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Relay Selection in Adaptive Buffer-Aided Space-Time Coding with TAS for Cooperative Wireless Networks

B.Ahvanth[1] and E.Ramassamy[2]
[1,2]Assistant Professor, Dept. of Electronics and Communication Engineering,
Manakula Vinayagar Institute of Technology, Puducherry, India
E-mail: ashi.ece@pec.edu
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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 a new hybrid relay selection protocol, in which the instantaneous signal to noise ratio in each link is calculated and compared at the destination. The transmit antenna selection (TAS) is adopted at the destination where a single transmit antenna at the transmitter and relay that maximizes the instantaneous received signal-to-noise ratio is selected for further transmissions to improve the performance of co-operative network. 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 schemes with TAS obtain performance gains over existing schemes.**
Keywords: **Hybrid relay selection, cooperative systems, buffer-aided relays, Transmit antenna selection, space-time codes.**

I. INTRODUCTION

In this paper, we propose an adaptive buffer-aided space time coding (STC) scheme and a buffer-aided relaying optimization (ABARO) Scheme [6] 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 (SNRins) and another part which is the optimization part for the adjustable STC schemes employed at the relay nodes. In the relay selection part two types of relay selection protocols are used namely best relay selection and hybrid relay selection [17]. The best relay selection selects the links with maximum instantaneous signal-to-noise ratio (SNRins). The hybrid relay selection divides the relays into two groups, which are AF and DF relay groups, and then exploits the merits of both relay groups. In this case, noise amplification in AF relay, and error propagation in DF relay, will be avoided.

Cooperative relay communication has become a widely used technique in wireless communication systems to combat fading effects induced by multipath propagation. It is also used to improve the reliability of data transmission [1],[2]. There are two main types of relay used: amplify-and-forward (AF) and decode-and-forward (DF). In AF protocol, the relay simply amplifies the received signal as well as its own received noise and then forwards it to the destination. The first part of this process is the major drawback of AF protocol. In DF protocol, the relay decodes the received signal, which experiences error propagation, then re-encodes it and forwards it to the destination. Recently, an alternative relay selection scheme based on a hybrid relay protocol has received a lot of attention. The proposed algorithm divided the relays into two groups, which are AF and DF relay groups, and then exploits the merits of both relay groups. In this case, noise amplification in AF relay, and error propagation in DF relay, will be avoided.

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For user-destination (u−D) and relay-destination (r−D) links, we adopt transmit antenna selection (TAS) where a single transmit antenna that maximizes the output signal-to-noise ratio (SNR) is selected. As such, the transmitter can be easily implemented with a single front end analog switch, and the receiver only needs to feed back the index of the selected transmit antenna. In the proposed algorithm ABARO is combined with hybrid relay selection and TAS, the BER performance of ABARO is obtained and it is compared with the addition of hybrid relay selection and TAS

II. COOPERATIVE SYSTEM MODEL

In this section, we extend the single-antenna system model to a two-hop multiple-antenna system that is shown in Fig.2.Each node contains N ≥ 2 antennas. Let s[j] denote a modulated data symbol vector with length M, which is a block of symbols in a packet. The data symbol vector s[j] can be sent from the source to the relays within one time slot since multiple antennas are employed [7]. We assume that the channels are static over the transmission period of s[j] and, for simplicity, we assume that N = M and the minimum buffer size is equal to M. In the first hop, the source node sends s[j] to the relay nodes and the received data are described by

$$r_{SR_k}[j] = \sqrt{\frac{P_S}{N}} F_{SR_k} S[j] + n_{SR_k}[j], \quad k = 1,2,\ldots,n_r, \; j = 1,2,\ldots,J \tag{1}$$

where FSRk [j] denotes the N × N CSI matrix between the source node and the k[th] relay and $n_{SR_k}[j]$stands for the N ×1 AWGN vector generated at the kth relay. At each relay node, an adjustable code vector is randomly generated before the forwarding procedure and the received data are expressed as

$$R_{R_kD}[j] = \sqrt{\frac{P_R}{N}}\, G_{R_kD}[j]V[j]C[j] + N_{R_kD}[j] = \sqrt{\frac{P_R}{N}}\, G_{R_kD}[j]C_{rand}, \qquad (2)$$

$$k = 1,2, \dots, n_r,\ j = 1,2, \dots, J$$

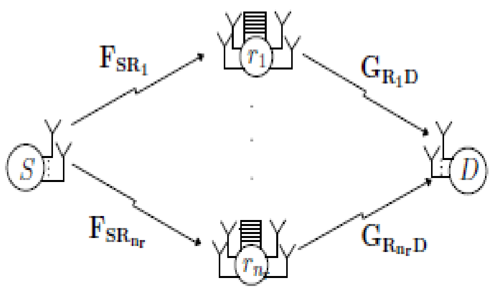

Fig.1 Cooperative System Model

A. Adjustable Space-Time Coding Scheme for MAS

To implement the adjustable STC scheme.Take the 2 × 2 Alamouti STBC scheme as an example, the adjustable STC scheme is encoded as:

$$C_{rand} = VC = \begin{bmatrix} v_1 & 0 \\ 0 & v_2 \end{bmatrix} \begin{bmatrix} r_{SR_k1} & -r_{SR_k2}^{*} \\ r_{SR_k2} & r_{SR_k1}^{*} \end{bmatrix}$$

$$= \begin{bmatrix} v_1 r_{SR_k1} & -v_1 r_{SR_k2}^{*} \\ v_2 r_{SR_k2} & v_2 r_{SR_k1}^{*} \end{bmatrix} \qquad (3)$$

where r_{SR_k1} and r_{SR_k2} are the first symbols in the separate groups, and the 2 × 2 matrix V denotes the randomized matrix whose elements at the main diagonal are generated randomly according to different criteria described.

III. ADAPTIVE BUFFER-AIDED STC AND RELAY OPTIMIZATION ALGORITHMS

The main idea of the ABARO algorithm is to choose the best relay node which contains the highest instantaneous SNR for transmission and reception in order to achieve full diversity order and higher coding gain as compared to standard STC and DSTC designs [4], [5]. The relay nodes are assumed to contain buffers to store the received data and forward the data to the destination over the best available channels. In addition, the best relay node is always chosen in order to enhance the detection performance at the destination. As a result, with buffer-aided relays the proposed ABARO scheme will result in improved performance. Before each transmission, the instantaneous SNR (SNRins) of the SR and RD links are calculated at the destination and conveyed with the help of signaling and feedback channels [15]. The expressions for the instantaneous SNR of the SR and RD links are respectively given by

$$SNR_{SR_k}[i] = \frac{\left\| f_{SR_k}[i] \right\|_F^2}{\sigma_r^2},$$

$$SNR_{R_kD}[i] = \frac{\left\| v_{eq}[i]\, g_{R_kD}[i] \right\|_F^2}{\sigma_d^2} \qquad (4)$$

and the best link is chosen according to

$$SNR_{opt}[i] = \arg\max SNR_{ins_{k,b}}[i],\ k = 1,2, \dots, n_r, b = 1,2, \qquad (5)$$

where b denotes the occupied number of packets in the buffer. After the best relay is determined, the transmission described in (1) and (2) is implemented. The *SNRins* is calculated first and then the destination chooses a suitable relay which has enough room in the buffer for the incoming data. For example, if the k[th] SR link is chosen but the buffer at the k[th] relay node is full, the destination node will skip this node and check the state of the buffer which has the second best link. In this case the optimal relay with maximum instantaneous SNR and minimum buffer occupation at a certain SNR level will be chosen for transmission. After the detection of the first group of the received symbol vector at the destination node, the adjustable code v will be optimized. The constrained ML optimization problem that involves the detection of the transmitted symbols and the computation of the adjustable code matrix at the destination is written as

$$s[j] = \arg\min \left\| r_{R_kD}[j] - \sqrt{\frac{P_R P_S}{N}}\, V_{eq}[j]H[j]s[j] \right\|^2 \qquad (6)$$

where *r[j]* is the received symbol vector in the j[th] group and *s[i]* denotes the detected symbol vector in the ith group.

Adjustable matrix optimization for ABARO is given by

$$V_{eq}[j+1] = V_{eq}[j] - \mu \sqrt{\frac{P_R P_S}{N}} \left(r_{R_kD}[j] - \sqrt{\frac{P_R P_S}{N}}\, V_{eq}[j]H[j]s[j] \right) H^H[j]s^H[j] \qquad (7)$$

A normalization of the original code vector v[j] that circumvents the power constraint is given by

$$V[j+1] = V[j+1]\frac{P_V}{\sqrt{\|V[j+1]\|_F^2}} \qquad (8)$$

A. Best Relay Selection Protocol

The relays equipped with multiple antennas will obtain a complete STC scheme and only one best relay node will be chosen according to the BRS algorithm. Assuming M = N, each node equips N ≥ 2 antennas and in the first hop, the M × 1 modulated signal vector s[j] is broadcast to the relays within 1 time slot and the M × 1 received symbol matrix $r_{SR_k}[j]$ is given by

$$r_{SR_k}[j] = \sqrt{\frac{P_S}{N}}F_{SR_k}S[j] + n_{SR_k}[j], \;\; k = 1,2,\dots,n_r, \; j = 1,2,\dots,J \qquad (9)$$

where F_{SR_k} denotes the channel coefficient matrix between the kth relay and the destination, and the AWGN noise vector $n_{SR_k}[j]$ is generated at the k^{th} relay node, The N × 1 received symbol vector is stored at the relays and the optimal relay will be chosen according to [27]. The opportunistic relay selection algorithm for the DSTC scheme and the MAS configuration is given by

$$SNR_k[i] = \arg max \frac{\|G_{R_kD}[j]\|_F^2}{\sigma_d^2}, \; k = 1,2,\dots,n_r, \qquad (10)$$

where GRkD[j] denotes the N ×N channel matrix between the k^{th} relay and the destination. After the best relay with the maximum SNR is chosen, the data is encoded by the DSTC scheme. The DSTC encoded and transmitted data in the second hop is received at the destination as described by

$$R[j] = \sqrt{\frac{P_R}{N}}G_{R_kD}[j]M[j] + N[j] \qquad (11)$$

where *M*[*j*] denotes the N × T DSTC encoded data, *R*[*j*] denotes the N × T received data matrix, and *N*[*j*] is the AWGN matrix

B. Hyprid Relay Selection Protocol

The block diagram of the proposed system is shown in Fig. 1. A general two-hop relay network consists of one source node, denoted as S, one destination node denoted as D, and N relays, distributed between S and D. The encoded bit streams are transmitted through hybrid relay networks. Each node in the proposed two-hop multi relay network is assumed to be equipped with a single antenna and the half-duplex transmission mode is considered. All links will experience quasi-static Rayleigh fading.

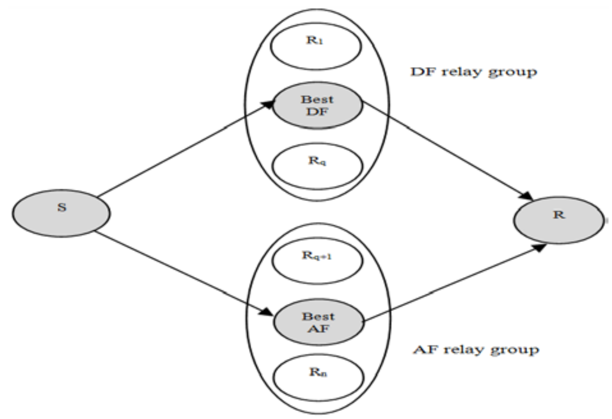

Fig.2 Co-operative System Model using Hybrid Relay Selection

For the proposed HRSP, each relay is included into either AF or DF relay group and then two relays among the groups will be selected by achieving maximum SNR at the destination. The first one is the best relay from AF group and the second is the best relay from DF group. The instantaneous SNR at the destination from the i^{th} relay can be evaluated as

$$\gamma_s^{AF} = max \frac{\gamma_{SR_k}\gamma_{R_kD}}{\gamma_{SR_k}\gamma_{R_kD}+1} \qquad (12)$$

Where $\gamma_{SR_k} = \frac{P_{SR_k}|F_{SR_k}|^2}{N_0}$ and $\gamma_{R_kD} = \frac{P_{R_kD}|F_{R_kD}|^2}{N_0}$ (13)

From (3), the corresponding SNR at the destination is equal to

$\gamma_s^{AF} = \max \; \gamma_{R_kD}$

where $\gamma_{R_kD} = \frac{P_{SR_k}|F_{R_kD}|^2}{N_0}$ is the instantaneous SNR of the $rj \longrightarrow D$ link. After the two relays are selected, the overall received signal at the destination can be expressed as

$$y_d = \begin{cases} \sqrt{P_{R_kD}}F_{R_kD}s(t) + n_{R_kD,} \\ \beta_i F_{R_kD}\left(\sqrt{P_{SR_k}}F_{SR_k}\right)s(t) + \beta_i F_{R_kD}n_{SR_k} + n_{R_kD,} \end{cases} \qquad (14)$$

C.Transmit Antenna Selection

We outline the STNC with TAS in the cooperative MIMO network as follows. The signals received at the destination D and relay *r* from user *u* in time slot *u* are

$$Y_{uD}(t) = h_{n_u D}\sqrt{P_{ou}}x_u s_u(t) + n_{uD}(t) \qquad (15)$$

and

$$Y_{ur}(t) = h_{n_u R}\sqrt{P_{ou}}x_u s_u(t) + n_{uR}(t) \qquad (16)$$

where $h_{n_u D}$ and $h_{n_u R}$ denote the Rayleigh channel vectors between *u*th antenna at user *u* and multiple antennas at the destination D and between the u^{th} antenna at user *u* and multiple antennas at relay *r* respectively, $n_{uD}(t)$ and $n_{uR}(t)$ are the additive white Gaussian noise (AWGN) vectors. In the first phase, TAS is applied between each user and the destination D. The optimal antenna amongst the *Nu* antennas at user *u* is selected to maximize the instantaneous SNR of the signal from user *u* to the destination D. In the second phase, each relay linearly combines the overheard symbols during the first phase to a single encoded signal and then forwards it to the destination D in the second phase. The signal received at the destination D from relay *r* in time slot *U* +*r* is

$$Y_{rD}(t) = h_{n_r D}\sum_{u=1}^{U}\sqrt{P_{ou}}x_u s_u(t) + n_{rD} \qquad (17)$$

where $h_{n_r D}$ denotes the Rayleigh channel vector between the r^{th} antenna at relay *r* and multiple antennas at the destination D, n_{rD} is the AWGN vector, P_{ou} is the transmit power of *xu* at relay *r*

TAS is applied between each relay and the destination D. The optimal antenna amongst the *Nr* antennas at relay R is selected to maximize the instantaneous SNR of the signal from relay R to the destination D. By combining the information on *xu* from user *u* and *R* relays, the instantaneous end-to-end SNR of *xu* at the destination D is written as

$$\gamma_u = \gamma_{uD} + \sum_{r=1}^{R}\gamma_{rD} \qquad (18)$$

Relay can use DAF or AAF protocols, in general DAF protocol performs better than AAF, so in order to enhance the performance of AAF, in addition to the TAS two types of relay selection techniques has been used.

IV. RESULTS AND DISCUSSION

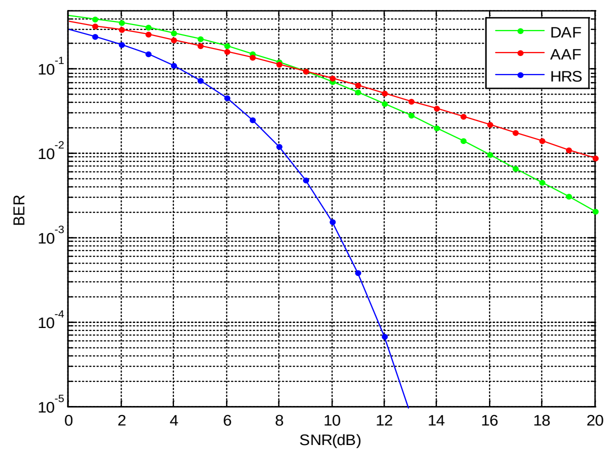

Fig.3 BER Performance of Hybrid Relay Selection

Fig.3. show the BER performance of the AAF, DAF and HRS protocol discussed in above Section with BER versus SNR. Increasing the number of relays in each group results in increased performance of the system. Among the three the hybrid relay selection(HRS) protocol shows improved performance, the Hybrid relay selection is employed among the cooperative systems with nr = 2 relay nodes. Compared to DAF the HRS protocol achieves 8dB to 10dB improvement but when comparing to AAF it is still better as shown in Fig. 2.

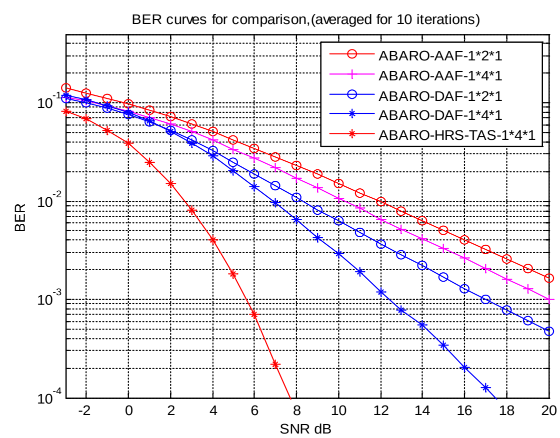

Fig.4 BER Performance of ABARO algorithm

According to the simulation results in Fig.4, a 5dB to 6dB gain can be achieved by using the proposed ABARO algorithm in combination with HRS and TAS at relays compared to the network using ABARO algorithm with DAF at the relay node and a 1dB to 2dB BER improvement can be achieved by employing additional number of relays. When comparing the curves of we also notice that the diversity order of the curves increases due to the increase of the number of relay nodes. 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.

V. CONCLUSION

We have proposed an ABARO scheme 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 simple AAF and DAF system. In addition, the proposed Hybrid Relay Selection and Transmit Antenna Selection has been included to enhance the performance in terms of lower bit error rate at the destination node compare to the STC-ed systems. It was also clear that the diversity order improves if the number of relay nodes increases. In ABARO symbols are queued in relay, by using hybrid relay selection best among AAF and DAF relay was found and by employing Transmit Antenna Selection the best antenna from the selected relays has been selected for further transmission through feedback by means of instantaneous SNR calculated at the destination.

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