RELAY SELECTION BASED SPACE-TIME CODING FOR TWO-WAY WIRELESS RELAY NETWORKS USING DIGITAL NETWORK CODING

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ABSTRACT

In this paper, we propose a novel decode-and-forward dual-relay selection technique based on Alamouti space time coding for two-way wireless relay networks (TWRNs). The two- and the three-phase TWRN protocol are used in the first and second version of the proposed technique, respectively, to exchange the information symbols of the communicating terminals. In order not to waste any power for transmitting information symbols known at any terminal and hence to improve the achievable coding gain, the proposed technique uses the concept of digital network coding in which the transmitted symbols of both terminals are combined at the relays into a symbol of the same constellation. To further improve the reliability of the communication and offer additional coding gain, Alamouti space time coding is incorporated in our technique. Simulation results show a substantially improved bit error rate (BER) performance of the proposed techniques as compared to the the state-of-the art techniques.

Index Terms— Two-way wireless relay networks, relay selection, distributed space-time coding, cooperative diversity, digital network coding.

I. INTRODUCTION

In wireless communication systems, the achievable data rate and the overall system performance in terms of BER are limited mainly due to multi-user interference and several channel impairments such as time-varying fading cased by Doppler spread and multipath propagation. Multi-antenna diversity techniques can efficiently be applied to combat these effects and overcome various channel impairments by using multiple antennas at one or both ends of the communication link [1]. Cooperative diversity techniques [2]–[4], have recently been introduced for wireless relay networks to provide similar diversity gains as in centralized multi-antenna systems. In cooperative diversity techniques, the main idea is to exploit the broadcast nature of wireless media where the information signal transmitted by the source terminal is resent by cooperating users that act as relays between source and destination. In a wireless relay network all nodes, i.e., the source terminal and the relays, can jointly process and transmit their information signals by sharing their antennas and creating a *virtual antenna array* and, therefore, exploiting a spatial diversity gain.

Several efficient cooperative diversity strategies have been proposed that exploit the spatial diversity provided by the relay nodes to improve the overall system performance in terms of BER and data rate while exhibiting reasonable encoding and decoding complexity [3]–[9]. Among them, distributed space-time coding (DSTC) techniques in which the relays encode their received signals in the spatial domain, over multiple antennas, and in time domain, over multiple time slots became particularly popular as they offer a diversity and coding gain at no additional cost of bandwidth or transmitted power and without requiring channel state information (CSI) at the transmitting nodes [5]–[9].

Recently, TWRNs have been considered where two terminals exchange their information via a distributed wireless relay network [10]–[17]. Based on the number of time slots required for the information exchange, TWRN protocols can be be categorized into three popular categories: the four-phase protocols, the three-phase protocols, and the two-phase protocols. Due to the increase in symbol rate associated with the two- and three-phase protocols, it has been shown that the techniques employing them outperform the conventional techniques using the four-phase protocols [10]–[14].

In the case that all relays in a multiple relay network are used to transmit their received symbol vectors, orthogonal access schemes as, e.g., time division multiplexing, frequency division multiplexing, code division multiplexing, and orthogonal coding can be applied [9], [18]. Orthogonal schemes are however associated with bandwidth limitations and reduced spectral efficiency. Therefore, non-orthogonal coding schemes may be applied that however suffer from high decoding complexity. A promising approach to overcome both limitations is to use relay selection techniques for one- and two-way non-orthogonal wireless relay networks [19]–[23]. Several single-relay selection techniques have been introduced in which the relay that has either i) the optimal signal-to-noise ration (SNR) or ii) the largest achievable data rate among all relays is selected for transmission [24], [25]. It has been proofed that the single-relay selection techniques enjoy full spatial diversity gain if all relays are involved in the selection procedure [20]. In [19], single- and dual-relay selection technique based on the min-max and the double-max criterion have been addressed that enjoy the full spatial diversity gain with low complexity as compared to the optimal technique. Furthermore, it has also been shown that dual-relay selection techniques outperform the single-relay selection techniques [19].

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In this paper, a novel decode-and-forward dual-relay selection technique based on Alamouti space time coding for TWRNs is proposed. The communicating terminals exchange their information symbols using the two-phase protocol in the first version of the proposed technique and using the three-phase protocol in the second version of the proposed technique. The concept of digital network coding is used to improve the overall performance of the relay network. In contrast to combination schemes that rely on the summation of the received signals, the proposed encoding techniques performed at the relays are not associated with any wasted in power for transmitting information signals known at any receiver. Alamouti space-time coding is incorporated in the proposed dual-relay selection techniques to further improve the performance and hence reliability of the communication. Simulations show a substantially improved performance in terms of BER of the proposed techniques as compared to the known techniques.

II. WIRELESS RELAY NETWORK MODEL

We consider a half-duplex TWRN with $R+2$ single-antenna nodes as illustrated in Fig. 1 consisting of two terminals $\mathcal{T}_1$ and $\mathcal{T}_2$ that exchange their information symbols via R nodes ($\mathcal{R}_1, \ldots, \mathcal{R}_R$) acting as distributed relays for the signals transmitted from the terminals. We denote the channels from $\mathcal{T}_1$ to $\mathcal{T}_2$, from $\mathcal{T}_1$ to the rth relay, and from $\mathcal{T}_2$ to the rth relay as f_0, f_r, and g_r, respectively. We assume channel reciprocity for the transmission from $\mathcal{T}_1$ to $\mathcal{T}_2$ and vice versa. Further, we consider the extended block fading channel model, for which in the two-phase scheme, it is assumed that the channels remain approximately constant over two consecutive time slots and to randomly evolve outside this time interval. Similarly, in the three-phase scheme, the channels are assumed to remain approximately constant over three time slots. We further assume that the relays are perfectly synchronized in terms of carrier frequency and symbol timing and the CSI is available at the receiving nodes. The nodes $\mathcal{T}_1$, $\mathcal{T}_2$, $\mathcal{R}_1, \ldots, \mathcal{R}_R$ have limited average transmit powers $P_{\mathcal{T}_1}$, $P_{\mathcal{T}_2}$, $P_{\mathcal{R}_1}, \ldots, P_{\mathcal{R}_R}$, respectively.

Throughout this paper, $(\cdot)^*$, $\mathrm{mod}(a,b)$, $\|\cdot\|$, $\oplus$, $\mathrm{diag}(\mathbf{a})$, $\mathbf{I}_T$, σ^2, $[\mathbf{a}]_i$, and $\mathrm{E}\{\cdot\}$ denote the complex conjugate, the remainder of the division of a by b, the Frobenius norm, the exclusive OR (XOR) operation, the $T \times T$ identity matrix, the noise variance, the ith entry of a vector $\mathbf{a}$, and the statistical expectation, respectively. Depending on the used context, $|\cdot|$ denotes the absolute value or the cardinality of a set.

III. TWO-PHASE TWO-WAY DF RELAY SELECTION TECHNIQUE

In this section, we consider the two-phase protocol proposed in [14], as it has been shown to achieve the best error rate performance among all TWRN protocols. In the first phase of this protocol from time-slot 1 to T, $\mathcal{T}_1$ and $\mathcal{T}_2$ transmit simultaneously the $T \times 1$ information symbol vectors $\mathbf{s}_{\mathcal{T}_1}$ and $\mathbf{s}_{\mathcal{T}_2}$, respectively, to the relays where $[\mathbf{s}_{\mathcal{T}_1}]_i \in \mathcal{S}_{\mathcal{T}_1}$, $[\mathbf{s}_{\mathcal{T}_2}]_i \in \mathcal{S}_{\mathcal{T}_2}$, $\mathrm{E}\left\{|[\mathbf{s}_{\mathcal{T}_1}]_i|^2\right\} = 1$, $\mathrm{E}\left\{|[\mathbf{s}_{\mathcal{T}_2}]_i|^2\right\} = 1$, and $\mathcal{S}_{\mathcal{T}_1}$, $\mathcal{S}_{\mathcal{T}_2}$ are two, not necessarily identical, symbol constellations. Remark that $\mathcal{S}_{\mathcal{T}_t}$ is the constellation of an entry of $\mathbf{s}_{\mathcal{T}_t}$ and not the vector constellation. This convention will be used throughout the paper when referring to constellations.

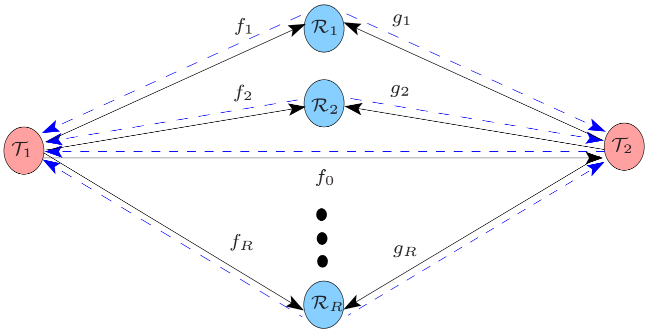

Fig. 1. TWRN with $R+2$ nodes.

In the first phase from time slot 1 to T, the $T \times 1$ vector received at the rth relay is given by

$$\mathbf{y}_{\mathcal{R},r} = \sqrt{2P_{\mathcal{T}_1}}\; f_r\; \mathbf{s}_{\mathcal{T}_1} + \sqrt{2P_{\mathcal{T}_2}}\; g_r\; \mathbf{s}_{\mathcal{T}_2} + \mathbf{n}_{\mathcal{R},r} \tag{1}$$

where f_r and g_r denote the flat fading channel from terminal $\mathcal{T}_1$ to the rth relay and from terminal $\mathcal{T}_2$ to the rth relay, respectively, and $\mathbf{n}_{\mathcal{R},r}$ denotes the $T \times 1$ noise vector at the rth relay in the first phase. We assume that the noise vector can be modeled as a spatially white independently and identically distributed complex circular Gaussian random variable with zero mean and covariance $\sigma^2 \mathbf{I}_T$. Each relay decodes the received symbols of the first and second terminal using the following ML decoder

$$\arg \min_{\mathbf{s}_{\mathcal{T}_1}, \mathbf{s}_{\mathcal{T}_2}} \left\| \mathbf{y}_{\mathcal{R},r} - (\sqrt{2P_{\mathcal{T}_1}} f_r \mathbf{s}_{\mathcal{T}_1} + \sqrt{2P_{\mathcal{T}_2}} g_r \mathbf{s}_{\mathcal{T}_2}) \right\|. \tag{2}$$

We remark that in (2), two symbol vectors are detected from each received symbol vector and thus, the decoder suffers from a high decoding complexity. Therefore the protocol proposed in [10] can be used instead to reduce the relay decoding complexity by using a combination function at the communicating terminals . Let $\tilde{\mathbf{s}}_{\mathcal{T}_1,r}$ and $\tilde{\mathbf{s}}_{\mathcal{T}_2,r}$ denote the decoded information symbols of the first and the second terminal at the rth relay, respectively. The symbols are combined at the rth relay into a single $T \times 1$ symbol vector as

$$[\mathbf{s}_{\mathcal{R},r}]_i = \mathcal{F}([\tilde{\mathbf{s}}_{\mathcal{T}_1,r}]_i, [\tilde{\mathbf{s}}_{\mathcal{T}_2,r}]_i) \tag{3}$$

where $\mathcal{F}(\cdot,\cdot)$ is a combination function that avoids wasting of transmit power for information that is known to either of the destination terminals. In [14], modular arithmetic was proposed to superimpose the symbols. In this case, we note that the ith symbol of $\mathbf{s}_{\mathcal{R},r}$ denoted by $[\mathbf{s}_{\mathcal{R},r}]_i$ belongs to a constellation $\mathcal{S}_{\mathcal{R}}$ with cardinality $|\mathcal{S}_{\mathcal{R}}| = \max\{|\mathcal{S}_{\mathcal{T}_1}|, |\mathcal{S}_{\mathcal{T}_2}|\}$. Denoting the jth element in the (scalar) constellation set $\mathcal{S}$ as $\mathcal{S}(j)$ where $j \in \{0, 1, \ldots, |\mathcal{S}| - 1\}$ and denote the inverse as $\mathcal{S}^{-1}(\;) = j$. Let us define $\mathbf{k}_{\mathcal{T}_1}$ and $\mathbf{k}_{\mathcal{T}_2}$ denote index vectors corresponding to symbols vectors of terminals $\mathcal{T}_1$ and $\mathcal{T}_2$, respectively, such that $\mathcal{S}_{\mathcal{T}_1}([\mathbf{k}_{\mathcal{T}_1}]_i) = [\mathbf{s}_{\mathcal{T}_1}]_i$ and $\mathcal{S}_{\mathcal{T}_2}([\mathbf{k}_{\mathcal{T}_2}]_i) = [\mathbf{s}_{\mathcal{T}_2}]_i$, the modular arithmetic function can be expressed as $\mathcal{F}_{\mathrm{m}}([\mathbf{s}_{\mathcal{T}_1}]_i, [\mathbf{s}_{\mathcal{T}_2}]_i) = \mathcal{S}_{\mathcal{R}}(\mathrm{mod}(\mathcal{S}_{\mathcal{T}_1}^{-1}([\mathbf{s}_{\mathcal{T}_1}]_i) + \mathcal{S}_{\mathcal{T}_2}^{-1}([\mathbf{s}_{\mathcal{T}_2}]_i), |\mathcal{S}_{\mathcal{R}}|)) = \mathcal{S}_{\mathcal{R}}(\mathrm{mod}([\mathbf{k}_{\mathcal{T}_1}]_i + [\mathbf{k}_{\mathcal{T}_2}]_i, |\mathcal{S}_{\mathcal{R}}|))$. In [26], the authors proposed XOR function that uses the bits representing each symbol to compute the superimposed symbol, such that

$$\mathcal{F}_{\mathrm{xor}}([\mathbf{s}_{\mathcal{T}_1}]_i, [\mathbf{s}_{\mathcal{T}_2}]_i) = [\mathbf{s}_{\mathcal{T}_1}]_i \oplus [\mathbf{s}_{\mathcal{T}_2}]_i. \tag{4}$$

In [10], another combination function using directly the symbols rather than the bits was proposed. It has been shown that the use of $\mathcal{F}_{\text{xor}}$ or the combination function proposed in [10] enjoys a better BER performance than the use of $\mathcal{F}_{\text{m}}$. In the second phase, a simple dual relay selection technique based on a *hybrid* selection criterion is used, in which two relays $\mathcal{R}_i$ and $\mathcal{R}_j$ are selected from all relay nodes according to the following rule:

$$i \quad = \quad \arg\max_{i} \min(|f_i|, |g_i|), \tag{5}$$

$$j \quad = \quad \begin{cases} \arg\max\limits_{j}(|g_j|), & |f_i| > |g_i| \\ \arg\max\limits_{j}(|f_j|), & |f_i| < |g_i| \end{cases} \tag{6}$$

Note that in (5) and (6) the first and the second relay are selected based on the max-min selection criterion and max selection criterion, respectively, where the first selected relay is the optimal one in the directions of both terminals [21], [22] and at least it is a good relay in one direction, while the second selected relay is the best relay in the other direction.

Let us assume that $T = 2$. The selected relays $\mathcal{R}_i$ and $\mathcal{R}_j$ precode $\mathbf{s}_{\mathcal{R},i}$ and $(\mathbf{s}_{\mathcal{R},j})^*$, respectively, in the second phase, with the 2×2 Alamouti space-time coding matrices, given by

$$\mathbf{A}_i \quad = \quad \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \quad \mathbf{A}_j = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}, \tag{7}$$

$$\breve{\mathbf{s}}_{\mathcal{R},i} \quad = \quad \mathbf{s}_{\mathcal{R},i}, \qquad \breve{\mathbf{s}}_{\mathcal{R},j} = (\mathbf{s}_{\mathcal{R},j})^* \tag{8}$$

before broadcasting the resulting signal vector to both terminals from the time-slot $T+1$ to $2T$. In the following, we only consider the signals received at terminal $\mathcal{T}_2$. The signal received at terminal $\mathcal{T}_1$ can be computed correspondingly. The received signals at $\mathcal{T}_2$ is given by

$$\mathbf{y}_{\mathcal{T}_2} = \sqrt{P_{\mathcal{R}_i}} g_i \mathbf{A}_i \breve{\mathbf{s}}_{\mathcal{R},i} + \sqrt{P_{\mathcal{R}_j}} g_j \mathbf{A}_j \breve{\mathbf{s}}_{\mathcal{R},j} + \mathbf{n}_{\mathcal{T}_2} \tag{9}$$

where $\mathbf{n}_{\mathcal{T}_2}$ is the noise vector at $\mathcal{T}_2$. Let us consider an error free decoding at the relays, i.e., $\mathbf{s}_{\mathcal{R},i} = \mathbf{s}_{\mathcal{R},j} = \mathbf{s}_{\mathcal{R}}$, the ML decoder can be expressed as

$$\hat{\mathbf{s}}_{\mathcal{R},\mathcal{T}_2} = \arg\min_{\mathbf{s}_{\mathcal{R}}} \left\| \mathbf{y}_{\mathcal{T}_2} - \sum_{r=\{i,j\}} \sqrt{P_{\mathcal{R}_r}} g_r \mathbf{A}_r \breve{\mathbf{s}}_{\mathcal{R}} \right\|. \tag{10}$$

To find $\hat{\mathbf{s}}_{\mathcal{T}_1}$ at $\mathcal{T}_2$, the decoder uses the inverse of $\mathcal{F}$ (denoted as $\mathcal{F}^{-1}$) with the knowledge of $\mathbf{s}_{\mathcal{T}_2}$, i.e., $[\hat{\mathbf{s}}_{\mathcal{T}_1}]_i = \mathcal{F}^{-1}([\hat{\mathbf{s}}_{\mathcal{R},\mathcal{T}_2}]_i, [\mathbf{s}_{\mathcal{T}_2}]_i)$. Hence, using the knowledge of their own transmitted symbols, the decoder can obtain their respective information symbol vector. For example in the case of using the modular arithmetic function, if $\hat{\mathbf{k}}_{\mathcal{R},\mathcal{T}_2}$ is defined such that $\mathcal{S}_{\mathcal{R}}([\hat{\mathbf{k}}_{\mathcal{R},\mathcal{T}_2}]_i) = [\hat{\mathbf{s}}_{\mathcal{R},\mathcal{T}_2}]_i$, then the resulting decoded information vector is $[\hat{\mathbf{s}}_{\mathcal{T}_1}]_i = \mathcal{F}_{\text{m}}^{-1}([\hat{\mathbf{s}}_{\mathcal{R},\mathcal{T}_2}]_i, [\mathbf{s}_{\mathcal{T}_2}]_i) = \mathcal{S}_{\mathcal{T}_1}(\text{mod}([\hat{\mathbf{k}}_{\mathcal{R},\mathcal{T}_2}]_i - [\mathbf{k}_{\mathcal{T}_2}]_i, |\mathcal{S}_{\mathcal{T}_1}|))$ at $\mathcal{T}_2$ where $\mathcal{F}_{\text{m}}^{-1}$ is the inverse of the modular arithmetic function at $\mathcal{T}_2$. Similar procedure can be performed at $\mathcal{T}_1$. Hence, in our transmission scheme, each relay combines the decoded symbols of both terminals into a single symbol of the same constellation using a specific combination function and broadcasts it to both terminals. Each terminal can decode the transmitted symbol of the other terminal from its received symbol of the relays using the information of its own transmitted symbol. Since an orthogonal space-time coding technique, i.e., Alamouti technique, is applied on the relay network, a symbol-wise decoder can be used to decode the received symbols at terminal $\mathcal{T}_2$ [6], [9] instead of using the ML decoder defined in (10).

IV. THREE-PHASE TWO-WAY DF RELAY SELECTION TECHNIQUE

In this section, we consider the three-phase protocol where in the first phase of this protocol from time-slot 1 to T, $\mathcal{T}_1$ transmits the $T \times 1$ information symbol vector $\mathbf{s}_{\mathcal{T}_1}$ and in the second phase of this protocol from time-slot $T+1$ to $2T$, $\mathcal{T}_2$ transmits the $T \times 1$ information symbol vector $\mathbf{s}_{\mathcal{T}_2}$. In the first phase, the $T \times 1$ vector received at the rth relay is given by

$$\mathbf{y}_{\mathcal{R}_1,r} = \sqrt{3P_{\mathcal{T}_1}}\ f_r\ \mathbf{s}_{\mathcal{T}_1} + \mathbf{n}_{\mathcal{R}_1,r} \tag{11}$$

where f_r denotes the flat fading channel from terminal $\mathcal{T}_1$ to the rth relay, and $\mathbf{n}_{\mathcal{R}_1,r}$ denotes the $T \times 1$ noise vector at the rth relay in the first phase. Similarly as in Sec. III, we assume that the noise vector is modeled as a spatially white independently and identically distributed complex circular Gaussian random variable with zero mean and covariance $\sigma^2 \mathbf{I}_T$. Similarly, in the second phase, from time slot $T+1$ to $2T$, the $T \times 1$ vector received at the rth relay is given by

$$\mathbf{y}_{\mathcal{R}_2,r} = \sqrt{3P_{\mathcal{T}_2}}\ g_r\ \mathbf{s}_{\mathcal{T}_2} + \mathbf{n}_{\mathcal{R}_2,r} \tag{12}$$

where g_r denotes the channel from terminal $\mathcal{T}_2$ to the rth relay and $\mathbf{n}_{\mathcal{R}_2,r}$ denotes the $T \times 1$ noise vector at the rth relay in the second phase. Similarly as in Sec. III, each relay decodes the received symbols of the first and the second terminal. Hence, making use of (11) and (12), the rth relay can decode the symbols as

$$\hat{\mathbf{s}}_{\mathcal{T}_1,r} \quad = \quad \arg\min_{\mathbf{s}_{\mathcal{T}_1}} \left\| \mathbf{y}_{\mathcal{R}_1,r} - \sqrt{3P_{\mathcal{T}_1}} f_r \mathbf{s}_{\mathcal{T}_1} \right\|, \tag{13}$$

$$\hat{\mathbf{s}}_{\mathcal{T}_2,r} \quad = \quad \arg\min_{\mathbf{s}_{\mathcal{T}_2}} \left\| \mathbf{y}_{\mathcal{R}_2,r} - \sqrt{3P_{\mathcal{T}_2}} g_r \mathbf{s}_{\mathcal{T}_2} \right\|. \tag{14}$$

Note that the complexity of the decoders defined in (13) and (14) increases linearly with the increase of the constellation size while the decoder in (2) suffers from a high complexity which increases quadratically with the increase of the constellation size. Similar to Sec. III and after decoding the information symbols $\tilde{\mathbf{s}}_{\mathcal{T}_1,r}$ and $\tilde{\mathbf{s}}_{\mathcal{T}_2,r}$ of the first and the second terminals at the rth relay, respectively, they are combined into a single symbol vector as

$$[\mathbf{s}_{\mathcal{R},r}]_i = \mathcal{F}([\tilde{\mathbf{s}}_{\mathcal{T}_1,r}]_i, [\tilde{\mathbf{s}}_{\mathcal{T}_2,r}]_i). \tag{15}$$

Similarly as in Sec. III, two relays $\mathcal{R}_i$ and $\mathcal{R}_j$ are selected based on the proposed *hybrid* selection criterion defined in (5). During the third phase, the relays $\mathcal{R}_i$ and $\mathcal{R}_j$ precode $\mathbf{s}_{\mathcal{R},i}$ and $(\mathbf{s}_{\mathcal{R},j})^*$, respectively, with the 2×2 Alamouti space-time coding matrices $\mathbf{A}_i$ and $\mathbf{A}_j$ defined in (7) before broadcasting the resulting signal vector to both terminals from the time-slot $2T+1$ to $3T$. Hence, the received signal vector at $\mathcal{T}_2$ is given by

$$\mathbf{y}_{\mathcal{T}_2} = \sqrt{P_{\mathcal{R}_i}} g_i \mathbf{A}_i \mathbf{s}_{\mathcal{R},i} + \sqrt{P_{\mathcal{R}_j}} g_j \mathbf{A}_j (\mathbf{s}_{\mathcal{R},j})^* + \mathbf{n}_{\mathcal{T}_2} \tag{16}$$

where $\mathbf{n}_{\mathcal{T}_2}$ is the noise vector at $\mathcal{T}_2$. Similar to Sec. III, the information symbols can be decoded at terminal $\mathcal{T}_2$ using the ML decoder defined in (10). Note that a symbol-wise decoder can also be used to decode the received symbols at terminal $\mathcal{T}_2$ [6], [9] instead of using the ML decoder defined in (10). After that, the decoder uses the inverse of $\mathcal{F}$ (denoted as $\mathcal{F}^{-1}$) with the knowledge of $\mathbf{s}_{\mathcal{T}_2}$ to recover $\hat{\mathbf{s}}_{\mathcal{T}_1}$ at $\mathcal{T}_2$, i.e., $[\hat{\mathbf{s}}_{\mathcal{T}_1}]_i = \mathcal{F}^{-1}([\hat{\mathbf{s}}_{\mathcal{R},\mathcal{T}_2}]_i, [\mathbf{s}_{\mathcal{T}_2}]_i)$.

V. SIMULATION RESULTS

In our simulations, we consider a TWRN with $R+2$ single-antenna relay nodes consisting of two terminals and $R=\{2,4,6\}$ relays, independent flat Rayleigh fading channels and a power distribution equal to $P_{\mathcal{T}_1} = P_{\mathcal{T}_2} = \sum_{r=i,j} P_{\mathcal{R}_r}$. For fair comparison of the BER performance of all techniques, the same total transmitted power ($P_T = P_{\mathcal{T}_1} + P_{\mathcal{T}_2} + \sum_{r=i,j} P_{\mathcal{R}_r}$ where $P_{\mathcal{R}_i} = P_{\mathcal{R}_j}$) and transmission rate are used.

The acronym "SRS", "DRS", "2-phase", "3-phase", and "The proposed scheme" stand for the single relay selection technique, the dual relay selection technique, the use of the two-phase TWRN protocol, the use of the three-phase TWRN protocol, and the proposed technique, respectively. In Figs. 2 and 3, the BER at terminal $\mathcal{T}_2$ is displayed versus the SNR with $R=2$ and $R=4$ using 4-QAM and $R=2$, $R=4$, and $R=6$ using 8-QAM modulation, respectively, where the proposed three-phase technique is compared with the three-phase dual-relay selection technique proposed in [19] and the three-phase single-relay selection technique proposed in [22]. From Figs. 2 and 3, it can be observed that the proposed technique outperforms the best known three-phase techniques.

In Figs. 4 and 5, the BER at terminal $\mathcal{T}_2$ is displayed versus the SNR with a total rate of 1 bpcu using $R=2$ and $R=4$, respectively, where the proposed two- and three-phase technique are compared with the two-and three-phase dual-relay selection technique proposed in [19] using 4-QAM and 8-QAM modulation, respectively and the two- and three-phase single-relay selection technique proposed in [22] using 4-QAM and 8-QAM modulation, respectively. From Figs. 4 and 5, the techniques which use the two-phase TWRN protocol outperform those which use the three-phase TWRN protocol due to the increase in symbol rate. Moreover, it can be observed that the proposed two- and three-phase technique outperform the state-of-the art two-and three-phase techniques.

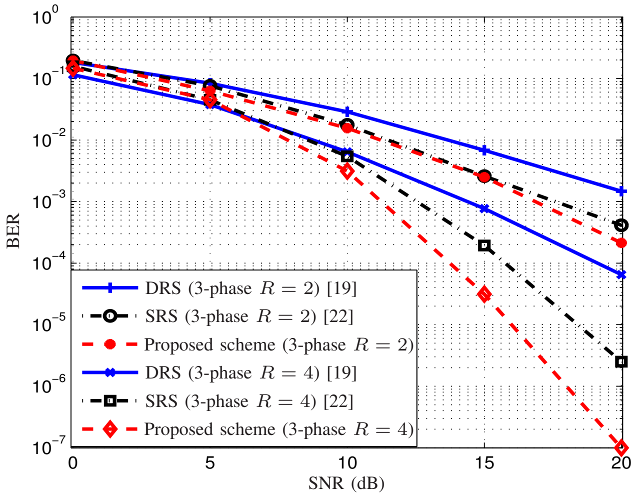

Fig. 2. BER versus SNR for several three-phase single and dual relay selection schemes with $R=2$ and $R=4$ using 4-QAM modulation.

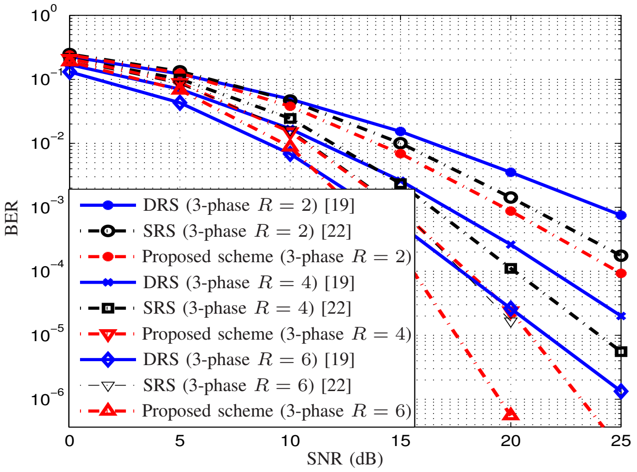

Fig. 3. BER versus SNR for several three-phase single and dual relay selection schemes with $R=2$, $R=4$ and $R=6$ using 8-QAM modulation.

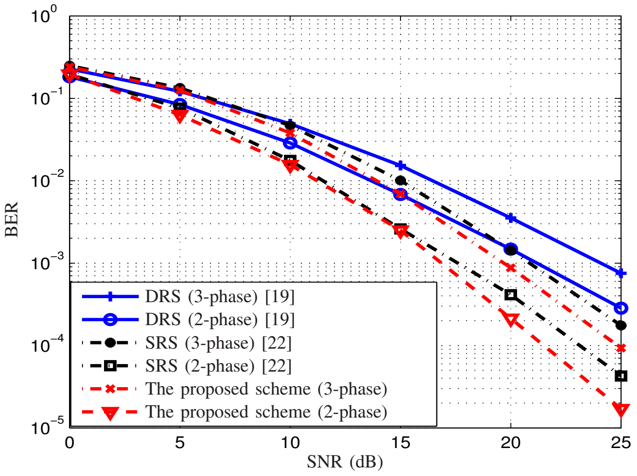

Fig. 4. BER versus SNR for several two and three-phase single and dual relay selection schemes with $R=2$ and a rate of 1 bpcu.

VI. CONCLUSION

In this paper, the design of decode-and-forward relay selection technique based on Alamouti space time coding using the two- and three phase protocol for TWRNs is proposed. In our transmission scheme, the relays use the concept of digital network coding in order not to waste power to transmit known information to either side which improves the overall system performance of the relay network. Simulation results show a substantially improved performance in terms BER of the proposed technique as compared to the known techniques and at the same time the proposed technique enjoys a lower complexity as compared to the optimal one.

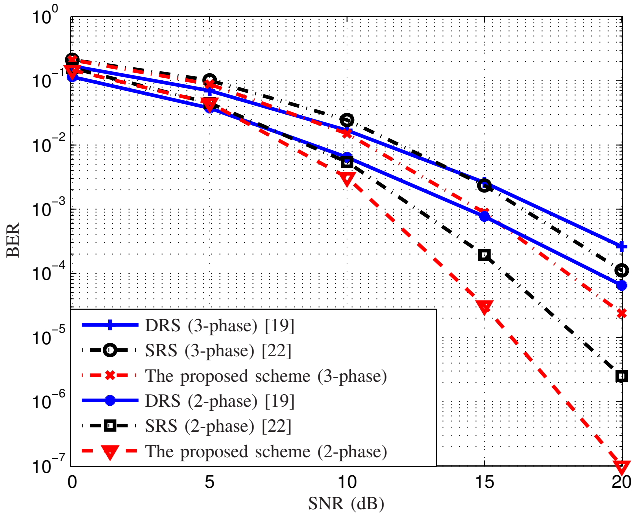

Fig. 5. BER versus SNR for several two and three-phase single and dual relay selection schemes with $R = 4$ and a rate of 1 bpcu.

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