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Opportunistic Transmission of Information in Cooperation Systems Using Distributed Space Time Codes

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***Abstract*— opportunistic Distributed space time coding (O-DSTC) is used in co-operative system which consists of two co-operative users (replacing relays) sending their information to a common destination. The term Opportunistic denotes the transmission being done in Space time coding scheme (STC) or Space frequency coding scheme (SFC) depending on mutual information and data rate. The term distributed comes from the fact that the virtual multi-antenna transmitters are randomly distributed. Employing DSTC or DSFC reduces the data rate loss due to relay nodes transmission without sacrificing the system diversity order. Distributed SFC is used for broadband multipath fading channel to exploit the frequency diversity of the channel. Performance analysis is carried out with STC and SFC based on channel capacity, BER and outage probability against SNR.**

***Keywords*— Cooperative diversity, distributed space-time coding (DSTC), Space Frequency Code (SFC), Bit Error Rate (BER).**

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I. Introduction

Diversity techniques are mainly used to overcome the fading problem in multipath Rayleigh channels. These introduce phase shifts, time delays, attenuations, and distortions that can destructively interfere with one another at the aperture of the receiving antenna. There are several wireless Diversity schemes that use two or more antennas to improve the quality and reliability of a wireless link. In some practical scenarios (e.g., handheld terminals, sensor nodes, etc.), it may be difficult to support multiple antennas due to the terminal size, power consumption, and hardware limitations. Cooperative diversity is emerging as an alternative method to obtain the transmit diversity by allowing single-antenna terminals to share their antennas to form a virtual antenna array. So far, a wide range of relaying protocols have been proposed. Most of these protocols belong to one of the following families of relaying schemes: Amplify and Forward (AF) [2], Decode and Forward (DF) [1] and Compress and Forward (CF). The amplify-and-forward strategy allows the relay station to amplify the received signal from the source node and to forward it to the destination station.

II. COOPERATIVE NETWORKS

Next generation wireless networks will go beyond the point to point or point to multipoint paradigms of classical cellular networks. They will be based on complex interactions, where the involved nodes cooperate with one another in order to improve the performance of their own communication and that of the global network. Cooperative communications based on relaying nodes have emerged as a promising approach to increase spectral and power efficiency, network coverage, and to reduce outage probability. Similarly to multi-antenna transceivers, relays provide diversity by creating multiple replicas of the signal of interest [3]. By properly coordinating different spatially distributed nodes in a wireless system, one can effectively synthesize a virtual antenna array that emulates the operation of a multi antenna transceiver.

In cooperative wireless communication, it's concerned with a wireless network, of the cellular or ad hoc variety, where the wireless agents, which call users, may increase their effective quality of service via cooperation. In a cooperative communication system, each wireless user is assumed to transmit data as well as act as a cooperative agent for another user. Cooperation leads to interesting tradeoffs in code rates and transmit power [4]. In the case of power, one may argue on one hand that more power is needed because each user, when in cooperative mode will exchange between them. On the other hand, the baseline transmits power for both users. In the face of this trade-off, one hopes for a net reduction of transmit power, given everything else being constant.

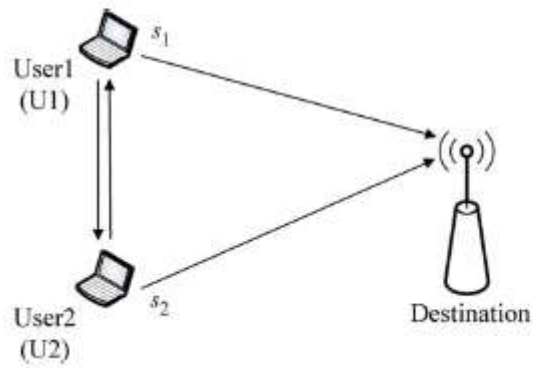

Fig.1 DECODE AND FORWARD COOPERATION SYSTEM

A. O-DSTC SYSTEM DESIGN

In this section the system model used throughout this paper is presented. Next, an O-DSTC schemes with full-duplex considerations, which are referred to as full-duplex-based O-DSTC. For the comparison purpose, the conventional S-DF is analyzed. As shown in Fig. 1, a cooperative diversity system consisting of two cooperative users (as denoted by U1 and U2), which assist each other using a DF protocol in transmitting their information (i.e.,S1and S2) to a common destination, where the subscripts 1 and 2 represent U1 and U2, respectively. Although only two cooperative users are considered, this is an essential scenario to be addressed, since a more generic scenario with multiple source users can be typically converted to the two-user cooperation by designing an additional grouping and partner selection protocol. In Fig. 2, O-DSTC scheme divides a total block into two time frames which are shared between U1 and U2. In the first time frame, both U1 and U2, respectively, transmit their own information S1and S2 to the destination.

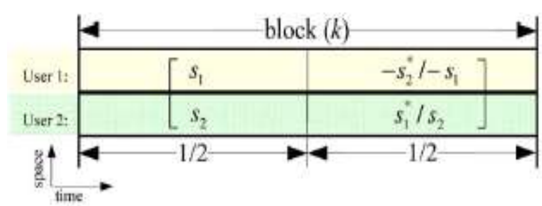

Fig. 2 Opportunistic distributed space time code

At the same time, by considering the full-duplex regime, U1 and U2 can receive and decode each other's information over the channels between the two users, called inter-user channels. In the subsequent time frame, U1 and U2 transmit –S2* and S1* in an opportunistic encoding manner depending on whether U1 and U2 decode each other's information successfully or not.

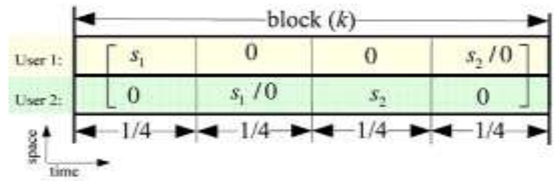

Fig. 3 Conventional S-DF cooperation.

Fig.3 shows the conventional S-DF cooperation scheme, where U1 and U2 are assisting each other's data transmissions (i.e., S1 and S2) using four time frames. Specifically, in the first time frame of block, U1 broadcasts its own information S1 to the destination and U2 that attempts to decode its received signal. Then, in the second time frame, U2 forwards its decoded outcome in a selective manner depending on whether it succeeds in decoding or not. If U2 decodes U1's transmission (S1) successfully, it will forward S1 to the destination. Otherwise, U2 just keeps silent in the second time frame. The process of transmitting S2 during the remaining two time frames of block is essentially same as the procedure of transmitting S1in the first two frames.

B. Proposed Opportunistic Transmission

As a baseline, let us consider the non-cooperative transmission with one block consisting of two time frames where two users take turns in accessing the time frames to transmit their own data with power at data rates and in bits per frame, respectively. One can see from Fig. 2 that, in full-duplex- based O-DSTC, two independent symbols are transmitted by using two time frames, which means that no extra channel resource is wasted by retransmission. Thus, when U1 and U2, respectively, transmit at data rates R1 and R2 in the full-duplex-based O-DSTC scheme, it is guaranteed to transmit the same amount of information (during one block) as the non-cooperative scheme. However, the proposed full-duplex-based O-DSTC scheme requires both U1 and U2 always transmitting in two frames, differing from non-cooperative scheme where U1 and U2 take turns in the time block to transmit their information. Hence, for a fair comparison with the non-cooperative transmission in terms of power consumption, we consider one-half power $E_S/2$ for each user during one time frame in the full-duplex-based O-DSTC scheme [8].

Accordingly, the received signal at the destination in the first time frame of block k is expressed as

$$y_d^1 = \sqrt{\frac{E_s}{2}} h_{1d} s_1 + \sqrt{\frac{E_s}{2}} h_{2d} s_2 + n_d^1 \qquad (1)$$

Where the superscript 1 represents the first time frame of block k, h_{1d} and h_{2d} are fading coefficients of the channel from U1 to destination and that from U2 to destination, respectively, and nd1 represents AWGN with zero mean and variance N_0.

Note that the fading coefficients are modeled as constant during one block (including two frames for full-duplex-based O-DSTC) and vary independently in next time block. Meanwhile, the full-duplex enables U1 and U2 to receive and decode each other's information over the inter-user channels at the same time. Hence, the received signals at U1 and U2 are y_1 and y_2 respectively, given by

$$y_1 = \sqrt{\frac{E_s}{2}} h_{21} s_2 + n_1 \qquad (2)$$

Where h_{21} represents the Rayleigh channel from U2 to U1 and n_1 is AWGN with zero mean and variance N_0,

$$y_2 = \sqrt{\frac{E_s}{2}} h_{12} s_1 + n_2$$

(3)

Where h_{12} represents the Rayleigh channel from U1 to U2 and n_2 is AWGN with zero mean and variance N_0. Then, U1 and U2 decode each other's information using their received signals as given by (2) and (3), respectively. For the full-duplex-based O-DSTC scheme, we consider that U1 and U2 will acknowledge each other and the destination if they succeed in decoding or not using feedback channels. It is assumed that both U1 and U2 always decode the acknowledgement information successfully, considering the fact that an acknowledgment consists of only one-bit information. In the second time frame of block, U1 and U2 encode and transmit s_1 and s_2 in an opportunistic manner depending on their decoded outcomes in the first frame. To be specific, if both U1 and U2 decode each other's information successfully, the Alamouti space-time coding will be utilized, i.e.,-S^*_2 and S^*_1 are transmitted by U1 and U2, respectively.

Otherwise, U1 and U2, respectively, transmit $-S_1$ and S_2 to the destination, instead of the Alamouti coding. This is due to the fact that, when either U1 or U2 fails to decode.

The use of Alamouti space-time code will introduce interference at the destination in decoding S_1 and S_2. Meanwhile, the destination cannot rely on its received signal in the first frame to decode S_1 and S_2, since two unknowns (S_1 and S_2) are in one equation, as shown in (1). In order to recover S_1 and S_2 at the destination in this case, U1 and U2 are allowed to transmit $-S_1$ and S_2 , respectively, to the destination in the second time frame, which guarantees the full multiplexing gain achieved and has the advantage of simple implementation for decoding S_1 and S_2 at the destination.

The mutual information from U2 to U1 as denoted by can be calculated from (2) as

$$I_{21} = \log_2\left(1 + \frac{|h_{21}|^2\gamma}{2}\right)$$

(4)

$$I_{12} = \log_2\left(1 + \frac{|h_{12}|^2\gamma}{2}\right)$$

(5)

In an information-theoretic sense, when the channel capacity falls below a predefined data rate, it is regarded as an outage event and the receiver is doomed to fail to decode the original data no matter what decoding algorithm is used. Hence, considering data rates R_1 and R_2 (for U1 and U2, respectively), the event that both U1 and U2 succeed in decoding can be described as $I_{12}>R_1$ and $I_{21}>R_2$, which is denoted by for notation convenience. Similarly, we use to represent the other case that either U1 or U2 or both fail to decode, i.e., $I_{12}<R_1$ and/or $I_{21}<R_2$. In the case of, the Alamouti space-time coding will be utilized, and $-S^*_1$ and S^*_2 are transmitted by U1 and U2 in the second time frame of block k. Thus, the received signal at the destination is written as

$$y_d^2(\theta = 1) = -\sqrt{\frac{E_s}{2}}h_{1d}s_2^* + \sqrt{\frac{E_s}{2}}h_{2d}s_1^* + n_d^2$$

(6)

Where the superscript 2 represents the second time frame and nd2 is the AWGN received at destination. Combining (1) and (6), we can obtain from Alamouti decoding algorithm as

$$\begin{bmatrix} h_{1d}^* & h_{2d} \\ h_{2d}^* & -h_{1d} \end{bmatrix} \begin{bmatrix} y_d^1 \\ y_d^2(\theta = 1)^* \end{bmatrix} = \sqrt{\frac{E_s}{2}} \begin{bmatrix} |h_{1d}|^2 + |h_{2d}|^2 & 0 \\ 0 & |h_{1d}|^2 + |h_{2d}|^2 \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} h_{1d}^* n_d^1 + h_{2d}\left(n_d^2\right)^* \\ h_{2d}^* n_d^1 - h_{1d}\left(n_d^2\right)^* \end{bmatrix}.$$

(7)

The mutual information from U1 and U2 to the destination is calculated from (7)

$$I_{1d}(\theta = 1) = I_{2d}(\theta = 1) = \log_2\left(1 + \frac{|h_{1d}|^2 + |h_{2d}|^2}{2}\gamma\right) \quad (8)$$

U1 or U2 or both fail to decode each other's information, U1 and U2, respectively, transmit $-s_1$ and s_2 to the destination. The received signal at the destination in the second time frame is given by

$$y_d^2(\theta = 2) = -\sqrt{\frac{E_s}{2}}h_{1d}s_1 + \sqrt{\frac{E_s}{2}}h_{2d}s_2 + n_d^2 \quad (9)$$

By solving (1) and (9), the destination can easily decode s_1 and s_2 as follows

$$\begin{bmatrix} h_{1d}^* & 0 \\ 0 & h_{2d}^* \end{bmatrix} \begin{bmatrix} y_d^1 - y_d^2(\theta = 2) \\ y_d^1 + y_d^2(\theta = 2) \end{bmatrix} = \begin{bmatrix} \sqrt{2E_s}|h_{1d}|^2 s_1 \\ \sqrt{2E_s}|h_{2d}|^2 s_2 \end{bmatrix} + \begin{bmatrix} h_{1d}^*\left(n_d^1 - n_d^2\right) \\ h_{2d}^*\left(n_d^1 + n_d^2\right) \end{bmatrix} \quad (10)$$

From which s_1 and s_2 are estimated as

$$\hat{s}_1 = \arg\min_{s \in \mathcal{S}_1} \left|h_{1d}^*[y_d^1 - y_d^2(\theta = 2) - h_{1d}\sqrt{2E_s}s]\right|^2$$

$$\hat{s}_2 = \arg\min_{s \in \mathcal{S}_2} \left|h_{2d}^*[y_d^1 + y_d^2(\theta = 2) - h_{2d}\sqrt{2E_s}s]\right|^2$$

In addition, it is pointed out that, by considering that both U1 and U2 notify the destination whether or not they succeed in decoding each other's information through feedback channels, the destination is able to determine which detection algorithm should be selected between (7) and (10) and used for decoding s_1 and s_2. Datas are estimated using euclidean distance decoding technique.BER is calculated by comparing transmitted and received data bits.

The capacity of a deterministic channel is defined as

$$C = \max_{f(\mathbf{x})} I(\mathbf{x}; \mathbf{y}) \text{ bits/channel use} \quad (11)$$

In which f (x) is the probability density function (PDF) of the transmit signal vector x, and I(x; y) is the mutual information of random vectors x and y. namely, the channel capacity is the maximum mutual information that can be achieved by varying the PDF of the transmit signal vector. From the fundamental principle of the information theory, the mutual information of the two continuous random vectors, x and y, is given as

$$I(\mathbf{x}; \mathbf{y}) = H(\mathbf{y}) - H(\mathbf{y}|\mathbf{x}) \quad (12)$$

In which H(y) is the differential entropy of y and H (y|x) is the conditional differential entropy of y when x is given. Using the statistical independence of the two random vectors z and x

$$H(\mathbf{y}|\mathbf{x}) = H(\mathbf{z}) \quad (13)$$

Using Equation (13), we can express Equation (11) as

$$I(\mathbf{x}; \mathbf{y}) = H(\mathbf{y}) - H(\mathbf{z})$$

(14)

From Equation (14), given that H (z) is a constant, we can see that the mutual information is maximized when H(y) is maximized.

In fading channels, the received signal has no constant power which be depending on the channel, can be described by probability models. Thus, signal to noise ratio will also become a random variable. And thus the maximum capacity of the channel becomes a random variable. Outage probability says according to the variable signal to noise ratio at the received end, what is the probability that a rate is not supported due to variable signal to noise ratio.

The mutual information from U1 to U2 is denoted by I_{12}, mutual information from U2 to U1 is denoted by I_{21}, mutual information from U1 to destination is denoted by I_{1d} and mutual information from U2 to destination is denoted by I_{2d} .considering data rates R_1 and R_2 for U1 and U2, respectively. The outage probability of full duplex base O-DSTC is given by

$$\begin{aligned}\mathrm{Pout}_{\mathrm{full-ODSTC}}\\ &= \Pr(\theta=1)\Pr(\mathrm{outage}|\theta=1)+\Pr(\theta=2)\Pr(\mathrm{outage}|\theta=2)\\ &= \Pr(I_{12}>R_1, I_{21}>R_2)\Pr[I_{1d}(\theta=1)<R_1]\\ &\quad +[1-\Pr(I_{12}>R_1, I_{21}>R_2)]\Pr[I_{1d}(\theta=2)<R_1]\end{aligned}$$

(15)

The full-duplex-based O-DSTC scheme utilizes an opportunistic encoding approach depending on whether U1 and U2 succeed in decoding each other's information. Weighing up on the outage probability performance of the proposed O-DSTC as well as the non-cooperative schemes, outcome shows that the O-DSTC scheme outperforms the non-cooperative schemes.

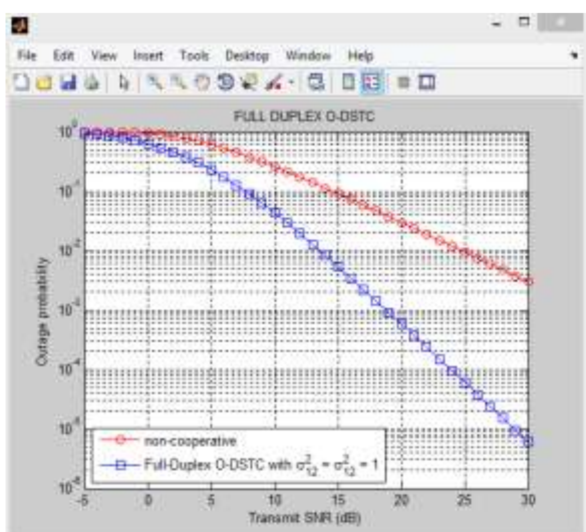

Fig.3 Outage Probability of full duplex O-DSTC

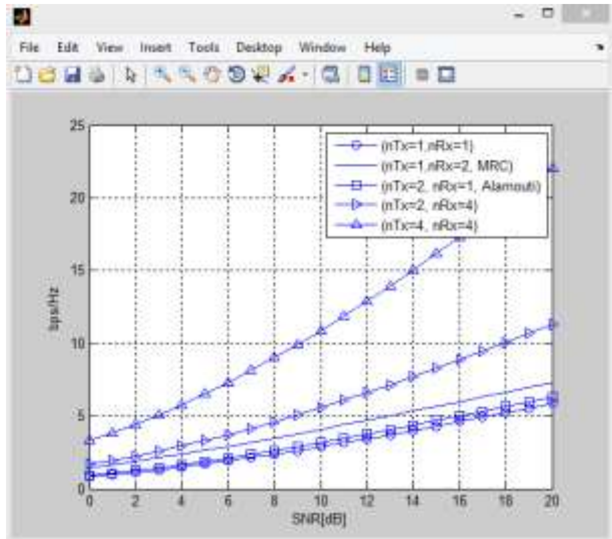

Fig.4 Channel capacity Plot of MIMO, MISO, SIMO and SISO

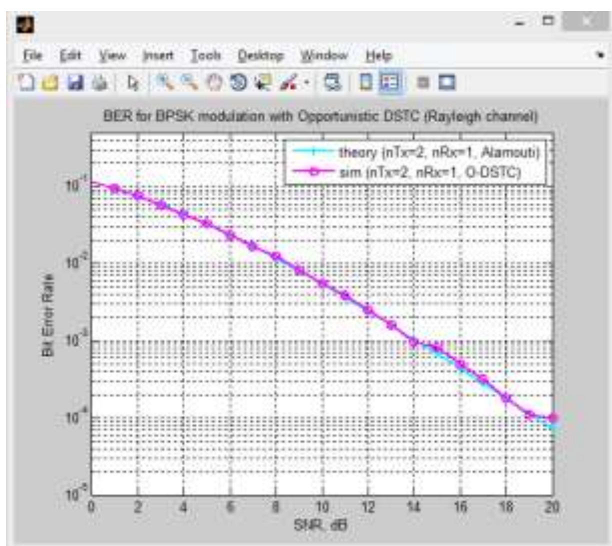

Fig.5 SNR Vs BER Plot of O_DSTC

III. CONCLUSION

A novel O-DSTC technique has been proposed in this project, which is based on DSTC applied in opportunistic manner. Performance of cooperative system using O-DSTC schemes is analyzed based on BER, capacity and outage probability. Opportunistic Distributed Space frequency coding (O-DSFC) is similar to Opportunistic Distributed space time coding, with the difference that the encoding is carried out in the antenna/frequency domains rather than in the antenna/time domains. Thus, space frequency coding is applicable to frequency domain transmission schemes.

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