Adaptive Buffer-Aided Space-Time Coding for Cooperative Wireless Networks

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***Abstract*—In this work, we propose an adaptive buffer-aided space-time coding scheme for cooperative wireless networks. A maximum likelihood receiver and adjustable code vectors are considered subject to a power constraint with an amplify-and-forward cooperation strategy. Each relay is equipped with a buffer and is capable of storing the received symbols before forwarding them to the destination. We also present an adaptive relay selection and optimization algorithm, in which the instantaneous signal to noise ratio in each link is calculated and compared at the destination. A stochastic gradient algorithm is then developed to compute the parameters of the adjustable code vector with reduced computational complexity. Simulation results show that the proposed buffer-aided scheme and algorithm obtain performance gains over existing schemes.**

***Index Terms*—Adaptive algorithms, cooperative systems, buffer-aided relays, space-time codes.**

I. Introduction

Cooperative multiple-input multiple-output (MIMO) systems, which employ multiple relay nodes with antennas between the source node and the destination node as a distributed antenna array, can obtain diversity gains by providing copies of the transmitted signals to improve the reliability of wireless communication systems [1], [2]. Such cooperative MIMO systems will be key to increasing the reliability and coverage in fifth generation (5G) wireless networks [4]. In traditional cooperative systems, amplify-and-forward (AF), decode-and-forward (DF) or compress-and-forward (CF) [1] cooperation strategies are often designed with the help of multiple relay nodes. Relay selection algorithms such as those designed in [2], [3] provide an efficient way to assist the communication between the source node and the destination node.

Although the best relay node is selected according to different optimization criteria, current relay selection focuses on the best relay selection (BRS) scheme [5] which selects the links with maximum instantaneous signal-to-noise ratio (SNR_{ins}). Recently a new cooperative scheme with a source, a destination and multiple relays equipped with buffers has been introduced and analyzed in [6]-[12]. The main idea is to select the best link during each time slot according to different criteria, such as maximum SNR_{ins} and maximum throughput. In [6], an introduction to buffered relaying networks is given, and a further analysis of the throughput and diversity gain is provided in [7]. In [8], [9], an adaptive link selection protocol with buffer-aided relays is proposed and an analysis of the network throughput and outage probability is developed. A max-link relay selection scheme that achieves achieves full diversity gain by selecting the strongest link in each time slot is proposed in [10]. A max-max relay selection algorithm is proposed in [12] and was then extended to mimic a full-duplex relaying scheme in [11] with the help of buffer-aided relays. The two main challenges of using buffer-aided relays are how to obtain accurate instantaneous channel state information (CSI) and how to deal with the delay. The calculation of the SNR_{ins} and comparisons are required before every transmission so that the key element of choosing the best relay node or the relay sets is the accuracy of the CSI in each link. The delay caused by the best relay selection strategy is another problem to some applications such as real-time transmission of video and speech. However, the authors in [6] have observed an improvement in performance due to the introduction of extra degrees of freedom by using buffer-aided relays as compared to standard relays. Therefore, it is suggested that the applications of buffer-aided relays could be used in cellular and sensor networks [6].

In this paper, we propose an adaptive buffer-aided space-time coding (STC) scheme and a buffer-aided relaying optimization (ABARO) algorithm for cooperative MIMO systems with feedback. The proposed algorithm can be divided into two parts: one is the relay selection part which chooses the best link with the maximum instantaneous SNR (SNR_{ins}) and checks if the state of the best relay node is available to transmit or receive, and another part which is the optimization part for the adjustable STC schemes employed at the relay nodes. The proposed algorithm is based on the maximum-likelihood (ML) criterion subject to constraints on the transmitted power at the relays for different cooperative systems. Due to the use of STC schemes at each relay node, an ML detector is employed at the destination node in order to achieve full diversity and coding gains. Suboptimal detectors can be also used at the destination node to reduce the detection complexity [13], [14]. Specifically, stochastic gradient (SG) estimation methods [15] are developed in order to compute the required parameters at a reduced computational complexity. We study how the adjustable code vectors can be employed at the buffer-aided relays combined with the relay selection process and how to optimize the adjustable code vectors by employing an ML criterion. The proposed relay selection and designs can be implemented with different types of STC schemes in cooperative MIMO systems using DF or AF protocols.

The paper is organized as follows. Section II introduces a cooperative two-hop relaying systems with multiple buffer-aided relays applying the AF strategy and adjustable STC schemes. In Section III the encoding and decoding procedure of the adjustable STC schemes are introduced and in Section IV the proposed relay selection and code optimization algorithms are derived. The results of the simulations are given in

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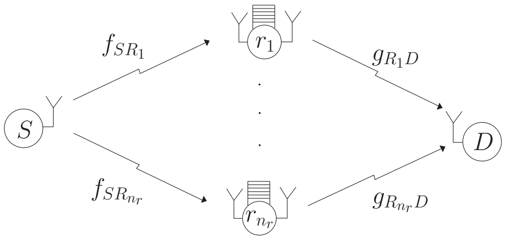

Fig. 1. Cooperative System Model with n_r Relay Nodes

Section V. Section VI gives the conclusions of the work.

Notation: the italic, the bold lower-case and the bold upper-case letters denote scalars, vectors and matrices, respectively. The operator $\| \boldsymbol{X} \|_F = \sqrt{\mathrm{Tr}(\boldsymbol{X}^H \cdot \boldsymbol{X})} = \sqrt{\mathrm{Tr}(\boldsymbol{X} \cdot \boldsymbol{X}^H)}$ is the Frobenius norm. $\mathrm{Tr}(\cdot)$ stands for the trace of a matrix, and the $N \times N$ identity matrix is written as $\boldsymbol{I}_N$.

II. Cooperative System Model

We consider a two-hop cooperative communication system, which consists of one source node, one destination node and n_r relay nodes (Relay 1, Relay 2, ..., Relay n_r) as shown in Fig. 1. All the nodes employ a single antenna and can either transmit or receive at one time. We consider only one user at the source node in the system that operates in a spatial multiplexing configuration, and we assume that perfect CSI, as well as the states of each relay, are available at the destination node. An appropriate signalling that provides global CSI at the destination node can ensure this assumption [10]. The assumption made in our work is the same as that in [6]-[12]. The destination node will send out the relay selection information together with the code vector via a feedback channel which is assumed error-free. The channel considered in this paper is assumed to be static over some blocks, non-selective Rayleigh block fading with additive white Gaussian noise (AWGN) and the channel coefficients remain constant during one time slot. We assume the feedback required in the proposed ABARO algorithm is short enough to be ignored compared to the symbol transmission period. If the cooperative system operates in time-division duplex (TDD) mode then the feedback information can be obtained at the transmitter subject to hardware differences and impairments.

Let $\boldsymbol{s}[j]$ denote one modulated data symbol block with N symbols in one packet and covariance matrix $E\big[\boldsymbol{s}\boldsymbol{s}^H\big] = \sigma_s^2 \boldsymbol{I}_N$, where σ_s^2 denotes the signal power. Assuming a channel that is static over one block, the destination node calculates the SNR_{ins} and then the optimal relay node is selected by choosing the highest SNR_{ins} of the link. In the first hop, the source node sends the first modulated packet $\boldsymbol{s}[i]$ to the selected relay node and the expression is given by

$$\begin{aligned} \boldsymbol{r}_{SR_k}[j] = \sqrt{P_S} f_{SR_k}[j]\boldsymbol{s}[j] + \boldsymbol{n}_{SR_k}[j], \\ k = 1, 2, ..., n_r,\ j = 1, 2, ..., J, \end{aligned} \tag{1}$$

where $f_{SR_k}[j]$ denotes the CSI between the source node and the kth relay, and $\boldsymbol{n}_{SR_k}[j]$ stands for the AWGN vector generated at the kth relay with variance σ_r^2. As mentioned before, each relay node contains a buffer and can store the received symbols if the buffer is not full. The buffer size B is defined as $M \leq B \leq MJ$, where M denotes the length of one packet and J denotes the number of blocks in one packet. After reception, the destination node calculates the SNR_{ins} of the *SR* link and the *RD* link, where the *SR* link stands for the link between the source node and the relay node and the *RD* link stands for the links between the relay node and the destination node. The selection information will be sent back to the selected relay node so that the relay will be ready for receiving or forwarding. We assume the best link is the kth *RD* link and the AF strategy is employed at the relays. The received data of the RD link is given by

$$\begin{aligned} \boldsymbol{r}_{R_kD}[j] = \sqrt{P_R} g_{R_kD}[j]\boldsymbol{r}_{SR_k}[j] + \boldsymbol{n}_{R_kD}[j], \\ k = 1, 2, ..., n_r,\ j = 1, 2, ..., J, \end{aligned} \tag{2}$$

where $g_{R_kD}[j]$ denotes the CSI between the kth relay and the destination node, and $\boldsymbol{n}_{R_kD}[j]$ stands for the AWGN vector generated at the destination node with variance σ_d^2.

In this work, randomized space-time coding (RSTC) schemes [16] and the algorithms in [17] are employed to obtain coding gain. The use of an adjustable code vector provides lower BER performance and higher diversity gain [16],[17]. The received data at the relay nodes is firstly divided into $i = M/N_{STC}$ groups, where N_{STC} stands for the number of symbols required to encode an STC scheme. Each group is then encoded to an adjustable STC scheme and forwarded to the destination node as given by

$$\begin{aligned} \boldsymbol{r}_{R_kD}[i] = \sqrt{P_R} g_{R_kD}[i]\boldsymbol{C}[i]\boldsymbol{v}[i] + \boldsymbol{n}_{R_kD}[i], \\ k = 1, 2, ..., n_r,\ i = 1, 2, ..., M/N_{STC}, \end{aligned} \tag{3}$$

where $\boldsymbol{C}[i]$ denotes the $T \times N_{STC}$ STC scheme and $\boldsymbol{v}[i]$ stands for the $N_{STC} \times 1$ randomized vector and T is the number of time instants of the STC scheme. Since the RSTC scheme is employed at relay nodes, the received vector $\boldsymbol{r}_{R_kD}[i]$ at the destination node can be rewritten as

$$\begin{aligned} \boldsymbol{r}_{R_kD}[i] &= \sqrt{P_R} g_{R_kD}[i]\boldsymbol{C}[i]\boldsymbol{v}[i] + \boldsymbol{n}_{R_kD}[i] \\ &= \sqrt{P_R}\boldsymbol{V}_{eq}[i]h[i]\boldsymbol{s}[i] + \sqrt{P_R}\boldsymbol{V}_{eq}[i]g[i]\boldsymbol{n}_{sr_k}[i] \\ &\quad + \boldsymbol{n}_{R_kD}[i] \\ &= \sqrt{P_R}\boldsymbol{V}_{eq}[i]h[i]\boldsymbol{s}[i] + \boldsymbol{n}[i], \end{aligned} \tag{4}$$

where $\boldsymbol{V}_{eq}[i] = \boldsymbol{I}_{T \times T} \otimes \boldsymbol{v}[i]$ denotes the $TN_{STC} \times TN_{STC}$ block diagonal equivalent adjustable code matrix and $\otimes$ is the Kronecker product and $h[i] = f_{SR_k}[i]g_{r_kd}[i]$ stands for the equivalent channel. The noise vector $\boldsymbol{n}[i]$ contains the equivalent received noise vector at the destination node, which can be modeled as AWGN with zero mean and covariance matrix $(\sigma_d^2 + \|\boldsymbol{V}_{eq}[i]g[i]\|_F^2\sigma_r^2)\boldsymbol{I}_T$. The detailed encoding and decoding procedure for employing an adjustable STC scheme is given in the following section.

III. Adjustable Space-Time Coding Scheme

In the DF protocol, the relays need to decode and store the data at the relays, and if the relay is chosen in the second hop the data will be encoded and forwarded to the destination. In the AF protocol, the received symbols are stored at the relays and wait for the decision from the destination node. In our previous work [17], we used different STC schemes with the AF protocol and obtained a performance improvement. In this paper, different STC schemes will be employed at the relay nodes with the AF protocol. In [16] and [17], the adjustable code vectors are employed to allow relays with a single antenna to transmit STC schemes. For example, the 2×2 Alamouti STBC scheme is used at the relay nodes. By multiplying a 1×2 randomized vector, the original 2×2 orthogonal Alamouti STBC scheme is transformed into the following code vector:

$$\begin{aligned} \boldsymbol{c}_{rand} = \boldsymbol{v}\boldsymbol{C} &= [v_1 \ v_2] \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix} \\ &= [v_1 s_1 + v_2 s_2 \quad v_2 s_1^* - v_1 s_2^*], \end{aligned} \tag{5}$$

where s_1 and s_2 are modulated symbols, and the 1×2 vector $\boldsymbol{v}$ denotes the randomized vector whose elements are generated randomly according to different criteria described in [16]. As shown in (5), the 2×2 STBC matrix changes to a 1×2 STBC vector which can be transmitted by the node with a single antenna in 2 time slots. Different STC schemes such as linear dispersion codes (LDC) in [18] can be easily adapted into the randomized vector encoding in (5). The transmission of the randomized STC schemes can be described as

$$\boldsymbol{r} = \sqrt{P_T} h \boldsymbol{c}_{rand} + \boldsymbol{n} = \sqrt{P_T} h \boldsymbol{v}\boldsymbol{C} + \boldsymbol{n}, \tag{6}$$

where h denotes the channel coefficient and is assumed to be constant within the transmission time slots, and $\boldsymbol{n}$ stands for the noise vector. The decoding methods of the randomized STC schemes are the same as that of the original STC schemes. At the destination, instead of the estimation of the channel coefficient h, the randomized channel vector $\boldsymbol{v}h$ is estimated. As a result, the transmission of a randomized STC vector is similar to the transmission of a deterministic STC scheme over an effective channel. Taking the randomized Alamouti scheme as an example, the linear ML decoding for the information symbols s_1 and s_2 is given by

$$\tilde{s_1} = h^*_{rand1} r_1 + h_{rand2} r_2^*, \ \tilde{s_2} = h^*_{rand2} r_1^* + h_{rand1} r_2^*, \tag{7}$$

where h_{rand1} and h_{rand2} are the randomized channel coefficients in $\boldsymbol{v}h$. Different decoding methods can be employed. In [17], optimization algorithms for the randomized coding vector $\boldsymbol{v}$ are proposed in order to obtain further coding gain.

IV. Adaptive Buffer-Aided Space-Time Coding And Relaying Optimization Algorithm

In this section, the proposed ABARO algorithm and the optimization problem that describes the best relay selection and the adjustable code matrix computation are presented. Before each transmission, the instantaneous SNR_{ins} of the *SR* and *RD* links are calculated at the destination as follows:

$$SNR_{SR_k}[i] = \frac{\sqrt{\|f_{SR_k}[i]\|_F^2}}{\sigma_r^2}, \ SNR_{R_kD}[i] = \frac{\sqrt{\|\boldsymbol{V}_{eq}[i]g[i]\|_F^2}}{\sigma_d^2}. \tag{8}$$

After the destination node computes SNR_{ins}, the best link is chosen by

$$SNR_{\text{opt}}[i] = \arg\max_k SNR_{\text{ins}_k}, k = 1, 2, \ \ldots, n_r. \tag{9}$$

The kth relay in the first time slot is determined and the transmission is expressed in (1). After the reception, the destination node calculates the instantaneous SNR in the *SR* and *RD* links, respectively, and chooses the best link for the next time slot. At the relay node, adjustable STC schemes are employed in order to enhance the transmission. The relay states are known at the destination node so that if the kth *RS* link is chosen but the buffer at the kth relay node is empty, the source node will skip this node and check the state of the buffer which has the second best link. The process repeats until the last information symbol is received at the destination node. After the detection at the destination node, the adjustable code vector $\boldsymbol{v}$ will be optimized and updated. The constrained ML optimization problem can be written as

$$\begin{aligned} \left[\hat{\boldsymbol{s}}[i], \hat{\boldsymbol{V}}_{eq}[i]\right] &= \underset{\boldsymbol{s}[i], \boldsymbol{V}_{eq}[i]}{\text{argmin}} \|\boldsymbol{r}_{R_kD}[i] - \sqrt{P_R}\boldsymbol{V}_{eq}[i]h[i]\boldsymbol{s}[i]\|^2, \\ & s.t. \ \text{Tr}(\boldsymbol{V}_{eq}[i]\boldsymbol{V}_{eq}^H[i]) \leq P_v, \end{aligned} \tag{10}$$

The computation of $\hat{\boldsymbol{s}}[i]$ described in the previous section is the same as the decoding procedure of the original STC schemes. The power constraint of the adjustable code matrix is given by P_v. In order to obtain the optimal coding vector $\boldsymbol{v}[i]$, the cost function in (10) should be minimized with respect to the equivalent code matrix $\boldsymbol{V}_{eq}[i]$ subject to a constraint on the transmitted power. The Lagrangian expression of the optimization problem in (10) is given by

$$\begin{aligned} \mathcal{L} =& \|\boldsymbol{r}_{R_kD}[i] - \sqrt{P_R}\boldsymbol{V}_{eq}[i]h[i]\boldsymbol{s}[i]\|^2 \\ &+ \lambda(Tr(\mathbf{V}_{\text{eq}}[i]\mathbf{V}_{\text{eq}}^H[i]) - P_v). \end{aligned} \tag{11}$$

Instead of using the second term in (11) to ensure the power constraint, we drop it and subsequently employ a normalization procedure to enforce the power constraint. By doing this, the computational cost decreases and the analysis of this power constrained optimization method is given in [17]. A stochastic gradient algorithm can be used to solve the optimization algorithm in (10) with lower cost than least-squares algorithms which require matrix inversions. By taking the instantaneous gradient of $\mathcal{L}$, discarding the power constraint and equating it to zero, we obtain

$$\nabla\mathcal{L} = -\sqrt{P_R}(\boldsymbol{r}_{R_kD}[i] - \sqrt{P_R}\boldsymbol{V}_{eq}[i]h[i]\boldsymbol{s}[i])\boldsymbol{s}^H[i]h^H[i], \tag{12}$$

and the ABARO algorithm for the proposed scheme is given by

$$\begin{aligned} \boldsymbol{V}_{eq}[i+1] =& \boldsymbol{V}_{eq}[i] - \mu\sqrt{P_R}(\boldsymbol{r}_{R_kD}[i] - \\ & \sqrt{P_R}\boldsymbol{V}_{eq}[i]h[i]\boldsymbol{s}[i])\boldsymbol{s}^H[i]h^H[i], \end{aligned} \tag{13}$$

where μ is the step size. The normalization of the code vector $\boldsymbol{v}[i]$ is given by

$$\boldsymbol{v}[i+1] = \boldsymbol{v}[i+1]\frac{P_v}{\sqrt{\boldsymbol{v}^H[i+1]\boldsymbol{v}[i+1]}}, \tag{14}$$

where P_v denotes the power of the adjustable code vector. A summary of the ABARO algorithm is shown in Table I.

V. Simulation

In this section we assess the proposed scheme and ABARO algorithms via simulations. We consider a cooperative system that employs the AF protocol with the randomized Alamouti (R-Alamouti) in [16]. BPSK modulation is employed, the feedback channel is assumed error-free and delay-free, and each

TABLE I

SUMMARY OF THE ADAPTIVE BUFFER-AIDED RELAYING OPTIMIZATION ALGORITHM

Initialization:

Empty the buffer at the relays,

for $j = 1, 2, ...$

if $j = 1$

compute: $SNR_{SR_k}[j] = \frac{\sqrt{\|h_{SR_k}[j]\|_F^2}}{\sigma_n^2}, \; k = 1, 2, ..., n_r$

compare: $SNR_{opt}[j] = \arg\max\{SNR_{SR_k}[j]\}, \; k = 1, 2, ..., n_r,$

$\boldsymbol{r}_{SR_k}[j] = \sqrt{P_S} f_{SR_k}[j]\boldsymbol{s}[j] + \boldsymbol{n}_{SR_k}[j],$

else

compute: $SNR_{SR_k}[j] = \frac{\sqrt{\|h_{sr_k}[j]\|_F^2}}{\sigma_n^2}, \; k = 1, 2, ..., n_r$

$SNR_{R_kD}[j] = \frac{\sqrt{\|\boldsymbol{V}_{eq}[j] g_{RkD}[j]\|_F^2}}{\sigma_d^2}, \; k = 1, 2, ..., n_r,$

compare: $SNR_{opt}[j] = \arg\max\{SNR_{SR_k}[j], SNR_{R_kD}[j]\}, \; k = 1, 2, ..., n_r,$

if $SNR_{max}[j] = SNR_{SR_k}[j]$ & $Relay_k$ is not full

$\boldsymbol{r}_{SR_k}[j] = \sqrt{P_S} f_{SR_k}[j]\boldsymbol{s}[j] + \boldsymbol{n}_{SR_k}[j],$

elseif $SNR_{max}[j] = \arg\max SNR_{R_kD}[j]$ & $Relay_k$ is not empty

$\boldsymbol{r}_{R_kD}[i] = \sqrt{P_R} g_{R_kD}[i]\boldsymbol{C}[i]\boldsymbol{v}[i] + \boldsymbol{n}_{R_kD}[i], \; i = 1, 2, ..., M/N_{STC},$

ML detection: $\hat{\boldsymbol{s}}[i] = \arg\min_{\boldsymbol{s}[i]} \|\boldsymbol{r}_{R_kD}[i] - \sqrt{P_R}\boldsymbol{V}_{eq}[i]h[i]\boldsymbol{s}[i]\|^2,$

$\boldsymbol{V}_{eq}[i+1] = \boldsymbol{V}_{eq}[i] - \mu\sqrt{P_R}(\boldsymbol{r}_{R_kD}[i] - \sqrt{P_R}\boldsymbol{V}_{eq}[i]h[i]\boldsymbol{s}[i])\boldsymbol{s}^H[i]h^H[i],$

$\boldsymbol{v}[i+1] = \boldsymbol{v}[i+1]\frac{\mathrm{P_v}}{\sqrt{\boldsymbol{v}^H[i+1]\boldsymbol{v}[i+1]}},$

elseif SNR_{SR_k} is max & $\mathrm{Relay_k}$ is full

skip this Relay,

elseif SNR_{R_kD} is max & $\mathrm{Relay_k}$ is empty

skip this Relay,

...repeat...

end

end

end

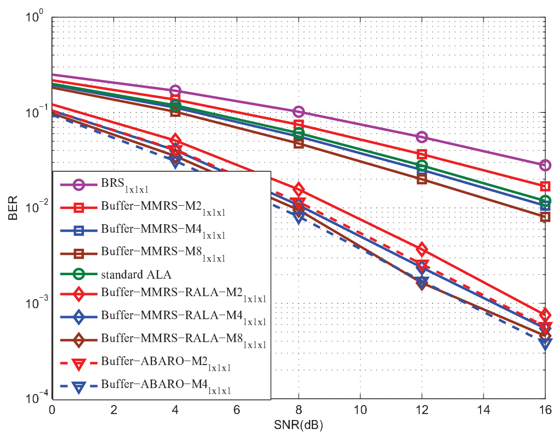

Fig. 2. BER performance vs. SNR for the system with 1 buffer-aided relay

link between the nodes is characterized by static block fading with AWGN. It is possible to employ different STC schemes with a simple modification and to incorporate ABARO. We employ $n_r = 1, 2$ relay nodes and a single antenna at each node, and set the symbol power σ_s^2 to 1.

The proposed ABARO algorithm with the Alamouti scheme and an ML receiver is evaluated with a single-relay system in Fig. 2. Different buffer sizes are considered at the relay node. It is shown that the BER result of the cooperative system with the best relay selection (BRS) algorithm in [5] and the max-max relay selection (MMRS) protocols in [12] achieve a diversity order of 1, and a 2dB to 3dB BER improvement can be achieved by employing MMRS algorithms as compared to the BRS algorithm. The BER performance the standard Alamouti scheme at the relays is given in Fig. 2. An improvement of diversity order can be observed when using STBC schemes at the relays. With the buffer size $B > 4$, the advantage of using STBC schemes at the relays disappears due to the diminishing returns in performance. According to the curves, with the increase of B at the relay nodes, the improvement in the BER reduces and with $B > 6$ the advantages of using buffer-aided relays are not significant. When the R-Alamouti scheme is considered at the relay node, an increase of diversity order is shown in Fig. 2 which leads to improved BER performance. As shown in the plots, when the RSTC scheme is considered at the relay node, the BER curve with $B = 6$ approaches that with $B = 8$ as well. According to the simulation results in Fig. 2, a 1dB to 2dB gain can be achieved by using the proposed ABARO algorithm at relays compared to the network using the RSTC scheme at the relay node. The diversity order of using the proposed ABARO algorithm is the same as that of using the RSTC scheme at the relay node.

In Fig. 3, the proposed ABARO SG algorithm is employed among the cooperative systems with $n_r = 2$ relay nodes. Compared to the MMRS algorithm derived in [12] with the same B, the ABARO algorithm achieves a 1dB to 2dB improvement as shown in Fig. 3. When comparing the curves of the traditional MMRS in Fig. 3 to those in Fig. 2, we notice

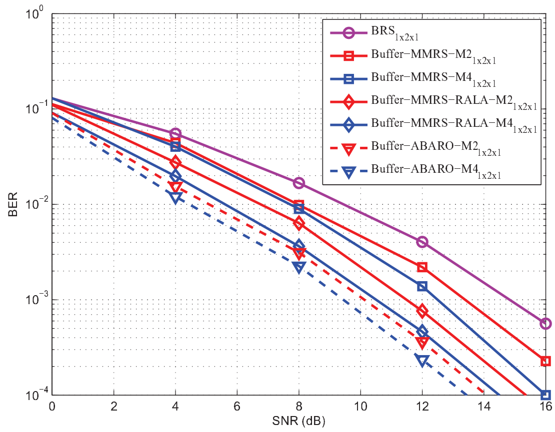

Fig. 3. BER performance vs. SNR for the system with 2 buffer-aided relays

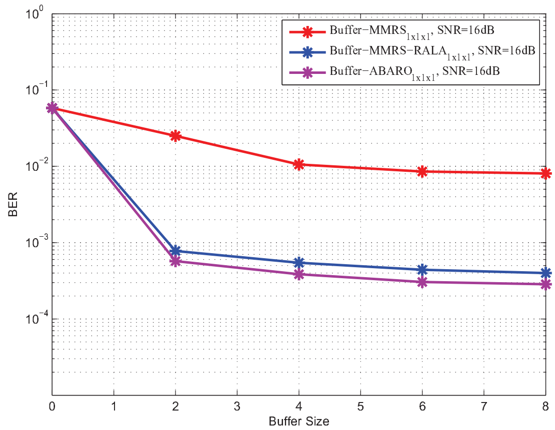

Fig. 4. Buffer size vs. BER performance

that the diversity order of the curves in Fig. 3 increases due to the increase of the number of relay nodes. The BER curves with the R-Alamouti scheme in Fig. 3 share the same diversity order with those in Fig. 2 but the curves of the proposed scheme and the ABARO algorithm achieve a lower BER. The reason for the same diversity order is because the same STC scheme is employed in both Fig. 2 and Fig. 3, but with more relay nodes, the ABARO algorithm has more choices to optimize the relays, resulting in better BER performance.

The comparison of different buffer sizes used at the relay node against the BER performance is given in Fig. 4. It is shown that a significant improvement in BER performance is obtained by using RSTC schemes and the ABARO algorithm as compared to the traditional MMRS algorithms under the same SNR condition. The proposed ABARO algorithm helps the cooperative system to achieve a further BER improvement as compared to the MMRS with RSTC schemes. The limitation of using larger buffers at the relay nodes is shown in this figure as well. In fact, the slope of all the curves gets smoother with the increase of the buffer size, which indicates that the advantages in BER performance of using buffer-aided relay nodes has diminishing returns.

VI. Conclusion

We have proposed a buffer-aided space-time coding scheme and the ABARO algorithm for cooperative systems with feedback using an ML receiver at the destination node to achieve a better BER performance. Simulation results have illustrated the advantage of using the STC schemes in the buffer-aided cooperative systems compared to the MMRS algorithms. In addition, the proposed ABARO algorithm can achieve a better performance in terms of lower bit error rate at the destination node compare to the STC-ed systems. The ABARO algorithm can be used with different STC schemes and can also be extended to cooperative systems with any number of antennas.

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