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Multiuser Decorrelating Detector in MIMO CDMA Systems over Rayleigh and Rician Fading Channels

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***Abstract*—Space-time spreading has been employed to exploit the spatial diversity in multiple-input multiple-output (MIMO) code-division multiple-access (DS-CDMA) systems. In the presence of multiuser interference, resulting from the cross - correlation between users' code sequences, the full system diversity cannot be achieved when using the conventional matched receiver. The performance of space–time transmit diversity is examined in a multiuser direct-sequence code-division multiple access (DS-CDMA) system over Rayleigh and Rician fading channels. The underlying space–time system employs N = 2 transmit antennas and L receive antennas at the user side and base-station. Signal to Noise ratio is calculated at the output of the space-time combiner and the performance of the system is analyzed when using the linear decorrelator detector to combat the effect of multiuser interference**.

***Index Terms*—Direct-sequence code-division multiple access, maximal-ratio combining, multiuser detection, transmit diversity.**

1. INTRODUCTION

With the recent demand for higher data rate and improved signal quality over wireless channels much research has been conducted to fulfil the promises of future wireless systems [1],[2].Space-time coding (STC) techniques that are based on MIMO systems were introduced in spatial diversity and coding gain. By exploiting the independent fading between the channels of different transmit and receive antennas, spatial diversity can be achieved. One major class of STCs is composed of space-time trellis codes (STTC) as a generalization of trellis-coded modulation (TCM) to multiple transmits antennas. Although offering tremendous performance, STTCs present major complexity issues that prohibit their implementation. Another class of STCs is referred to as space-time block codes (STBCs) [3]. These codes are known to provide the same system diversity (no coding gain) but with much less complexity than STTCs. An example of STBC was first introduced by Alamouti [4] as a simple space-time transmit diversity scheme, which is based on two transmit and multiple receive antennas. The signal detection of this scheme is based on a maximum likelihood (ML) receiver which can be implemented using linear processing.

Within the framework of space-time coding, the researchers have recently focused on the application of such codes in direct-sequence code-division multiple-access (DSCDMA) systems [5]−[14]. In [9], Yang and Hanzo considered the performance of downlink multicarrier DS-CDMA systems when space-time spreading is used for transmit diversity over Rayleigh fading channels. Wavegedara *et. al* [10] has proposed a space-time coding scheme with chip interleaving design in a multiuser system. They have also investigated the performance of their space time coded scheme when using decision feedback sequence estimation, and compared its performance to the optimum ML sequence estimator. The authors in [13] have investigated the problem of interference suppression in a space-time coded DS-CDMA system that employs two dimensional decision feedback equalization.

Most of existing works in space-time coding consider the performance of such codes over quasi-static Rayleigh fading channels, where time variations of the channels is assumed to be constant over a frame and varies independently from one frame to another. Interest then grew to exploit the time diversity of the fading channel leading to new or modified design of STC in fast-fading channels. For instance, the authors in [15] have proposed a modified STTC design for fast-fading Channels where the fading coefficients change independently from one symbol to the other. The authors in [16] proposed a space-time spreading

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scheme suitable for DS-CDMA systems over Rayleigh fast-fading channels. In [17], Sacramento and Hamouda investigated the performance of the space-time spreading and transmit diversity in the uplink of a MIMO DS-CDMA system over Nakagami-m fast-fading channels.

In this paper we consider the system presented in [16] operating over Rayleigh and Rician fading channels. Signal-to-noise ratio (SNR) at the output of the space-time (ST) combiner is calculated. In a two-transmit and L-receive antenna configuration, and for a given fading severity, we show analytically and by simulations the performance of the system when using a decorrelator detector. In our work, to simplify the analysis, we assume Rayleigh and Rician fading channels between each pair of transmit and receive antenna.

In Section II, we present the multiuser system model. In Section III, we calculate the bit error rate performance of the system. Section IV presents simulation results to assess the accuracy of our theoretical results. In Section V, we conclude our paper.

II SYSTEM MODEL

We are interested in a multiuser DS-CDMA wireless communication system. Without loss of generality, we start by considering the simple case of a single-user system that employs two antennas at the transmitter side and a single antenna at the receiver side (see Fig. 1). If we let x_1 and x_2 be the input symbols to the space-time spreader (STS) (i.e. x_1 and x_2 can be considered as the odd and even symbols of the desired user), each data symbol is modulated and then spread using two spreading codes, s_i, i = 1, 2. Following the notation of [16], a space-time spreading matrix is formed as follows,

	TX Antenna 1	TX Antenna 2
t,	$x_1{}^*s_1 + x_2{}^*s_2$	$x_1s_2 - x_2\,s_1$
$t+T$,	$x_1s_2 - x_2\,s_1$	$x_1{}^*s_1 + x_2{}^*s_2$

(1)

Here * denotes a complex conjugate operation. The encoder produces two code words $x_1{}^*s_1 + x_2{}^*s_2$ and $x_1s_2 - x_2\,s_1$ which are transmitted by antenna 1 and 2 respectively at time t and switched with respect to the transmit antennas at time $t+T$.

Given the above space-time spreading scheme, the received signal at the lth receive antenna is given by

$$r_0^l = h_{1l,0}(x_1^*s_1 + x_1s_2) + h_{2l,0}(x_1s_2 - x_2s_1) + \eta_0^l \quad (2)$$

$$r_1^l = h_{1l,1}(x_1s_2 - x_2s_1) + h_{2l,1}(x_1^*s_1 + x_2^*s_2) + \eta_1^l \quad (3)$$

at times t, and t+T, respectively. The noise samples n_0^l and n_1^l are independent samples of zero-mean complex Gaussian process with variance $\sigma_n^2 = N0/2$ per dimension. The coefficients $h_{nl,j}$ model the fading between then^{th}, n = 1, 2, transmit and l^{th}, l = 1... L, receive antennas at time j, j = 0, 1.

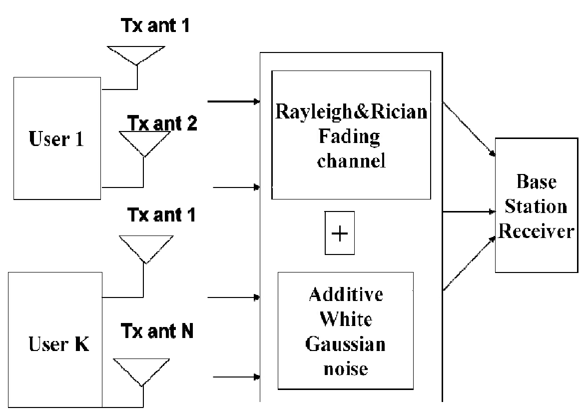
The receiver then applies de spreading using two matched filters (each is matched to one of the two assigned code sequences) and the output of these filters, after sampling, is given in a vector form by

$$\boldsymbol{y}_0^l = \boldsymbol{X}_0\boldsymbol{h}_0^l + \boldsymbol{N}_0^l \quad (4)$$

$$\boldsymbol{y}_1^l = \boldsymbol{X}_1\boldsymbol{h}_1^l + \boldsymbol{N}_1^l \quad (5)$$

at times t, and $t + T$, respectively, with

$$\boldsymbol{y}_0^l = [y_{0,1}^l \quad y_{0,2}^l]^T, \boldsymbol{y}^l 1 = [y_{1,1}^l \quad y_{1,2}^l]^T \quad (6)$$



(a) K users Transmitters

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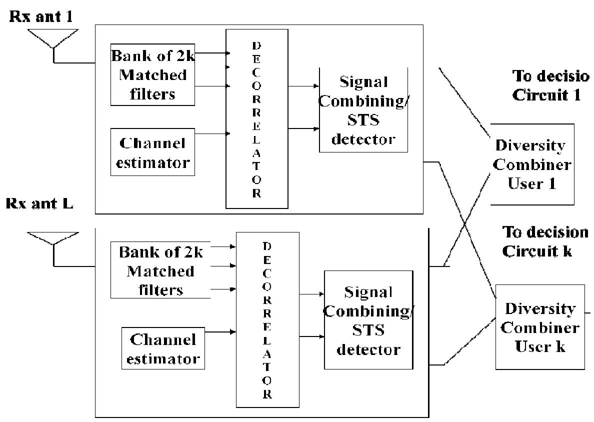

(b) Base station receiver

Fig. 1. Multiuser STS DS-CDMA system operating in Nakagami-*m* fading environment (a) K-user transmitters (b) Base station receiver

$$\boldsymbol{X}0 = \begin{bmatrix} x_1^* + x_2^*\rho_{12} & x_1\rho_{12} - x_2 \\ x_1^*\rho_{21} + x_2^* & x_1 - x_2\rho_{21} \end{bmatrix},$$

$$\boldsymbol{X}1 = \begin{bmatrix} x_1\rho_{12} - x_2 & x_1^* + x_2^*\rho_{12} \\ x_1 - x_2\rho_{21} & x_1^*\rho_{21} + x_2^* \end{bmatrix} \quad (7)$$

$$\boldsymbol{h}_0^l = \begin{bmatrix} h_{1l,0} \\ h_{2l,0} \end{bmatrix}, \boldsymbol{h}_1^l = \begin{bmatrix} h_{1l,1} \\ h_{2l,1} \end{bmatrix}, \quad (8)$$

$$\boldsymbol{N}_0^l = [N_{0,1}^l \quad N_{0,2}^l]^T, \boldsymbol{N}_1^l = [N_{1,1}^l \quad N_{1,2}^l]^T \quad (9)$$

$\boldsymbol{y}_0^l$ And $\boldsymbol{y}_1^l$ are (2×1) vectors with elements $y_{0,i}^l$, $y_{1,i}^l$,$i = 1,2$, $\rho_{i,j}$ is the cross-correlation between $i\ th$ and jth spreading codes. The channel fading vector h_j^l consists of $h_{nl,j}$,$n = 1,2, l = 1, \ldots, L, j = 0,1$, while $\boldsymbol{N}_{0,i}^l$ and $\boldsymbol{N}_{1,i}^l$ $i = 1,2$, are complex Gaussian random variables, each with variance $N_0 / 2$ per dimension. Following the matched filters, the receiver performs signal combining according to

$$\hat{x}1 = \sum_{l=1}^{L}(h_{1l,0}\, y_{0,1}^{l*} + h_{2l,0}^* y_{0,2}^l + h_{1l,1}^* y_{1,2}^l + h_{2l,1} y_{1,1}^{l*}) \quad (10)$$

$$\hat{x}2 = \sum_{l=1}^{L}(h_{1l,0}\, y_{0,2}^{l*} - h_{2l,0}^* y_{0,1}^l - h_{1l,1}^* y_{1,1}^l + h_{2l,1} y_{1,2}^{l*}) \quad (11)$$

and Signal to noise ratio is calculated.

We now consider a synchronous multiuser DS-CDMA system. Using vector notation, the single-user model can be generalized to the multiuser DS-CDMA case with K users. We consider here BPSK modulation. The output of the $2K$ matched filters at the lth receive antenna can be expressed at times t and $t + T$, respectively, as

$$\boldsymbol{Y}_0^l = \boldsymbol{R}\boldsymbol{H}_0^l X + \boldsymbol{N}_0^l \quad (12)$$

$$\boldsymbol{Y}_1^l = \boldsymbol{R}\boldsymbol{H}_1^l X + \boldsymbol{N}_1^l, \quad (13)$$

Where $\boldsymbol{Y}_j^l, j = 0,1$, is defined as

$$\boldsymbol{Y}_j^l = [y_{j,11}^l, y_{j,12}^l, \ldots, y_{j,k1}^l, \ldots, y_{j,k2}^l, \ldots, y_{j,K1}^l, y_{j,K2}^l]^T \quad 14)$$

And $y_{j,ki}^l$, $i = 1,2, j = 0,1$, is the $i\ th$ matched filter output of user k at times t and t + T. The cross-correlation matrix R is given by

$$\boldsymbol{R} = \begin{bmatrix} \rho_{1,1} & \ldots & \rho_{1,k} & \cdots & \rho_{1,2K} \\ \rho_{2,1} & \ldots & \rho_{2,k} & \cdots & \rho_{2,2K} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \rho_{2K,1} & \ldots & \rho_{2K,k} & \cdots & \rho_{2K,2K} \end{bmatrix} \quad (15)$$

The (2K × 2K) channel coefficients matrix, H_j^l, j = 0, 1, at times t and t + T, is defined as

$$\boldsymbol{H}_j^l = \begin{bmatrix} h_{j,1}^l & 0 & \ldots & 0 & 0 \\ 0 & h_{j,2}^l & \ldots & 0 & 0 \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & h_{j,K-1}^l & \ldots \\ 0 & 0 & \ldots & 0 & h_{j,K}^l \end{bmatrix} \quad (16)$$

Where, the (2 × 2) channel coefficients sub-matrices $h_{0,k}^l$ and $h_{1,k}^l$ define the fading coefficients $h_{il,j,k}$, ,$j = 0,1$, and $i = 1,2$, between the i^{th} transmit antenna of user k and the l^{th} receive antenna. That is

$$\boldsymbol{h}_{0,k}^l = \begin{bmatrix} h_{1l,0,k} & -h_{2l,0,k} \\ h_{2l,0,k} & h_{1l,0,k} \end{bmatrix} \quad (17)$$

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$$\boldsymbol{h}_{1,k}^{l} = \begin{bmatrix} h_{2l,1,k} & -h_{1l,1,k} \\ h_{1l,1,k} & h_{2l,1,k} \end{bmatrix} \quad (18)$$

The transmitted data vector (2K × 1) for the K-user system is given by

$\boldsymbol{X} =$
$[x\_1{,}1, x\_1{,}2, \ldots, x\_(k,1), x\_(k,2), \ldots x\_(K,1), x\_(K,2]^\wedge T\ )$ (19)

Where, $x_{k,i}$, is the kth user data symbols, and $\boldsymbol{N}_j^l$, is the complex Gaussian noise vector with elements each with variance $N0/2$ per dimension. The signals at the output of the matched filters are then combined to give,

$$\hat{x}k,1 = \sum_{l=1}^{L}(h_{1l,0,k}\ y_{0,k1}^{l*} + h_{2l,0,k}^{*} y_{0,k2}^{l} + h_{1l,1}^{*} y_{1,k2}^{l} + h_{2l,1,k} y_{1,k1}^{l*}) \quad (20)$$

$$\hat{x}k,2 = \sum_{l=1}^{L}(h_{1l,0,k}\ y_{0,k2}^{l} - h_{2l,0,k}^{*} y_{0,k1}^{l*} - h_{1l,1}^{*} y_{1,k1}^{l*} + h_{2l,1,k} y_{1,k2}^{l}) \quad (21)$$

III. PERFORMANCE ANALYSIS

We shall now consider the BER performance of the space time system in the presence of multiuser interference resulting from the non-orthogonality of the spreading codes. To combat the effect of multiuser interference, we employ a decorrelator detector before the signal combining scheme in Eq. (20) and (21). We consider a base station receiver with L antennas.

Without loss of generality, we consider user one as the desired user and drop its corresponding subscript. The outputs of the decorrelator detector, at times t and $t + T$, are then given by

$$\boldsymbol{Z}_0^l = \boldsymbol{R}^{-1}\boldsymbol{Y}_0^l = \boldsymbol{H}_0^l\boldsymbol{X} + \boldsymbol{R}^{-1}\boldsymbol{N}_0^l \quad (22)$$

$$\boldsymbol{Z}_1^l = \boldsymbol{R}^{-1}\boldsymbol{Y}_1^l = \boldsymbol{H}_1^l\boldsymbol{X} + \boldsymbol{R}^{-1}\boldsymbol{N}_1^l \quad (23)$$

Where, $\boldsymbol{R}^{-1}$ is the inverse of the cross-correlation matrix and the (2K × 1) vectors, $\boldsymbol{Z}_0^l = \boldsymbol{R}^{-1}\boldsymbol{Y}_0^l$ and $\boldsymbol{Z}_1^l = \boldsymbol{R}^{-1}\boldsymbol{Y}_1^l$ represent the output of the decorrelator at time $j = t, t + T$, respectively.

From Eq. (22) and (23), one can express the first two elements of the vector $\boldsymbol{z}_0^l$ as

$$Z_{1l,0}^{l} = h_{1l,0}x_1 - h_{2l,0}x_2 + (\boldsymbol{R}^{-1}\boldsymbol{N}_0^l)_{11} \quad (24)$$

$$Z_{2l,0}^{l} = h_{2l,0}x_1 + h_{1l,0}x_2 + (\boldsymbol{R}^{-1}\boldsymbol{N}_0^l)_{21} \quad (25)$$

Where, $Z_{il,j}^{l}, (\boldsymbol{R}^{-1}\boldsymbol{N}_0^l)_{i1}$, with $i = 1{,}2\ , j = 0{,}1$ represent the ith element of the (2K × 1) vectors Z_0^l, $R^{-1}N_0^l$ respectively. Similarly, the first two elements of the vector Z_1^l can be written as

$$Z_{11,1}^{l} = h_{2l,1}x_1 - h_{1l,1}x_2 + (\boldsymbol{R}^{-1}\boldsymbol{N}_1^l)_{11} \quad (26)$$

$$Z_{21,1}^{l} = h_{1l,1}x_1 - h_{2l,1}x_2 + (\boldsymbol{R}^{-1}\boldsymbol{N}_1^l)_{21} \quad (27)$$

Where, $z_{i1,j}^{l}, (\boldsymbol{R}^{-1}N_1^l)_{i1}$ with $i = 1{,}2, j = 0{,}1$, represent the ith element of the (2K × 1) vectors $\boldsymbol{Z}_1^l, \boldsymbol{R}^{-1}\boldsymbol{N}_1^l$, respectively. And the receiver performs the signal combining scheme and the signal to noise ratio is calculated.

IV. SIMULATION RESULTS

Simulations are performed using m sequence codes of length 31 chips. We consider BPSK transmission. We consider Rayleigh and Rician fading channels between transmit antennas and receive antennas. In generating the Rayleigh and Rician fading, we used the method described in [18] since it has proved to be very efficient.

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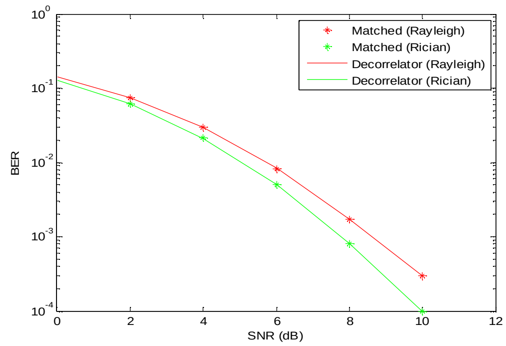

Fig 1. Simulation Vs theoretical results for the bit error rate of a two user STS scheme in Rayleigh and Rician fading channel for a CDMA System.

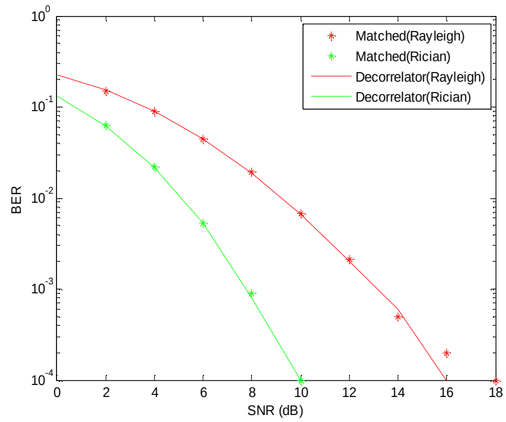

Fig 2. Simulation Vs theoretical results for the bit error rate of a two user STS scheme in Rayleigh and Rician fading channel for a MIMO CDMA System.

In Fig.1 we show the theoretical bit error rate in along with the simulation results for a 2-user system with Rayleigh and Rician fading channel for a CDMA system. We can note that at 6dB Matched filter operating over Rayleigh fading channel is 0.071 and Rician fading channel is 0.0041In case of a Decorrelator detector operating over Rayleigh fading channel is 0.0061 and Rician fading channel is 0.0040.One can see that Rician fading channel performs better than Rayleigh fading channel in case of Matched filter and Decorrelator detector and as well as Decorrelator detector performs better than Matched filter.

In Fig.2 we show the theoretical bit error rate in along with the simulation results for a 2-user system with Rayleigh and Rician fading channel for a MIMO CDMA system. We can note that at 6dB Matched filter operating over Rayleigh fading channel is 0.0082and Rician fading channel is 0.0051. In case of Decorrelator detector operating over Rayleigh fading channel is 0.0064 and Rician fading channel is 0.0050.We can see that Rician fading channel performs better than Rayleigh fading channel in case of Matched filter and Decorrelator detector and as well as Decorrelator detector performs better than Matched filter.

V. CONCLUSION

The Bit error rate for a space-time spreading scheme in DS-CDMA system operating over Rayleigh and Rician fading channels using a Decorrelator detector and BPSK modulation has been calculated. We assumed a transmitter with two antennas and a receiver with *L* antennas. Signal to noise ratio is calculated at the output of the space-time combiner and the performance of the system is analyzed when using the linear decorrelator detector to combat the effect of multiuser interference. The results obtained demonstrate that the system exhibits an improved performance in a Rician environment compared to Rayleigh environment. Simulating results for the fading channel are in excellent agreement with the theoretical results.

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