# Two-way differential strategy for wireless sensor networks


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**ABSTRACT**

In this paper, a novel optimal two-way amplify and forward (AF) differential beamforming method for wireless sensor network is proposed. The proposed method is an advanced signal processing technique used to enhance the performance and reliability of the communication link by exploiting the diversity provided by multiple antennas. Unlike current state-of-the-art methods which require the knowledge of channel state information (CSI) at both transmitting and receiving antennas or at least at the receiving antennas, the suggested method does not need CSI at any transmitting or receiving antenna. Moreover, the proposed method enjoys high error performance with high diversity and coding gain and has a very low encoding and decoding complexity. Through our simulations, the proposed method is proved to outperform the best known non-coherent multi-antenna methods.





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## 1. INTRODUCTION

In future communication networks, increasing data rate while maintaining an acceptable error rate is one of the main goals to be achieved. Other factors are also considered while optimizing the system performance such as delay, encoding and decoding complexity, and network coverage. On the other hand, the system performance of these networks can be impacted by different factors such as multipath fading and interference. These factors limit the throughput and reduce the error performance [1]–[10]. Several spatial diversity methods have been suggested to eliminate the aforementioned impairments, e.g., relay selection methods [5], [7], beamforming methods [11], [12], and space-time coding (STC) methods [10], [13]–[20]. Recently, distributed spatial diversity methods for cooperative communication networks have been suggested to increase the overall throughput and network coverage, and to reduce the effects of these channel impairments [21]–[25]. Those methods can remarkably improve the performance of wireless relaying systems by increasing the data rate and reducing the bit-error rate (BER). Also, receiving different versions of the transmitted signal via various relays with different amplitudes and phases increases the system diversity. In particular, applying efficient techniques to combine the various received signals could lead to a remarkable improvement in system performance.

The relay node, as an intermediate point that: i) obtains the signal through the source-node link, ii) processes the signal, and iii) transmits the signal to the receiver-node. Many processing protocols could be applied at the relay such as amplify and forward (AF) protocol, combine and forward (CF) protocol, and decode and forward (DF) protocol. These techniques enhance the obtained signal to noise ratio (SNR), throughput, and the performance in terms of BER, however different level of complexity is associated with each technique. Therefore, complexity-performance tradeoff is a major concern in such systems that requires to be optimized along with the number of deployed relays. Intuitively, increasing the number of relays distributed between the source and the destination improve the overall system performance in terms of BER and throughput [26]–[32]. Several spatial-diversity methods have been recently suggested considering that the channel state information (CSI) is available at every node in the whole system [5], [7]. In these methods, a slow fading channel model is considered. However, other methods assume that CSI is only available at the destination [8], [17]–[19]. Unlike the previous methods, both blind and differential diversity methods [10], [11], [13]–[15], [22]–[25] provide an increase in the diversity gain without the need to have the CSI at any transmitting or receiving nodes. Unfortunately, the latter methods suffer from several issues such as low error performance, large delay, and low throughput when compared to other methods.

Recently, two-directional communication techniques have been suggested as a way to enhance the overall error performance and achievable data rate [6], [10], [14]. Two-directional techniques are categorized according to the number of phases required for the terminals to exchange their data into two-phase [10], three-phase [6], and four-phase [11] protocols. Note that the number of phases required to exchange the information highly affect the overall performance and the achievable data rate. Moreover, the relay nodes distributed randomly between the terminals are utilized to process and forward the data using a certain coding scheme. The relay nodes can process and encode the received signals using orthogonal, e.g., STC, or non-orthogonal coding techniques. STC is considered as an efficient way to send the information symbols during several phases and using several relay nodes to achieve high performance in terms of BER and high data rate with low encoding and decoding complexity [10], [14]. Non-orthogonal schemes have high diversity and coding gain. However, these schemes suffer from very high decoding complexity which increases exponentially with the number of relay nodes or constellation size in some cases, especially due to channel estimation. Recently, several distributed special diversity schemes have been suggested to offer full diversity and high coding gain without needing CSI at any node in the whole network to reduce the overall encoding and decoding complexity and overhead due to channel estimation [10], [11], [13]–[15], [22]–[25]. More recent techniques and types related to wireless relay and sensor networks have been studied [33]–[37].

In this paper, a novel technique for wireless relay networks is proposed and verified via mathematical analysis and numerical simulations. Unlike current state-of-the-art research where it is assumed that CSI is available at both transmitter-and-receiver or only at the receiver, the proposed technique does not require any CSI neither at transmitter nor at the receiver. The proposed technique for wireless relay network has shown a remarkable improvement in the system's performance compared to existing systems in terms of BER. This paper is organized as follows: in section 2 the system model is discussed and detailed mathematical analysis is provided. In section 3, numerical analysis and results are provided showing the performance improvements. In section 4, conclusion and future directions are investigated.

## 2. METHOD

In this work, a novel optimal bi-directional AF multi-antenna method for wireless sensor network is proposed. Unlike current state-of-the-art methods which require the channel knowledge at both transmitting and receiving antennas or at least at the receiving antennas, the proposed method does not require channel knowledge at any antenna. Moreover, the proposed method enjoys high error performance with high diversity and coding gain, and has a very low encoding and decoding complexity.

### 2.1. System model

The communication system model is shown in Figure 1. It consists of two transmitting nodes $\tau_1$ and $\tau_2$ that are communicating in a half-duplex mode in the presence of R intermediate relays denoted as $\mathcal{R}_1, \mathcal{R}_2, \dots, \mathcal{R}_R$. It is assumed that there is no direct link between the two transmitting nodes. Moreover, each intermediate relay $\mathcal{R}_i$ has a single antenna that is utilized for both transmission and reception. The relays can only communicate through the transmitting nodes, and they do not share the received data symbols internally. Let $x_{\tau 1}^{(i)}$ and $x_{\tau 2}^{(i)}$ be the transmitted symbols by terminal-1 ($\tau_1$) and terminal-2 ($\tau_2$) respectively, where $i$ represents the transmission time slot index. The channel coefficients between $\tau_1$ and the R relays are given by the vector $f \in \mathbb{C}^{R\times 1}$ where $f = (f_1, f_2, \dots\dots, f_R)$ and $f_i$ represents the channel coefficient between $\tau_1$ and $i^{th}$ relay $\mathcal{R}_i$. Similarly, the channel coefficients between $\tau_2$ and the R relays are given by the vector $g \in \mathbb{C}^{R\times 1}$ where $g = (g_1, g_2, \dots\dots, g_R)$ and $g_i$ represents the channel coefficient between $\tau_2$ and $i^{th}$ relay $\mathcal{R}_i$. Let $y_{R1}^{(i)}$ and $y_{R2}^{(i)}$ be the vectors received by an intermediate relay from the first and the second transmitters respectively which are given as (1) and (2):

$$y_{R_1}^{(i)} = \sqrt{P_{\tau_1}} f x_{\tau_1}^{(i)} + n_{R_1}^{(i)} \quad (1)$$

$$y_{R_2}^{(i)} = \sqrt{P_{\tau_2}} g x_{\tau_2}^{(i)} + n_{R_2}^{(i)} \quad (2)$$

where $P_{\tau_1}$ and $P_{\tau_2}$ are the transmitted power of terminal-1 ($\tau_1$) and terminal-2 ($\tau_2$), respectively and the relay noise vectors $n_{R_1}^{(i)}$, $n_{R_2}^{(i)}$ have a circularly symmetric Gaussian distribution with variance $\sigma^2$. Let $y_{\tau 1}^{(i)}$ represents the received signal at terminal-1 from all relays and $y_{\tau 2}^{(i)}$ represents the received signal at terminal-2 from all relays, then:

$$y_{\tau_1}^{(i)} = \sqrt{P_R} f^{\mathrm{T}} x_{R_1}^{(i)} + \mathrm{n}_{\tau_1}^{(i)} \quad (3)$$

$$y_{\tau 2}^{(i)} = \sqrt{P_R} g^{\mathrm{T}} x_{R_2}^{(i)} + \mathrm{n}_{\tau_2}^{(i)} \quad (4)$$

where $P_R$ defines the relays transmitting power, $x_{R_1}^{(i)}$ and $x_{R_2}^{(i)}$ define symbol vectors retransmitted by relays to terminal-1 and terminal-2 correspondingly, and the node noise $\mathrm{n}_{\tau_1}^{(i)}$ and $\mathrm{n}_{\tau_2}^{(i)}$ have a circularly symmetric Gaussian distribution with variance $\sigma^2$. The channel vectors $f$ and $g$ follow the same Gaussian distribution with unity variance.

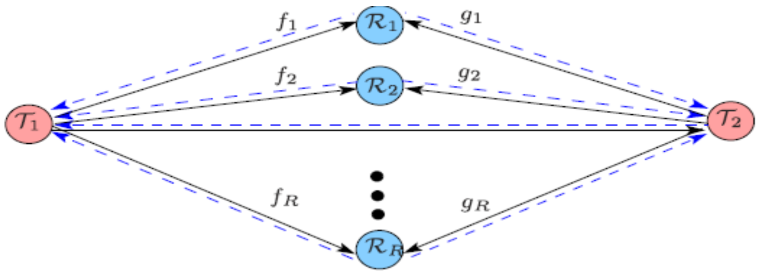


Figure 1. System model

#### 2.1.1. Distributed differential space time coding

In this system, it is assumed that there is no CSI at either nodes or relays and the differential technique for two-way communication [9]–[15] is considered for signal transmission. The transmission scheme is arranged in terms of blocks in time domain and during this interval, each node transmits T=R symbols. In particular, let us define $s_{\tau_1}^{(i)}$ and $s_{\tau_2}^{(i)}$ as the symbol vectors to be transmitted in $i^{th}$ block as (5):

$$s_{\tau_1}^{(i)} = \left[s_{\tau_1,1}^{(i)} \quad \cdots \quad s_{\tau_1,T}^{(i)}\right]^{\mathrm{T}}, s_{\tau_2}^{(i)} = \left[s_{\tau_2,1}^{(i)} \quad \cdots \quad s_{\tau_2,T}^{(i)}\right]^{\mathrm{T}} \quad (5)$$

Also define the differentially encoded vectors $x_{\tau_1}^{(i)}$ and $x_{\tau_2}^{(i)}$ as (6):

$$x_{\tau_1}^{(i)} = \mathrm{diag}\left(x_{\tau_1}^{(i-1)}\right) s_{\tau_1}^{(i)}, x_{\tau_2}^{(i)} = \mathrm{diag}\left(x_{\tau_2}^{(i-1)}\right) s_{\tau_2}^{(i)} \quad (6)$$

where $\mathrm{diag}(*)$ is a function that takes $T$ elements and generates a $T$ by $T$ diagonal matrix. The symbol vectors received during $i^{th}$ block by $r^{th}$ array are then defined as (7):

$$y_{R_1,r}^{(i)} = \sqrt{P_{\tau_1}} f_r x_{\tau_1}^{(i)} + n_{R_1,r}^{(i)}, y_{R_2,r}^{(i)} = \sqrt{P_{\tau_2}} g_r x_{\tau_2}^{(i)} + n_{R_2,r}^{(i)} \quad (7)$$

Consider the operator $\Phi_{R,r}^{(i)}$ that is used to perform a transformation for the vectors $y_{R_1,r}^{(i)}$ and $y_{R_2,r}^{(i)}$ as (8):

$$y_{R,r}^{(i)} = \Phi_{R,r}^{(i)}\left(y_{R_1,r}^{(i)} \odot y_{R_2,r}^{(i)}\right) \quad (8)$$

where $\odot$ stands for kronecker product and $\Phi_{R,r}^{(i)}$ is a power scaling matrix of diagonal form that is defined as (9):

$$\Phi_{R,r}^{(i)} = \text{diag}\left(\left|y_{R_1,r}^{(i)} \odot y_{R_2,r}^{(i)}\right|\right)^{-1} \tag{9}$$

i.e. $\Phi_{R,r}^{(i)}$ ensures equal power elements in $y_{R,r}^{(i)}$. Consider the following relation in terms of the input signal where $x_R^{(i)} = x_{\tau_1}^{(i)} \odot x_{\tau_2}^{(i)}$. Recalling the above procedure, then the received signal could be written as (10):

$$y_{R,r}^{(i)} = \Phi_{R,r}^{(i)}\left(\sqrt{P_{\tau_1}P_{\tau_2}} f_r g_r x_R^{(i)} + n_{R,r}^{(i)}\right) \tag{10}$$

where $n_{R,r}^{(i)}$ is a corresponding noise term. Now, let us use space-time block code methodology in reformulating the problem from relays transmission perspective for the vectors $y_{R,r}^{(i)}$. Therefore, we define a space time code structure by a set of permutation matrices $\mathrm{A}_1, \dots, \mathrm{A}_\mathrm{T}$ and $\mathrm{B}_1, \dots, \mathrm{B}_\mathrm{T}$. Then, restrict possible codes to ones, for which permutation matrices possess mutual exclusivity property i.e., either Ai=0 or Bi=0. After that, we define code matrix of r^th relay $\mathrm{X}_{\mathrm{R,r}}^{(\mathrm{i})} \in \mathbb{C}^{\mathrm{T}\times\mathrm{R}}$ corresponding to the vector received at *r^th* relay $\mathrm{y}_{R,r}^{(i)}$. This code matrix formation can then be represented by applying operator $\chi$:

$$\mathrm{X}_{R,r}^{(i)} = \chi(\mathrm{y}_{R,r}^{(i)}) = \left[\mathrm{A}_1\mathrm{y}_{R,r}^{(i)} + \mathrm{B}_1\mathrm{y}_{R,r}^{(i)} \quad \cdots \quad \mathrm{A}_\mathrm{T}\mathrm{y}_{R,r}^{(i)} + \mathrm{B}_\mathrm{T}\mathrm{y}_{R,r}^{(i)}\right]^\mathrm{T} \tag{11}$$

Let then each relay $R$ transmit r^th column of its correspondent code matrix $\mathrm{X}_{R,r}^{(i)}$. Signal vector received at second node $\mathrm{y}_{\tau_2}^{(i)}$ can then be then written as (12):

$$\begin{aligned}
\mathrm{y}_{\tau_2}^{(i)} &= \mathrm{X}_R^{(\mathrm{i})}\Delta_g^{(i)}\Delta_f^{(i)}\mathrm{g} + n_{\tau_2}^{(i)} \\
&= \left(\mathrm{S}_{\tau_1}^{(i)} \odot \mathrm{S}_{\tau_2}^{(i)} \odot \mathrm{X}_{\tau_1}^{(\mathrm{i}\text{-}1)} \odot \mathrm{X}_{\tau_2}^{(\mathrm{i}\text{-}1)}\right)\Delta_g^{(i)}\Delta_f^{(i)}\mathrm{g} + \mathrm{n}_{\tau_2}^{(i)} \\
&= \left(S_{\tau_1}^{(i)} \odot S_{\tau_2}^{(i)} \odot X_R^{(i\text{-}1)}\right)\Delta_g^{(i)}\Delta_f^{(i)} g
\end{aligned} \tag{12}$$

where,

$$\mathrm{X}_R^{(\mathrm{i})} = \chi\left(\mathrm{x}_R^{(\mathrm{i})}\right), \mathrm{S}_{\tau_1}^{(\mathrm{i})} = \chi\left(\mathrm{s}_{\tau_1}^{(\mathrm{i})}\right), \mathrm{S}_{\tau_2}^{(\mathrm{i})} = \chi\left(\mathrm{s}_{\tau_2}^{(\mathrm{i})}\right), X_{\tau_1}^{(\mathrm{i}\text{-}1)} = \chi\left(\mathrm{x}_{\tau_1}^{(\mathrm{i}\text{-}1)}\right), X_{\tau_2}^{(\mathrm{i}\text{-}1)} = \chi\left(\mathrm{x}_{\tau_2}^{(\mathrm{i}\text{-}1)}\right) \tag{13}$$

$\Delta_g^{(i)}$ and $\Delta_f^{(i)}$ being diagonal matrices defined as (14) and (15):

$$\Delta_{g,kk}^{(i)} = \begin{cases} \exp(j\measuredangle g_k), \text{ if } \mathrm{B}_i = 0 \\ \exp-(j\measuredangle g_k), \text{ if } \mathrm{A}_i = 0 \end{cases} \tag{14}$$

$$\Delta_{f,kk}^{(i)} = \begin{cases} \exp(j\measuredangle f_k), \text{ if } \mathrm{B}_i = 0 \\ \exp(-j\measuredangle f_k), \text{ if } \mathrm{A}_i = 0 \end{cases} \tag{15}$$

Now, decoding of $\mathrm{s}_{\tau_1}^{(i)}$ can then be performed using (16):

$$\mathrm{s}_{\tau_1}^{(i)} = \underset{\mathrm{s}_{\tau_1}^{(i)}}{\operatorname{argmin}} \left\|\mathrm{y}_{\tau_2}^{(i)} - \left(\mathrm{S}_{\tau_1}^{(i)} \odot \mathrm{S}_{\tau_2}^{(i)} \odot \widehat{\mathrm{X}}_R^{(\mathrm{i}\text{-}1)}\right){\widehat{\mathrm{X}}_R^{(\mathrm{i}\text{-}1)}}^{-1}\mathrm{y}_{\tau_2}^{(i-1)}\right\| \tag{16}$$

Similarly, an estimate for $\mathrm{s}_{\tau_2}^{(i)}$ is obtained.

### 2.1.2. Simple distributed differential beamforming

This scheme performs transmission in four time slots [11], [24]. We start by defining symbols transmitted by first and second relays $x_{\tau_1}^{(i)}$ and $x_{\tau_2}^{(i)}$ as differentially encoded as (17):

$$x_{\tau_1}^{(i)} = x_{\tau_1}^{(i-1)}s_{\tau_1}^{(i)}, x_{\tau_2}^{(i)} = x_{\tau_2}^{(i-1)}s_{\tau_2}^{(i)} \tag{17}$$

Now, define the signals received by the *r^th* relay from the first terminal in *i^th* and (i-1)*^th* blocks as $y_{R1,r}^{(i)}, y_{R1,r}^{(i-1)}$, and similarly from the second node as $y_{R2,r}^{(i)}$ and $y_{R2,r}^{(i-1)}$ respectively. In this analysis, M-phase shift keying

(M-PSK) is considered for transmission. Then, the definition of the signals transmitted by the r-th relay $x_{R1,r}^{(i)}$ and $x_{R2,r}^{(i)}$ as (18) and (19):

$$x_{R1,r}^{(i)} = \sqrt{P_R}\exp\left(-j\measuredangle y_{R1,r}^{(i)} - j\measuredangle y_{R2,r}^{(i-1)} + j\measuredangle y_{R2,r}^{(i)}\right) \tag{18}$$

$$x_{R2,r}^{(i)} = \sqrt{P_R}\exp\left(-j\measuredangle y_{R2,r}^{(i)} - j\measuredangle y_{R1,r}^{(i-1)} + j\measuredangle y_{R1,r}^{(i)}\right) \tag{19}$$

The same precoding procedure is performed at all relays. Hence, the estimated symbols at terminal nodes can be calculated using as (20) and (21):

$$\hat{s}_{\tau 2}^{(i)} = \underset{\hat{s}_{\tau 2}^{(i)}}{\operatorname{argmin}} \left|\exp\left(j\measuredangle y_{\tau 1}^{(i)}\right) - \exp\left(j\left(\measuredangle y_{\tau 1}^{(i-1)} - \measuredangle s_{\tau 1}^{(i)} - \measuredangle \hat{s}_{\tau 2}^{(i-1)} + \measuredangle \hat{s}_{\tau 2}^{(i)}\right)\right)\right| \tag{20}$$

$$\hat{s}_{\tau 1}^{(i)} = \underset{\hat{s}_{\tau 1}^{(i)}}{\operatorname{argmin}} \left|\exp\left(j\measuredangle y_{\tau 2}^{(i)}\right) - \exp\left(j\left(\measuredangle y_{\tau 2}^{(i-1)} + \measuredangle s_{\tau 2}^{(i)} + \measuredangle \hat{s}_{\tau 1}^{(i-1)} + \measuredangle \hat{s}_{\tau 1}^{(i)}\right)\right)\right| \tag{21}$$

#### 2.1.3. General rank beamformer (GRB)

Suppose now for vectors f and g known covariance matrices are $R_{ff}$ and $R_{gg}$. Define filter matrices $\Phi_{\tau_1}$ and $\Phi_{\tau_2}$ to maximize the SNR at the receivers [12]. Introduce supplementary vectors $w_d$ and $w_u$:

$$\mathrm{w}_d = \sqrt{\frac{P_T}{(1+\lambda_{\max})v^{\mathrm{H}}\mathrm{R}_{nn}}}\mathrm{u},\ \mathrm{w}_u = \mathrm{v} \tag{22}$$

where v is a normalized eigenvector of $\mathrm{R}_{nn}^{-1}\mathrm{R}_{ff}$ for maximum eigenvalue $\lambda_{max}$ and u is principal eigenvector of $R_{gg}$. Matrices $\Phi_{\tau_1}$ and $\Phi_{\tau_2}$ are then defined as (23):

$$\Phi_{\tau_2} = \mathrm{w_d w_u^H},\ \Phi_{\tau_1} = \mathrm{w_u^* w_d^T} \tag{23}$$

#### 2.1.4. The proposed differential beamforming scheme using maximum ratio combining

Now, suppose that relays are able to exchange received data symbols. This can be thought as a substitution of single antenna relay array of size *R* by a single relay with *R* antennas. Assume using AF approach, i.e., relay does not decode received symbols. Relay performs array processing of multiplying by matrices $\Phi_{\tau_1}$ and $\Phi_{\tau_2}$. Then received signals at first and second nodes are defined as (24):

$$y_{\tau_1}^{(i)} = \Phi_{\tau_1}\mathrm{y}_{R_1}^{(i)} + n_{\tau_1}^{(i)},\ y_{\tau_2}^{(i)} = \Phi_{\tau_2}\mathrm{y}_{R_2}^{(i)} + n_{\tau_2}^{(i)} \tag{24}$$

Using maximum ratio combining (MRC) approach $\Phi_{\tau_1}$ and $\Phi_{\tau_2}$ are to be defined as (25):

$$y_{\tau_1}^{(i)} = \Phi_{\tau_1}y_{R_1}^{(i)} + n_{\tau_1}^{(i)},\ y_{\tau_2}^{(i)} = \Phi_{\tau_2}y_{R_2}^{(i)} + n_{\tau_2}^{(i)} \tag{25}$$

Decoding at receivers then can be performed using (25).

## 3. RESULTS AND DISCUSSION

In this section, we introduce the simulation results of the system model discussed in section 2. Figures 2 and 3 show the BER versus the SNR of a cooperative communication system composed of two terminals $\tau_1$ and $\tau_2$ and two relay nodes (*R*=2). In our simulations, Rayleigh flat-fading channels are considered, and the transmission was simulated for $10^5$ channel realizations. For each channel realization 48 time slots were simulated. In the transmission from $\tau_1$ to $\tau_2$, the total transmitted power is divided equally among the source terminal $P_{\tau_1}$ and the relay node $P_r$ such that $P_{\tau_1} = P_r$ where the total relay power $P_{\mathcal{R}}$ is also equally divided among all its transmitting antennas. For Figure 2, 16-PSK modulation was used for four phase schemes such as simple distributed differential beamforming scheme, differential MRC scheme, and GRB scheme. For the three phase schemes such as differential space time coding scheme 8-PSK modulation was used to equalize spectral efficiency. For the two-phase schemes such as differential space time coding scheme [10], 4-PSK modulation was used to equalize spectral efficiency. The AF protocol is performed using one bit per channel use (bpcu).

By inspecting Figure 2, the BER performance ranking of the schemes explained in section 2 from the worst to the best will be, differential space time coding scheme explained in subsubsection 2.1.1 has the worst performance, then GRB scheme explained in subsubsection 2.1.3, followed by simple distributed differential beamforming scheme explained in subsubsection 2.1.2 and finally the proposed differential MRC scheme explained in subsubsection 2.1.4, where MRC scheme has a superior performance. This is due to the fact that MRC scheme allows received symbol exchange between individual relays. GRB scheme has the best performance in low SNR region, due to the knowledge of correlation properties of channels and received symbol exchange between relays. At high SNR region, differential MRC scheme however, has a better performance, due to instantaneous channel information usage.

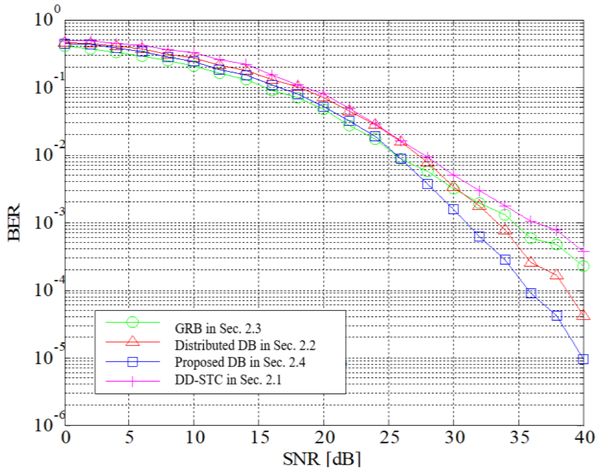


Figure 2. Performance comparison for relay transmission schemes using the AF protocol with 1 bpcu and R=2

In Figure 3 the suggested scheme explained in subsubsection 2.1.4 is compared to the state-of-the-art coherent and non-coherent schemes suggested in [10]–[14] using the AF protocol and two bpcu. Figure 3 clearly shows that the performance of the suggested scheme outperforms the best known two-there and four-phase distributed space time coding schemes suggested in [10], [13], [14], as well as the distributed beamforming schemes suggested in [11], [12]. Note that the diversity gain is related to the slope of the BER curve at high SNR values while the coding gain is related to the shift of the BER curve to the left, e.g., by doubling the power, the BER curve will be shifted 3 dB to the left without any change to the slope of the BER curve which means that the added coding gain is 3 dB in this case. From Figure 3, we can observe that the proposed method is steeper and shifted horizontally more to the left than the other methods. This is why the proposed method has high diversity and coding gain.

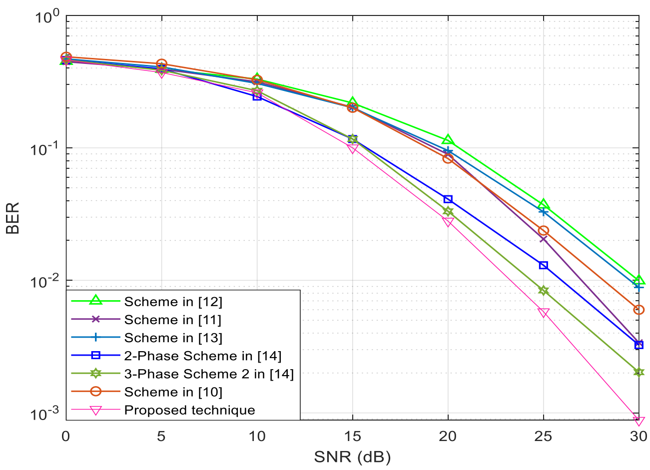


Figure 3. Performance comparison for relay transmission schemes using the AF protocol with 2 bpcu and R=2

In Figure 4 the proposed method suggested in subsubsection 2.1.4 is compared with the state-of-the-art coherent and non-coherent methods suggested in [10], [12]–[14], [33], [36] using the AF protocol and one bpcu. Figure 4 clearly shows that the performance of the proposed method outperforms the best known two-there and four-phase distributed space time coding schemes proposed in [10], [13], [14], [33], as well as the distributed beamforming method proposed in [12]. It is clearly observed that the BER difference between the optimal beamforming method proposed in [36], which require all CSI at all transmitting and receiving antennas, and the proposed method, which does not require CSI at any transmitting or receiving antenna, is just 3 dB. Note that the optimal difference between coherent and non-coherent method is 3 dB.

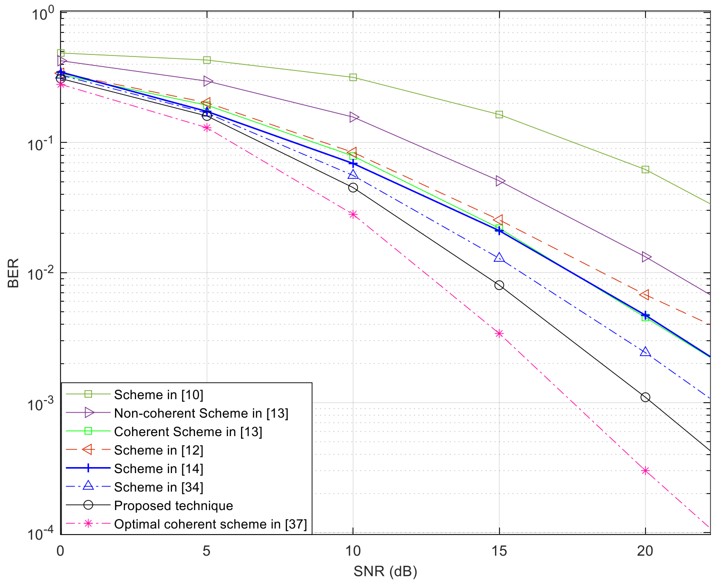


Figure 4. Performance comparison for relay transmission schemes using the AF protocol with 1 bpcu and R=2

## 4. CONCLUSION

This paper proposes a new cooperative communication system technique that operates in a bi-directional manner. The technique is validated through mathematical analysis and numerical simulations. Unlike existing methods, which require the availability of CSI at either the transmitter, receiver, or both, the proposed method eliminates the need for CSI at any transmitting or receiving antenna. The results demonstrate that the suggested cooperative communication system technique significantly enhances system performance, particularly in terms of BER, outperforming the current state-of-the-art methods.

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