Dynamic Buffer-aided Distributed Space Time Coding Techniques for Cooperative DS-CDMA Systems

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Abstract—In this work, we propose a dynamic buffer-aided distributed space-time coding (DSTC) scheme for cooperative direct-sequence code-division multiple access systems. We first devise a relay selection algorithm that can automatically select the optimum set of relays among both the source-relay phase and the relay-destination phase for DSTC transmission according to the signal-to-interference-plus-noise ratio (SINR) criterion. Multiple relays equipped with dynamic buffers are introduced in the network, which allows the relays to store data received from the sources and wait until the most appropriate time for transmission. The proposed technique improves the quality of the transmission with an acceptable delay as the buffer size is adjustable. Simulation results show that the proposed dynamic buffer-aided DSTC scheme and algorithm outperforms prior art.

Index Terms—DS-CDMA networks, cooperative systems, relay selection, greedy algorithms, space time coding, buffer.

I. INTRODUCTION

The ever-increasing demand for performance and reliability in wireless communication has encouraged the development of numerous innovative techniques. Among them, cooperative diversity is one of the key techniques that has been considered in recent years [1] as an effective tool to improving transmission performance and system reliability. Several cooperative schemes have been proposed [2], [3], [4], and among the most effective ones are Amplify-and-Forward (AF), Decode-and-Forward (DF) [4] and various distributed space-time coding (DSTC) technique [5], [6], [7], [8], [9]. For an AF protocol, relays cooperate and amplify the received signals with a given transmit power amplifying their own noise. With the DF protocol, relays decode the received signals and then forward the re-encoded message to the destination. DSTC schemes exploit spatial and temporal transmit diversity by using a set of distributed antennas. With DSTC, multiple redundant copies of data are sent to the receiver to improve the quality and reliability of data transmission. Applying DSTC at the relays provides multiple processed signal copies to compensate for the fading and noise, helping to achieve the attainable diversity and coding gains and interference mitigation.

In cooperative relaying systems, different strategies that employ multiple relays have been recently introduced in [10], [11], [12], [13], [14], [15]. The aim of relay selection is to find the optimum relay or set of relays that results in the greatest improvement of reliability. Recently, a new cooperative scheme with buffers equipped at relays has been introduced and analyzed in [16], [17], [18], [19]. The main purpose is to select the best link according to a given criterion. In [16], a brief introduction of the buffer-aided relaying protocols for different networks is carefully described and the some practical challenges are discussed. Later, a further study of the throughput and diversity gain of the buffer-aided system is introduced in [17]. In [18], a new selection technique that is able to achieve the full diversity gain by selecting the strongest available link in every time slot is detailed. In [19], a max-max relay selection (MMRS) scheme for half-duplex relays with buffers is proposed. In particular, relays with the optimum source-relay links and relay-destination links are chosen and controlled for transmission and reception, respectively.

In this work, we propose buffer-aided DSTC schemes and algorithms for cooperative direct-sequence code-division multiple access (DS-CDMA) systems. In the proposed buffer-aided DSTC schemes, a relay pair selection algorithm automatically selects the optimum set of relays according to the signal-to-interference-plus noise ratio (SINR) criterion. Specifically, the proposed algorithms can be divided into two parts. Initially, a link combination associated with the optimum relay group is selected, which determines if the buffer is ready for transmission or reception. In the second part, DSTC is performed from the selected relay combination to the destination when the buffers are switched to the transmission mode. The direct transmission occurs between the source and the relay combination when the buffers are in the reception mode. With dynamic buffers equipped at each of the relays, the proposed schemes take advantage of the high storage capacity, where multiple blocks of data can be stored so that the most appropriate ones can be selected at a suitable time instant. The key advantage of introducing the dynamic buffers in the system is their ability to store multiple blocks of data according to a chosen criterion so that the most appropriate ones can be selected at a suitable time instant with the highest efficiency.

This paper is organized as follows. In Section II, the system model is presented. In Section III, the buffer-aided cooperative DSTC scheme is explained. In Section IV, the dynamic buffer design is given and explained. In Section V, simulation results are presented and discussed. Finally, conclusions are drawn in Section VI.

II. DSTC COOPERATIVE DS-CDMA SYSTEM MODEL

We consider the uplink of a synchronous DS-CDMA system with K users, L relays equipped with finite-size buffers capable of storing B packets and N chips per symbol that
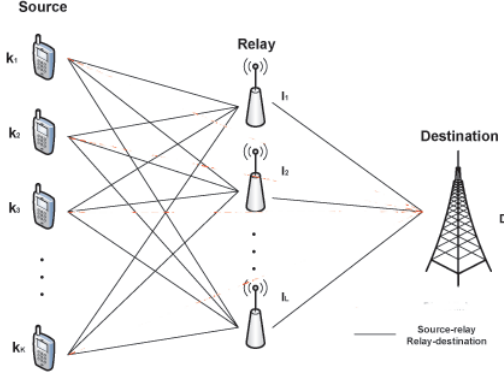
Fig. 1. Uplink of a cooperative DS-CDMA system.

experiences flat fading channels. The system is equipped with a cooperative protocol at each relay and we assume that the transmit data are organized in packets comprising P symbols. The received signals are filtered by a matched filter and sampled at chip rate to obtain sufficient statistics. The whole transmission is divided into two phases. In the first phase, the source transmits the data to each of the relay over two consecutive time instants, the decoded data over two time slots, $\hat{b}_{r_l d,k}(2i-1)$ and $\hat{b}_{r_l d,k}(2i)$, is stored at relay l and is prepared to send data to the destination. A DSTC scheme is then employed at the following phase, where the corresponding 2×2 Alamouti [20], [21], [22] detected symbol matrix over relay m and relay n for user k among two consecutive time instants is given by

$$\mathbf{B}_k = \begin{bmatrix} \hat{b}_{r_m d,k}(2i-1) & -\hat{b}_{r_n d,k}^*(2i) \\ \hat{b}_{r_n d,k}(2i) & \hat{b}_{r_m d,k}^*(2i-1) \end{bmatrix}. \qquad (1)$$

Consequently, the received signal from relay m and n to the destination over two consecutive time slots yields the $2N \times 1$ received vectors described by

$$\mathbf{y}_{r_{m,n}d}(2i-1) = \sum_{k=1}^{K} \mathbf{h}_{r_m d}^k \hat{b}_{r_m d,k}(2i-1) + \mathbf{h}_{r_n d}^k \hat{b}_{r_n d,k}(2i) + \mathbf{n}(2i-1), \qquad (2)$$

$$\mathbf{y}_{r_{m,n}d}(2i) = \sum_{k=1}^{K} \mathbf{h}_{r_n d}^k \hat{b}_{r_m d,k}^*(2i-1) - \mathbf{h}_{r_m d}^k \hat{b}_{r_n d,k}^*(2i) + \mathbf{n}(2i), \qquad (3)$$

where $\mathbf{h}_{r_l d}^k = a_{r_l d}^k \mathbf{s}_k h_{r_l d,k}$ denotes an $N \times 1$ effective signature vector for user k from the l-th relay to the destination with $m, n \in [1, 2, ..., L]$. The quantity $a_{r_l d}^k$ represents the k-th user's amplitude from the l-th relay to the destination, $\mathbf{s}_k = [s_k(1), s_k(2), ... s_k(N)]^T$ is the $N \times 1$ signature sequence for user k and $h_{r_l d,k}$ are the complex channel fading coefficients for user k from the l-th relay to the destination. The $N \times 1$ noise vectors $\mathbf{n}(2i-1)$ and $\mathbf{n}(2i)$ contain samples of zero mean complex Gaussian noise with variance σ^2, $\hat{b}_{r_l d,k}(2i-1)$ and $\hat{b}_{r_l d,k}(2i)$ are the decoded symbols at the output of relay l after using a cooperative protocol at time instants $(2i-1)$ and $(2i)$, respectively. Equivalently, (2) and (3) can be rewritten as

$$\mathbf{y}_{r_{m,n}d} = \mathbf{H}_{r_{m,n}d}^k \mathbf{b}_{r_{m,n}d,k} + \mathbf{n}_{r_{m,n}d}, \qquad (4)$$

where $\mathbf{y}_{r_{m,n}d} = \left[\mathbf{y}_{r_{m,n}d}^T(2i-1), \mathbf{y}_{r_{m,n}d}^T(2i) \right]^T$ represents the received signal from relay m and n over two time instants.

The 2 N x 2 Alamouti matrix with the effective signatures for user k is given by

$$\mathbf{H}_{r_{m,n}d}^k = \begin{bmatrix} \mathbf{h}_{r_m d}^k & \mathbf{h}_{r_n d}^k \\ (\mathbf{h}_{r_n d}^k)^* & -(\mathbf{h}_{r_m d}^k)^* \end{bmatrix}, \qquad (5)$$

where $\mathbf{h}_{r_l d}^k = a_{r_l d}^k \mathbf{s}_k h_{r_l d,k}$ denotes the effective signature for user k from the l-th relay to the destination with $m, n \in [1, 2, ..., L]$. The 2×1 vector $\mathbf{b}_{r_{m,n}d,k} = \left[\hat{b}_{r_m d,k}(2i-1), \hat{b}_{r_n d,k}(2i) \right]^T$ is the processed vector when the DF protocol is employed at relays m and n at the corresponding time instant, and $\mathbf{n}_{r_{m,n}d} = \left[\mathbf{n}(2i-1)^T, \mathbf{n}(2i)^T \right]^T$ is the noise vector that contains samples of zero mean complex Gaussian noise with variance σ^2. This scheme groups the relays into different pairs and a more reliable transmission can be achieved if proper relay pair selection is performed.

III. PROPOSED DYNAMIC BUFFER-AIDED COOPERATIVE DSTC SCHEME

In this section, we present a dynamic buffer-aided cooperative DSTC scheme, where each relay is equipped with an adjustable buffer so that the processed data can be stored and the buffer can wait until the channel pair associated with the best performance is selected. Consequently, processed data are stored at the corresponding buffer entries and then re-encoded when the appropriate time interval comes. Specifically, the size B of the buffer is adjustable according to a given criterion (e.g. the input SNR, channel condition) so that a large amount of data can be eliminated from the corresponding buffers and symbols can be sent directly or wait with a shorter delay when the corresponding buffer size decreases. This method effectively improves transmission reliability, and ensures that the most suitable signal is selected from the buffer entries and sent to the destination.

The algorithm begins with a SINR calculation for all possible channel combinations. In the case of the Alamouti code, every two relays are combined into a group and lists of all possible corresponding channel pairs are considered. The SINR is then calculated and recorded as follows:

$$\text{SINR}_{sr_{m,n}} = \frac{\sum_{k=1}^{K} \mathbf{w}_{s_k r_m}^H \mathbf{w}_{s_k r_m} + \mathbf{w}_{s_k r_n}^H \mathbf{w}_{s_k r_n}}{\sum_{k=1}^{K} \sum_{\substack{l=1 \\ l \neq m,n}}^{L} \mathbf{w}_{s_k r_l}^H \mathbf{w}_{s_k r_l} + \sigma^2}, \qquad (6)$$

$$\text{SINR}_{r_{m,n}d} = \frac{\sum_{k=1}^{K} (\mathbf{w}_{r_m d}^k)^H \mathbf{w}_{r_m d}^k + (\mathbf{w}_{r_n d}^k)^H \mathbf{w}_{r_n d}^k}{\sum_{k=1}^{K} \sum_{\substack{l=1 \\ l \neq m,n}}^{L} (\mathbf{w}_{r_l d}^k)^H \mathbf{w}_{r_l d}^k + \sigma^2}, \qquad (7)$$

In Eq. (6), $\text{SINR}_{sr_{m,n}}$ denotes the SINR for the combined paths from all users to relay m and relay n, $\mathbf{w}_{s_k r_l}$ is the detector used at the relays. When the RAKE receiver is adopted at the corresponding relay, $\mathbf{w}_{s_k r_l}$ is expressed as

$$\mathbf{w}_{s_k r_l} = \mathbf{h}_{s_k r_l}, \qquad (8)$$

where $\mathbf{h}_{s_k r_l} = a_{s_k r_l} \mathbf{s}_k h_{s_k r_l}$ is the channel vector from user k to relay l. Similarly, if the linear minimum mean-square error (MMSE) receiver [23] is employed at the relays, $\mathbf{w}_{s_k r_l}$ is equal to

$$\mathbf{w}_{s_k r_l} = \left(\sum_{k=1}^{K} \mathbf{h}_{s_k r_l} \mathbf{h}_{s_k r_l}^H + \sigma^2 \mathbf{I} \right)^{-1} \mathbf{h}_{s_k r_l}, \qquad (9)$$

$\mathbf{h}_{s_k r_l} = a_{s_k r_l} \mathbf{s}_k h_{s_k r_l}$ is the effective signature vector from user k to the relay l. Similarly, in Eq. (7), $\text{SINR}_{r_{m,n}d}$ represents the SINR for the combined paths from relay m and relay n to the destination. The receive filter $\mathbf{w}_{r_l d}^k$ is employed by the detector used at the destination. When the RAKE receiver is adopted at the destination, $\mathbf{w}_{r_l d}^k$ is expressed as

$$\mathbf{w}_{r_l d}^k = \mathbf{h}_{r_l d}^k. \qquad (10)$$

Similarly, if the linear MMSE receiver is employed at the relays, $\mathbf{w}_{r_l d}^k$ is equal to

$$\mathbf{w}_{r_l d}^k = \left(\sum_{k=1}^{K} \mathbf{h}_{r_l d}^k (\mathbf{h}_{r_l d}^k)^H + \sigma^2 \mathbf{I} \right)^{-1} \mathbf{h}_{r_l d}^k. \qquad (11)$$

The above equations correspond to a cooperative system under the assumption that signals from all users are transmitted to the selected relays m and n. Both RAKE and MMSE receivers are considered here for the purpose of complexity, it should be mentioned that other detectors [24] can also be used. We then sort all these SINR values in a decreasing order and select the one with the highest SINR as given by

$$\text{SINR}_{p,q} = \arg \max_{m,n \in [1,2,...,L]} \{\text{SINR}_{sr_{m,n}}, \text{SINR}_{r_{m,n}d}\}, \quad (12)$$

where $\text{SINR}_{p,q}$ denotes the highest SINR associated with the relay p and relay q. After the highest SINR corresponding to the combined paths is selected, two different situations need to be considered as follows.

Source-relay link:

If the highest SINR belongs to the source-relay link, then the signal sent to the target relays p and q over two time instants is given by

$$\mathbf{y}_{sr_l}(2i-1) = \sum_{k=1}^{K} b_k(2i-1) \mathbf{w}_{s_k r_l} + \mathbf{w}_{sr_l}(2i-1), l \in [p,q], \qquad (13)$$

$$\mathbf{y}_{sr_l}(2i) = \sum_{k=1}^{K} b_k(2i) \mathbf{w}_{s_k r_l} + \mathbf{w}_{sr_l}(2i), l \in [p,q]. \qquad (14)$$

The received signal is then processed by the detectors as the DF protocol is adopted. Therefore, the decoded symbols that are stored and sent to the destination from the l-th relay are obtained as

$$\hat{b}_{r_l d, k}(2i-1) = Q(\mathbf{w}_{s_k r_l}^H \mathbf{y}_{sr_l}(2i-1)), \qquad (15)$$

and

$$\hat{b}_{r_l d, k}(2i) = Q(\mathbf{w}_{s_k r_l}^H \mathbf{y}_{sr_l}(2i)), \qquad (16)$$

where $Q(\cdot)$ denotes the slicer. After that, the buffers are switched to the reception mode, the decoded symbol is consequently stored in the corresponding buffer entries. Clearly,

these operations are performed when the corresponding buffer entries are not full, otherwise, the second highest SINR is chosen as given by

$$\text{SINR}_{p,q}^{\text{pre}} = \text{SINR}_{p,q} \qquad (17)$$

$$\text{SINR}_{u,v} \in \max\{\text{SINR}_{sr_{m,n}}, \text{SINR}_{r_{m,n}d}\} \setminus \text{SINR}_{p,q}^{\text{pre}}, \quad (18)$$

where $\text{SINR}_{u,v}$ denotes the second highest SINR associated with the updated relay pair $\Omega_{u,v}$. $\{\text{SINR}_{sr_{m,n}}, \text{SINR}_{r_{m,n}d}\} \setminus \text{SINR}_{p,q}^{\text{pre}}$ denotes a complementary set where we drop the $\text{SINR}_{p,q}^{\text{pre}}$ from the link SINR set $\{\text{SINR}_{sr_{m,n}}, \text{SINR}_{r_{m,n}d}\}$. Consequently, the above process repeats in the following time instants.

Relay-destination link:

If the highest SINR is selected from the relay-destination link, in the following two consecutive time instants, the buffers are switched to transmission mode and the decoded symbol for user k is re-encoded with the Alamouti matrix as in (1) so that DSTC is performed from the selected relays p and q to the destination as given by

$$\mathbf{y}_{r_{p,q}d}(2i-1) = \sum_{k=1}^{K} \mathbf{w}_{r_p d}^k \hat{b}_{r_p d, k}(2i-1) + \mathbf{w}_{r_q d}^k \hat{b}_{r_q d, k}(2i) + \mathbf{n}(2i-1), \qquad (19)$$

$$\mathbf{y}_{r_{p,q}d}(2i) = \sum_{k=1}^{K} \mathbf{w}_{r_q d}^k \hat{b}_{r_p d, k}^*(2i-1) - \mathbf{w}_{r_p d}^k \hat{b}_{r_q d, k}^*(2i) + \mathbf{n}(2i). \qquad (20)$$

The received signal is then processed by the detectors at the destination. Clearly, the above operation is conducted under the condition that the corresponding buffer entries are not empty, otherwise, the second highest SINR is chosen according to (17) and (18) and the above process is repeated.

IV. PROPOSED DYNAMIC BUFFER SCHEME

The size J of the buffers plays a key role in the performance of the system, which improves with the increase of the size as buffers with greater size allow more data packets to be stored. In this case, extra degrees of freedom in the system or choices for data transmission are available. Hence, in this section, we release the limitation on the size of the buffer to further explore the additional advantage brought by dynamic buffer design where the buffer size can vary according to different criteria such as the input SNR and the channel condition. When considering the input SNR, extra buffer space is required when the transmission is performed in the low SNR region so that the data associated with the best channels can be selected among a greater number of candidates. On the other hand, in the high SNR region, a small buffer size is employed as most of the processed symbols are appropriate when compared with the situation in the low SNR region. In this work, we assume that the buffer size J is inversely proportional to the input SNR, namely, with the increase of the SNR, the buffer size decreases automatically. The algorithm for calculating the buffer size J is detailed in Table. I.

TABLE I
THE ALGORITHM TO CALCULATE THE BUFFER SIZE J

(1) **If**	$\mathrm{SNR_{cur}} = \mathrm{SNR_{pre}} + d_1$	
(2) **then**	$J_{\mathrm{cur}} = J_{\mathrm{pre}} - d_2,$	

where $\mathrm{SNR_{cur}}$ and $\mathrm{SNR_{pre}}$ represent the input SNR after and before increasing its value,

J_{cur} and J_{pre} denote the corresponding buffer size before and after decreasing its value,

d_1 and d_2 are the step sizes for the SNR and the buffer size, respectively.

The buffer size can be determined by the current selected channel pair condition. In particular, we set a threshold γ that denotes the channel power, if the current selected channel power is under γ, the buffer size increases as more candidates need to be saved in order to select the best symbol, on the contrary, if the current selected channel pair power exceeds γ, we decrease the buffer size as there is a high possibility that the transmission is not significantly affected. The approach based on the channel power for varying the buffer can be summarized in Table. II.

TABLE II
THE ALGORITHM FOR CALCULATE BUFFER SIZE J BASED ON THE CHANNEL POWER

(1) **If**	$\min \|h_{s_k r_l}\|^2 \le \gamma$ **or** $\min \|h_{r_l d}\|^2 \le \gamma, \ l \in [1, L]$
	$J_{\mathrm{cur}} = J_{\mathrm{pre}} + d_3$
(2) **else**	
	$J_{\mathrm{cur}} = J_{\mathrm{pre}} - d_3$
end	

where d_3 represents the step size when adjusting the buffer size.

Then, we analyse the computational complexity required by the proposed relay pair selection algorithm. The exhaustive relay pair search requires $(7KNL^3 7KNL^2)$ multiplications and $(2KNL^3 2KNL^2 + KL^3 KL^2 2L^2 + 2L)$ additions, while the proposed greedy relay pair selection algorithm only requires less than $(21KNL^2 7KNL)$ multiplications and $(6KNL^2 + 3KL^2 3KLL + 1)$ additions, which is an order of magnitude less costly. Therefore, when a large number of relays participate in the transmission, with a careful control of the buffer size J, a good balance of complexity and performance is achieved.

At last, we analyze the average delay of the proposed schemes and algorithms. The major delay comes from three aspects. Firstly, the improvement of the performance brought by the buffer–aided relays comes at the expense of the transmission delay [25]. Secondly, the DSTC scheme will introduce further delay as the DSTC scheme takes two time–slots to transmit two packets in a time [26], [27], [28]. Finally, extra computational delay is required as the proposed relay selection algorithms are conducted in the transmission.

V. SIMULATIONS

In this section, a simulation study of the proposed buffer-aided DSTC technique for cooperative systems is carried out.

The DS-CDMA network uses randomly generated spreading codes of length $N = 16$. The corresponding channel coefficients are taken as uniformly random variables and are normalized to ensure the total power is unity for all analyzed techniques. We assume perfectly known channels at the receivers. Equal power allocation with normalization is assumed to ensure no extra power is introduced during the transmission. We consider packets with 1000 BPSK symbols and step size $d = 2$ when conducting the dynamic schemes. We consider fixed buffer–aided exhaustive (FBAE)/fixed buffer–aided greedy (FBAG) [29] relay pair selection strategies (RPS) and dynamic buffer–aided exhaustive (DBAE)/dynamic buffer–aided greedy(DBAG) [29] RPS, and we assumed perfect channel state information is available at the relays and the destination and that the performance of the system with channel estimation algorithms is slightly degraded.
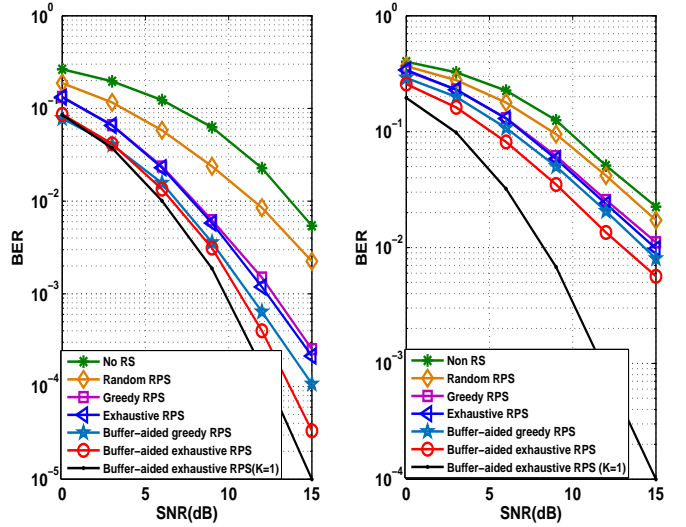

Fig. 2. a) Performance comparison for buffer-aided scheme and non buffer-aided scheme in cooperative DS-CDMA system with perfect decoding at the relay, RAKE at the destination b) Performance comparison for buffer-aided scheme and non buffer-aided scheme in cooperative DS-CDMA system with MMSE at the relay, RAKE at the destination

In order to verify that the fixed buffer-aided relay pair DSTC cooperative scheme contributes to the performance gain, we compare the performance between the situations of the transmission with fixed size buffers and without buffers in Fig. 2. The first example shown in Fig. 2(a) illustrates the performance comparison between the proposed buffer-aided DSTC transmission with different RPS and DSTC transmission with relay pair selections and no buffers when better decoding techniques are adopted. The system has 3 users, 6 relays, perfect decoding is assumed at each relay and the matched filter is adopted at the destination. Specifically, for the no relay selection (RS) DSTC technique, all relays participate in the DSTC transmission (every two consecutive relays are working in pairs). Similarly, for the non buffer-aided schemes, the RPS process only occurs during the second phase (relay-destination), where the random selection algorithm chooses an arbitrary relay pair, the proposed greedy algorithm chooses two relays associated with two optimum

relay-destination links and the exhaustive relay pair schemes examines all possible relay pairs and selects the one with the highest SINR. In contrast, the proposed buffer-aided scheme automatically selects the relay pair over both source-relay links and relay-destination links. Moreover, with the help of the buffers, the most appropriate data are sent and better overall system performance can be achieved. The performance for a single-user buffer-aided exhaustive RPS DSTC is presented here for comparison purposes. Consequently, the results reveal that our proposed buffer-aided strategies ($J = 6$) perform better than the one without buffers. In particular, Fig. 2(a) also illustrates that our proposed buffer-aided schemes can approach the single user bound very closely.

The second example depicted in Fig. 2(b) compares the proposed buffer-aided DSTC transmission with different RPS and DSTC transmission with relay pair selections and no buffers. In this scenario, where we apply the linear MMSE receiver at each of the relay and the RAKE at the destination in an uplink cooperative scenario with 3 users, 6 relays and buffer size $J = 6$. Similarly, the performance bounds for a single-user buffer-aided exhaustive RPS DSTC are presented for comparison purposes. The results also indicate that our proposed buffer-aided strategies ($J = 6$) perform better than the one without buffers. Furthermore, the BER performance curves of our greedy RPS algorithm approaches the exhaustive RPS, while keeping the complexity reasonably low for practical use.

When we compare the curves in Fig. 3, the dynamic buffer techniques are more flexible than the fixed buffer ones as they explore the most suitable buffer size for the current transmission according to a given criterion. In this case, there is a greater possibility to select the most appropriate data when the transmission is operated in poor condition as more candidates are stored in the buffer space. On the other hand, the transmission delay can be avoided when the outer condition improves as most of the candidates are appropriate. Simulation results verify these points and indicate that the DBAE/DBAG RPS outperform the FBAE/FBAG ($J = 8$) RPS and the advantage increases when adopting the single user case. Furthermore, it can also be seen that the BER performance curves of the greedy relay pair selection algorithm [30] approaches the exhaustive search, whilst keeping the complexity reasonably low for practical utilization.

Fig. 4. a) performance comparison for fixed buffer design (channel power criterion) b)performance comparison for dynamic buffer design (channel power criterion)

The third example compares the FBAE/FBAG RPS scheme in Fig. 4(a) and the DBAE/DBAG RPS strategy in Fig. 4(b) in a DSTC cooperative system, where we apply the linear MMSE receiver at each of the relay and the matched filter (MF or RAKE receiver) at the destination in an uplink cooperative scenario with 3 users, 6 relays and fixed buffer size $J = 8$. Similarly, the performance for a single-user buffer-aided exhaustive RPS DSTC is presented for comparison purposes. In both figures, the buffer-aided exhaustive search RPS algorithm performs better than the greedy one. The average dynamic buffer size J is highly dependant on the threshold γ and the step size d, clearly, with careful control on these parameters, better performance can be achieved. The simulation results also indicate that our proposed dynamic design perform better than the fixed buffer size ones when we apply the same relay selection method, as depicted in Fig. 4.
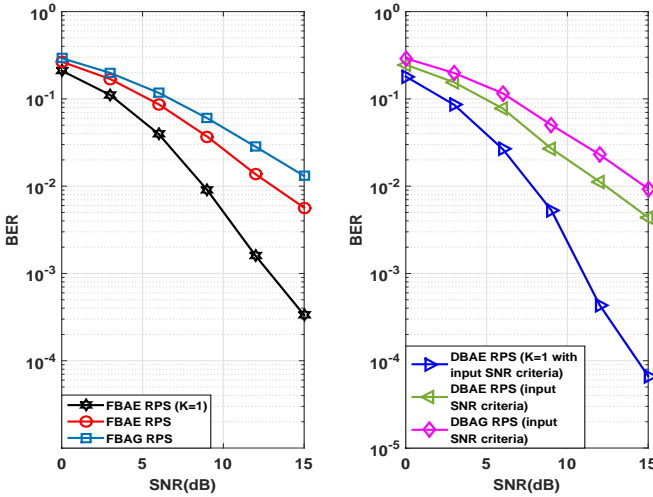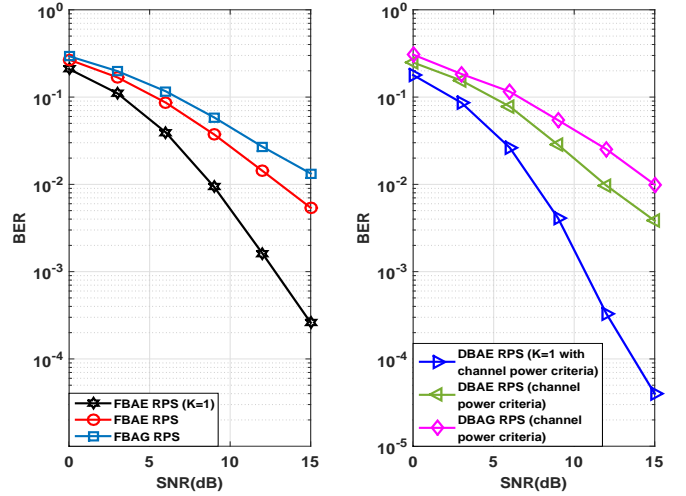

Fig. 3. a) performance comparison for fixed buffer design (input SNR criterion) b) performance comparison for dynamic buffer design (input SNR criterion)

The second example illustrates the performance comparison for the fixed buffer-aided design in Fig. 3(a) and dynamic buffer-aided design in Fig. 3(b) in a cooperative DSTC system with different relay pair selection strategies (RPS). The overall network has 3 users, 6 relays, the linear MMSE receiver is applied at each relay and the matched filter is adopted at the destination. For dynamic algorithms, the buffer size J decreases when approaching higher SNR region. In both figures, the buffer-aided exhaustive greedy RPS algorithm performs better than the greedy one.

VI. CONCLUSIONS

In this work, we have presented a dynamic buffer-aided DSTC scheme for cooperative DS-CDMA systems with different relay pair selection techniques. With the help of

the dynamic buffers, this approach effectively improves the transmission performance and help to achieve a good balance between bit error rate (BER) and delay. Simulation results show that the performance of the proposed dynamic design can offer good gains as compared to fixed buffer-aided schemes.

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