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Improving performance of the asynchronous cooperative relay network with maximum ratio combining and transmit antenna selection technique

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Abstract

In this paper, a new amplify and forward (AF) asynchronous cooperative relay network using maximum ratio combining (MRC) and transmit antenna selection (TAS) technique is considered. In order to obtain a maximal received diversity gain, the received signal vectors from all antennas of the each relay node are jointly combined by MRC technique in the first phase. Then, one antenna of each relay node is selected for forwarding MRC signal vectors to the destination node in the second phase. The proposed scheme not only offers to reduce the interference components induced by inter-symbol interference (ISI) among the relay nodes, but also can effectively remove them with employment near-optimum detection (NOD) at the destination node as compared to the previous distributed close loop extended-orthogonal space time block code (DCL EO-STBC) scheme. The analysis and simulation results confirm that the new scheme outperforms the previous cooperative relay networks in both synchronous and asynchronous conditions. Moreover, the proposed scheme allows to reduce the requirement of the Radio-Frequency (RF) chains at the relay nodes and is extended to general multi-antenna relay network without decreasing transmission rate.

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1. Introduction

Space-time block coding (STBC) can be employed in the distributed manner, referred as a distributed STBC (DSTC), to exploit the spatial diversity available more efficiently and provide coding gain in these networks. Generally, there are two types of relaying methods that were discussed in the literatures: (1) amplify and forward (AF) [1-6], that is linear process, in which the received

signals are amplified then transmitted to the destination node, and (2) decode and forward (DF) [7-12], that decodes the received signal from the source, re-encode the decoded data, and transmit to the destination node. This paper focuses on simple relaying protocols based on amplify and forward strategy since it is easier to implement them in the small relay nodes and moreover, it does not require the knowledge of the channel fading gains at the relay nodes. Therefore, we can avoid imposing bottlenecks on the rate by requiring some relays to decode.

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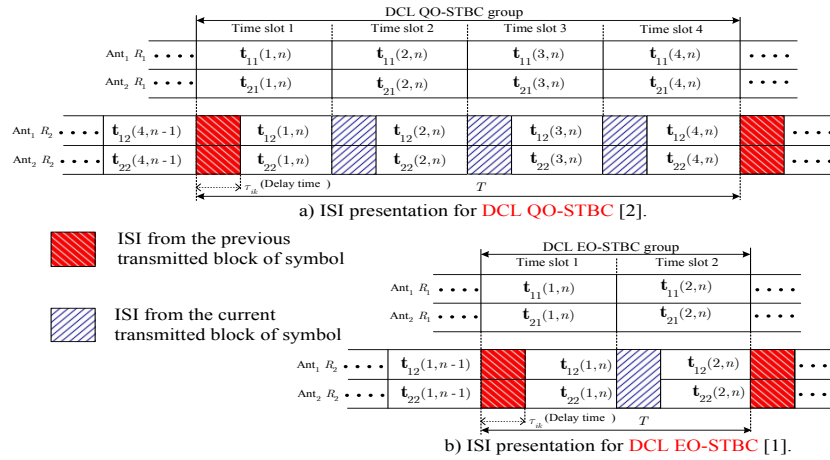


Fig. 1. Example number of ISI components for DCL EO-STBC [1] and DCL QO-STBC [2].

The distributed close loop extended orthogonal space time block code (DCL EO-STBC) [1] and distributed close loop quasi-orthogonal space time block code (DCL QO-STBC) [2] are proposed for two dual-antenna relay nodes in the AF strategy. It has been shown that both the DCL EO-STBC and DCL QO-STBC achieve cooperative diversity order of four with unity data transmission rate between the relay nodes and the destination node. However, the existing research on DSTC schemes [1], [2], [3], and [8], where each relay antenna processes its received signal independently, so that this received signal combining is not optimal for multi-antenna relay networks because the co-located antennas of the each relay are treated as distributed antennas.

Additionally, due to the distributed nature of cooperative relay nodes, the received DSTC symbols at the destination node will damage the orthogonal feature by introducing inter-symbol interference (ISI) components and degrade significantly the system performance. In the asynchronous cooperative relay networks, the number of ISI components depends on both the structure of the DSTC and the number of the imperfect synchronous links [11]. The Fig. 1 illustrates a representation of ISI components at the received symbols for the DCL EO-STBC [1]

and DCL QO-STBC [2]. It could be evident that the DCL EO-STBC scheme has less number of ISI components than the DCL QO-STBC one. Note that, they have the similar configuration network and the imperfect synchronous channel assumptions. Moreover, the destination node uses the detection of interference cancellation, called near-optimum detection (NOD) [1], [9] and parallel interference cancellation detection [2], to eliminate ISI components, which is only solution at the receiver.

As mentioned earlier, although a lot of phase feedback schemes can be proved to improve the distributed close loop system performance, other problems of these systems have to use all antennas of the relay node for forwarding the signals to the destination node. This improvement comes along with an increase in complexity, size, and cost in hardware design [5]. Moreover, the previous DSTC schemes can not be directly applied on the multi-antenna relay networks, where each relay has more than two antennas.

In this paper, we propose the asynchronous cooperative relay network using optimal MRC technique for jointly combining received signals from the source node. In the second phase, the TAS technique utilizes at the relay nodes which chooses the best antenna to retransmit the resulting

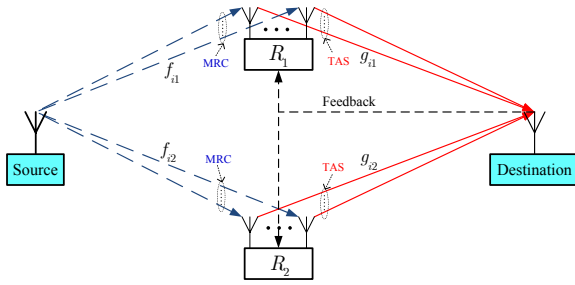


Fig. 2. The proposed cooperative relay network with MRC/TAS technique.

signals to the destination. Different with all of the above-mentioned papers, our proposed scheme uses TAS technique to reduce the number of the ISI components and the requirement of the RF chains. Moreover, the destination node utilizes the NOD to remove the ISI components effectively.

The rest of the paper is organized as follows: In the Sec. 2, we describe a new asynchronous cooperative relay network with the MRC and TAS technique (MRC/TAS) at the relay nodes; the Sec. 3 represents the application of the near-optimum detection (NOD) at the destination node for the proposed scheme; simulation results and performance comparisons are represented in Sec. 4; finally, the conclusion follows in Sec. 5.

Notations: the bold lowercase \mathbf{a} and bold uppercase \mathbf{A} denote vector and matrix, respectively; $[\cdot]^T$, $[\cdot]^*$, $[\cdot]^H$ and $\|\cdot\|^2$ denote transpose, conjugate, Hermitian (complex conjugate) and Frobenius, respectively; \mathcal{A} indicates the signal constellation.

2. The proposed asynchronous cooperative relay network with MRC/TAS technique

In this paper, a new asynchronous cooperative relay network with MRC and TAS technique is considered as shown in Fig. 2. This model consists of a source node, a destination node and two relay nodes. Each terminal node, i.e. the source node and the destination node, is equipped with a single antenna while each relay node is equipped with

N_R antennas. It is assumed that there is no Direct Transmission (DT) connection between the source and the destination due to shadowing or too large distance. The relay node operating is assumed in half-duplex mode and AF strategy. The channel coefficient from the source node to i th the antenna of the k th relay node and the channel coefficient from the i th antenna of the k th relay node to the destination node indicate f_{ik} and g_{ik} (for $k = 1, 2; i = 1, \dots, N_R$), respectively. The noise terms of the relay and destination node are assumed AWGN with distribution $CN(0, 1)$. The total transmission power of one symbol is fixed as P (dB). Thus, the optimal power allocation is adopted as follows [12]

$$P_1 = \frac{P}{2}, P_2 = \frac{P}{4}, \quad (1)$$

where P_1 and P_2 are the average transmission power at the source and each relay node, respectively.

2.1. In the first phase (broadcast phase)

The information symbols are transmitted from the source node to the destination node via two different phases. In the first phase, the source node broadcasts the sequence of quadrature phase-shift keying (QPSK), which is grouped into symbol vector $\mathbf{s}(n) = [s(1, n) \quad -s^*(2, n)]^T$. The received symbol vector at i th antenna of the k th relay node is given by

$$\mathbf{r}_{ik}(n) = \sqrt{P_1} f_{ik} \mathbf{s}(n) + \mathbf{v}_{ik}(n), \quad \text{for } k = 1, 2; i = 1, \dots, N_R \quad (2)$$

where $\mathbf{v}_{ik}(n)$ is the additive Gaussian noise vector at each antenna of each relay node.

In the conventional DSTC scheme [1, 2], the transmitted symbols from each relay antenna at the same relay node is designed to be a linear function of the received signal and its conjugate. It is clear that this is not optimal for networks whose relays have multiple antennas because the co-located antennas of the same relay are treated as distributed

antennas. In order to achieve the optimal received diversity gain, the received symbols at the each relay node are combined by using MRC technique as follow

$$\mathbf{r}_k(n) = \frac{1}{\|f_k\|_F} \begin{bmatrix} r_{1k}(n) & \cdots & r_{N_R k}(n) \end{bmatrix} \begin{bmatrix} f_{1k}^* \\ \vdots \\ f_{N_R k}^* \end{bmatrix}, \quad (3)$$

for $k = 1, 2; i = 1, \dots, N_R,$

where $\mathbf{r}_k(n)$ is received symbol vector at k th relay node after using MRC process and $\|f_k\|_F = \sqrt{|f_{1k}|^2 + \cdots + |f_{N_R k}|^2}$. The transmitted symbol vector from selected transmit antenna $\mathbf{t}_k(n)$ is described by a linear function of $\mathbf{r}_k(n)$ and its conjugate $\mathbf{r}_k^*(n)$ as follow

$$\mathbf{t}_k(n) = \sqrt{\frac{P_2}{P_1 + 1}} (\mathbf{A}_k \mathbf{r}_k(n) + \mathbf{B}_k \mathbf{r}_k^*(n)). \quad (4)$$

This paper uses distributed matrices $\mathbf{A}_k, \mathbf{B}_k$ with Alamouti DSTC [13] to obtain a unity transmission rate and linear complexity detection. Note that, the factor $\sqrt{P_2/(P_1 + 1)}$ in the equation (4) ensures that the average transmission power at each relay node is P_2 .

2.2. In the second phase (cooperative phase).

In the second phase, the transmit antenna of each relay node can be selected by below criterion [14], which achieves a maximal transmitted diversity gain

$$u^{(k)} = \max_{i=1, \dots, N_R} |g_{ik}|^2; \text{ for } k = 1, 2; i = 1, \dots, N_R, \quad (5)$$

where $u^{(k)}$ is the selected transmit antenna index of the k th relay node. g_k ($k = 1, 2$) denotes the channel gain from the selected transmit antenna of the k th relay node to the destination node. The TAS technique allows to achieve the transmitted diversity gain in the second phase.

As the previous mention in [1-2], the transmitted signals from the cooperative relay nodes to the destination will undergo different time delays due

to different locations of the relay nodes. Therefore, the received symbols at the destination node may not align. Without loss of generality, we assume that both antennas of the first relay node (denotes R_1) and the destination node are synchronized perfectly, whereas both antennas of the second relay node (denotes R_2) and the destination node are synchronized imperfectly (*e.i.* $\tau_2 = \tau_{12} = \tau_{22} \neq 0$) as shown in Fig. 3. The received symbols at the destination are written as follow

$$\mathbf{y}(1, n) = \mathbf{t}_1(1, n)g_1(n) + \mathbf{t}_2(1, n)g_2(n) + \mathbf{t}_2(2, n-1)g_2(n-1) + \mathbf{z}(1, n), \quad (6)$$

$$\mathbf{y}(2, n) = \mathbf{t}_1(2, n)g_1(n) + \mathbf{t}_2(2, n)g_2(n) + \mathbf{t}_2(1, n)g_2(n-1) + \mathbf{z}(2, n), \quad (7)$$

where $\mathbf{z}(n)$ is the additive Gaussian noise vector at the destination. By substituting (4) into (6) and (7), then taking the conjugate of $\mathbf{y}(2, n)$, the received symbols at the destination can be rewritten as

$$\mathbf{y}(1, n) = \sqrt{\frac{P_2 P_1}{1 + P_1}} (\|f_1\|_F g_1(n) \mathbf{s}(1, n) + \|f_2\|_F g_2(n) \mathbf{s}(2, n)) + \sqrt{\frac{P_2 P_1}{1 + P_1}} \|f_2\|_F g_2(n-1) \mathbf{s}^*(1, n-1) + \sqrt{\frac{P_2}{1 + P_1}} (g_1(n) \mathbf{v}_1(1, n) - g_2(n) \mathbf{v}_2^*(2, n)) + \mathbf{z}(1, n), \quad (8)$$

$$\mathbf{y}^*(2, n) = \sqrt{\frac{P_2 P_1}{1 + P_1}} (\|f_2\|_F g_2^*(n) \mathbf{s}(1, n) - \|f_1\|_F g_1^*(n) \mathbf{s}(2, n)) + \sqrt{\frac{P_2 P_1}{1 + P_1}} g_2^*(n-1) \mathbf{s}^*(2, n) + \sqrt{\frac{P_2}{1 + P_1}} (g_1^*(n) \mathbf{v}_1^*(2, n) + g_2^*(n) \mathbf{v}_2(1, n)) + \mathbf{z}^*(2, n), \quad (9)$$

The equation (8) and (9) can be rewritten in vector form as

$$\mathbf{y}'(n) = \begin{bmatrix} \mathbf{y}(1, n) \\ \mathbf{y}^*(2, n) \end{bmatrix} = \sqrt{\frac{P_2 P_1}{1 + P_1}} \mathbf{H} \mathbf{s}'(n) + \sqrt{\frac{P_2 P_1}{1 + P_1}} \mathbf{I}_{\text{int}}(n) + \mathbf{w}(n), \quad (10)$$

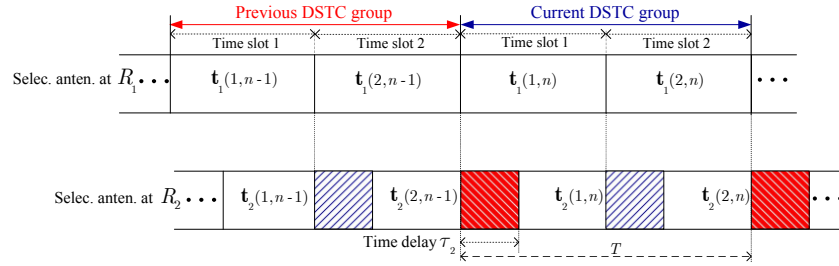


Fig. 3. Representation of ISI components between the selected transmit relay antenna and the destination antenna.

where

$$\mathbf{H} = \begin{bmatrix} \|f_1\|_F g_1(n) & \|f_2\|_F g_2(n) \\ \|f_2\|_F g_2^*(n) & -\|f_1\|_F g_1^*(n) \end{bmatrix}; \mathbf{s}'(n) = \begin{bmatrix} \mathbf{s}(1, n) \\ \mathbf{s}(2, n) \end{bmatrix},$$

$$\mathbf{I}_{int}(n) = \begin{bmatrix} \mathbf{I}_{int}(1, n) \\ \mathbf{I}_{int}(2, n) \end{bmatrix} = \begin{bmatrix} \|f_2\|_F g_2(n-1) \mathbf{s}^*(1, n-1) \\ \|f_1\|_F g_2^*(n-1) \mathbf{s}^*(2, n) \end{bmatrix},$$

and

$$\mathbf{w}(n) = \sqrt{\frac{P_2}{1+P_1}} \begin{bmatrix} g_1(n) \mathbf{v}_1(1, n) - g_2(n) \mathbf{v}_2^*(2, n) \\ g_1^*(n) \mathbf{v}_1^*(2, n) + g_2^*(n) \mathbf{v}_2(1, n) \end{bmatrix} + \begin{bmatrix} \mathbf{z}(1, n) \\ \mathbf{z}^*(2, n) \end{bmatrix}.$$

As similar literatures, the effects of ISIs from the previous symbols in (8) and (9) are represented by $g_2(n-1)$. The strengths of $g_2(n-1)$ can be expressed as a ratio as [1]:

$$\beta = |g_2(n-1)|^2 / |g_2(n)|^2. \quad (11)$$

The second term of (10), i.e. $\mathbf{I}_{int}(n)$ called ISI components, and the Fig. 3 give that the received symbols at the destination have two ISI components. The ISI components of proposed scheme are reduced in compared to the previous DSTC schemes [1, 2] (See Fig. 1 in Section 1). It is important that the number of ISI components of the proposed scheme always equals two and is independent of the number of the transmitted relay-antennas. Moreover, the above analyses show that the TAS technique not only allows to reduce the requirement of RF chains at the relay nodes, but also increases at twice the transmit power at each transmitted antenna

as comparison to the previous cooperative relay networks. However, the number of feedback bits of the proposed scheme is quite larger than the DCL EO-STBC scheme. It is a reasonable price for the advantages of the proposed scheme.

3. Near-Optimum Detection (NOD) for the proposed scheme

As remarked above, although the number of ISI components have been reduced by using TAS technique, the ISI components have still existed in the received symbol vector at the destination node. The existing ISI components can lead to substantial degradation in system performance. To the end this lack of the asynchronous cooperative relay network, the near-optimum detection (NOD) scheme is employed at the destination node before the information detection. In fact, the symbol $\mathbf{s}(1, n-1)$ is known through the use of pilot symbols at the start of the packet. Therefore, the interference components $\mathbf{I}_{int}(1, n) = \|f_2\|_F g_2(n-1) \mathbf{s}^*(1, n-1)$ in the equation (10) can effectively eliminate as follows:

Step 1: Remove the ISI components

$$\hat{\mathbf{y}}(n) = \begin{bmatrix} \mathbf{y}'(1, n) - \mathbf{I}_{int}(1, n) \\ \mathbf{y}'(2, n) \end{bmatrix} \quad (12)$$

Step 2: Apply the matched filter by multiplying the signals removed the ISI components in (12) by \mathbf{H}^H . Therefore, the estimated signals can be

represented as

$$\begin{aligned} \mathbf{y}''(n) &= \begin{bmatrix} \mathbf{y}''(1, n) \\ \mathbf{y}''(2, n) \end{bmatrix} = \mathbf{H}^H \hat{\mathbf{y}}(n) \\ &= \sqrt{\frac{P_1 P_2}{P_1 + 1}} (\Delta \mathbf{s}'(n) + \Lambda \mathbf{s}^*(2, n)) + \mathbf{w}_D(n), \end{aligned} \quad (13)$$

where $\mathbf{y}''(1, n)$ and $\mathbf{y}''(2, n)$ are given by

$$\begin{aligned} \mathbf{y}''(2, n) &= \sqrt{\frac{P_1 P_2}{P_1 + 1}} (\lambda \mathbf{s}(2, n) + \Lambda(2, n) \mathbf{s}^*(2, n)) \\ &\quad + \mathbf{w}_D(2, n), \end{aligned} \quad (14)$$

$$\begin{aligned} \mathbf{y}''(1, n) &= \sqrt{\frac{P_1 P_2}{P_1 + 1}} (\lambda \mathbf{s}(1, n) + \Lambda(1, n) \mathbf{s}^*(2, n)) \\ &\quad + \mathbf{w}_D(1, n), \end{aligned} \quad (15)$$

with

$$\Delta = \mathbf{H}^H \mathbf{H} = \begin{bmatrix} \lambda & 0 \\ 0 & \lambda \end{bmatrix}, \quad \lambda = \sum_{k=1}^2 \|f_k\|_F^2 |g_k(n)|^2,$$

$$\Lambda = \mathbf{H}^H \begin{bmatrix} 0 \\ \|f_1\|_F g_2^*(n-1) \mathbf{s}^*(2, n) \end{bmatrix},$$

and $\mathbf{w}_D(n) = \mathbf{H}^H \mathbf{w}(n)$.

Step 3: Apply the Least Square (LS) at the destination to estimate the transmitted signals from the source node.

As seen the equation (14) $\mathbf{y}''(2, n)$ is only related to $\mathbf{s}(2, n)$. In addition, it can be proved that $\mathbf{w}_D(2, n)$ is a circularly symmetric Gaussian random variable with zero-mean and covariance $\sigma_{\mathbf{w}}^2$. Assuming the CSI at the destination node, $\tilde{\mathbf{s}}(2, n)$ can be detected as follow

$$\begin{aligned} \tilde{\mathbf{s}}(2, n) &= \arg \min_{\mathbf{s}(2, n) \in \mathcal{A}} \left| \mathbf{y}''(2, n) - \sqrt{\frac{P_1 P_2}{P_1 + 1}} (\lambda \mathbf{s}(2, n) \right. \\ &\quad \left. + \Lambda(2, n) \mathbf{s}^*(2, n)) \right|^2. \end{aligned} \quad (16)$$

where $\mathbf{s}(2, n) \in \mathcal{A}$ is possible transmitted symbol.

Similarly, substituting $\tilde{\mathbf{s}}(2, n)$ back to the equation (15), $\mathbf{y}''(1, n)$ also is only related to $\mathbf{s}(1, n)$. Therefore, $\tilde{\mathbf{s}}(1, n)$ can be detected by

$$\begin{aligned} \tilde{\mathbf{s}}(1, n) &= \arg \min_{\mathbf{s}(1, n) \in \mathcal{A}} \left| \mathbf{y}''(1, n) - \sqrt{\frac{P_1 P_2}{P_1 + 1}} (\lambda \mathbf{s}(1, n) \right. \\ &\quad \left. + \Lambda(1, n) \tilde{\mathbf{s}}^*(2, n)) \right|^2. \end{aligned} \quad (17)$$

Due to the presence of the interference component $\mathbf{I}_{int}(n)$ in (10), which will destroy the orthogonality of the received signal causing a degradation in the system performance when the conventional detector, e.g., the maximum likelihood without interference cancellation, uses at the destination node [1]. However, the received symbol $\mathbf{y}''(2, n)$ in the equation (14) has no ISI component via the using NOD. It is noticeable from this equation that the application of the NOD at the destination effectively removes the interference components due to the impact of imperfect synchronous among the relay nodes.

4. Comparison results

In this section, we present some numerical results to demonstrate the performance of our proposed cooperative relay network with MRC and TAS technique. In all figures, the bit error rates (BER) are shown as a function of the total transmit power in the whole network. The transmit information symbols are chosen independently and uniformly from QPSK constellation. It is assumed that all channels are quasi-static Rayleigh fading channels. The destination node completely acquires the channel information states from the source to the relays and from the relays to the destination.

Firstly, Fig. 4 illustrates the BER performance of the proposed MRC/TAS DSTC and DCL EO-STBC scheme [1] in the perfect synchronous case where each relay node equips two antennas. As seen the Fig. 4, the proposed scheme outperforms the previous DCL EO-STBC scheme. For example, to achieve a BER = 10^{-3} we need

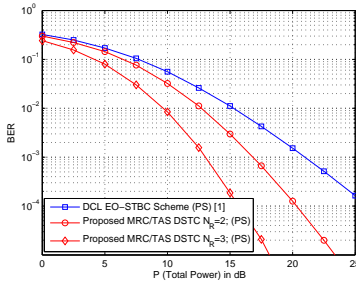


Fig. 4. BER performance comparison of the proposed MRC/TAS and DCL EO-STBC scheme [1] in the perfect synchronous case.

P of ~ 17 dB for the proposed MRC/TAS DSTC scheme and ~ 21 dB for the DCL EO-STBC scheme. Secondly, the system performance of the MRC/TAS DSTC is simulated in the perfect synchronous assumption and using three antennas at each relay. The left curve of the Fig. 4 shows that the system performance of proposed scheme is improved considerably with increasing the number of antennas of each relay node. The improvement of the proposed scheme is because that our scheme achieves both maximal received diversity gain in the first phase and cooperative transmit diversity gain in the second phase. Moreover, the proposed scheme has less requirement of RF chains of the relay than the previous works and remains unity transmission rate between the relay and the destination.

The impact of imperfect synchronization is performed by changing the value of $\beta = 0, -6$ dB, which means adjusting the effect of different time delays. Fig. 5 shows the BER performance comparisons of the proposed MRC/TAS DSTC scheme and the previous DCL EO-STBC scheme [1] with the utilizing NOD at the destination node. In this case, the MRC/TAS DSTC scheme has similar configuration network as comparison with DCL EO-STBC scheme [1]. The BER performance of the proposed scheme outweighs the previous cooperative relay network. As shown in Fig. 5, when the BER is 10^{-3} (at

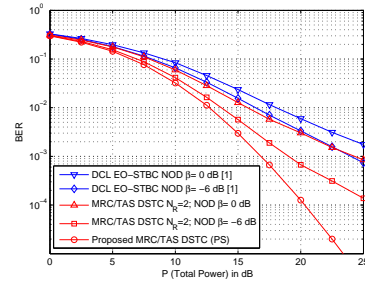


Fig. 5. BER performance comparison of the MRC/TAS DSTC ($N_R = 2$) and the DCL EO-STBC [1] with the utilizing NOD scheme.

$\beta = -6$ dB), the proposed scheme can get an approximate 5 dB gain over the DCL EO-STBC scheme. It could be noticeable that the proposed MRC/TAS DSTC scheme is more robust against the effect of the asynchronous.

In order to examine the advantages of increasing the number of the relay-antennas, the BER of the proposed scheme is performed with three antennas at each relay node and various asynchronous channel conditions. The Fig. 6 demonstrates that the MRC/TAS DSTC scheme owning three relay-antennas has greater system performance than, in the similar asynchronous condition, the DCL EO-STBC one using two antennas at each relay node. For example, at the BER of 10^{-3} (at $\beta = -6$ dB), the proposed scheme can obtain about 9 dB gain over the DCL EO-STBC one. The enhancing performance is achieved as the MRC/TAS DTSC scheme can get a higher gain including both received and transmitted diversity.

5. Conclusions

This paper proposes the AF asynchronous cooperative relay network using MRC and TAS technique. The use of MRC technique for combining multiple received symbols is proved to obtain maximal received diversity gain in compared to conventional DSTC scheme [1,2]. In the second phase, the TAS technique allows to reduce the ISI components among the relay

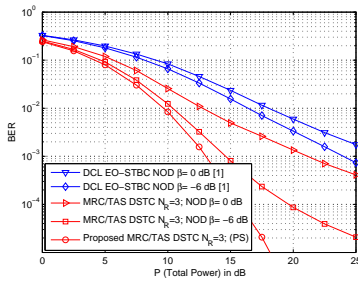


Fig. 6. BER performance comparison of the MRC/TAS DSTC ($N_R = 3$) and the DCL EO-STBC [1] with the utilizing NOD scheme.

nodes. The analyses and simulation results demonstrate that the proposed scheme with the employment of the NOD works effectively in various synchronization error levels. In other words, the MRS/TAS DSTC scheme is more robust against the effect of the asynchronous. The proposed scheme has less requirement of RF chains at the relay and exploits the the advantage of multi-antennas more effectively in comparison to the previous one. We believe that the MRC/TAS DSTC scheme can be useful for the distributed relay networks using multi-antennas at the relay nodes like sensor wireless network or Ad hoc network under the asynchronous conditions.

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