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A low complexity distributed differential scheme based on orthogonal space time block coding for decode-and-forward wireless relay networks

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ABSTRACT

This work proposes a new differential cooperative diversity scheme with high data rate and low decoding complexity using the decode-and-forward protocol. The proposed model does not require either differential encoding or channel state information at the source node, relay nodes, or destination node where the data sequence is directly transmitted and the differential detection method is applied at the relay nodes and the destination node. The proposed technique enjoys a low encoding and decoding complexity at the source node, the relay nodes, and the destination node. Furthermore, the performance of the proposed strategy is analyzed by computer simulations in quasi-static Rayleigh fading channel and using the decode-and-forward protocol. The simulation results show that the proposed differential technique outperforms the corresponding reference strategies.

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1. INTRODUCTION

Transmit diversity, a form of spatial diversity, has been studied extensively as a method of combating detrimental effects in wireless fading channels [1]–[4] instead of using time and frequency diversity. In the last years, space diversity using multiple input multiple output (MIMO) systems [5], [6] has received much attention because it can be combined with other forms of diversity [7]–[10] and, additionally, it improves the overall performance in terms of bite error rate and data rate without requiring extra bandwidth or transmission power [11], [12]. MIMO systems have been suggested to increase the channel capacity linearly with the minimum number of transmitting and receiving antennas.

Advances made in MIMO signal processing techniques have shown tremendous improvements in reliability and throughput [13]–[19]. However due to size, cost, and hardware constraints, the use of MIMO techniques in ad-hoc networks may not always be feasible especially in small devices. Hence, it might not be practical to use multiple-antennas for certain applications. As a solution to this problem, cooperative communication, a spatial diversity method, becomes a practical alternative to MIMO when the size of the wireless device is limited [20]–[22]. Recently, there has been a growing interest in the so-called cooperative diversity techniques where multiple terminals in a network cooperate to form a virtual antenna array in order to exploit spatial diversity in a distributed fashion [23], [24]. Hence, node cooperation can yield significant performance gains in wireless networks [23], [24]. In particular, cooperating nodes can achieve a diversity gain in fading channels [20]–[24]. Recently, several cooperative transmission techniques and protocols have been proposed. These protocols can be categorized into two principal classes: the amplify-and-forward (AF) protocol [13], [21] and the decode-and-forward (DF) protocol [7], [23]. Early transmit diversity schemes were designed for coherent detection [7]–[12] with channel estimates assumed available at the receiver. However, the complexity and cost of channel estimation grow with the number of transmit and receive antennas. As a solution to this problem, transmit diversity techniques that do not require channel estimation are desirable such as differential techniques. Recently, different approaches of differential space-time modulation techniques have been proposed [25]–[32]. At this end, differential space-time block coding (DSTBC) techniques are useful for wireless communications with multiple transmitting antennas [25]–[27]. With DSTBC, the channel state information (CSI) is not required either at the transmitters or at the receivers which is important for applications when the CSI changes too fast to be estimated and utilized. The design of DSTBC has attracted the attention of many researchers in recent years [15], [16]. For two transmitters, the design of DSTBC is well established because of the existence of full rate complex orthogonal code. But for more than two transmitters, the design of DSTBC is still an active area of research. For practical use, there is a strong interest to reduce the decoding complexity of DSTBC with as little loss of coding gain as possible. In many papers, their authors considered cooperative networks employing the differential unitary space time coding (DUSTC) technique which does not require CSI at source node, relay nodes, or destination node [25]–[32], however using DUSTC in broadcast phase and relay phase increases the decoding complexity at relay nodes and destination node exponentially with the increase of the number of relay nodes or the data rate, i.e., spectral efficiency, r bps/Hz [31].

In this paper, a new cooperative diversity technique with full rate and low complexity is proposed. This model also does not require either a differential encoding at the source node or relay nodes or the CSI at the source node, relay nodes or destination node like [1], [13]–[19], [21]. In this system, more than two relay nodes are considered. Moreover, the complexity in the proposed system is very low at source node, relay nodes, and destination node where the proposed system of L nodes operating at a data rate, i.e., spectral efficiency, *r* bps/Hz requires a symbol-wise decoder with decoding search space of 2^r search for each symbol at the destination node while cooperative networks of *L* nodes employing DUSTC and operating at a data rate *r* bps/Hz requires a decoding search space of 2^{rL} for *L* symbols at each relay node and at the destination node. Furthermore, the bit error performance of the proposed system is analyzed by computer simulation and it is shown that it outperforms the DUSTC system given in [25]–[32] for two, three, and four relay nodes.

2. METHOD

In this work, a novel distributed space-time coding approach using the DF protocol and M-ary phase shift keying (MPSK) constellations is suggested. The proposed approach does not require any channel knowledge at any part of the system. Moreover, it enjoys a high error performance and a low encoding and decoding complexity at all nodes in the whole network.

2.1. System model

We consider a wireless network with L+2 nodes, a source node {S}, a destination node {D} and L relay nodes $\{\mathrm{R_k}\}_{\mathrm{l=1}}^{\mathrm{L}}$ which are randomly and independently distributed as shown in Figure 1. The source node intends to send its information symbols to the destination node while the L other nodes serve as relays. We also assume that the total transmit power P_t is divided equally between the source node and the relay nodes. Moreover, the power of the relay nodes is equally distributed among the relays, so that the power of the source node is $P_s = \frac{1}{2}P_t$ and the power of each relay is $P_r = \frac{1}{2L}P_t$ where P_t is the total transmitted power. Each relay processes the received signals independently. All nodes in the whole network, i.e., the source node, destination node, and all relay nodes, are equipped with single antennas. It is assumed that each node can transmit and receive, but not simultaneously, i.e., half duplex operation. The channel from the source node to the l^{th} relay 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. Moreover, it is assumed that the CSI is unknown either at the transmitting node or at the receiving node. Both channels, f_l and g_l, are assumed as quasi-static flat Rayleigh fading. The cooperation process can be divided into two phases, broadcast phase and relay phase. During the first phase, broadcast phase, the information is transmitted from the source node to the relay nodes as shown in Figure 2. In the second phase, relay phase, each relay node decodes and transmits the signal to the destination nodes as shown in Figure 3.

We further assume that there are (2L-2) symbols $\mathrm{s}(l)$, $l = \{0,1,2, \dots 2L-3\}$ drawn from MPSK constellation. In this article, $(.)^*$denotes complex conjugate of $(.)$ and $\|.\|$ denotes the Frobenious norm. It is assumed that the channel coefficients f_l and g_l are independent, zero mean complex Gaussian random variables of variance one but they remain unchanged during each block.

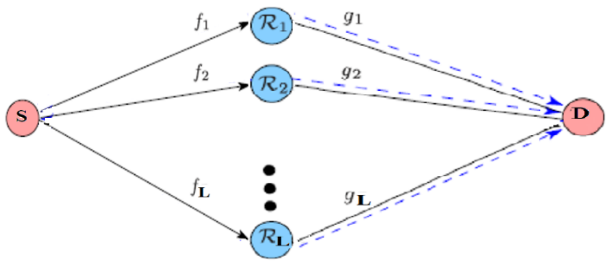

Figure 1. Wireless relay network with L relay nodes

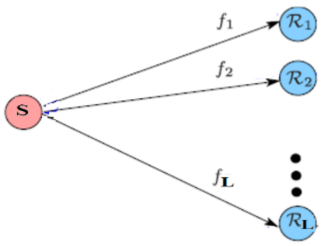

Figure 2. Broadcast phase

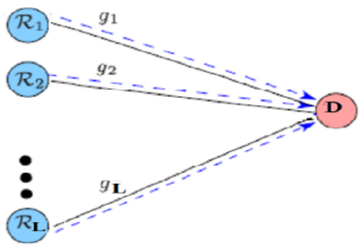

Figure 3. Relay phase

2.2. Broadcast phase

The source-relay channel and relay-destination channel are assumed independent of each other. All channels are assumed as quasi static flat Rayleigh fading, i.e., they are constant during each block which consists of several frames and change independently from one block to another. In Figure 1, $f_{l,k}$ is the complex channel coefficient from source node to the l^{th} relay node of the k^{th} transmission frame, and $g_{l,k}$ is the complex channel coefficient from the l^{th} relay node to the destination node of the k^{th} transmission frame. Let us assume that each frame has two phases where during each frame, the source node sends (2L-2) information symbols. Let also assume that $\mathrm{s}^{(k)}$ is the source symbol sequence with elements $\mathrm{s}^{(k)}(i)$, $i \in \{0,1,2,\ldots,2L-3\}$. In the first phase, broadcast phase, the source node transmits (2L-2) symbols to the relay terminals where the initial (2L-2) symbols of the initial frame are known at the source node, relay nodes and destination node, and they are assumed to be ones, $\mathrm{s}^{(0)} = [1,1,..,1]$, to initialize the differential encoding. At the end of transmission, the received signal vector at the l^{th} relay node of the k^{th} frame is given by (1):

$$\mathrm{r}_l^{(k)} = f_{l,k}\,\mathrm{s}^{(k)} + \mathrm{n}_l^{(k)}, \tag{1}$$

where $\mathrm{r}_l^{(k)} = [r_l^{(k)}(0),\ r_l^{(k)}(1), \ldots\ldots,\ r_l^{(k)}(2\mathrm{L}-3)]$, $\mathrm{s}^{(k)} = [s^{(k)}(0),\ s^{(k)}(1),\ \ldots\ldots,\ s^{(k)}(2\mathrm{L}-3)]$, $\mathrm{n}_l^{(k)} = n_l^{(k)}(0), n_l^{(k)}(1),\ldots, n_l^{(k)}(2\mathrm{L}-3)]$, and $n_l^{(k)}(i)$ is the additive channel noise of the i^{th} time slot at the l^{th} relay node with independent, zero mean, complex Gaussian random variables of unity variances. At the relay nodes, the received signals in the k^{th} transmission frame are combined as in (2).

$$p_l^{(k)}(i-1) = r_l^{(k)}(i-1)\, r_l^{(k)}(i), \tag{2}$$

Note that $|s^{(k)}(i)| = 1$ since the symbols are drawn from MPSK constellations. If we consider a noise-free scenario, then $|p_l^{(k)}(i)| = |f_{l,k}|^2$. Therefore, the information symbol $s^{(k)}(i)$ can be reconstructed by applying the following maximum likelihood (ML) decoder:

$$\hat{s}_l^{(k)}(i) = \arg\ \min_{s\in S_i} \left\| p_l^{(k)}(i) - |p_l^{(k)}(i)|\, s \right\|, \tag{3}$$

where $i = \{0,1,2,3,\ldots 2L-3\}$, S_i denotes all possible symbols of MPSK constellation transmitted over one frame. At the end of the transmission, the l^{th} relay contains the estimated data sequence $\hat{s}_l^{(k)}(i)$. Basically, we search for the symbol that minimizes the cost-function given in (3) by substituting all possible symbols of MPSK constellation.

2.3. Relay phase

By using L relay nodes, a low complexity and full rate space time coding scheme with complex orthogonal design is performed. An orthogonal design is used to minimize the decoding complexity by applying a symbolwise decoder at the receiver side. During the second phase, relay phase, the estimated symbol sequence of the relays is space time block coded in the following designed code matrices.

2.3.1. Two relay system

In the orthogonal design, there are several codes. For two relay-node system, Alamouti's code is the optimal one. Therefore, if the system contains only two relays, the relay detected symbol sequence is orthogonally space time block coded using the Alamouti's matrix as (4):

$$\mathrm{X}^{(k)} = \begin{bmatrix} \hat{s}_1^{(k)}(0) & \hat{s}_2^{(k)}(1) \\ -\left\{\hat{s}_2^{(k)}(3)\right\}^* & \left\{\hat{s}_3^{(k)}(2)\right\}^* \end{bmatrix}, \tag{4}$$

where $\hat{s}_l^{(k)}(i)$ is the i^{th} estimated symbol in the k^{th} frame on the l^{th} relay.

2.3.2. Three relay system

If the system contains three relay nodes, there are several orthogonal designs. The best choice is to find an orthogonal code with full-rate. Therefore, in three relay system, the estimated symbol sequence at the relays is space time block coded in terms of the following full rate, low complexity orthogonal matrix.

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

2.3.3. L relay system

Similar to section 2.3.2, if the system contains L relay nodes, there are several orthogonal designs. The best choice is to find an orthogonal code with full-rate. Therefore, in L relay system, the estimated symbol sequence at the relays is space time block coded in terms of the following full rate, low complexity orthogonal matrix.

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

2.4. Differential detection technique

The received signal vector, $\mathrm{r}_d^{(k)} = [r_d^{(k)}(0), r_d^{(k)}(1), \dots\ r_d^{(k)}(2L-3)]^T$, at the destination terminal in the k$^{\text{th}}$ frame is given by (7):

$$\mathrm{r}_d^{(k)} = \mathrm{X}^{(k)}\mathrm{g}_k + \mathrm{n}_d^{(k)}, \tag{7}$$

where $\mathrm{g}_k = [g_{1,k}, g_{2,k}, \dots, g_{L,k}]$ is the channel state information (CSI) between the relay nodes and destination terminal and $\mathrm{n}_d^{(k)} = [n_d^{(k)}(0), n_d^{(k)}(1), \dots\ n_d^{(k)}(2L-3)]^T$ is the noise vector in the k^{th} frame at the destination terminal. In case of two relay system, the received signals in the k^{th} frame at the destination node, assuming that the destination node does not receive a copy from the source node, are given by (8).

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

For three-relay system and at the destination node, the received signals in the kth frame are given by (9).

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

For L-relay system and at the destination node, the received signals in the kth frame are given by (10).

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

For the sake of simplicity and in order to reconstruct the data sequence, let us assume that $g_{l,k} = g_{l,k-1} = g_l, \forall l \in \{1,2,3,\dots,L\}$ and consider noise-free case, therefore, the received signals in the kth frame given by (10) are combined as (11).

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

To reconstruct the original information symbols, the following ML decoders can be used

$$
\begin{aligned}
&\left[\hat{s}^{(k)}(0)\ \hat{s}^{(k)}(1)\right] = \arg\ \min_{s_i \in S_i}\left\|\mathrm{y}_1^{(k)} - [s_1\ s_2]\ \mathrm{y}_1^{(0)}\ \right\|,\\
&\left[\hat{s}^{(k)}(2)\ \hat{s}^{(k)}(3)\right] = \arg\ \min_{s_i \in S_i}\left\|\mathrm{y}_2^{(k)} - [s_1\ s_2]\ \mathrm{y}_2^{(0)}\ \right\|,\\
&\left[\hat{s}^{(k)}(2L-4)\ \hat{s}^{(k)}(2L-3)\right] = \arg\ \min_{s_i \in S_i}\left\|\mathrm{y}_{\mathrm{L-1}}^{(k)} - [s_1\ s_2]\ \mathrm{y}_{\mathrm{L-1}}^{(0)}\ \right\|,
\end{aligned} \tag{12}
$$

where $\mathrm{y}_l^{(0)}$, which is used to detect the signals differentially, is the received signal vector for the arbitrary initial symbols $\mathrm{s}^{(0)}$. Note that $\widehat{g_l} = \frac{\mathrm{y}_l^{(k)}(0)+\mathrm{y}_l^{(k)}(1)}{2}$ and $\widehat{g_{l+1}} = \left(\frac{\mathrm{y}_l^{(k)}(0)-\mathrm{y}_l^{(k)}(1)}{2}\right)^*$ where $l = [1,2,3, \dots L-1]$. Therefore, the previous ML decoder expressed in (12) can be simplified to be a fast symbol-wise decoder, given by (13)

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

3. RESULTS AND DISCUSSION

Our simulation results show the performance of a half-duplex wireless relay network using independent quasi-static flat Rayleigh fading channels. As explained in section 2.1, it is assumed that the total power P_t is distributed equally between the source node and relay nodes. The relay power is equally distributed among all relays as well such that $P_s = L\,P_r = \frac{1}{2}P_t$ and $P_r = \frac{1}{2L}P_t$ where P_t is the power of the r^{th}

relay and P_s is the power of the source node. In this section, we use a Monte Carlo simulation with 10^6 runs to compare the symbol error rate (SER) performance of the proposed DF distributed differential cooperative space time coding technique with the SER performance of the DF cooperative distributed unitary space time coding technique suggested in [25]–[32] as function of total signal-to-noise (SNR), where the total SNR is the ration between the total transmitted power to the total power of the noise. In our simulation results, the 4-PSK modulation is used in all figures. Moreover, we consider a wireless network with L+2 nodes, one source node {S}, one destination node {D} and L relay nodes, which are randomly and independently distributed as explained in section 2.1 and shown in Figure 1. The source node, destination node, and all relay nodes are equipped with single antennas. In addition to that, it is assumed that the CSI is unknown all nodes in the whole network. In the simulation results, the simulated SER curves for both techniques using the DF protocol and using two, three, and four relays are generated. It is observed that the performance of the proposed technique is better than the conventional DUSTC one with much less complexity.

In Figures 4 to 6, the performance analysis of the cooperative networks depends on the error term occurred due to decoding errors made in the relays as shown in (3). Therefore, if we assign more SNR, i.e., 40 dB more, at source-relays links, SNR_{s-r}, than relays-destination links SNR_{r-d}, the diversity and coding grain can be improved as shown in Figures 7 to 9. The SNR at the source- relays links is $SNR'_{s-r} = SNR_{s-r} + 40\ dB$, however in Figures 4 to 6, it is assumed that the total SNR is $SNR_{total}=SNR_{s-r} + SNR_{r-d}$ where $SNR_{s-r} = SNR_{r-d}$. The complexity of the proposed system is low at source node, relay nodes and destination node where the proposed system of L relay nodes operating at a data rate r bps/Hz requires a decoding search space of 2^r search for each symbol at each relay node and at the destination node while cooperative networks of L relay nodes employing DUSTC and operating at the same data rate requires a decoding search space of 2^{rL} for L symbols at each relay node and at the destination node.

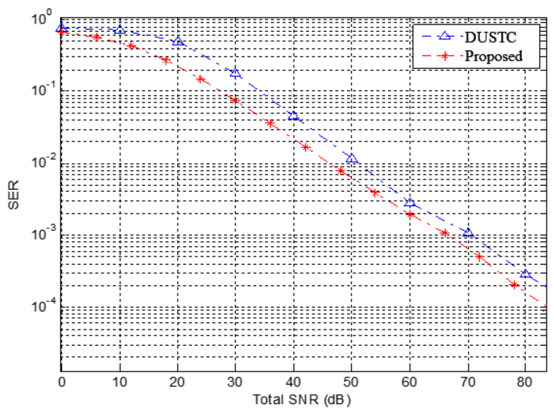

Figure 4. SER performance vs. SNR for different DSTBC techniques using four relays and 4-PSK modulation

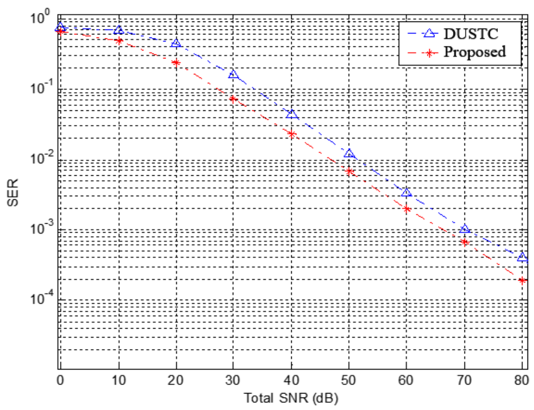

Figure 5. SER performance vs. SNR for different DSTBC techniques using three relays and 4-PSK modulation

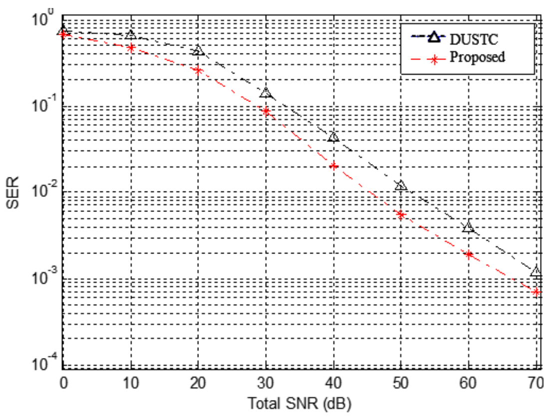

Figure 6. SER performance vs. SNR for different DSTBC techniques using two relays and 4-PSK modulation

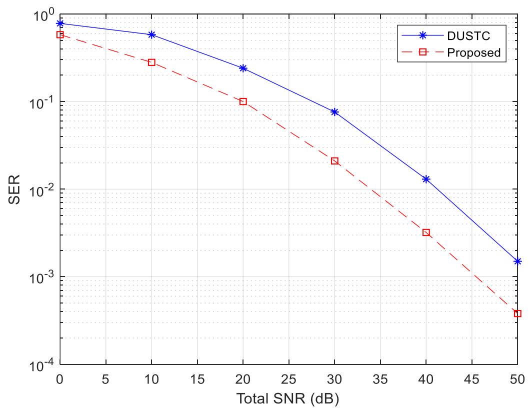

Figure 7. SER performance vs. SNR for different DSTBC techniques using two relays and 4-PSK modulation when $SNR'_{s-r} = SNR_{s-r} + 40\ dB$

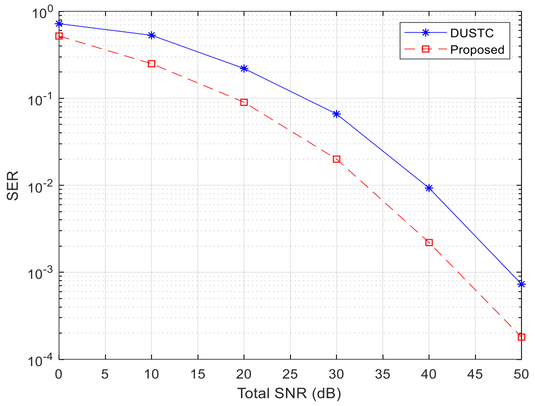

Figure 8. ER performance vs. SNR for different DSTBC techniques using three relays and 4-PSK modulation when $SNR'_{s-r} = SNR_{s-r} + 40\ dB$

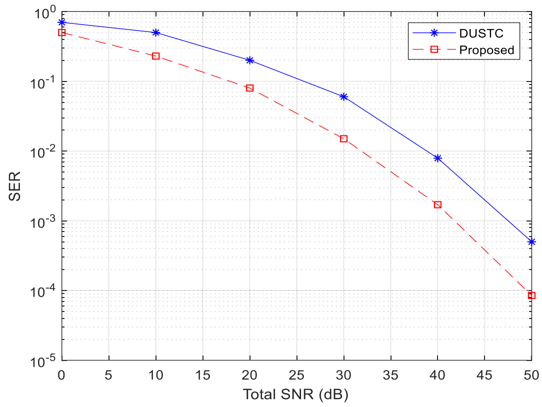

Figure 9. ER performance vs. SNR for different DSTBC techniques using four relays and 4-PSK modulation when $SNR'_{s-r} = SNR_{s-r} + 40\ dB$

4. CONCLUSION

In this paper, we have proposed a differential space-time coding technique. The proposed technique enjoys high error performance with full data-rate and low encoding and decoding complexity as compared with the traditional DUSTC technique. The bit error performance of the proposed system is analyzed by computer simulation. The performance of the proposed technique outperforms the reference techniques for two, three, and four relay systems.

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