

Research Article

Decision-Feedback Aided Multiple-Symbol Differential Detection in Two-Way Relay Transmission

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In this paper, noncoherent transmission algorithms are proposed in a two-way relay transmission (TWRT), where differential space-time block codes based multiple-symbol differential detection (MSDD) is performed. Specifically, generalized likelihood ratio test aided MSDD (GLRT-MSDD) is developed with the exhaustive search in the TWRT. In order to solve the challenging problem of high complexity, the GLRT-MSDD model is reformulated and a decision-feedback aided MSDD (DF-MSDD) model is derived. Furthermore, performance analysis and the simulations confirm that the proposed DF-MSDD provides solid bit error-rate performance with a lower complexity than GLRT-MSDD in the TWRT.

1. Introduction

In one-way transmission, 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 the CSI. Therefore, noncoherent detection, such as transmitted-reference and differential detection, becomes attractive alternative [2–4]. Unfortunately, there is 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]. Furthermore, multiple-symbol differential detection (MSDD) receives much research attention [6–8].

On the other hand, the drawback of one-way transmission is the low power efficiency. A well-established scheme of enhancing the power efficiency is the two-way relay transmission (TWRT) by exploiting network coding. However, it is challenging for the coherent transmission at the relay to estimate the unknown carrier phase offset. Recently, a symbol by symbol noncoherent detection is presented in TWRT with binary continuous phase frequency shift keying in [9]. Furthermore, MSDD has been introduced in TWRT modulated with frequency shift keying [10] and also investigated in ultra-wideband (UWB) impulse TWRT [11].

In this paper, differential space-time block codes (DSTBC) based MSDD is further developed in TWRT. Due to exploiting the multipath diversity and spatial diversity of DSTBC, a performance gain is achieved compared with single-input single-output (SISO) transmission in TWRT. Specifically, a generalized likelihood ratio test (GLRT) aided MSDD, dubbed GLRT-MSDD, is proposed firstly. It is interesting to point out that, when compared to the existing MSDDs advocated in the noncoherent TWRT [10, 11], the system performance is significantly improved by employing the DSTBC with the proposed GLRT-MSDD. However, it imposes an exponentially increasing complexity with the number of the observation windows. Thus, the GLRT-MSDD is impractical when the number of the observation windows increases, and it is necessary to seek a more practical algorithm in the TWRT. Decision-feedback (DF) represents the computationally efficient algorithm in signal detection and estimation [12]. According to the DF theory, we propose a transformation for DSTBC aided GLRT-MSDD and propose DF based MSDD (DF-MSDD), which allow us to simplify the classic exhaustive search as detection with a lower computational complexity. The proposed MSDD algorithms are particularly attractive for the noncoherent TWRT and can be applied in many noncoherent transmission scenarios. Relying on this technique, in this paper the system description and simulation experiments are

discussed in the DSTBC aided UWB TWRT. More explicitly, the major contributions of this paper are summarized as follows.

(1) In view of the particularity of the UWB system, some existing MSDDs cannot be easily extended to multi-antenna UWB TWRT. Thus, some transformation and reconstruction are imposed to conceive the GLRT-MSDD in the DSTBC aided UWB TWRT. When compared to the existing MSDDs of [10, 11], the proposed GLRT-MSDD is attractive, because more accurate detection information can be efficiently obtained without perfect channel state information.

(2) Aiming to reduce the excessive complexity of the proposed GLRT-MSDD in the DSTBC aided UWB TWRT, we propose a DF-MSDD, which is capable of decreasing the dimension of search space. When the previous detected symbols are substituted into the metric of GLRT-MSDD, the current symbol will be detected easily with DF-MSDD.

(3) The theoretical lower bound of the DF-MSDD is analyzed to validate its solid performance in the DSTBC aided UWB TWRT. Particularly, when the size of the observation window in MSDD is large, it is difficult to predict the BER performance by simulations in the TWRT. However, the estimation of the BER performance can be easily obtained with the aid of the theoretical analysis of the proposed DF-MSDD.

It is worth emphasizing that the proposed MSDDs can be generalized in many other TWRT by implementing a reasonable transformation. Particularly, the UWB signal contains a lot of dense multipaths components [13]. Therefore, using the optimal coherent detector will increase the difficulty and cost of system implementation. Thus, noncoherent schemes become inevitable in UWB TWRT. In the following, the GLRT-MSDD and DF-MSDD will be derived in the DSTBC aided UWB TWRT.

The structure of this paper is formulated as follows. The system description of the TWRT is offered in Section 2. The GLRT-MSDD in the DSTBC aided UWB TWRT is presented in Section 3. In Section 4, the proposed DF-MSDD is detailed for reducing the computational complexity of GLRT-MSDD. From the perspective of effectiveness, theoretical lower bound for performance analysis of the DF-MSDD is derived in Section 5. Considering the practicability, the computational complexity and the detection performance of the proposed MSDDs are discussed by simulations in Section 6. Finally, conclusions are drawn in Section 7.

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

2. System Description

In this section, the multiple-input multiple-output (MIMO) system description will be introduced for DSTBC aided UWB TWRT. As shown in Figure 1, a three-node network model is considered, where A_1 and A_2 are the user nodes equipped

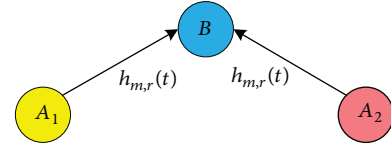


FIGURE 1: In the up-link phase of the DSTBC aided UWB TWRT, the user node A_1 or A_2 sends information to the relay node B .

with T ($T > 1$) transmit antennas, respectively, and B is the relay node equipped with R ($R > 1$) receive antennas. In the up-link phase of the DSTBC aided UWB TWRT, the user node A_1 or A_2 sends information to the relay node B . At the transmitter, S denotes the data rate, and TS bits map to $T \times T$ unitary matrices \mathbf{C}_i , which is the i -th information symbol. With the aid of differential encoding, the transmission symbol is given as

$$\mathbf{G}_{i+1} = \mathbf{G}_i \mathbf{C}_{i+1}, \quad (1)$$

where $i = 0, 1, \dots, M-1$, and M denotes the total number of transmission symbols. The DSTBC information symbol is selected from a codeword set as $\mathbf{C}_i \in \Omega$. $T \times T$ matrices \mathbf{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 [14–16], the proposed MSDDs are applicable to the TWRT where the number of antennas is more than 2. For simplicity, the transmit antenna is set to $T = 2$ in the following. Each DSTBC symbol maps onto the information-bearing DSTBC symbol [17], and it belongs to the set $\Omega = \{\mathbf{C}^0, \mathbf{C}^1, \mathbf{C}^2, \mathbf{C}^3\}$. The corresponding rules for bits information and DSTBC symbols are given as follows. $00 \rightarrow \mathbf{C}^0 = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$, $01 \rightarrow \mathbf{C}^1 = \begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix}$, $10 \rightarrow \mathbf{C}^2 = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}$, $11 \rightarrow \mathbf{C}^3 = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$. In the transmitted symbols \mathbf{G}_i , the reference symbol is $\mathbf{G}_0 = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$. Define $m = 1, 2$ and $n = 1, 2$; then for the i -th symbol \mathbf{G}_i , the m -th row and the n -th column entry can be represented by the UWB signal $g_{m,2i+n-1}$, and the correspondence between $g_{m,2i+n-1}$ and the transmitted symbol is given as

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

where $s_m(t)$ is the transmitted signal for the m -th antenna, and 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 two 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 (2) is reformulated as

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

In the noncoherent transmission, we assume that the channel is quasi-static fading; i.e., the channel is assumed to be constant during T intervals [13]. The channel impulse response between the m -th transmit antenna and the r -th ($1 \leq r \leq R$) receive antenna is given by

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

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

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

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

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

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 sides. In two adjacent time intervals, a receive antenna obtains information of one symbol. Then, the i -th information symbol received by the r -th antenna can be expressed as $[y_r(t + 2iT) \ y_r(t + 2iT + T)]$. To help understand and implement the proposed algorithms, the received signal of the i -th information symbol from R receive antenna can be rewritten with matrix as

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

Based on the received signal, the GLRT-MSDD will be formulated in the DSTBC aided UWB TWRT.

In the following, inspired by the conclusions drawn in a single antenna TWRT, we will investigate the algorithm in multiantenna TWRT.

3. GLRT-MSDD in DSTBC Aided UWB TWRT

It is assumed that the number of the observation windows is N DSTBC symbols. Our target is how to detect $N - 1$ information-bearing symbols jointly from the N received symbols. As such, the relationship between the information symbols \mathbf{C}_i and the received symbols is investigated. Firstly, $N - 1$ information symbols are expressed as the set $\mathbb{C} = [\mathbf{C}_1, \mathbf{C}_2, \dots, \mathbf{C}_{N-1}]$. Furthermore, \mathbf{C} will be detected from the received signal $\{y_r(t)\}$ of N observation window, where $0 <$

$t \leq NT_s$. When $y_r(t)$ is obtained, the signal matrices will be combined with R received signal as (7). With the aid of the GLRT criterion [8], \mathbf{C} can be determined with

$$\Lambda(y_r(t) | \bar{\mathbf{C}}, \bar{\rho}_{m,r}(t)) = 2 \int_0^{(N-1)T_s} y_r(t) \bar{x}_r(t) dt - \int_0^{(N-1)T_s} (\bar{x}_r(t))^2 dt, \quad (8)$$

where $\bar{x}_r(t)$ is the candidate received signal, which is determined with the candidate information symbols $\bar{g}_{m,j}$ and the template $\bar{\rho}_{m,r}(t)$ given by

$$\bar{x}_r(t) = \sqrt{\frac{E_b}{2}} \sum_{m=1}^2 \sum_{j=1}^{2N} \bar{g}_{m,j} \bar{\rho}_{m,r}(t - (j-1)T_f) + n_r(t), \quad (9)$$

where $\{\bar{\rho}_{m,r}(t)\}$ is the optimum template formulated as

$$\bar{\rho}_{m,r}(t) = \frac{1}{M\sqrt{2E_b}} \sum_{j=1}^{2N} \bar{g}_{m,j} y_r(t + (j-1)T_f). \quad (10)$$

Substituting (9) and (10) into (8), we have

$$\begin{aligned} \Lambda(y_r(t) | \bar{\mathbf{C}}, \bar{\rho}_{m,r}(t)) \\ = \sum_{m=1}^2 \Lambda(y_r(t) | \{\bar{g}_{m,j}\}, \bar{\rho}_{m,r}(t)). \end{aligned} \quad (11)$$

Inspired by the GLRT-MSDD rule of the single antenna TWRT [8], in the DSTBC aided UWB TWRT, $\bar{\mathbf{C}}$ can be determined as

$$\begin{aligned} \bar{\mathbf{C}} &= \arg \max_{\bar{\mathbf{C}} \in \Omega^{N-1}} \left\{ \max_{\bar{\rho}_{m,r}(t)} \Lambda(y_r(t) | \bar{\mathbf{C}}, \{\bar{\rho}_{m,r}(t)\}_{m=1}^2) \right\} \\ &= \sum_{m=1}^2 \arg \max_{\bar{\mathbf{C}} \in \Omega^{N-1}} \left\{ \max_{\bar{\rho}_{m,r}(t)} \Lambda(y_r(t) | \{\bar{g}_{m,j}(t)\}_{j=1}^{2M}, \bar{\rho}_{m,r}(t)) \right\}, \end{aligned} \quad (12)$$

where $\bar{\mathbf{C}} = [\bar{\mathbf{C}}_1, \bar{\mathbf{C}}_2, \dots, \bar{\mathbf{C}}_{N-1}]$ is the candidate information symbols. According to the criterion proposed in [18], (12) is equivalent to

$$\bar{\mathbf{C}} = \arg \max_{\bar{\mathbf{C}} \in \Omega^{N-1}} \left\{ \sum_{\beta=1}^{N-1} \sum_{\gamma=0}^{\beta-1} \text{Tr} \left[\left(\prod_{i=\gamma+1}^{\beta} \bar{\mathbf{C}}_i \right) \mathbf{Q}_{\beta,\gamma} \right] \right\}, \quad (13)$$

where $\mathbf{Q}_{\beta,\gamma}$ 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

$$\mathbf{Q}_{\beta,\gamma} = \sum_{r=1}^R \left(\int_0^{T_i} \mathbf{y}_{\beta}^T(t) \mathbf{y}_{\gamma}(t) dt \right), \quad (14)$$

where T_i is the integration interval. By GLRT-MSDD in (13), $N - 1$ consecutive symbols will be estimated according to

the observation of N received symbols. It can be seen that the MSDD in (13) is an exhaustive search process. Hence, the proposed GLRT-MSDD in the DSTBC aided UWB TWRT imposes an exponentially increasing complexity with the number of observation windows N . To address this issue, DF mechanism is introduced and DF-MSDD is demonstrated for the DSTBC aided UWB TWRT in the next section.

4. DF-MSDD in DSTBC Aided UWB TWRT

By exploiting the decision-feedback algorithm, instead of optimizing all the symbols over an observation window of GLRT-MSDD, the previous decision symbols are fed back and implemented into the GLRT-MSDD metric. For example, in the observation window of $[\tilde{\mathbf{C}}_{\beta-N+1}, \dots, \tilde{\mathbf{C}}_{\beta-1}, \tilde{\mathbf{C}}_{\beta}]$, the previous decision-feedback symbols, i.e., $[\tilde{\mathbf{C}}_{\beta-N+1}, \tilde{\mathbf{C}}_{\beta-N+2}, \dots, \tilde{\mathbf{C}}_{\beta-1}]$, are substituted into (13), and then the DF-MSDD for the DSTBC aided UWB TWRT is derived as

$$\hat{\mathbf{C}}_{\beta} = \arg \max_{\tilde{\mathbf{C}}_{\beta} \in \Omega} \left\{ \sum_{\gamma=\beta-N+1}^{\beta-1} \text{Tr} \left[\left(\prod_{i=\gamma+1}^{\beta-1} \tilde{\mathbf{C}}_i \right) \tilde{\mathbf{C}}_{\beta} \mathbf{Q}_{\beta,\gamma} \right] \right\}. \quad (15)$$

According to the DF-MSDD given in (15), it is obvious that only a codeword symbol is detected in an observation window. Thus, when compared to the GLRT-MSDD, the computational complexity index of DF-MSDD will be reduced from $N - 1$ to 1. In addition, the range of the correlation function will become smaller for the DF-MSDD than GLRT-MSDD in the DSTBC aided UWB TWRT. When the DF-MSDD is applied into the TWRT, an efficient noncoherent transmission will be obtained.

Remark 1. In the up-link of the TWRT, the proposed GLRT-MSDD or the DF-MSDD can be employed. Furthermore, the logical exclusion or (XOR) network coding is adopted at the relay for operating the information from users. In the down-link, the network information encoded is transmitted from the relay to the users. Then, through the use of the XOR operation of the received signal and self-information, the two users will obtain the information from each other.

Remark 2. In fact, the proposed GLRT-MSDD and DF-MSDD are suitable under two scenarios as follows. (1) The DSTBC aided UWB TWRT consists of two phases. The two users A_1 and A_2 transmit signals to the relay simultaneously in the first phase, and then GLRT-MSDD/DF-MSDD and the XOR operation are operated at the relay, respectively. Furthermore, the network information encoded is broadcasted in the second phase. (2) There are three phases in the TWRT. In the first and the second phases, user A_1 or A_2 transmits signals, respectively; then the XOR is operated at the relay. Furthermore, in the third phase, the relay receives the network information encoded and broadcasts it to the users.

5. Performance Analysis of DF-MSDD in DSTBC Aided UWB TWRT

The multiple access phase of the DSTBC aided UWB TWRT is considered, and the performance of the proposed DF-MSDD will be analyzed in the following. In the observation window of $[\mathbf{C}_{\beta-N+1}, \dots, \mathbf{C}_{\beta-1}, \mathbf{C}_{\beta}]$, assume that the decision-feedback symbols of $[\mathbf{C}_{\beta-N+1}, \mathbf{C}_{\beta-N+2}, \dots, \mathbf{C}_{\beta-1}]$ are correct. Then, the lower bound of the BER performance for the DF-MSDD can be evaluated by means of the genie-based DF-MSDD receiver [19]. Suppose the event of transmitting the codeword symbol \mathbf{C}^k is denoted as Θ_k with $k = 0, 1, 2, 3$. Without loss of generality, it is assumed that Θ_0 happened. Then, the probability of transmitting \mathbf{C}^0 is formulated as

$$P_0 = P(\Theta_0 > \Theta_1, \Theta_0 > \Theta_2, \Theta_0 > \Theta_3, \Theta_0 > \Theta_4). \quad (16)$$

To obtain P_0 , the details of correction function $\mathbf{Q}_{\beta,\gamma}$ in (15) should be investigated. With matrix form, it can be formulated as

$$\mathbf{Q}_{\beta,\gamma} = \mathbf{S}_{\beta,\gamma} + \mathbf{N}_{\beta,\gamma}, \quad (17)$$

where $\mathbf{S}_{\beta,\gamma}$ and $\mathbf{N}_{\beta,\gamma}$ are the signal component and the noise component, respectively. The noise component is regarded as approximately Gaussian [20]. For notational simplicity, we introduce the channel energy between the m -th transmit antenna and the r -th receive antenna as $E_{m,r} = \int_0^{T_i} (\rho_{m,r}(t))^2 dt$, and the total channel energy from two transmit antennas can be expressed by $E_c = R \sum_{r=1}^R (E_{1,r} + E_{2,r})$. Based on the notation, the conditional probability density function of Θ_0 is derived as

$$f(\Theta_0) = \frac{1}{\sqrt{2\pi}\sigma_0} \exp\left(-\frac{(\Phi_0 - \mu_0)^2}{2\sigma_0^2}\right), \quad (18)$$

whose mean is $\mu_0 = E_b(N - 1)E_c$, and whose variance is $\sigma_0^2 = (N - 1)(E_b N_0 E_c + N_0^2 B T_i)$ [12], in which B is the bandwidth of the filter at the receiver. Then, according to the conditional probability density function, we can obtain the codeword correct probability of Θ_0 as

$$\begin{aligned} P_c(\Theta_0) &= \int_0^{+\infty} \text{erf}\left(\frac{\Phi_0}{\sqrt{2}\sigma_0}\right) f(\Theta_0) d\Phi_0 \\ &= \int_0^{+\infty} \text{erf}\left(\frac{\Phi_0}{\sqrt{2}\sigma_0}\right) \frac{1}{\sqrt{2\pi}\sigma_0} \\ &\quad \cdot \exp\left(-\frac{(\Phi_0 - \mu_0)^2}{2\sigma_0^2}\right) d\Phi_0. \end{aligned} \quad (19)$$

Therefore, the codeword error probability of Θ_0 can be evaluated by

$$P_e(\Theta_0) = 1 - P_c(\Theta_0). \quad (20)$$

According to the relationship between the codeword error probability and the bit error probability, the BER is derived as

$$P_{BER}(\Theta_0) = \frac{1}{2} P_e(\Theta_0). \quad (21)$$

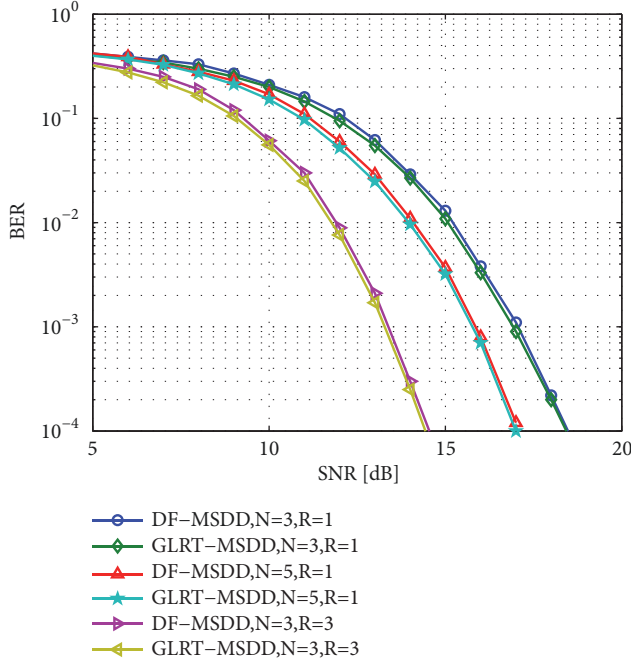


FIGURE 2: BER performance comparison of the proposed GLRT-MSDD and DF-MSDD in the DSTBC aided UWB TWRT, where the receive antenna is fixed to $R = 1, 3$, and the number of observation windows is $N = 3, 5$, respectively.

Considering the average BER over the channels, we can show the lower bound of the genie-based DF-MSDD in the DSTBC aided UWB TWRT as

$$P_{BER} = \int_{-\infty}^{+\infty} P_{BER}(\Theta_0) P(h) dh, \quad (22)$$

where $P(h)$ is the conditional channel probability.

Note that when the size of the observation window is large, it is difficult to implement the numerical simulation to predict the detection performance in DSTBC aided UWB TWRT. Using the lower bound of the genie-based DF-MSDD, the BER performance of the TWRT can be predicted accurately.

6. Simulations and Discussions

In this section, Monte-Carlo simulations are carried out to validate the advantages of the proposed noncoherent transmission in the DSTBC aided UWB TWRT. For illustrative purpose, we consider the proposed MSDDs during the multiple access phase. The channel is given as the IEEE 802.15.3a CM2 model [17]. The monocycle waveform $\omega(t)$ is generated with $\omega(t) = [1 - 4\pi(t/T_\omega)^2] \exp[-2\pi(t/T_\omega)^2]$, where the pulse duration is $T_\omega = 0.287$ ns. The frame duration is $T_f = 80$ ns, and the maximum excess delay of the channel is chosen as $T_n = 40$ ns, where $T_f > T_n$ eliminates the intersymbol interference. Furthermore, the BER performance of the proposed MSDDs is evaluated in

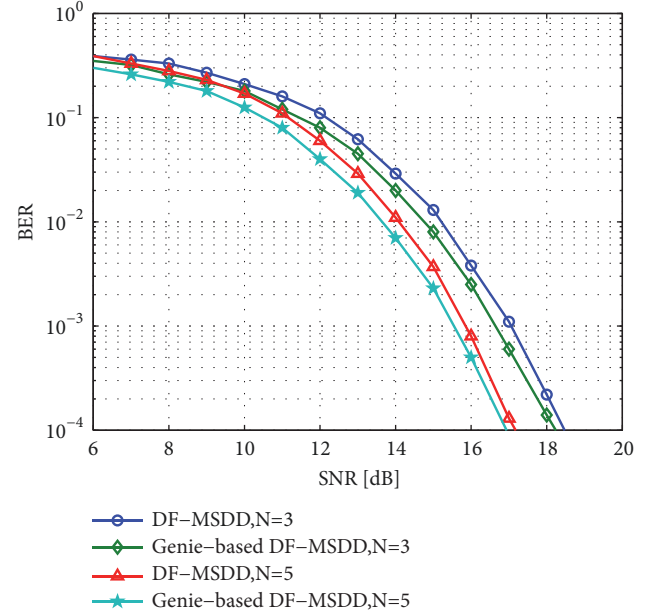


FIGURE 3: BER performance comparison of the genie-aided DF-MSDD and the simulated DF-MSDD, where the receive antenna is $R = 1$, and the number of observation windows is $N = 3, 5$, respectively.

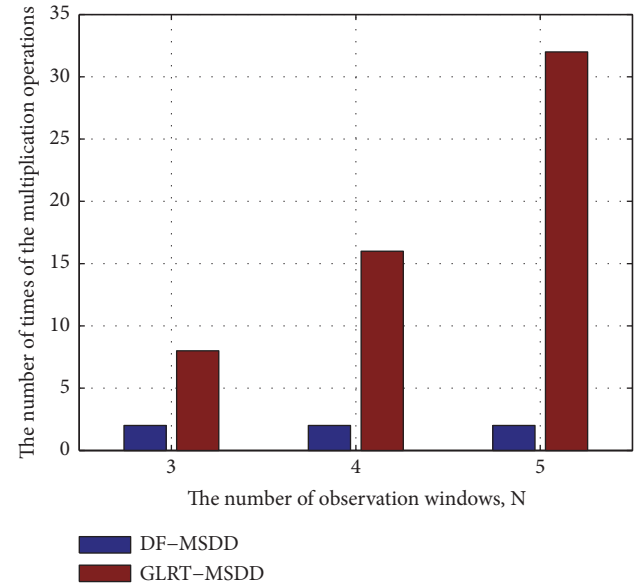


FIGURE 4: Complexity comparison of GLRT-MSDD and DF-MSDD in the DSTBC aided UWB TWRT against different number of observation windows, $N = 3, 4, 5$.

Figures 2 and 3, and complexity comparison of GLRT-MSDD and DF-MSDD is shown in Figure 4.

Test Scenario 1. In this test, the advantages of the proposed GLRT-MSDD and DF-MSDD will be illustrated in the DSTBC aided UWB TWRT. Specifically, the BER performance of proposed MSDDs is compared by varying the receive antenna when $R = 1$ and 3, respectively. Furthermore,

when the receive antenna is $R = 1$, BER performance comparison of the MSDDs is demonstrated with different number of observation windows when $M = 3, 5$, respectively. We can clearly see from Figure 2 that the DF-MSDD yields a BER performance close to that of GLRT-MSDD at all SNRs in the DSTBC aided UWB TWRT.

Test Scenario 2. The theoretical analysis of the genie-aided DF-MSDD is evaluated. It can be seen from Figure 3 that the genie-aided DF-MSDD provides good performance approximation with the simulated DF-MSDD. On the other hand, there is a gap between the theoretical evaluation and the simulated DF-MSDD. This is due to the error propagation of the decision-feedback in the simulated DF-MSDD.

Test Scenario 3. In Figure 4, we compare the computational complexity of GLRT-MSDD and DF-MSDD in terms of multiplication operation, where the red and blue bars represent the computational complexity of the GLRT-MSDD and DF-MSDD algorithms, respectively. It is readily seen that the GLRT-MSDD imposes significantly higher computational complexity than the DF-MSDD when N is large. This is consistent with the complexity analysis. This implies that it might be difficult to use the GLRT-MSDD in the multiantenna UWB TWRT when the transmit antennas $T > 2$ or in the “massive” MIMO systems, where the DF-MSDD might be more promising.

7. Conclusions

In contrast to the existing noncoherent transmission in UWB TWRT, the proposed GLRT-MSDD generates the performance gain of diversity and multiplexing by employing the DSTBC. Based on this contribution, the GLRT-MSDD achieves appealing BER performance by exploiting exhaustive search algorithm. Furthermore, when the proposed GLRT-MSDD is reformulated, a low-complexity DF-MSDD is derived to facilitate the practical implementation. In addition, the genie-aided DF-MSDD is analyzed to provide theoretical approximation with the simulated DF-MSDD, and complexity analysis proves that the DF-MSDD requires a lower computational complexity than the GLRT-MSDD. Finally, Monte-Carlo simulations confirm that DF-MSDD provides BER performance extremely identical to that of GLRT-MSDD benchmark regardless of the number of the observation windows and the receive antenna, but with a smaller complexity.

Data Availability

The data used in this paper is obtained by Matlab simulation. Figures 2, 3, and 4 are Matlab simulation that anyone can access.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

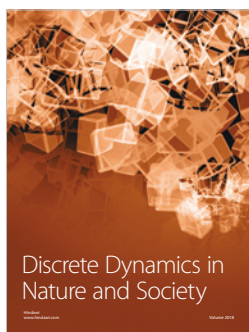
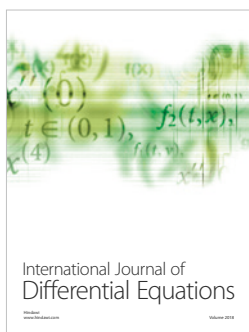
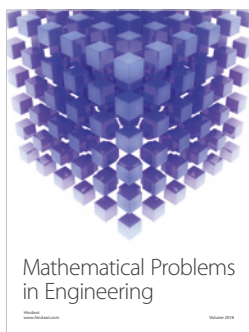
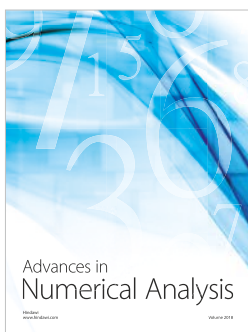
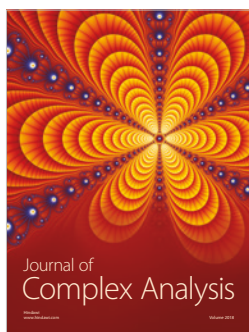
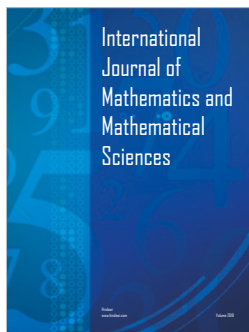
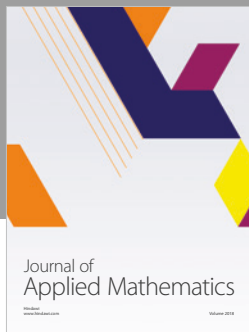
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