Journal of Theoretical and Applied Information Technology

www.jatit.org

PERFORMANCE IMPROVEMENT OF MC-CDMA SYSTEM THROUGH DSTBC SITE DIVERSITY

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ABSTRACT

Multi-carrier code division multiple access (MC-CDMA) systems receive a great deal of attention due to their great potential in achieving high data rates in wireless communication. Nevertheless, when transmission over fading channel multi-cell interference occurs and this degrades the performance of the system. Site diversity technique is applied to the system to overcome this problem. Due to non orthogonality of spreading codes multi-cell interference is not completely eradicated. In this paper space time block code (STBC) site diversity with multiple input multiple output technique (MIMO) is proposed to improve the performance of MC-CDMA systems and is extended to differential space time block codes (DSTBC). Investigation is done with combining techniques under Rayleigh channel conditions. Simulation results shows that DSTBC outperforms STBC site diversity.

Keywords: *MC-CDMA, MIMO, STBC, DSTBC*

1. INTRODUCTION

Broadband wireless access for evolving mobile internet and multimedia services are driving a surge of research on future wireless communication systems, which have to be highly spectral efficient in order to support multi-user access and high data rates. Therefore, MC-CDMA formed by combining orthogonal frequency division multiplexing (OFDM) with code division multiple accesses (CDMA) became significant research topics [1-3]. The former is well suited for high data rate applications in frequency selective fading channels and the later is a multiplexing technique where number of users is simultaneously available to access a channel. With its capability of synchronous transmission, MC-CDMA is suitable for downlink of cellular communication systems [4]. High data rate MC-CDMA systems can additionally employ MIMO techniques, e.g., Alamouti codes and STBC [3].

Data transmission involves spreading operations which are carried out by short channelisation code and long scrambling code. Short channelisation code helps in separating the signals of different users present within the cell and long scrambling code mitigates the effects of interference produced by users belonging to other cells. However, the scrambling codes are generally not orthogonalised among cells. Therefore, since the signals from other cells cannot be orthogonalised to the signals of its own cell, multi-cell interference exists. In high data rate transmission system over frequency selective fading channel, multi-cell interference results in degradation of bit-error rate (BER) and this characteristic affects the performance of MC-CDMA systems.

Site diversity technique has been proposed for realizing CDMA and OFDM systems to minimize multi-cell interference [5-7]. Site diversity system transmits encoded signals from several base stations and these signals are combined at the receiver with decoding operation. This method does not have inter-cell interference. Scrambling codes are assigned to each base station to maintain orthogonality among the signals between the cells and reduces interference among them. The same technique is applied to MC-CDMA system. In this work STBC and DSTBC with multiple antennas are used in the base stations and also exploiting several base stations the site diversity is obtained. Moreover, by using various combining techniques the performance of the system is analyzed.

2. STBC SITE DIVERSITY TECHNIQUE FOR MC-CDMA SYSTEM

STBC site diversity technique encodes STBC data to several base stations considering base stations as the antenna branches of STBC [8]. Encoding is performed by two adjacent symbols and it is assumed that the j^{th} symbol is S_j and the next symbol is S_{j+1} , where $j = 2n$ and n is an integer. The encoded pattern of branch 1, x_1, and that of branch 2, x_2, is given by

$$x_1 = S_j(t = t_j); S_{j+1}(t = t_{j+1})$$
$$x_2 = -S^*_{j+1}(t = t_j); S^*_j(t = t_{j+1}) \qquad (1)$$

where t is the symbol time, t_j is the j^{th} symbol time. In the above example, the symbols are encoded between the adjacent symbols. These patterns are assigned to several base stations and are transmitted simultaneously. At the receiver, the signals are received and combined with different path loss and different fading fluctuation. The received signals r_j , r_{j+1} are shown as follows,

$$r_j = \alpha_A S_j - \alpha_B S^*_{j+1} + n_j (t = t_j)$$
$$r_{j+1} = \alpha_A S_{j+1} + \alpha_B S^*_j + n_{j+1} (t = t_{j+1}) \qquad (2)$$

where α_A and α_B are the channel responses of the signals from base station A and base station B respectively and n_j is the noise. STBC decoding is performed to the signals from both base stations to obtain diversity gain and the data stream is separated at the receiver [9].

Configuration for multiple antenna STBC MC-CDMA system transmitter and receiver are shown in Fig.1 and Fig.2 respectively for the downlink case. At the transmitter the signals of each branch is transmitted from each base station. So the base stations has two pairs of STBC encoded pattern for site diversity as one base station has two adjacent base stations when linear cell system is considered. Therefore two spreading parts should be prepared and the assignment of channelisation and scrambling codes are done as given in [10].The transmitter consists of information source which contains the data of multi-user. With these data, STBC coding, spreading and OFDM modulation functions are carried out. The OFDM is realized through IFFT operation and cyclic prefix data is added to it.

The multi-user matrix is denoted as $x=[x_1.....x_n.....x_N]$ and includes the information of all the users.
where $x_n = [x_{1,n}...x_{j,n}...x_{Nu,n}]^T$ is a vector of length N_u.

N_u is the number of users,

N is the number of transmitted symbol vectors,

$[.]^T$ denotes the transpose operation.

In case of $N_t = 2$, 3 transmit antennas, the STBC G_2, G_3 are used respectively [7]. For the multi-user case, the coded sequences are defined by

$$G_2^* = \begin{pmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{pmatrix} \qquad (3)$$

$$G_3^* = \begin{pmatrix} x_1 & -x_2 & -x_4 & x_1 & x_1^* & -x_2^* & -x_4^* & x_1^* \\ x_2 & x_1 & x_4 & -x_3 & x_2^* & x_1^* & x_4^* & -x_3^* \\ x_3 & -x_4 & x_1 & x_2 & x_3^* & -x_4^* & -x_1^* & x_2^* \end{pmatrix} \qquad (4)$$

where [.]* denotes the complex conjugate operation

Since L time slots are used to transmit N symbols, the rate R of the code is defined by $R= N/L$. Hence, the rate of G_2 is one and the rate of G_3 is ½. The L^{th} column of G^*_{Nt} represents the transmitted symbols at time slot l while the t^{th} row of G^*_{Nt} represents the transmitted symbols from the antenna t. It can be noted that for G^*_3 the last four columns are the complex conjugate of the first four columns. After STBC coding, the multi-user coded sequences G^*_{Nt} is spreaded over each STBC coded symbol as with classical MC-CDMA. It is considered that the lengths of the spreading sequences is equal to Lc. and are orthogonal. Here it is assumed that $L_c \le N_c$, where N_c is the number of sub-carriers of the OFDM and N_u users are transmitted with the same power. In the case of synchronous downlink, the data modulated spreading codes of the N_u users are added. Then, the multi-carrier modulation is easily performed by an IFFT.

The receiver consists of OFDM demodulation which performs the operation of FFT. The demodulated OFDM signals are decoded and equalized before despreading. Since STBC is carried out on L OFDM symbols, the receiver has to deal with L successive symbols as a whole. The assumptions for this process are given as below:

i. Frequency non-selective Rayleigh fading per sub-carrier and time invariance during L symbols is assumed to permit the recombination of symbols.

ii. There exists uncorrelated channels from each transmit antenna t to each receive antenna r.

iii. Ideal time and frequency interleaving.

iv. Complex channel fading coefficients are independent between each sub-carrier K.

This has the advantage of giving the asymptotical performance of the system, since optimal spatial and frequency diversity is obtained. In the MIMO case, when STBC is used, the signal received during L adjacent OFDM symbols is equal to

$$R_r = H_r C G_{Nt}^{*} + N_r \tag{5}$$

where $R_r = [r_{ir} \ldots r_{lr} \ldots r_{Lr}]$ is a $N_t L_c \times L$ matrix of the L received signals r_{lr} at the r^{th} antenna, with r_{lr} is the vector of the L_c sub-carriers received at time l

C is the spreading code

H_r = diag$(H_{ir} \,.\,.\, H_{lr} \,.\,.\, H_{Lr})$ is the diagonal channel matrix with L received signals of length $N_t L_c \times N_t L_c$

G_{Nt}^{*} is the $N_t L_u \times L$ matrix of multi-user coded sequences

N_r is $N_t L_c \times L$ matrix of the L noise vector.

Then, STBC decoding operation is performed as, $G_{Nt}^{r\ 1st\ row}$ with N_t = 2, 3

For instance with N_t =2,

$$G_2^{r1st\,row} = \begin{pmatrix} r_{1r} \\ r_{2r}^{*} \end{pmatrix} \tag{6}$$

This process should be performed on each receiving antenna $r = 1,2,\ldots Nr$. Then $NNu \times LLc$ equalization matrix G_{Nt}^{Gr} is obtained for each receive antenna by applying equalization coefficients matrices G_{tr} and G_{Nt} which are used at the transmitter. G_{tr} is a diagonal matrix containing the equalization coefficients $g_{tr,k}$, for the channel tr ($t \in \{1,2,3,4\}$, $r \in \{1,2\}$). As a result, these signals have the diversity gain of STBC and the orthogonality among site diversity users between base station A and B are maintained. Only one spreading code pattern is assigned to each base station and the orthogonality of users in the cell are maintained even if non site diversity users exist in the cell.

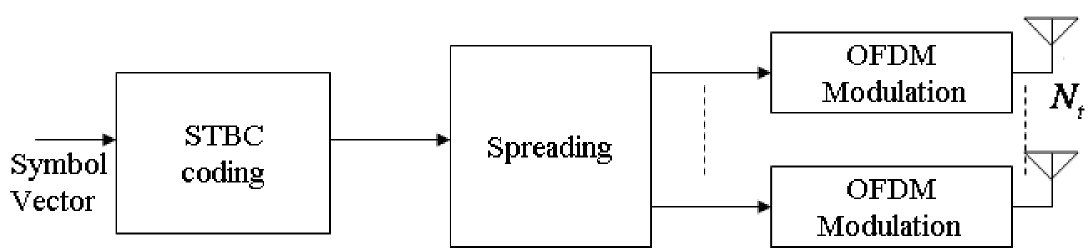

Figure1 Block diagram of STBC diversity for MC-CDMA transmitter

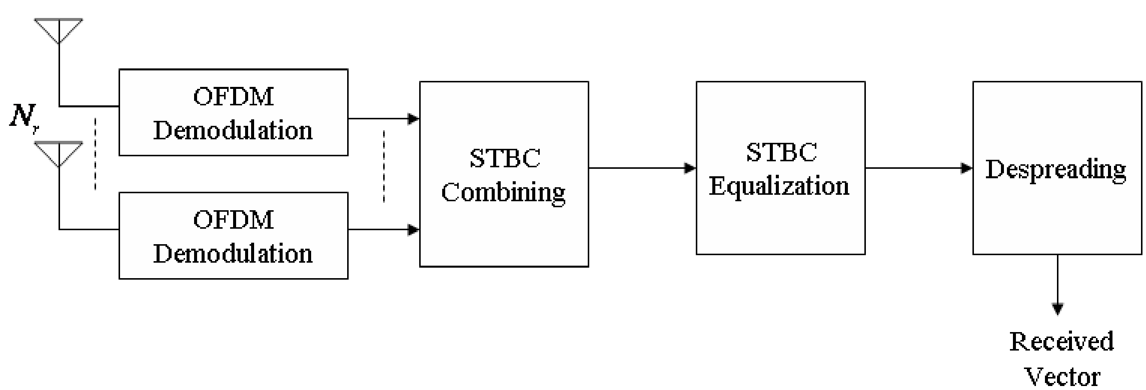

Figure 2 Block diagram of STBC diversity for MC-CDMA receiver

3. DSTBC SITE DIVERSITY TECHNIQUE FOR MC-CDMA SYSTEM

Recent advances in communicating across multiple-antenna wireless communication links show that these links can support very high data rates with low error probabilities, especially when the wireless channel response is known at the receiver. However, the assumption that the channel is known is questionable in a rapidly changing mobile environment, or when multiple transmitting antennas are employed [11]. A new class of signals called space-time signals are proposed that is well-tailored for Rayleigh flat-fading channels where neither the transmitter nor the receiver knows the fading coefficients. The space-time signals are suited particularly well to piecewise-constant fading models. The signals are modified in order to work when the fading condition changes continuously. The modified signals are denoted as differential space-time modulation and achieve full-antenna diversity and are easily implemented. Differential phase-shift keying (DPSK) has long been used in single-antenna unknown-channel links when the channel has a phase response that is approximately constant from one time sample to the next. Differential modulation encodes the transmitted information into phase differences from symbol to symbol. The receiver decodes the information in the current symbol by comparing its phase to the phase of the previous symbol. DPSK is widely used because many continuously fading channels change little between successive time samples. In fact, many continuously fading channels are approximately constant for a time interval T often much larger than two samples [12, 13].

For differential space time modulation (DSTM), consider a multiple input single output (MISO) system with t transmit antennas. Let the group $\zeta = \{G_1,\ldots,G_N\}$ where members of G are defined by

$$G_t^T G_t = G_t G_t^T = I \quad (7)$$

and $\{.\}^T$ denotes conjugate transpose. With the group thus defined, and assuming a simple bit-to-matrix mapping, the rate for DSTM using group codes is

$$R = \frac{1}{t} \log_2(N) \ \ b/s\ Hz \quad (8)$$

where, N is the number of elements in ζ .

The idea behind DSTM is that the matrix group codes can be differentially encoded much like symbols in a DPSK modulator. In order to send a block G_k, the standard encoding equation is

$$C_k = C_{k-1} G_k \quad (9)$$

where, $k = 1, 2, \ldots\ldots, K$, G_k represents data bits mapped from group G and C_k is the encoded block that is actually transmitted at time k. C_0 is an initialization matrix that is not used to transmit data and can be any $t \times t$ matrix that satisfies $C_0 C_0^t = tI$. Fig.3 shows how the elements of the encoded blocks C_k are interpreted in space and time.

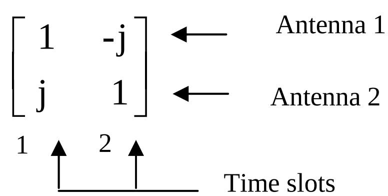

Figure 3 Time and space mapping of the matrix elements for differentially encoded blocks

After encoding and transmission, received blocks can be expressed as,

$$Y_k = H C_k a_k + w_k \quad (10)$$

where, $k = 1, 2, \ldots\ldots, K$

H is the channel coefficient matrix

$a_k = [a_1(2k-1)\, a_2(2k-1)]^T$ and

$a_1(2k-1)$, $a_2(2k-1)$ are Guassian process

$w_k = [w_{2k-1}\, w_{2k}]^T$ is a noise vector and

w_{2k-1}, w_{2k} are zero mean complex Guassian random variables

When channel state information (CSI) is not available at the receiver, the maximum likelihood (ML) detector for G_k based only on the two most recent blocks Y_k and Y_{k-1} is

$$\hat{G}_k = \arg \max_{G \in \zeta} \mathrm{Re\,Tr}\,\{G Y_k^T Y_{k-1}\} \quad (11)$$

which represents the standard decoding equation for DSTM. The fact that G_k is estimated from the received data without CSI is the key advantage of this encoding strategy. For coherent modulation, encoding is often used to decrease the number of bit errors per given symbol error. The idea behind encoding is, observing that when a symbol is improperly detected, it is most likely to be wrongly detected as one of the symbols closest to (in a Euclidean sense) the actual transmitted symbol [13]. Therefore, data bits should be mapped to symbols such that there is only one bit different between nearest neighbors in the symbol constellation. This maximizes the probability that there is only one bit error for each symbol error.

4. SIMULATION RESULTS

The proposed system is simulated in MATLAB and the simulation parameters are given in Table 1. Figure 4 shows the BER performance of the system with and without diversity. The diversity technique uses the conventional Alamouti's code. Figure4 clearly indicates the improvement in performance with the use of diversity technique under Rayleigh fading channel.

Table1. Simulation parameters

Parameters	Details
Symbol length	64
No. of sub-carriers	124
Channel estimation	Perfect estimation
Channelisaton code	Walsh-Hadamard code of length 63
Scrambling code	Random code of length 63
Channel	Rayleigh fading channel with AWGN floor
Combining techniques	Selective, equal gain and maximal ratio combining
No. of antennas	2, 4 and 6
Modulation	16 QAM, DPSK

The system is simulated with STBC and DSTBC using three types of combining techniques [14, 15] and the performance is obtained. Simulation is also carried out for each combining technique by varying the transmitting antennas. Figure 5 shows the performance of STBC diversity over MIMO MC-CDMA system under selective combining technique with varying number of antennas. It can be noticed that when the number of antennas are increased, the symbol error rate (SER) is decreased. Two, four and six antennas are used to simulate the performance. When the number of antennas is increased the error rate reduces gradually as maximum use of diversity exploitation is made and the error rate reduction can be easily witnessed. Performance of the system with equal gain combining and maximal ratio combining technique is shown in

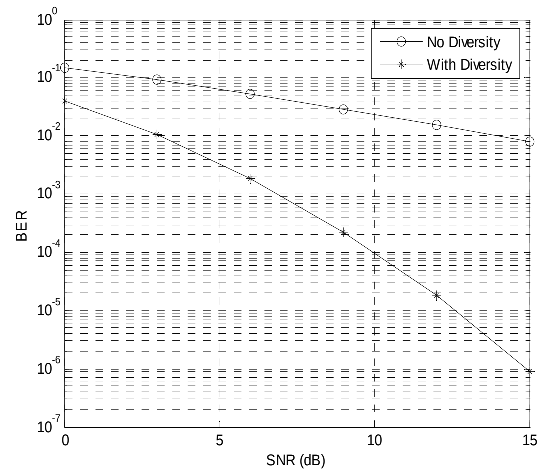

Figure 4 Performance of the system with and without diversity

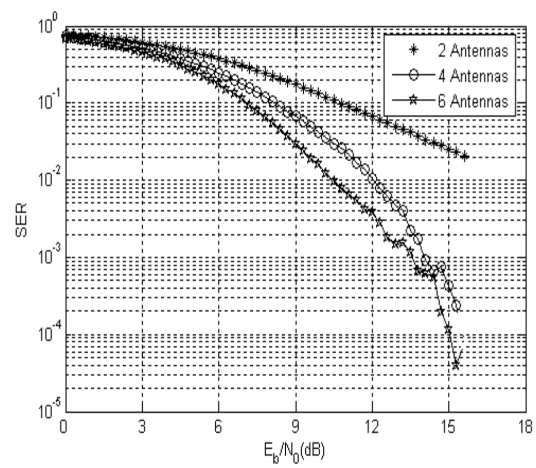

Figure 5 Performance of the system using STBC with selective combining technique

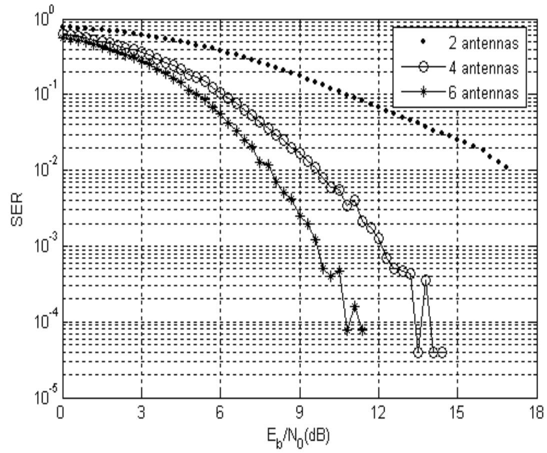

Figure 6 Performance of the system using STBC with equal gain combining technique

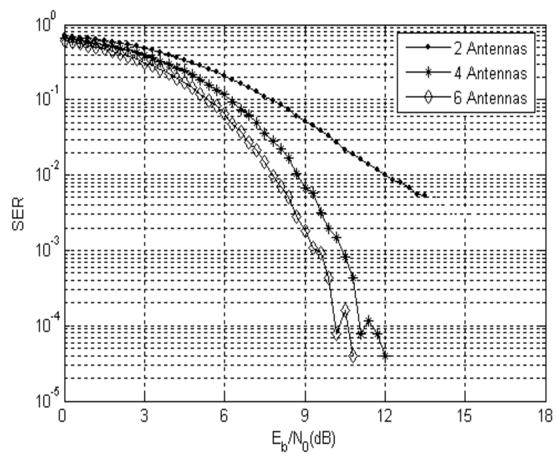

Figure 7 Performance of the system using STBC with maximal ratio combining technique

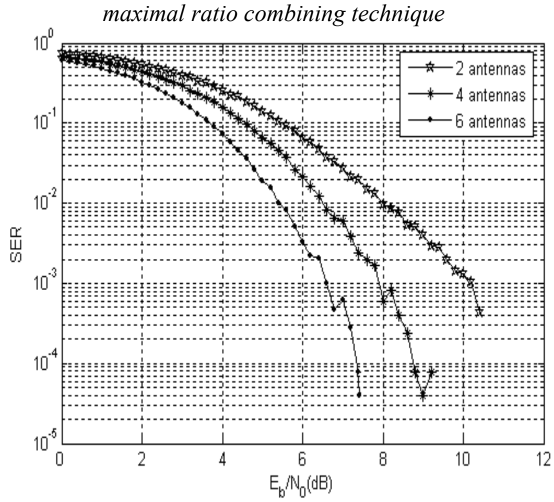

Figure 8 Performance of the system using DSTBC with selective combining technique

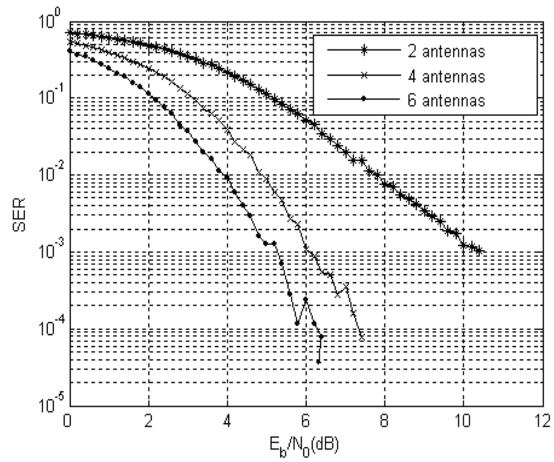

Figure 9 Performance of the system using DSTBC with equal gain combining technique

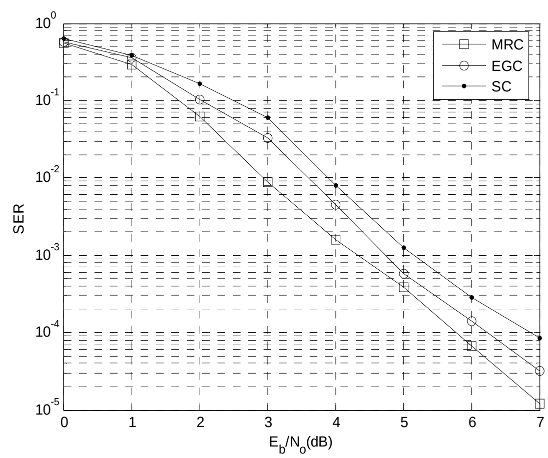

Figure 10 Performance of the system using DSTBC with different combining techniques for 4 antennas

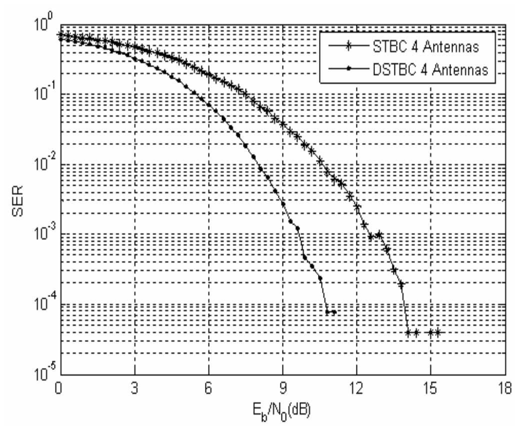

Figure 11 Performance of the system using STBC and DSTBC with selective combining technique for 4 antennas

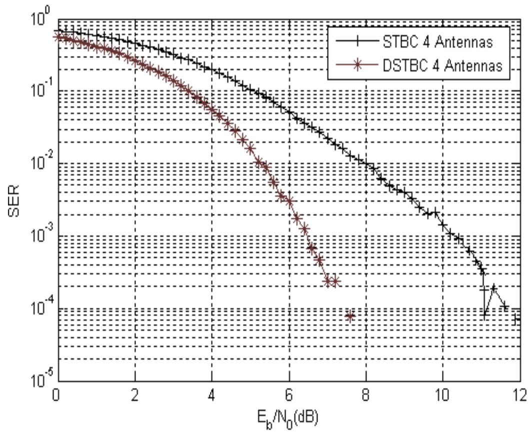

Figure 12 Performance of the system using STBC and DSTBC with equal gain combining technique for 4 antennas

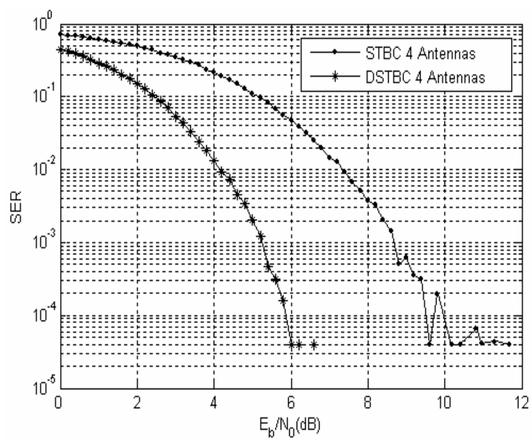

Figure 13 Performance of the system using STBC and DSTBC with maximal ratio combining technique for 4 antennas

figures 6 and 7 respectively. In both the cases SER decreases with increase in number of antennas. Figure 8 shows the performance of DSTBC diversity over MIMO MC-CDMA system with selective combining technique for various antennas. The figure clearly portraits the increase in performance of the system as SER reduces with increase in number of antennas. Use of equal gain combining technique for DSTBC also produces the same result of reduction in SER with increase in number of antennas and was clearly indicated in Figure 9. On consideration of different combining techniques with DSTBC, it can be viewed that maximal ratio combining technique gives better performance and is best opted than other combining techniques and was shown in Figure10 in the occasion of four antennas. Figure11 shows the performance of the system using STBC and DSTBC site diversity scheme with selective combining technique for 4 antennas. The figure clearly depicts that DSTBC based site diversity scheme gives better performance than STBC based site diversity scheme. Figure12 and 13 delivers the performance of the system using STBC and DSTBC site diversity scheme under 4 antennas with equal gain combining technique and maximal ratio combining technique respectively. They too indicate that the DSTBC based site diversity scheme gives better performance than STBC based site diversity. From these it can be concluded that DSTBC outperforms STBC site diversity and maximal ratio combining technique is the best opted combining technique.

5. CONCLUSION

In this paper, site diversity scheme for MC-CDMA system is proposed using STBC and DSTBC with MIMO technique to improve the performance of mobile terminals in the downlink. This method reduces interference of the multi-cell by jointly assigning the scrambling code according to STBC encoding pattern along with multiple antennas. With this method, the performance of the mobile terminal can be improved. Simulated results shows that DSTBC based site diversity outperform STBC based site diversity in terms of SER. Further from the analysis, it was identified that maximal ratio combining technique provides reduced error rate and is the best opted combining technique.

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