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 effectively 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 so that the interference can be more effectively mitigated. As a result, better performance can be achieved when appropriate signal processing and relay selection strategies are applied. Recently, a new cooperative scheme with buffers equipped at relays has been introduced and analyzed in [10], [11], [12], [13]. The main purpose is to select the best link according to a given criterion.

In this work, we propose a dynamic buffer-aided DSTC scheme for cooperative direct-sequence code-division multiple access (DS-CDMA) system. The proposed algorithm automatically selects the optimum set of relays according to the signal-to-interference-plus noise ratio (SINR) criterion. With dynamic buffers equipped at each of the relays, multiple blocks of data can then be stored so that the most appropriate ones can be selected at a suitable time instant.

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. 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. In the proposed scenario, 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 $[\hat{b}_{r_l d,k}(2i-1), \hat{b}_{r_l d,k}(2i)]$ 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 [14] detected symbol matrix over relay m and relay n for user k among two consecutive time instants is given by

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

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 f

$$\mathbf{y}_{r_{m,n}d} = \mathbf{H}^k_{r_{m,n}d}\mathbf{b}_{r_{m,n}d,k} + \mathbf{n}_{r_{m,n}d}, \tag{2}$$

where $\mathbf{y}_{r_{m,n}d} = \left[\mathbf{y}_{r_{m,n}d}(2i-1), \mathbf{y}_{r_{m,n}d}(2i)\right]^T$ represents the received signal from relay m and n over two time instants. $\mathbf{H}^k_{r_{m,n}d} = \begin{bmatrix} \mathbf{h}^k_{r_m d} & \mathbf{h}^k_{r_n d} \\ (\mathbf{h}^k_{r_n d})^* & -(\mathbf{h}^k_{r_m d})^* \end{bmatrix}$ denotes the Alamouti channel matrix for user k, $\mathbf{h}^k_{r_l d} = a^k_{r_l d}\mathbf{s}_k h_{r_l d,k}$ denotes the channel matrix for user k from the l-th relay to the destination with $m,n \in [1,2,...,L]$. The quantity $a^k_{r_l d}$ represents the k-th user's amplitude from the l-th relay to the destination,

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$\mathbf{s}_k = [s_k(1), s_k(2), ...s_k(N)]^T$ is the $N \times 1$ signature sequence for user k and $h_{r_l d,k}$ are the channel fading coefficients for user k from the l-th relay to the destination. $\mathbf{b}_{r_{m,n}d,k} = \left[\hat{b}_{r_m d,k}(2i-1), \hat{b}_{r_n d,k}(2i)\right]^T$ is the processed symbol when the DF protocol is conducted at relay m and n at the corresponding time instant, and $\mathbf{n}_{r_{m,n}d} = [\mathbf{n}(2i-1), \mathbf{n}(2i)]^T$ is the noise vector that contain 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 conducted.

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 proper symbols can be sent directly or wait with a shorter delay when the corresponding buffer size decreases. This method effectively improves the quality of the transmission, guarantees that the most suitable signal is selected from the buffer entries and sent to the destination with a higher reliability.

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 all possible lists of corresponding channel pairs are considered. The corresponding SINR is then calculated and recorded as follows:

$$\mathrm{SINR}_{sr_{m,n}} = \frac{\sum\limits_{k=1}^{K} \mathbf{h}_{s_k r_m}^H \mathbf{h}_{s_k r_m} + \mathbf{h}_{s_k r_n}^H \mathbf{h}_{s_k r_n}}{\sum\limits_{k=1}^{K} \sum\limits_{\substack{l=1 \\ l \neq m,n}}^{L} \mathbf{h}_{s_k r_l}^H \mathbf{h}_{s_k r_l} + \sigma^2}, \quad (3)$$

$$\mathrm{SINR}_{r_{m,n}d} = \frac{\sum\limits_{k=1}^{K} (\mathbf{h}_{r_m d}^k)^H \mathbf{h}_{r_m d}^k + (\mathbf{h}_{r_n d}^k)^H \mathbf{h}_{r_n d}^k}{\sum\limits_{k=1}^{K} \sum\limits_{\substack{l=1 \\ l \neq m,n}}^{L} (\mathbf{h}_{r_l d}^k)^H \mathbf{h}_{r_l d}^k + \sigma^2}, \quad (4)$$

where $\mathrm{SINR}_{sr_{m,n}}$ denotes the SINR for the combined paths from all users to relay m and relay n, and $\mathrm{SINR}_{r_{m,n}d}$ represents the SINR for the combined paths from relay m and relay n to the destination. $\mathbf{h}_{s_k r_l} = a_{s_k r_l} \mathbf{s}_k h_{s_k r_l}$ is the channel vector from user k to the relay l. The above equations correspond to a cooperative system under the assumption that all users are transmitted to the selected relays m and n. We then sort all these SINR values in a decreasing order and select the one with the highest SINR as given by

$$\mathrm{SINR_{p,q}} = \arg \max_{m,n \in [1,2,...,L]} \{\mathrm{SINR_{sr_{m,n}}}, \mathrm{SINR_{r_{m,n}d}}\}, \quad (5)$$

where $\mathrm{SINR_{p,q}}$ 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

$$\mathbf{y}_{sr_l}(2i-1) = \sum_{k=1}^{K} b_k(2i-1) \mathbf{h}_{s_k r_l} + \mathbf{n}_{sr_l}(2i-1), l \in [p,q], \quad (6)$$

$$\mathbf{y}_{sr_l}(2i) = \sum_{k=1}^{K} b_k(2i) \mathbf{h}_{s_k r_l} + \mathbf{n}_{sr_l}(2i), l \in [p,q]. \quad (7)$$

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

$$\hat{b}_{r_l d,k}(2i-1) = Q(\mathbf{w}^H \mathbf{y}_{sr_l}(2i-1)), \quad (8)$$

and

$$\hat{b}_{r_l d,k}(2i) = Q(\mathbf{w}^H \mathbf{y}_{sr_l}(2i)), \quad (9)$$

where $\mathbf{w}^H$ stands for different linear detectors employed at the corresponding relay and $Q(\cdot)$ denotes the slicer. After that, the buffers are then 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

$$\mathrm{SINR_{p,q}^{pre}} = \mathrm{SINR_{p,q}} \quad (10)$$

$$\mathrm{SINR_{u,v}} \in \max\{\mathrm{SINR_{sr_{m,n}}}, \mathrm{SINR_{r_{m,n}d}}\} \setminus \mathrm{SINR_{p,q}^{pre}}, \quad (11)$$

where $\mathrm{SINR_{u,v}}$ denotes the second highest SINR associated with the updated relay pair $\Omega_{u,v}$. $\{\mathrm{SINR_{sr_{m,n}}}, \mathrm{SINR_{r_{m,n}d}}\} \setminus \mathrm{SINR_{p,q}^{pre}}$ denotes a complementary set where we drop the $\mathrm{SINR_{p,q}^{pre}}$ from the link SINR set $\{\mathrm{SINR_{sr_{m,n}}}, \mathrm{SINR_{r_{m,n}d}}\}$. 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

$$\mathbf{y}_{r_{p,q}d}(2i-1) = \sum_{k=1}^{K} \mathbf{h}_{r_p d}^k \hat{b}_{r_p d,k}(2i-1) + \mathbf{h}_{r_q d}^k \hat{b}_{r_q d,k}(2i) + \mathbf{n}(2i-1), \quad (12)$$

$$\mathbf{y}_{r_{p,q}d}(2i) = \sum_{k=1}^{K} \mathbf{h}_{r_q d}^k \hat{b}_{r_p d,k}^*(2i-1) - \mathbf{h}_{r_p d}^k \hat{b}_{r_q d,k}^*(2i) + \mathbf{n}(2i). \quad (13)$$

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 (10) and (11) and the above process is repeated.
Dynamic buffer design:
The size B of the buffers also plays a key role in the performance of the system, which improves with the increase of the size as buffers with greater size allows more data packets to be stored. In this case, extra degrees of freedom in the system or choices for data transmission are available. Specifically, the buffer size can vary according to different criteria such as the input SNR and the channel condition. When considering the input SNR, larger buffer space is required when the transmission is operated in low SNR region so that the most proper data can be selected among a relatively larger amount of inappropriate candidates. On the other hand, in 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 B is inversely proportional to the input SNR, namely, with the increase of the SNR, the buffer size decreases automatically. 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. Mathematically, this criteria can be summarized as

If $\quad \min \|h_{s_k r_l}\|^2 \leq \gamma \quad$ **or** $\quad \min \|h_{r_l d}\|^2 \leq \gamma, \quad l \in [1, L]$
$\qquad B = B + d$
else
$\qquad B = B - d$
end

Where d represents the step size when adjusting the buffer size. The key advantage of the proposed scheme is its ability to select the most appropriate symbols before they are forwarded to the next phase. In practice, the performance highly depends on the buffer size B, the number of users K and the accuracy of the detection at the relays.

IV. 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 guarantee 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..

The first example shown in Fig. 1 illustrates the performance comparison between the fixed buffer-aided deign and dynamic buffer-aided design in cooperative DSTC system with different relay pair selection strategies (RPS). The overall network has 3 users, 6 relays, the linear minimum mean-square error (MMSE) receiver is applied at each relay and the matched filter is adopted at the destination. For dynamic algorithms,

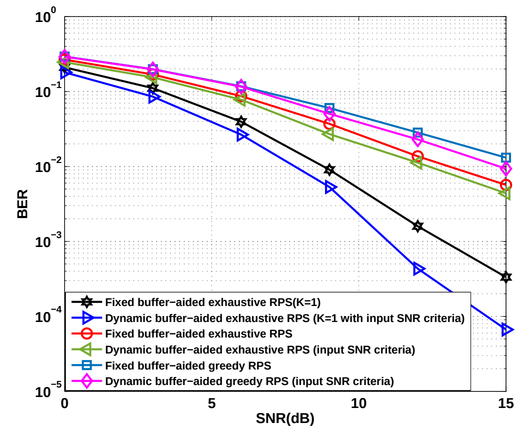

Fig. 1. performance comparison between fixed buffer design and dynamic buffer design (input SNR criteria)

the buffer size B decreases when approaching higher SNR region. The dynamic buffer techniques behave more flexible than the fixed buffer ones as they explore the most suitable buffer size for the current transmission according to a given criteria, 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 fact and indicate that the dynamic buffer-aided exhaustive/greedy RPS algorithms outperform the fixed ($B = 8$) buffer-aided exhaustive/greedy strategies 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 [15] approaches the exhaustive search, whilst keeping the complexity reasonably low for practical utilization.

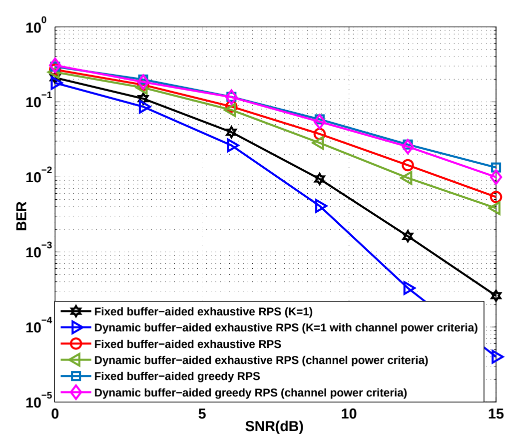

Fig. 2. performance comparison between fixed buffer design and dynamic buffer design (channel power criteria)

The second example depicted in Fig. 2 compares the fixed buffer-aided relay pair selection (RPS) scheme and the dynamic buffer-aided relay pair selection (RPS) strategy in DSTC cooperative system. where we apply the linear MMSE receiver at each of the relay and the matched filter (MF) the destination in an uplink cooperative scenario with 3 users, 6 relays and fixed buffer size $B = 8$. Similarly, the performance bounds for a single-user buffer-aided exhaustive RPS DSTC are presented for comparison purposes. The average dynamic buffer size B is highly depended 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 designs perform better than the fixed buffer size ones when apply the same relay selection method.

V. CONCLUSIONS

In this work, we have presented a dynamic buffer-aided DSTC scheme for cooperative DS-CDMA systems with d-ifferent 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. If this work is accepted we will include further details about the dynamic buffer approach.

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