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A computationally efficient non-coherent technique for wireless relay networks

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ABSTRACT

This article introduces a full-rate differential distributed orthogonal space-time coding technique using the amplify-and-forward protocol. The proposed technique has a markedly low encoding and decoding complexity at all transmitting and receiving terminals. Furthermore, the method does not need either differential encoding or channel state information at any transmitting or receiving terminal where the information symbols are directly transmitted. Instead, the differential detection scheme is performed at the destination terminal. In our simulations, the performance of the suggested technique is performed by computer simulations in Rayleigh fading channel, using the amplify-and-forward protocol, to show that our proposed differential technique outperforms the corresponding reference techniques.

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1. INTRODUCTION

Space diversity using multi-antenna techniques has been introduced as an efficient way of counteracting the effects in wireless fading channels without the need for extra time or frequency slots as in conventional diversity techniques (time- and frequency-diversity) and without requiring additional power [1]–[6]. Recently, space-diversity techniques that use multiple-input multiple-output (MIMO) systems have been studied extensively [7]–[12]. These systems have attracted a lot of attention since they can be merged with other types of diversity techniques to provide additional coding and diversity gain without expanding the bandwidth or the transmission power [13]–[19]. Furthermore, MIMO techniques have been proposed to improve the channel throughput linearly with the minimum number of transmitting and receiving antennas.

Due to hardware limitations, multi-antenna techniques in ad-hoc networks may not always be feasible, especially with small device applications. As a solution, another form of space diversity is accomplished by exploiting the antennas of multiple terminals, called relays, to combat the fading due to the multi-path and shadowing propagation similar to MIMO systems [1], [20], [21]. Hence, this solution is usually dubbed "the relay channels". Furthermore, an extension of the relay channel for multi-node networks is named "cooperative diversity" [22], [23]. This solution has been proposed to increase achievable data rates and decrease susceptibility to channel variations using cooperation among different users by allowing users to cooperate in transmitting and/or receiving at the physical layer.

Currently, many cooperative protocols have been suggested. These are divided into two main categories: the amplify and forward (AF) protocols [1], [13], [20] and the decode and forward (DF) protocols [7], [22]. Cooperative techniques can be categorized into two main classes regarding the availability of the channel state information (CSI). The first one is the coherent techniques [1], [22], where the channel information is estimated before performing these techniques. However, the complexity and cost of channel estimation grow with the number of transmit and receive antennas. The second class is the non-coherent and differential techniques that do not require channel estimation at the transmitter or receiver side. Recently, different non-coherent differential space-time modulation techniques have been introduced [24]–[31].

Differential space-time block coding (DSTBC) techniques are considered one of the most potent methods for multi-antenna communication systems [24]–[26]. The advantage of these techniques relies on the fact that the CSI is not needed at the transmitters or the receivers. Moreover, DSTBC techniques can be used if the CSI changes too fast. Therefore, many DSTBC designs have been proposed recently [1], [20]–[27]. In the case of using two transmit antennas, the design of DSTBC is well established since there is a full rate complex orthogonal code. However, the design of DSTBC is still an active area of research in the case of using more than two transmit antennas. Nowadays, one of the attractive areas of research is to offer a DSTBC technique that enjoys a low complexity with as little loss of coding and diversity gain as possible. Subsequently, the differential unitary space-time coding (DUSTC) techniques, which do not require CSI at any antenna, have been proposed [24]–[29]. However, DUSTC techniques suffer from very high decoding complexity at the receiver side, which increases exponentially with the number of relay nodes or the data rate, i.e., spectral efficiency [30].

This article introduces a new AF differential cooperative communication technique with a full data rate and very low complexity. The proposed approach does not need differential encoding or CSI at any transmitting or receiving node where the information symbols are directly transmitted. The differential detection scheme is performed at the destination. The suggested technique has low complexity at the source node, relay nodes, and destination node. It employs the cooperative network using L relays, operating at a data rate (spectral efficiency) of r bps/Hz. It needs only a symbol-by-symbol detector (symbol-wise detector) with a decoding search space of 2^r searches for every information symbol at the destination terminal. This is juxtapositioned with a DUSTC system using the same number of L relays and operating at the same spectral efficiency r bps/Hz, which needs a decoding search space of 2^{rL} searches for L information symbols at the receiver side. In the presented simulations hereafter, the performance of the suggested technique is performed by computer simulations in Rayleigh fading channel and using the AF protocol, where it is shown that the proposed approach outperforms the DUSTC one proposed in [24]–[29] for two, three, and four relay nodes.

2. RESEARCH METHOD

In this work, an efficient AF differential cooperative diversity technique with low encoding and decoding complexity is proposed. The proposed technique does not require any CSI at any receiving or transmitting node in the whole system to decode the information symbols. Note that M-ary phase-shift keying (MPSK) constellations are applied to generate the information symbols as explained in the next.

2.1. System model

In the proposed cooperative system, L relay nodes $\{R_k\}_{l=1}^{L}$ are used, and two terminal nodes, a source node $\{S\}$ and a destination node $\{D\}$. All nodes are randomly distributed, as shown in Figure 1. Two terminals, a source node {S} and a destination node {D} want to communicate, while the other L nodes operate as relays. The total transmitted power of the source node and all other relay nodes, P_t, is divided equally between the source terminal and relays. Moreover, the power of the relays is equally divided among all relays so that the power of the source is $P_s = \frac{1}{2}P_t$. The power of each relay is $P_r = \frac{1}{2L}P_t$ where P_t is the total transmitted power.

Each node in the network is equipped with a single antenna that can transmit and receive, but not simultaneously (half-duplex operation). Let us consider the channel coefficient for the link from the source node to the l^{th} relay node is denoted by f_l, while the one from the l^{th} relay node to the destination node is denoted by g_l, as shown in Figure 1. Furthermore, we assume that the CSI is not available at any node in the whole network. Additionally, all channel links are considered quasi-static flat Rayleigh fading. The transmission has two phases: a broadcast phase and a relay phase. A symbol is sent from the source terminal to the relays during the broadcast phase, as shown in Figure 2. In the relay phase, each relay amplifies and sends the received signal to the destination terminal, as shown in Figure 3.

This work considers ($2L$-2) symbols $s(i)$, $i = \{0,1,2,\ldots 2L-3\}$ taken from MPSK constellation. Note that $(.)^*$is the complex conjugate of $(.)$ and $\|.\|$is the Frobenious norm. Moreover, we consider a block fading channel in which the channel coefficients remain constant during each block. However, they are changing from one block to another as independent, zero-mean complex Gaussian random variables of variance one.

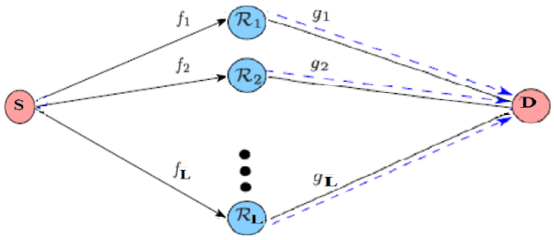

Figure 1. Cooperative communication network using *L* relay terminals

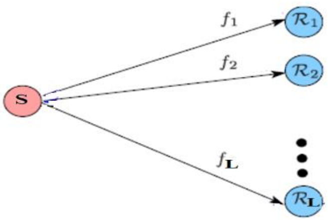

Figure 2. The first phase (broadcast phase)

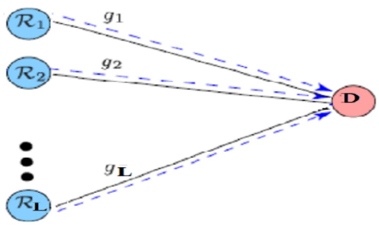

Figure 3. The second phase (relay phase)

2.2. Broadcast phase

As explained in Section 2.1, we consider the case of block fading channels where all channel coefficients are assumed to be constant during each transmission block. However, the channel coefficients change independently from one block to another. It is noted that each transmission block consists of many transmission frames.

In Figure 1, $f_{l,k}$ is the link between the source terminal and the l^{th} relay of the k^{th} transmission frame, and $g_{l,k}$ is the link between the l^{th} relay and the destination terminal of the k^{th} transmission frame. As explained in the previous section, each frame consists of two phases. During each transmission frame, the source terminal broadcasts *(2L-2)* information symbols where $\mathbf{s}^{(k)}$ is the source information symbol sequence with entries $s^{(k)}(i), i \in \{0,1,2,\ldots,2L-3\}$. During the first transmission phase (the broadcast transmission phase), the source terminal broadcasts *(2L-2)* information symbols to the relays. Note that the first *(2L-2)* information symbols of the first transmission frame are ones, $\mathbf{s}^{(0)} = [1,1,..,1]$, to be used later in the differential decoding at the destination side. After broadcasting the information symbols during the first transmission phase, the signal vector obtained at the l^{th} relay of the k^{th} transmission frame can be expressed as (1):

$$\mathbf{z}_l^{(k)} = f_{l,k}\,\mathbf{s}^{(k)} + \mathbf{w}_l^{(k)} \quad (1)$$

where $\mathbf{z}_l^{(k)} = [z_l^{(k)}(0), z_l^{(k)}(1), \ldots, z_l^{(k)}(2\mathrm{L}-3)]$, $\mathbf{s}^{(k)} = [s^{(k)}(0), s^{(k)}(1), \ldots, s^{(k)}(2\mathrm{L}-3)]$, $\mathbf{w}_l^{(k)} = w_l^{(k)}(0), w_l^{(k)}(1), .., w_l^{(k)}(2\mathrm{L}-3)]$, and $w_l^{(k)}(i)$ is the noise signal received on the l^{th} relay terminal during the i^{th} slot, and is generated as a complex Gaussian random variable with zero-mean and unit variance. During the k^{th} transmission frame, the received signals at the relay nodes can be merged as (2).

$$q_l^{(k)}(i) = \left(z_l^{(0)}(i)\right)^* z_l^{(k)}(i) \quad (2)$$

Note that $s^{(k)}(i)\left(s^{(0)}(i)\right)^* = s^{(k)}(i)$ and $f_{l,k}(f_{l,0})^* = |f_{l,k}|^2$. In the case of a noise-free scenario, $q_l^{(k)}(i) = |f_{l,k}|^2 s^{(k)}(i)$. Thus, the l^{th} relay generates the estimated signal as (3):

$$\hat{x}_l^{(k)}(i) = \frac{1}{\alpha_l^{(k)}} q_l^{(k)}(i) \quad (3)$$

where $i = \{0,1,2,3,\ldots 2L-3\}$, $\beta_l^{(k)}$ is a constant factor and could be given as $\beta_l^{(k)} = \frac{1}{|q_l^{(k)}(i)|}$ to normalize the transmitted power.

2.3. Relay phase

During the second transmission phase, i.e., the relay transmission phase, a full data rate, and orthogonal space-time block coding (OSTBC) scheme with low decoding complexity using L relay nodes is applied. Hence, the received signals at the relay nodes are orthogonally space-time block coded using OSTBC matrices, as shown in the following subsections.

2.3.1. Two relay system

In the case of using only two relay nodes, the received signals at the relay nodes are orthogonally encoded by the following full data rate OSTBC encoding matrix as (4):

$$\mathbf{X}^{(k)} = \begin{bmatrix} \hat{x}_1^{(k)}(0) & \hat{x}_2^{(k)}(1) \\ -\left\{\hat{x}_1^{(k)}(1)\right\}^* & \left\{\hat{x}_2^{(k)}(0)\right\}^* \end{bmatrix} \tag{4}$$

where $\left\{\hat{x}_l^{(k)}(i)\right\}$ is the i^{th} obtained signal by the l^{th} relay node during the k^{th} transmission frame.

2.3.2. Three relay system

In the case of using only three relay nodes, the received signals at the relay nodes are orthogonally encoded by the following full data rate OSTBC encoding matrix as (5).

$$\mathbf{X}^{(k)} = \begin{bmatrix} \hat{x}_1^{(k)}(0) & \hat{x}_2^{(k)}(1) & 0 \\ -\left\{\hat{x}_{1,k}^{(k)}(1)\right\}^* & \left\{\hat{x}_2^{(k)}(0)\right\}^* & 0 \\ 0 & \hat{x}_2^{(k)}(2) & \hat{x}_3^{(k)}(3) \\ 0 & -\left\{\hat{x}_2^{(k)}(3)\right\}^* & \left\{\hat{x}_3^{(k)}(2)\right\}^* \end{bmatrix} \tag{5}$$

2.3.3. L relay system

In the case of using L relay nodes, the received signals at the relay nodes are orthogonally encoded by the following full sat rate OSTBC encoding matrix as (6).

$$\mathbf{X}^{(k)} = \begin{bmatrix} \left\{\hat{x}_1^{(k)}(0)\right\} & \left\{\hat{x}_2^{(k)}(1)\right\} & 0 & .\ . & . & 0 \\ -\left\{\hat{x}_1^{(k)}(1)\right\}^* & \left\{\hat{x}_2^{(k)}(0)\right\}^* & 0 & .\ . & . & 0 \\ 0 & \left\{\hat{x}_2^{(k)}(2)\right\} & \left\{\hat{x}_3^{(k)}(3)\right\} & .\ . & . & 0 \\ 0 & -\left\{\hat{x}_2^{(k)}(3)\right\}^* & \left\{\hat{x}_3^{(k)}(2)\right\}^* & .\ . & . & . \\ . & . & . & .\ . & . & . \\ . & . & . & .\ . & . & . \\ . & . & . & .\ . & \left\{\hat{x}_{L-1}^{(k)}(2L-4)\right\} & \left\{\hat{x}_L^{(k)}(2L-3)\right\} \\ 0 & 0 & 0 & .\ . & -\left\{\hat{x}_{L-1}^{(k)}(2L-3)\right\}^* & \left\{\hat{x}_L^{(k)}(2L-4)\right\}^* \end{bmatrix} \tag{6}$$

2.4. Differential detection technique

During the k^{th} transmission frame, the destination node obtains the vector $\mathbf{y}_d^{(k)} = [y_d^{(k)}(0), y_d^{(k)}(1), \dots\ y_d^{(k)}(2L-3)]^T$ as (7):

$$\mathbf{y}_d^{(k)} = \mathbf{X}^{(k)}\mathbf{g}_k + \mathbf{w}_d^{(k)}, \tag{7}$$

where $\mathbf{g}_k = \left[g_{1,k}, g_{2,k}, \dots, g_{L,k}\right]$ is the channel link from the relays to the destination node and $\mathbf{w}_d^{(k)} = [w_d^{(k)}(0), w_d^{(k)}(1), \dots\ w_d^{(k)}(2L-3)]^T$ is the noise signals received by the destination node during the k^{th} transmission frame. If two relay nodes are used during the k^{th} transmission frame, the obtained signals by the destination terminal, considering that there is no direct link between the destination terminal and the source terminal, can be expressed as (8).

$$\begin{aligned} y_d^{(k)}(0) &= g_{1,k}\, \hat{x}_1^{(k)}(0) + g_{2,k}\, \hat{x}_2^{(k)}(1) + w_d^{(k)}(0) \\ y_d^{(k)}(1) &= -g_{1,k}\left\{\hat{x}_1^{(k)}(1)\right\}^* + g_{2,k}\left\{\hat{x}_2^{(k)}(0)\right\}^* + w_d^{(k)}(1) \end{aligned} \tag{8}$$

If three relay nodes are used during the k[th] transmission frame, the obtained signals by the destination terminal can be expressed as (9).

$$\begin{aligned} y_d^{(k)}(0) &= g_{1,k}\,\hat{x}_1^{(k)}(0) + g_{2,k}\,\hat{x}_2^{(k)}(1) + w_d^{(k)}(0),\\ y_d^{(k)}(1) &= -g_{1,k}\left\{\hat{x}_1^{(k)}(1)\right\}^* + g_{2,k}\left\{\hat{x}_2^{(k)}(0)\right\}^* + w_d^{(k)}(1),\\ y_d^{(k)}(2) &= g_{2,k}\,\hat{x}_2^{(k)}(2) + g_{3,k}\,\hat{x}_3^{(k)}(3) + w_d^{(k)}(2),\\ y_d^{(k)}(3) &= -g_{2,k}\left\{\hat{x}_2^{(k)}(3)\right\}^* + g_{3,k}\left\{\hat{x}_3^{(k)}(2)\right\}^* + w_d^{(k)}(3) \end{aligned} \tag{9}$$

If L relay nodes are used during the kth transmission frame, the obtained signals by the destination terminal can be expressed as (10).

$$\begin{aligned} y_d^{(k)}(0) &= g_{1,k}\,\hat{x}_1^{(k)}(0) + g_{2,k}\,\hat{x}_2^{(k)}(1) + w_d^{(k)}(0),\\ y_d^{(k)}(1) &= -g_{1,k}\left\{\hat{x}_1^{(k)}(1)\right\}^* + g_{2,k}\left\{\hat{x}_2^{(k)}(0)\right\}^* + w_d^{(k)}(1),\\ y_d^{(k)}(2) &= g_{2,k}\,\hat{x}_2^{(k)}(2) + g_{3,k}\,\hat{x}_3^{(k)}(3) + w_d^{(k)}(2),\\ y_d^{(k)}(3) &= -g_{2,k}\left\{\hat{x}_2^{(k)}(3)\right\}^* + g_{3,k}\left\{\hat{x}_3^{(k)}(2)\right\}^* + w_d^{(k)}(3),\\ .y_d^{(k)}(2L-4) &= g_{L-1,k}\,\hat{x}_{L-1}^{(k)}(2L-4) + g_{L,k}\,\hat{x}_3^{(k)}(2L-3) + w_d^{(k)}(2L-4),\\ y_d^{(k)}(2L-3) &= -g_{L-1,k}\left\{\hat{x}_2^{(k)}(2L-3)\right\}^* + g_{L,k}\left\{\hat{x}_3^{(k)}(2L-4)\right\}^* + w_d^{(k)}(2L-3) \end{aligned} \tag{10}$$

To simplify the previous equations and to recover the information symbols, we consider the noise-free case and $g_{l,k} = g_{l,k-1} = g_l\,, \forall l \in \{1,2,3,\dots,L\}$, therefore, during the k^{th} transmission frame, the obtained signals given by (10) can be rewritten as (11).

$$\begin{aligned} \mathbf{r}_\mathbf{1}^{(k)} &= \begin{bmatrix} y_d^{(k)}(0) \\ \left(y_d^{(k)}(1)\right)^* \end{bmatrix} = \begin{bmatrix} \hat{x}_1^{(k)}(0) & \hat{x}_2^{(k)}(1) \\ -\hat{x}_1^{(k)}(1) & \hat{x}_2^{(k)}(0) \end{bmatrix} \begin{bmatrix} g_1 \\ (g_2)^* \end{bmatrix},\\ \mathbf{r}_\mathbf{2}^{(k)} &= \begin{bmatrix} y_d^{(k)}(2) \\ \left(y_d^{(k)}(3)\right)^* \end{bmatrix} = \begin{bmatrix} \hat{x}_1^{(k)}(2) & \hat{x}_2^{(k)}(3) \\ -\hat{x}_1^{(k)}(3) & \hat{x}_2^{(k)}(2) \end{bmatrix} \begin{bmatrix} g_2 \\ (g_3)^* \end{bmatrix},\\ \mathbf{r}_\mathbf{L-1}^{(k)} &= \begin{bmatrix} y_d^{(k)}(2L-4) \\ \left(y_d^{(k)}(2L-3)\right)^* \end{bmatrix} = \begin{bmatrix} \hat{x}_1^{(k)}(2L-4) & \hat{x}_2^{(k)}(2L-3) \\ -\hat{x}_1^{(k)}(2L-3) & \hat{x}_2^{(k)}(2L-4) \end{bmatrix} \begin{bmatrix} g_{L-1} \\ (g_L)^* \end{bmatrix} \end{aligned} \tag{11}$$

To detect the original data sequence, the following maximum likelihood (ML) detectors are applied as (12):

$$\begin{aligned} \left[\hat{s}^{(k)}(0)\ \hat{s}^{(k)}(1)\right] &= \arg\ \min_{s_i\in S}\left\|\mathbf{r}_\mathbf{1}^{(k)} - [s_1\ s_2]\,\mathbf{r}_\mathbf{1}^{(0)}\ \right\|,\\ \left[\hat{s}^{(k)}(2)\ \hat{s}^{(k)}(3)\right] &= \arg\ \min_{s_i\in S}\left\|\mathbf{r}_\mathbf{2}^{(k)} - [s_1\ s_2]\,\mathbf{r}_\mathbf{2}^{(0)}\ \right\|,\\ \left[\hat{s}^{(k)}(2L-4)\ \hat{s}^{(k)}(2L-3)\right] &= \arg\ \min_{s_i\in S}\left\|\mathbf{r}_\mathbf{L-1}^{(k)} - [s_1\ s_2]\,\mathbf{r}_\mathbf{L-1}^{(0)}\ \right\| \end{aligned} \tag{12}$$

where S contains the possible values of all MPSK information symbols sent during one transmission frame and $\mathbf{r}_l^{(0)}$, used to initialize the differential detection, is the vector related to the initial symbol vector $\mathbf{s}^{(0)}$. Let us consider $\widehat{g}_l = \frac{\mathbf{r}_l^{(k)}(0)+\mathbf{y}_l^{(k)}(1)}{\mathbf{2}}$, $\widehat{g_{l+1}} = \left(\frac{\mathbf{r}_l^{(k)}(0)-\mathbf{r}_l^{(k)}(1)}{\mathbf{2}}\right)^*$ and $l = [1,2,3, \dots L-1]$. Therefore, the ML detector given by (12) can be modified to be a symbol-wise detector, as (13).

$$\begin{aligned} \hat{s}^{(k)}(2l-2) &= \arg\ \min_{s_i\in S}\left\|\left(\widehat{g}_l\,\mathbf{r}_l^{(k)}(0) + \widehat{g_{l+1}^*}\,\mathbf{r}_l^{(k)}(1)\right) - \left(|\widehat{g}_l|^2 + |\widehat{g_{l+1}}|^2\right) s\ \right\|,\\ \hat{s}^{(k)}(2l-1) &= \arg\ \min_{s_i\in S}\left\|\left(\widehat{g_{l+1}}\,\mathbf{r}_l^{(k)}(0) - \widehat{g}_l^*\,\mathbf{r}_l^{(k)}(1)\right) - \left(|\widehat{g}_l|^2 + |\widehat{g_{l+1}}|^2\right) s\ \right\| \end{aligned} \tag{13}$$

3. RESULTS AND DISCUSSION

This section shows the performance of the proposed cooperative communication network using independent flat Rayleigh fading channels. It is considered that the total power is divided equally between the source and all relay nodes as explained in section 2.1. The relay power is distributed equally among all relay nodes. In this section, a Monte Carlo simulation with 10^6 runs is performed to compare the symbol error rate (SER) performance of the suggested DSTBC strategy with the SER performance of the DUSTC strategy suggested in [24]–[31] as function of total signal-to-noise (SNR), where the total SNR is the ratio between the total transmitted power to the total power of the noise. In the simulations, the AF protocol and the 4-phase shift keying (PSK) modulation are used in all simulation figures. Furthermore, we consider a half-duplex relay network with L + 2 nodes, a source {S}, a destination {D} and L relays that are randomly distributed between the source and destination as explained in section 2.1 and as shown in Figure 1. All nodes, including the source and destination, are equipped with single antennas. Moreover, it is assumed that the CSI is unavailable at all nodes. In the simulation results, the simulated SER curves for both strategies using the AF protocol and using two, three, and four relay nodes are generated. We can easily observe that the performance of the proposed strategy is better than the DUSTC strategy with much less complexity. As a conclusion, this article proposes a full data rate AF differential strategy with low encoding and decoding complexity as compared to the traditional DUSTC technique. Moreover, the proposed strategy enjoys a better performance in terms of SER as well.

Figures 4-6 illustrate the performance of a relay network shown in Figure 1 using block Rayleigh flat-fading channels as explained in section 2.1. In this network, the total power P_t is divided equally between the source terminal and relays, where the total relay power is also equally divided among all relays such that $P_s = L\,P_r = \frac{1}{2}P_t$ and $P_r = \frac{1}{2L}P_t$. In this part, a Monte Carlo simulation with 10^6 runs is performed to generate each curve in Figures 4, 5, and 6 to fairly compare the symbol error rate (SER) performance of the proposed differential distributed cooperative space time code with the SER performance of the cooperative networks using the DUSTC technique suggested in [24]–[31] as a function of total signal-to-noise (SNR). The total SNR is the ratio of the total transmitted power to the total noise power.

In the simulation results for both techniques, the 4-PSK constellation is considered. From Figure 1, the wireless network consists of $L + 2$ nodes, one source node {S}, one destination node {D}, and L relay nodes $\{R_l\}_{l=1}^{L}$ which are randomly and independently distributed as explained in section 2.1 and illustrated in Figure 1. Whether it is a source terminal, a destination terminal, or any relay, each node has a single antenna. It processes the received signals independently and can transmit or receive, but not simultaneously (half-duplex operation). Furthermore, we assume that there is no CSI at any node, and all channel links are considered quasi-static flat Rayleigh fading. After generating the simulated SERs for both techniques using the AF protocol when L= 4, 3 and 2, as shown in Figures 4-6, respectively. It is observed that the performance of the proposed technique is better than the conventional DUSTC technique.

The complexity in the proposed system is very low at the source terminal, relays, and the destination terminal, where the proposed technique using L relays and operating at a data rate r bps/Hz requires a decoding search space of 2^r search for each symbol at the destination terminal. This is significantly better than the cooperative DUSTC technique using L relays and operating at the same data rate, which requires a decoding search space of 2^{rL} for L symbols at the destination terminal.

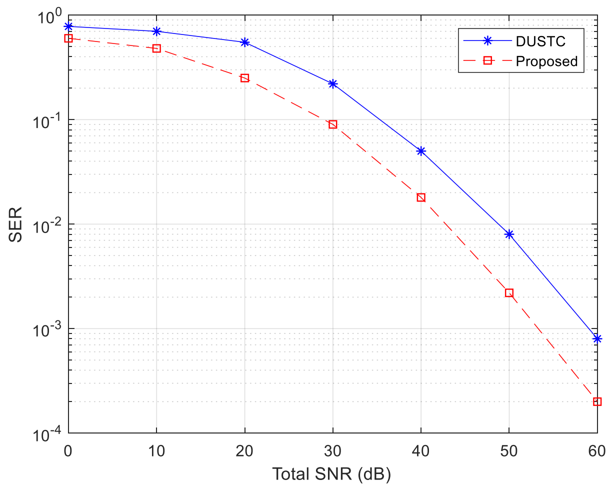

Figure 4. SER performance of the proposed technique as compared to the conventional DUSTC technique using four relays and 4-PSK modulation

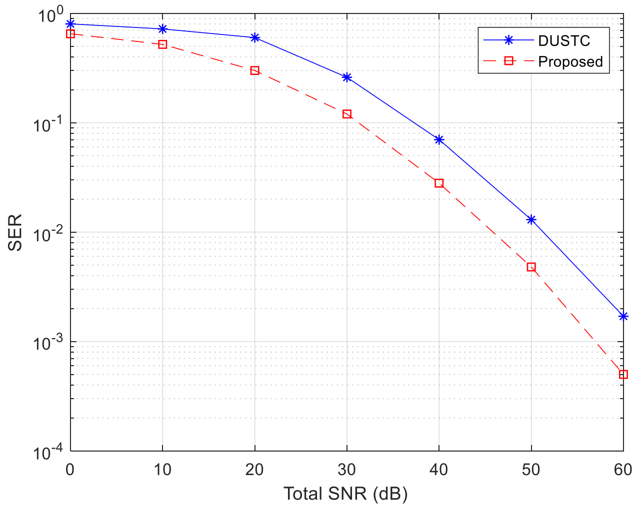

Figure 5. SER performance of the proposed technique as compared to the conventional DUSTC technique using three relays and 4-PSK modulation

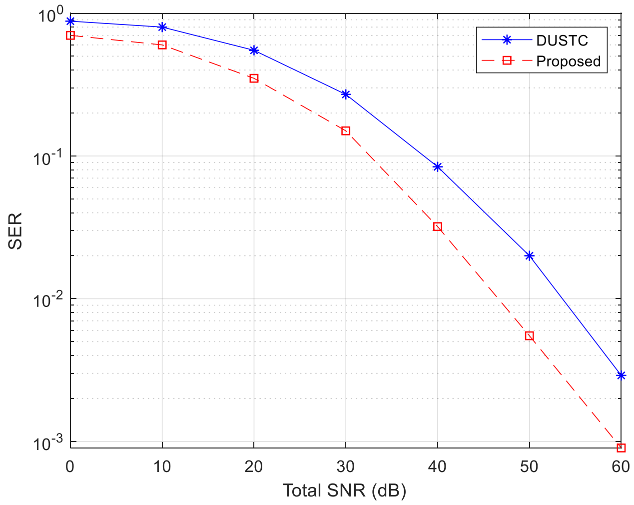

Figure 6. SER performance of the proposed technique as compared to the conventional DUSTC technique using two relays and 4-PSK modulation

4. CONCLUSION

This article has suggested a full data rate AF differential orthogonal space-time block coding technique. The proposed technique enjoys a low encoding and decoding complexity with a high error performance and without requiring CSI at any transmitting or receiving node. Compared to the traditional DUSTC technique, the proposed approach enjoys a better performance in terms of SER, with much less encoding and decoding complexity.

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