A Transmitter Model for Performance Improvement and Interference Mitigation of Multi-User STBC-CDMA System in Correlated MISO Channels

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***Abstract*—In this contribution, multi-user Space-Time Block Coding (STBC) Code Division Multiple Access (CDMA) system is simulated to investigate the effect of multi-user interference along with the spatial correlation of Multiple-Input Single-Output (MISO) channels. The correlative model is considered for MISO channel. Simulation results declare that spatial correlation degrades the performance of STBC CDMA system. On the other hand, simulations show a huge degradation due to multi-user interference. In order to improve the performance of this system, a transmitter model that utilizes two distinct precoders is proposed in this paper. An anti-correlation precoder and an interference cancellation precoder are used in this model. Simulation results illustrate that this model could achieve a satisfactory performance improvement.**

Keywords-STBC; Spatially Correlated channel; Precoding; Downlink CDMA system; multi-user interference

I. INTRODUCTION

Recent researches demonstrate that multiple-antenna structure can be used in wireless systems to achieve lower error rate, higher performance and coding gain. In conventional STBC designs [1]-[2], it is assumed that the code design criteria are calculated due to spatially uncorrelated condition and also there is no channel state information at the transmitter (CSIT). This may not be accurate in practical situations where multiple antennas are spatially correlated.

However by exploiting the CSIT combined with STBC at the transmitter, a precoder can be designed to reduce the problem of spatial correlation [3]. Moreover, as stated in [4], if an STBC is capacity lossless for an i.i.d. multiple-antenna channel, then combining this STBC with a linear precoder is capacity optimal for the channel with CSIT. Pairwise error probability (PEP) is regarded in this paper as the performance measurement criterion. The effect of channel correlation is addressed in the literature for single user scenarios [5]-[6]. Working with the 3G systems and 4G candidates, the multiple access techniques should be considered. However, handling interference is one of the most important dilemmas in all multiple access wireless communications especially in CDMA systems.

Multi-user detection is a well known classic method in uplink communication that performs the processing in the receiver [7]. This technique can not be always implemented in downlink transmission [8]. Interference cancellation precoding is a technique used for mitigating the destructive effect of multiple access interference in downlink CDMA communication systems [9] and shifts the processing procedure from receiver to transmitter and thus reduces the complexity of the receiver. Precoding techniques for multi-user single antenna systems have already been studied in [10] and also for multi-user multiple antennas in [9].

In our previous work [11], by using an anti-correlation precoder for every separate user, we investigated a multi-user STBC CDMA system to improve the bit error rate (BER) performance in correlated channel. Despite the number of interfering users, this type of precoder could mitigate the performance degradation caused by correlation. Some other results also were shown in [12].

In this paper a transmitter model that utilizes two distinct precoders is proposed. An anti-correlation precoder and an interference cancellation precoder are used in this model.

The rest of the paper is organized as follows. Section II describes the system model and anti-correlation precoder for STBC single user case. In section III, STBC CDMA system in spatially correlated channel is considered. Interference cancellation in STBC CDMA system is considered in section IV. The results and comprehensive discussions are presented in section V. Finally Section VI concludes the paper.

II. SYSTEM MODEL AND ANTI-CORRELATION PRECODER FOR STBC SINGLE USER

We consider a system in which signals are transmitted via N_T transmit antennas and are received with N_R receive antennas simultaneously. Therefore

$$\mathbf{Y} = \mathbf{HFS} + \mathbf{N}, \tag{1}$$

where $\mathbf{Y}$ is an $N_R \times T$ matrix that includes all received signals during T time slots; $\mathbf{S}$ is an $N_T \times T$ matrix that includes all coded transmitted signals, $\mathbf{H}$ is an $N_R \times N_T$ channel matrix stands for a Rayleigh fading channel [13], $\mathbf{N}$ is the additive white Gaussian noise (AWGN) and $\mathbf{F}$ is the precoding matrix which will be discussed later.

978-0-7695-3886-0/09 $26.00 © 2009 IEEE
DOI 10.1109/EMS.2009.91

The receiver performs maximum-likelihood (ML) detection to obtain

$$\hat{\mathbf{S}} = \arg\min_{\mathbf{S}\in\mathbb{C}} \left\|\mathbf{Y} - \mathbf{HFS}\right\|_F^2 , \tag{2}$$

where $\mathbb{C}$ is the STBC codebook, and the subscript F denotes the Frobenius norm.

In general form, as stated in the kronecker model [13], transmit and receive correlations are separable. This assumption can be justified by the fact that these arrays are sufficiently far apart with enough random scattering between them. Therefore, the model of the channel can be written as

$$\mathbf{H} = \mathbf{R_r}^{1/2}\mathbf{H_w}\mathbf{R_t}^{1/2}, \tag{3}$$

where $\mathbf{H_w}$ is the i.i.d. complex Gaussian matrix with zero mean and unit variance, $\mathbf{R_t} = \mathbf{R_t}^{1/2}\mathbf{R_t}^{1/2H}$ is the transmit antenna correlation and $\mathbf{R_r} = \mathbf{R_r}^{1/2}\mathbf{R_r}^{1/2H}$ is the receive antenna correlation respectively and superscript H denotes the Hermitian operation. In the same way as mentioned in [14], in a practical, common, simplified correlation model in downlink transmission, it is assumed that a correlation between the transmit antennas may be accrued. The received signal at the mobile is a combination of several paths reflected from several local scatters, leading to uncorrelated fading across the receive antennas. Hence, in a practical and simplified correlation model, the receive antenna correlation is neglected and finally the channel model reduced to

$$\mathbf{H} = \mathbf{H_w}\mathbf{R_t}^{1/2}. \tag{4}$$

Elements of $\mathbf{R_t}$ are illustrated by $\mathbf{R_t} = [\rho_{ij}], \forall i, j$ and $\rho_{ii} = 1$ where ρ_{ij} is called "correlation coefficient".

The receiver is assumed to know the channel perfectly, i.e. it knows the channel realization while the transmitter only knows the transmit correlation. Using PEP criterion for this system, regarding [2], following equations could be considered:

$$P((s^k(t) \rightarrow s^l(t)) \le e^{-d_{\min}^2(t)/2}, \tag{5}$$

$$d_{\min}^2(t) = \left\|\mathbf{H_W(t)}\mathbf{R_t^{1/2}}\mathbf{FE}\right\|^2 . \tag{6}$$

This is the probability of detecting the most probable error detection $s^l(t)$ instead of a different code $s^k(t)$ which is transmitted. After some mathematical operations regarding [14], the cost function of finding the desired precoder is

$$\max_{\mathbf{F}} J = \det(\mathbf{I} + \mathbf{R_t^{1/2}}\mathbf{FEE^*F^*}\mathbf{R_t^{*1/2}}),$$
$$\text{Subject to } \operatorname{Trace}(\mathbf{FF^*}) = \mathrm{P}_0 = 1, \tag{7}$$

where $\mathbf{E}$ is the minimum distance code error matrix defined in [14]. For finding on optimal solution for this cost function, the optimization theory should be used. Finally, solution of the optimization problem is achieved as follows [14]

$$\mathbf{F} = \mathbf{V_r}\mathbf{\Phi_f}\mathbf{V_e^*}, \tag{8}$$

$$\mathbf{\Phi^2}_{\mathbf{f}} = (\gamma\mathbf{I} - \mathbf{\Lambda_r^{-2}}\mathbf{\Lambda_e^{-1}})_+, \tag{9}$$

Where γ is a positive constant calculated from the trance constraint, $\mathbf{V_r}$ and $\mathbf{\Lambda_r}$ come from singular value decomposition (SVD) of the correlation matrix **R**, and finally $\mathbf{V_e^*}$ and $\mathbf{\Lambda_e^{-1}}$ are calculated from eigenvalue decomposition (EVD) of the distance error matrix $\mathbf{E}$. The notation $(.)_+$ means that only non-negative values are allowed.

III. STBC CDMA SYSTEM IN SPATIALLY CORRELATED CHANNEL

We consider the STBC-CDMA downlink system with K users; two transmit antennas and one receive antenna. The transmitted baseband data for every user is $S_{k,i} = (b_k C_k)_i$ which is transmitted through 2 time durations from two antennas as described in Alamouti's structure [1]. b_k is the k[th] user's data and C_k is its corresponding spreading code. Let $h_{k,j,i}$ be the channel coefficient between i[th] transmit antenna and the j[th] receiver antenna of the k[th] user. The received signal at the j[th] receiver antenna at the t[th] and (t+1)[th] time interval can be written as equations (10) and (11), respectively.

$$r_j^t = \sum_{k=1}^{K} h_{k,j,1}S_{k,1} + \sum_{k=1}^{K} h_{k,j,2}S_{k,2} + n_j^t \tag{10}$$

$$r_j^{t+1} = \sum_{k=1}^{K} h_{k,j,1}(-S_{k,2}{}^*) + \sum_{k=1}^{K} h_{k,j,2}(S_{k,1}{}^*) + n_j^{t+1} \tag{11}$$

In these equations we assumed that the channel coefficient remains constant over two time periods in which a space-time codeword completes. Moreover, we assume that the channel coefficients are correlated. As we will show in section V, this effect reduces the performance of the system. Therefore, in this section we use the precoding technique to mitigate this effect. The spread space-time coded data of every user is processed by an anti-correlation precoder matrix, prior to transmission. As all users' data are transmitted from the same antennas, the correlation effect and so the precoder matrix is similar for all users. In order to design the precoder matrix, we construct the matrices for every separate user as follows.

The data matrix due to k[th] user is $\mathbf{S_k}(t) = \begin{bmatrix} S_{k,1} & -S_{k,2}^{*} \\ S_{k,2} & S_{k,1}^{*} \end{bmatrix}$, and the k[th] user's channel matrix is $\mathbf{H_k}(t) = \begin{bmatrix} h_{k,1,1} & h_{k,1,2} \end{bmatrix}$ for a 2×1 system. In a correlated channel, $\mathbf{H_k(t) = H_{kw}(t)R_t^{1/2}}$. Now we could design the precoder as described in this section. The transmitted data matrix for every user is now $\mathbf{FS_k}(t)$ [11]-[12].

IV. INTERFERENCE CANCELATION IN STBC CDMA CORRELATED SYSTEM

The other factor that degrades the performance of CDMA system, even in the uncorrelated condition, is the interference that comes from the nature of multi-user CDMA systems.

According to equations (10) and (11), the matrix of the channel is:

$$\mathbf{H} = \begin{bmatrix} h_{1,1,1} & h_{1,1,2} & & & \\ h_{1,1,2}^{*} & -h_{1,1,1}^{*} & & \mathrm{O} & \\ & & \ddots & & \\ & \mathrm{O} & & h_{K,1,1} & h_{K,1,2} \\ & & & h_{K,1,2}^{*} & -h_{K,1,1}^{*} \end{bmatrix} \quad (12)$$

Hence,

$$\mathbf{H}_k(t) = \mathbf{H}_{kw}(t)\mathbf{R}_t^{1/2} = \begin{bmatrix} h_{(w)k,1,1} & h_{(w)k,1,2} \end{bmatrix} \begin{bmatrix} \eta_{1,1} & \eta_{1,2} \\ \eta_{2,1} & \eta_{2,2} \end{bmatrix} \quad (13)$$
$$= \begin{bmatrix} h_{(w)k,1,1}\eta_{1,1} + h_{(w)k,1,2}\eta_{2,1} & h_{(w)k,1,1}\eta_{1,2} + h_{(w)k,1,2}\eta_{2,2} \end{bmatrix}$$

where $\eta_{i,j} \approx \rho_{i,j} \big/ \sqrt{\rho_{i,i}\rho_{j,j}}$. Therefore, each element of the matrix in equation (12) is calculated as below

$$\begin{aligned} h_{k,1,1} &= h_{(w)k,1,1}\eta_{1,1} + h_{(w)k,1,2}\eta_{2,1} \\ h_{k,1,2} &= h_{(w)k,1,1}\eta_{1,2} + h_{(w)k,1,2}\eta_{2,2} \end{aligned} \quad (14)$$

The matrix of spreading codes for all users and the whole data matrix of the users which are transmitted in two consecutive time internals via two transmission antennas are shown in following equations by $\overline{\mathbf{C}}$ and $\mathbf{B}$ respectively.

$$\overline{\mathbf{C}} = \begin{bmatrix} C_{1,1}, C_{1,2}, \ldots, C_{K,1}, C_{K,2} \end{bmatrix} \quad (15)$$

$$\mathbf{B} = \begin{bmatrix} b_{1,1}, b_{1,2}, \ldots, b_{K,1}, b_{K,2} \end{bmatrix} \quad (16)$$

Considering [15] and by defining $\mathbf{R_C} = \overline{\mathbf{C}}^{H}\overline{\mathbf{C}}$, the matrix of interference cancellation precoder which is shown by $\mathbf{M}$ is calculated as below

$$\mathbf{M} = (\mathbf{H}^{H}\mathbf{R_C}\mathbf{H})^{-1} \quad (17)$$

Therefore, the precoded data matrix is composed as $\mathbf{S = MB}$ and this quantity is considered as a new input data for the system. Therefore, we use both interference cancellation precoder (**M**) and anti-correlation precoder (**F**) with each other as shown in Fig. 1. The block diagram of proposed STBC CDMA system is depicted in Fig. 1.

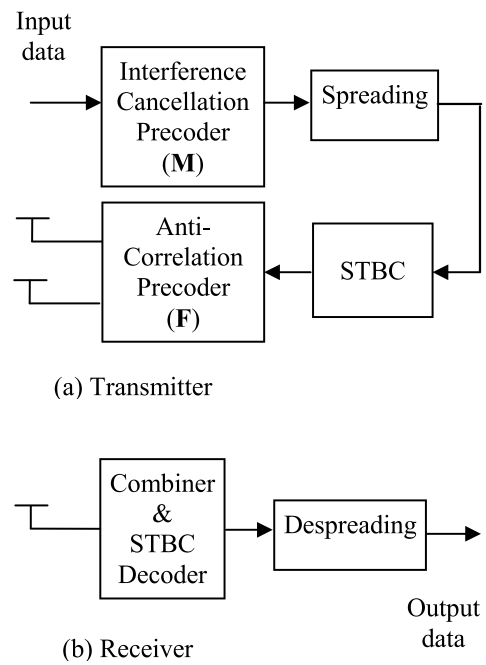

Figure 1. The block diagram of proposed STBC CDMA system

V. SIMULATION RESULTS

In this section, some simulation results are provided. All the figures are obtained via simulation process with MATLAB. We assumed the channel is frequency flat fading MIMO wireless channel [13].

It is supposed that base station transmits data for 2 active users. In Fig. 2, the performance of the STBC-CDMA system is shown in correlated channel with various correlation coefficients, in comparison with the uncorrelated channel. It is apparent that channel correlation degrades the performance of the CDMA system.

To consider the multi-user effect more thoroughly, in Fig. 3 the BER curves are provided against number of interfering users, at $E_b / N_0 = 15dB$. It is shown in this figure that although the anti-correlation procoder could improve the performance of the system in correlation channel, but the performance of the system degrades considering the effect of number of interfering users. The effect of interference prohibits completely compensating of the performance degradation. In subsequent figures the interference cancellation precoder is also considered.

Fig. 4 compares the performance of the multi-user system with single-user case, considering the spread data. Moreover, the effect of using anti-correlation precoder is shown in this figure. It is apparent that in a single-user system when the interference is absent, the effect of correlation is almost compensated.

In Fig. 5 the precoder is exploited for multi-user interference cancellation in uncorrelated system. Fig. 6 is allocated to correlated channel and the effect of applying anti-correlation F is depicted in this figure. The result of multi-user system is compared with the single user case.

Fig. 7 shows the performance of the system when both precoders are exploited. It is apparent that the system achieves a significant performance in this case.

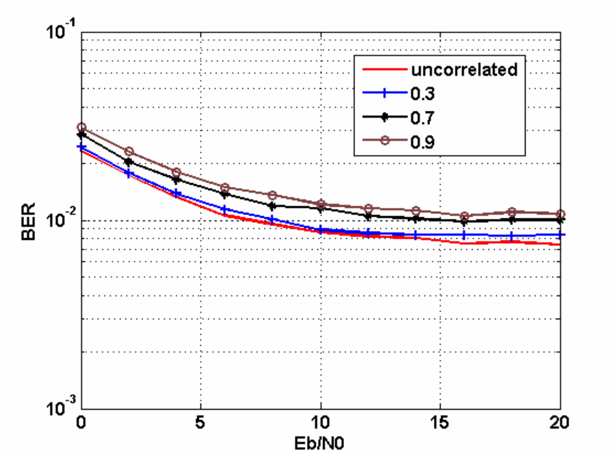

Figure 2. Performance of STBC multi-user CDMA system in correlated channel for different correlation coefficients.

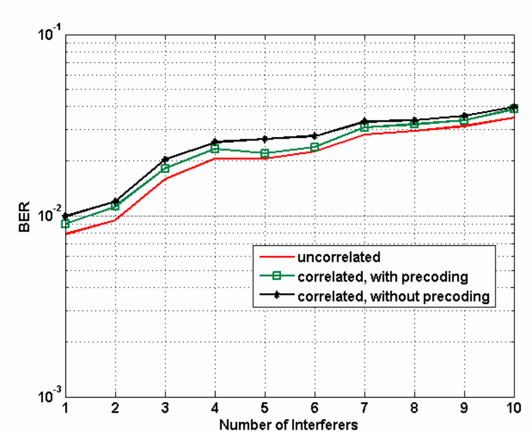

Figure 3. Performance of STBC multi-user CDMA system for different number of interfering users.

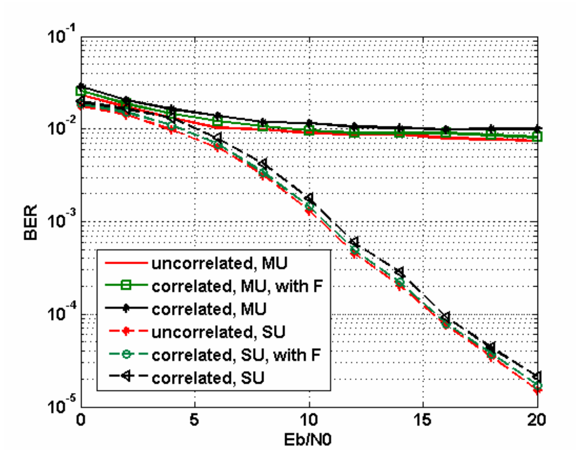

Figure 4. Performance of STBC multi-user CDMA system (MU) in correlated and uncorrelated channels versus the single user (SU) system.

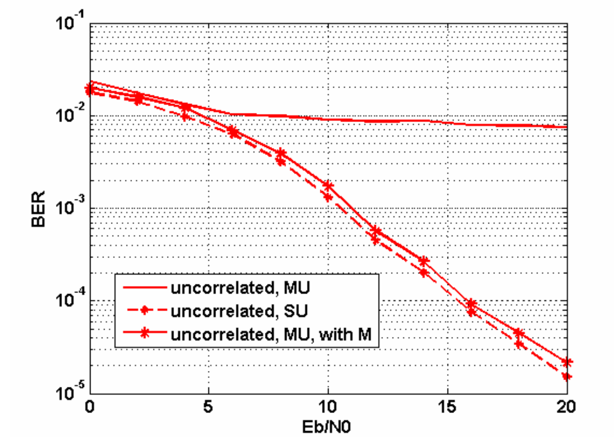

Figure 5. Effect of the precoder (M) on the performance of STBC multi-user CDMA system versus the single user case in uncorrelated channel.

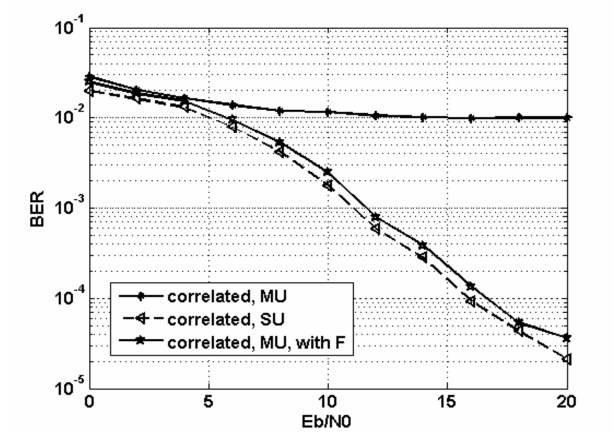

Figure 6. Effect of the precoder (F) on the performance of STBC multi-user CDMA system versus the single user case in correlated channel.

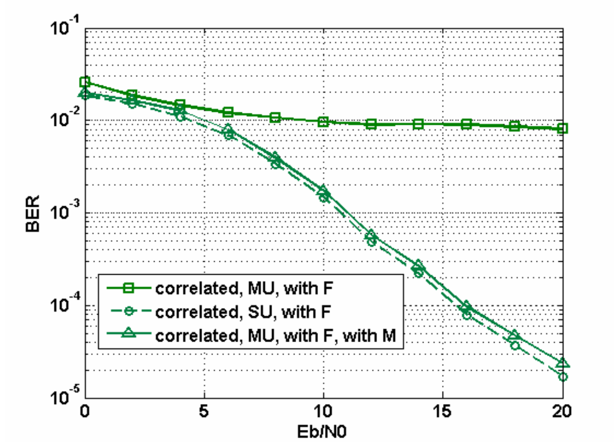

Figure 7. Effect of both precoders (M and F) on the performance of STBC multi-user CDMA system versus single user in correlated channel.

VI. CONCLUSION

In this paper, multi-user STBC CDMA system was simulated in spatially correlated MISO channel. The effect of multi-user interference and spatial correlation were investigated. Simulation results showed huge degradation due to multi-user interference. These results also declare that spatial correlation degrades the performance of STBC CDMA system. In this paper, a transmitter model that utilizes two distinct precoders was proposed to improve the performance of this system. This model contains an anti-correlation precoder and an interference cancellation precoder. Simulation results illustrated that this model could mitigate both degradations, and so, improve the performance of the system.

ACKNOWLEDGMENT

The authors would like to acknowledge Iran Telecommunication Research Center (ITRC) for their support for this work.

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