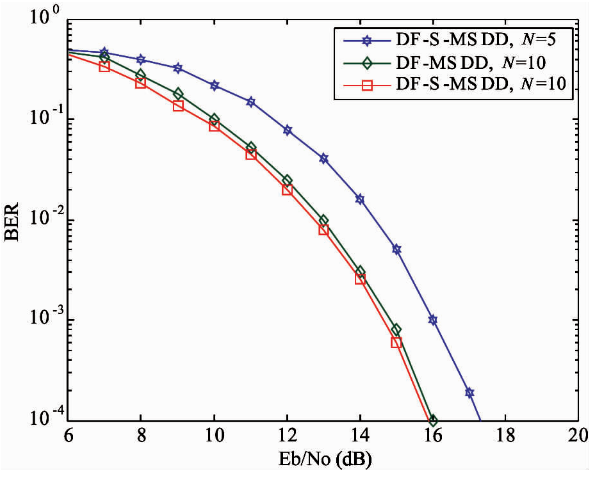

Fig. 2 BER performance comparison of the proposed DF-S-MSDD and DF-MSDD in the UWB system

edge of the observation window. On the other hand, DF-S-MSDD requires a low computational complexity by exploiting the decision-feedback. Finally, Monte-Carlo simulations confirm that DF-S-MSDD provides the BER performance better than the DF-MSDD benchmarker regardless of the number of the observation window, whereas with a reasonable complexity.

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