Performance Enhancement of MC-CDMA System through STTC based STBC Site Diversity

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***Abstract*— The combination of multiple antennas and multi-carrier code division multiple access (MC-CDMA) is a strong candidate for the downlink of future mobile communications. The study of such systems, in scenarios that model real life transmissions is an additional step towards an optimised achievement. Nevertheless, when transmitting 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 multi-cell interference. Due to non orthogonality of spreading codes multi-cell interference is not completely eradicated. To overcome this problem, spreading codes are assigned to each base station. Space time trellis code (STTC) site diversity with multiple input multiple output (MIMO) technique was introduced to reduce multi-cell interference further. In this paper balanced STTC (B-STTC) site diversity is proposed to improve the performance of MC-CDMA system and is extended to STTC based STBC site diversity. Simulation result shows that STTC based STBC site diversity outperforms B-STTC site diversity.**

***Index Terms*— MC-CDMA, STTC, B-STTC, STTC based STBC, site diversity**

I. Introduction

Broadband wireless access for evolving mobile internet and multimedia services are driving a surge of research on future wireless communication systems to support multi-user access and high data rates. Multi-carrier code division multiple access (MC-CDMA), which suits high data rate applications with multiplexing technique appears to be a promising technique in achieving high data rates [1]. MC-CDMA is robust to multi-path fading, inheriting the advantages of conventional CDMA where frequency diversity can be achieved in a broadband channel [2]. With its capability of synchronous transmission, MC-CDMA is suitable for downlink of cellular communication systems [3]. The challenge of achieving reliable data transmission over wireless link is more difficult due to the fact that received signals from multi-path add destructively causing multi-cell interference which results in serious performance degradation. To achieve reliable communication over wireless links antenna diversity [4] derived by employing spatially separated antennas at the transmitter and receiver was introduced. High data rate MC-CDMA systems additionally employ multiple input multiple output (MIMO) [5] techniques to mitigate fading.

Data transmission involves spreading operations by the use of 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 system faces multi-cell interference due to fading channel resulting in degradation of bit-error rate (BER).

Site diversity technique has been proposed for realising CDMA and orthogonal frequency division multiplexing (OFDM) systems to minimize multi-cell interference [5-7], where space time block code (STBC) is used to gain diversity effect among several base stations. STBC site diversity system transmits the encoded signals from several base stations and these signals are combined at the receiver with STBC decoding operation. STBC branches and the scrambling codes are assigned to each base station to maintain orthogonality of signals between the cells and to reduce interference among them. The same technique is extended to MC-CDMA system. However, the scrambling codes assigned are generally non orthogonal among cells and hence multi-cell interference still exists. Using STBC with multiple antennas at each base station, site diversity was achieved with further reduction in multi-cell interference [8]. STBC does not provide coding gain and in view of this it is worthwhile to consider a joint design of error control coding, modulation, transmit and receive diversity to develop an effective signalling scheme called space time trellis code (STTC) [9], which combats the effects of fading. STTC became extremely popular as it can simultaneously offer coding gain with spectral efficiency and full diversity over fading channels. STTC was used to obtain site diversity with multiple antennas at base station and it outperformed STBC based site diversity in terms of error rates [10]. A new class of 4- phase shift keying (4-PSK) STTC using points of constellation with same probability called as balanced STTC (B-STTC) [11] was proposed for multiple transmit antennas.

STTC based STBC codes introduced in [12], achieves more diversity gain and achieves better performance in terms of error rates. In this work B-STTC with multiple antennas at base station is used to obtain site diversity for MC-CDMA system. Further, it is extended to STTC based STBC to obtain site diversity.

This paper is organised as follows; section 2 describes STTC site diversity technique for MC-CDMA system. Section 3 explains about B-STTC site diversity for the system. STTC based STBC site diversity is dealt in section 4. This is followed by simulation results and discussion in section 5. Finally, conclusion is drawn in section 6.

II. STTC SITE DIVERSITY TECHNIQUE FOR MC-CDMA SYSTEM

The system model of space-time trellis coded modulation with N transmit antennas and M receive antennas are shown in Fig.1 and 2 respectively. The information symbol $s(t)$ at time t is encoded by the space-time encoder as N complex base-band symbols. Each base-band symbol $c_i(t)$ is transmitted simultaneously from different antenna. A space-time code symbol $c(t)$ is an N column vector $c(t) = [c_1(t), c_2(t), ..., c_N(t)]$. The signal obtained at the receive antenna is superposition of the faded version of the signals from N transmit antennas. The received signal at antenna j is given as

$$r_j(t) = \sqrt{E_s}\, h_{ij}(t) c_i(t) + n_j(t)\,,\ i = 1,...,N;\ j = 1,...,M \qquad (1)$$

where E_s is the average energy of the signal constellation
$h_{ij}(t)$ is the path gain at time t
$n_j(t)$ is the noise present at the receive antenna at time t

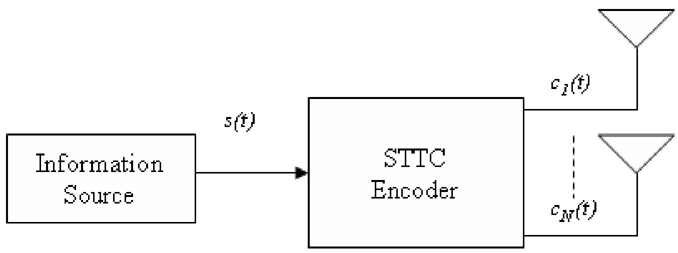

Fig. 1 Block diagram of STTC transmitter

The space-time decoder needs to know the path gains, also called channel state information (CSI), to decode the transmitted codeword. The received signal $r_i(t)$ is weighted by the path gains and the Euclidean distance is used as the input to the maximum likelihood detector for decoding process.

STTC is described by the trellis diagram and is illustrated in Fig.3 and the encoder structure for the generator matrix is given in Fig.4 for 4-state STTC with two-transmit antennas. The trellis diagram is similar to those used in the trellis coded modulation (TCM). State bits are shown at the right of the trellis; each line represents a possible transition with the input bits shown besides the line. Current state outputs and inputs are shown in the matrix at the left of the trellis and are grouped together for different transmit antennas. Symbol bits are fed as input to the upper and lower branches. The branch coefficients are arranged alternatively in the generator matrix, with a_i representing the most significant bit and b_i, the least significant bit. The output of the encoder is computed as

$$x_t^k = \left(\sum_{p=0}^{v1} I_{t-p}^1\, a_{t-p}^k + \sum_{q=0}^{v2} I_{t-p}^2\, b_{t-q}^k \right) \bmod 4,\ k = 1,2 \qquad (2)$$

where I is the input symbol bits to the generator matrix
$v1$ is the memory order of the upper branch
$v2$ is the memory order of the lower branch.

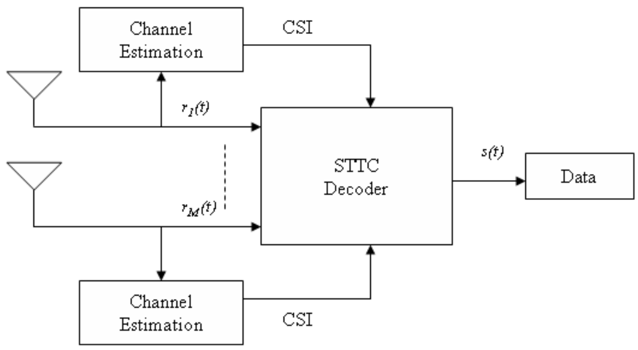

Fig. 2 Block diagram of STTC receiver

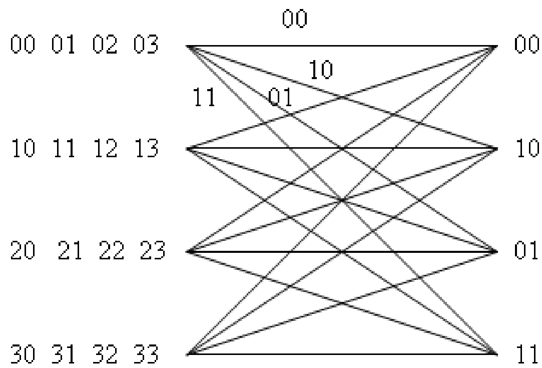

Fig. 3 Trellis diagram for STTC

When a codeword $c=(c_1,c_2,...,c_l)$ with length l is transmitted the codeword length and the maximum likelihood receiver might decide erroneously in favour of another codeword $e=(e_1,e_2,...,e_l)$. Matrix *B* of size $N\times l$ was constructed with elements $(e_j^i-e_j^i), i=1,...,N; j=1,...,l$ and *r* denotes the rank of the matrix *B* with eigen values λ_i, the distance matrix *A* is calculated as $A=B.B^*$. With this the performance based on rank and determinant criteria and Euclidean distance criteria of space-time codes over Rayleigh fading channels, assuming perfect CSI are made available to the receiver.

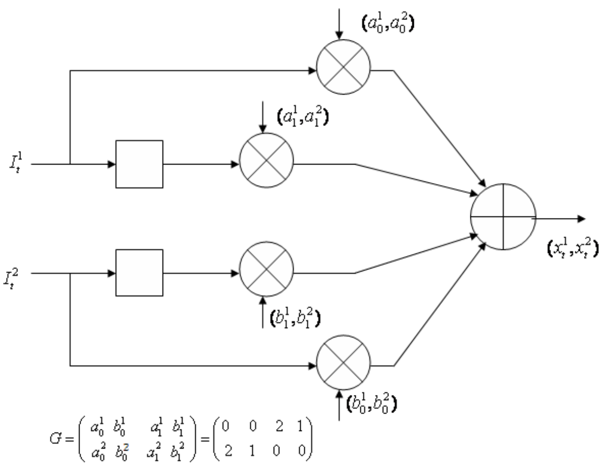

Fig. 4 Matrix generator for STTC

When diversity gain *rM* is small, the rank and determinant criteria will determine the performance [13]. When the diversity gain is large (with more number of antennas), the Euclidean distance criterion will determine the performance of STTC in terms of BER [14].

III. B-STTC Site Diversity Technique For MC-CDMA System

A new class of 4- phase shift keying (4-PSK) STTC using points of constellation with same probability called as B-STTC [11] is proposed for multiple transmit antennas. Compared to the known codes like STBC and STTC, B-STTC offers best performance in terms of error rates and therefore systematic search for good codes can be reduced to B-STTC.

Considering a binary input data generated by a memory less source S = {0, 1} with equally probable symbols and the modulation for a given state $X=[x_1\ x_2,...,x_n]^T$ with shift register realized by ($v+1$) blocks of *n* bits. The MIMO symbol $Y=[y_1\ y_2,...,y_n]^T$ generated by the STTC encoder is given by a deterministic relation

$$Y=C.X \tag{3}$$

where *C* is the generator matrix given by

$$C=\begin{pmatrix} c_{1,1}^1 \dots c_{n,1}^1 \dots c_{1,v+1}^1 \dots c_{n,v+1}^1 \\ c_{1,1}^k \dots c_{n,1}^k \dots c_{1,v+1}^k \dots c_{n,v+1}^k \\ c_{1,1}^{nT} \dots c_{n,1}^{nT} \dots c_{1,v+1}^{nT} \dots c_{n,v+1}^{nT} \end{pmatrix} \tag{4}$$

Here STTC is defined by mapping, such that state *X* associates to codeword *Y* and can be obtained for several states.

Due to the random source S = {0, 1}, for a given state *X* the encoder can have only 4 equally probable next states and the transition probabilities between these states corresponds to a Markov chain. The steady state probabilities of the states *X* are all equal as the matrix is symmetrical. For a balanced code, by using (3), the generated codeword *Y* is also equally probable, or in other words the generated symbols of the constellation are with equal probability.

Properties of Balanced STTC

The design of the B-STTC is based on the following properties:

Theorem 1: If a MIMO code with a L-length shift-register is fully balanced then $L > L_{min}$.

Theorem 2:For a balanced MIMO code with L-length shift-register with any additional Column matrix C_i, the resulting MIMO code with $(L+1)$ length shift register is also balanced.

Definition 1**:** The vectors $C_1, C_2 ..., C_L$ are linearly independent if

$$x_1C_1+x_2C_2+.....+x_LC_L=0 \tag{5}$$

with $x_i\in\{0,1\}$ holds if and only if all $x_i = 0$

Definition 2**:** A set of linearly independent vectors $C_1,...,C_m$ is called a base, if and only if

$$\mathrm{span}(c_1,c_2,...,c_m)=\left\{\sum_{i=1}^{m} x_i c_i \,/\, x_i\in\{0,1\}\right\} \tag{6}$$

Balanced codes are generated based on the properties and it gives better performance compared to STTC. B-STTC is said to be fully balanced if and only if the generated obtained for MC-CDMA system.

IV. STTC BASED STBC SITE DIVERSITY TECHNIQUE FOR MC-CDMA SYSTEM

STTC based STBC site diversity is proposed to improve the reliability of MC-CDMA system in multi-path fading environments. The proposed scheme simultaneously exploits diversity gain and channel efficiency [12]. It not only acquires diversity gain and coding gain from the STTC system without provoking a bandwidth expansion, but also a diversity gain from the STBC system. Fig. 5 and 6 shows the block diagram of STTC based STBC site diversity transmitter and receiver respectively for MC-CDMA. As illustrated in this figure, the data bits are encoded by an STTC and fed to STBC encoder. The modulated data from STBC encoder is spreaded and transmitted as that of conventional MC-CDMA system.

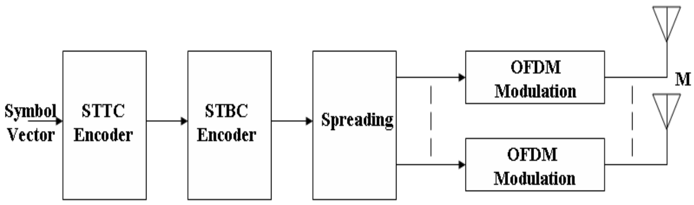

Fig. 5 Block diagram of STTC based STBC site diversity transmitter for MC-CDMA system

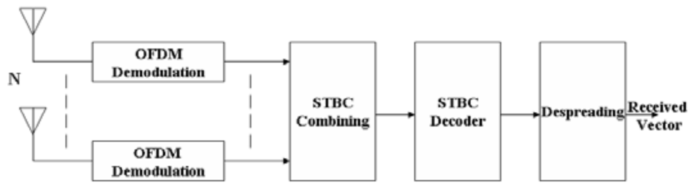

Fig. 6 Block diagram of STTC based STBC site diversity receiver for MC-CDMA system

The interleaved data bits are fed to STBC encoder after it is first modulated by a STTC encoder. For the case of two transmit antennas, the STBC encoder takes two constellation symbols x_0 and x_1 , and generates blocks $x_0, x_1, -x_1^*$ and x_0^*. At time $t = t_0$, the x_0 signal is transmitted from first antenna and x_1 is transmitted from second antenna. During the next period $t = t_0 + T$, signals $-x_1^*$ and x_0^* are transmitted from first and second antenna respectively.

The received signals assuming that the fading remains fixed over a duration of $2T_s$ where T_s is the symbol duration are expressed as

$$\begin{aligned} r_0 &= h_0 x_0 + h_1 x_1 + n_0 \\ r_1 &= -h_0 x_1^* + h_1 x_0^* + n_1 \end{aligned} \tag{7}$$

where

h_0 and h_1 are the path gains modelled as independent samples of a zero mean complex Gaussian random variable

n_0 and n_1 are random Gaussian variables with zero mean and variance σ^2

With perfect CSI the receiver generates soft estimates [15] as follows

$$\begin{aligned} \tilde{x}_0 &= h_0^* r_0 + h_1 r_1^* \\ &= \left(|h_0|^2 + |h_1|^2\right) x_1 + h_0^* n_0 + h_1 n_1^* \\ \tilde{x}_1 &= h_1^* r_0 + h_0 r_1^* \\ &= \left(|h_0|^2 + |h_1|^2\right) x_0 + h_1^* n_0 + h_0 n_1^* \end{aligned} \tag{8}$$

The Viterbi decoder builds the following metric for the branch symbol x_i , which corresponds to the first transmitted symbol x_0 as given below

$$\begin{aligned} m(\tilde{x}_0, x_i) &= \left(|h_0|^2 + |h_1|^2\right)|x_i|^2 + d^2(\tilde{x}_0, x_i) \\ m(\tilde{x}_1, x_i) &= \left(|h_0|^2 + |h_1|^2\right)|x_i|^2 + d^2(\tilde{x}_1, x_i) \end{aligned} \tag{9}$$

where

$d^2(\tilde{x}_0, x_i)$ and $d^2(\tilde{x}_1, x_i)$ are the Euclidean distance given by $(\tilde{x}_0, x_i)(\tilde{x}_0, x_i)^*$ and $(\tilde{x}_1, x_i)(\tilde{x}_1, x_i)^*$ respectively.

Considering two transmitting and receiving antennas, and when the coded sequence $C = [c_0, c_0^*, c_1, -c_1^*, ..., c_{2L-1}, -c_{2L-1}^*, c_{2L-2}^*]$ is transmitted, the maximum likelihood decoder in the receiver gives $E = [e_0, e_0^*, e_1, -e_1^*, ..., e_{2L-1}, -e_{2L-1}^*, e_{2L-2}^*]$ decoded data where e_0, e_1 are the decoded data of the symbols c_0, c_1 with error probability approximated by the Chernoff bound [16] as

$$P(C \to E | h_0, h_1) = \exp\left\{ -\frac{E_s}{4\sigma^2} \sum_{i=0,2}^{2L-2} \left\{ \left[|c_i - e_i|^2 + |c_{i+1} - e_{i+1}|^2 \right] \left[|h_{0i}|^2 + |h_{1i}|^2 \right] \right\} \right\} \tag{10}$$

where

L is the symbol transmission period

E_s is the average energy of the signal constellation

For an independent Rayleigh fading distribution of rM and $|h_1|$ with probability density of $P(|h_{1i}|) = 2|h_{1i}|\exp(-|h_{1i}|^2)$,

$$P(C \to E) \le E\prod_{i=0,2}^{2L-2}\exp\left\{-\frac{E_s}{4\sigma^2}\left[\gamma_i^2+\gamma_{i+1}^2\right]\left[|h_{0i}|^2+|h_{1i}|^2\right]\right\}$$
$$= \prod_{j=0}^{M_R}\prod_{i=1}^{M_T}E\left(\exp\left\{-\varphi(\gamma_i+\gamma_{i+1})|h_{1,j}|^2\right\}\right) \tag{11}$$

where

$$\varphi = \frac{E_s}{4\sigma^2} \text{ and } \gamma_i = |c_i - e_i|^2$$

For an high signal to noise ratio (SNR), $(1+\varphi.(\gamma_i+\gamma_{i+1})) \approx (\varphi.(\gamma_i+\gamma_{i+1}))$ and hence

$$P(C \to E) \le \left(\prod_{i=1}^{r}\left[|c_i-e_i|^2+|c_{i+1}-e_{i+1}|^2\right]\right)^{-M}\varphi^{-rM}$$
$$= \left(\prod_{i=1}^{r}\left[|c_i-e_i|^2+|c_{i+1}-e_{i+1}|^2\right]^{1/r}\right)^{-rM}\varphi^{-rM} \tag{12}$$

where

r is the rank of the coded matrix

rM is the diversity gain

$\prod_{i=1}^{r}\left[|c_i-e_i|^2+|c_{i+1}-e_{i+1}|^2\right]^{1/r}$ is the coding gain

STBC decoding operation is performed as, $G_M^{r1^{st}\,row}$ with different values of M. For M=2

$$G_2^{r1^{st}\,row} = \begin{pmatrix} r_{1M} \\ r_{2M}^* \end{pmatrix} \tag{13}$$

This process is performed on each receiving antenna. On completion, equalisation matrix G_M^{Gr} is obtained for each receive antenna by applying equalisation coefficients G_{NM}. G_{NM} is a diagonal matrix containing the equalisation coefficients of the channel between the transmitting and receiving antennas.

Considering the equalisation coefficient matrices $G_{MN} = \tilde{H}^*$ where $\tilde{H}^*$ is the conjugate diagonal matrix of the normalized channel coefficient for each of the L_c sub-carriers. When $K = M$ i.e. when the K symbols or their replicas are transmitted at the same time, the equalisation coefficient matrix for G_2^* is given as

$$G_2^{Gr} = \begin{pmatrix} G_{1r} & -G_{2r}^* \\ G_{2r} & -G_{1r}^* \end{pmatrix} \tag{14}$$

In order to recover the symbol x_1 transmitted through two channels, the signal r_{1M} received at time t = 1 from the antenna M = 1 has to be equalised by G_{1r} provided s_1 was transmitted at time t = 1 from the antenna M = 1. Meanwhile, $-r_{2M}^*$ received at time t = 2 has to be equalised by $-G_{2r}^*$ given that s_1^* was transmitted at time t = 2 from the antenna M = 2.

IV. Performance Analysis

The proposed site diversity for MC-CDMA system is simulated using MATLAB and the simulation parameters are given in Table 1. Fig.7 shows the symbol error rate (SER) performance with respect to energy per bits to the spectral noise density (E_b/N_0) of the system with and without diversity under Rayleigh fading channel. The diversity technique uses two antennas at the transmitter and receiver terminal. The result indicates that when diversity was used there is an improvement in SER performance of the system due to the exploitation of multiple antennas in the transmitter and receiver.

TABLE I
SIMULATION PARAMETERS

Parameters	Descriptions
Modulation	4 PSK
Symbol length	64
No. of sub-carriers	124
Channel estimation	Perfect estimation
Channelisation code	Walsh-Hadamard code of length 63
Scrambling code	Random code of length 63
Channel	Rayleigh fading channel with AWGN floor

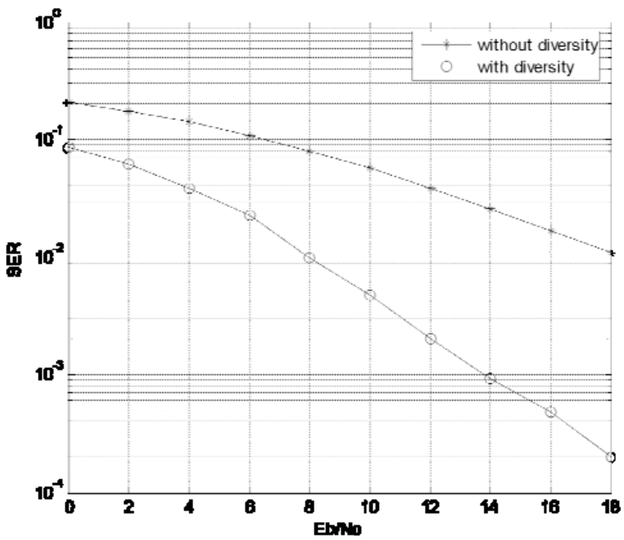

Fig. 7 Performance of the system with and without diversity

Performance of MC-CDMA system with STTC site diversity is evaluated by varying the transmitting and receiving antennas. Fig. 8 illustrates the performance of the system in terms of SER and E_b/N_0 with STTC site diversity for two, three, four and five transmit and receive antennas. It is observed from the plots that the system with five transmit and receive antennas gives better performance in SER when compared to the system with two, three and four antennas. The improvement in SER for the larger number of antennas is due to the maximum utilisation of diversity. The maximum number of antennas used for simulation is restricted to five as further increase of it introduces hardware complexity and increases the cost of the system.

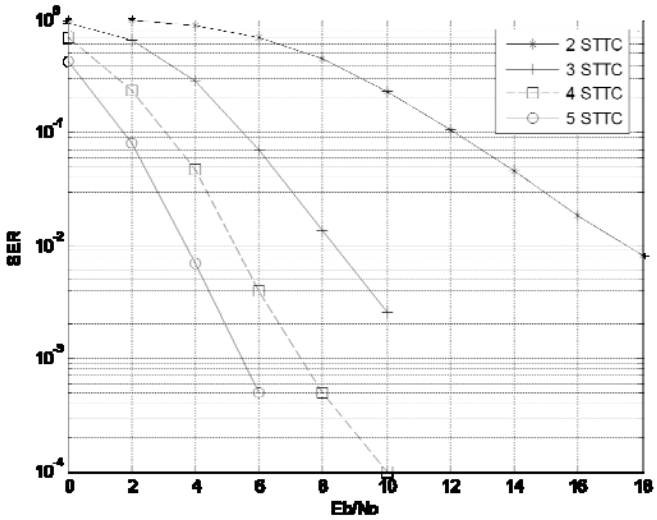

Fig. 8 Performance of the system with STTC site diversity for various antennas

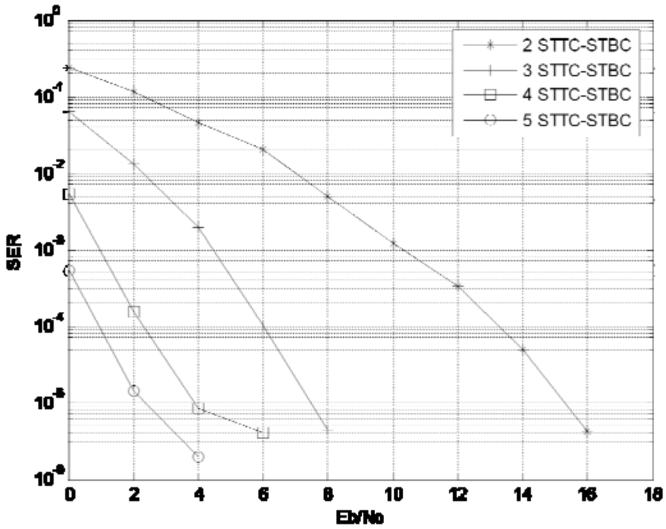

Fig. 10 Performance of the system with STTC based STBC site diversity for various antennas

Fig. 9 depicts SER versus E_b/N_0 performance of the system with B-STTC site diversity for various numbers of antennas. The result portrays that the SER of the system with five transmit and receive antennas outperforms two, three and four transmit and receive antennas. Fig. 10 renders the same scenario of the system with STTC based STBC site diversity for different antennas. Similar conditions of diversity utilisation observed in Fig.8 and 9 are noticed here irrespective of the coding techniques used for site diversity i.e. improvement of SER is noticed clearly when there is increase in number of antennas.

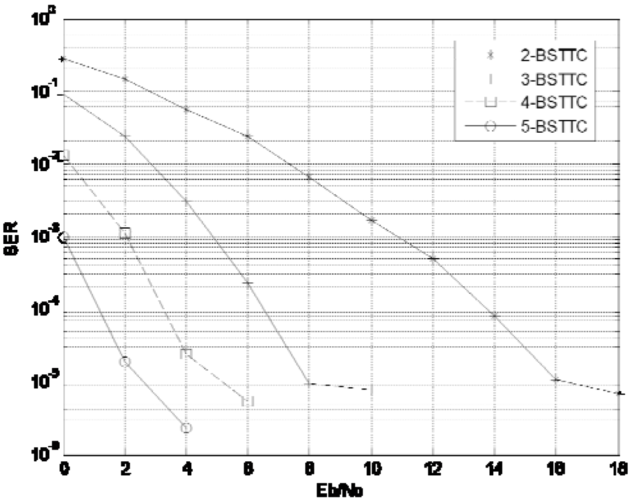

Fig.9 Performance of the system with B-STTC site diversity for various antennas

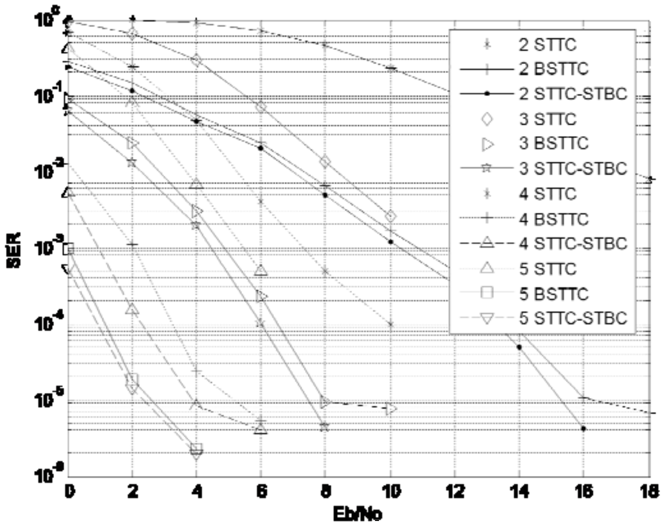

Fig.11 Performance comparison of the system with STTC, B-STTC and STTC based STBC site diversity for various transmit and receive antennas

SER performance is compared for STTC, B-STTC and STTC based STBC site diversity of the system for different transmit and receive antennas in Fig. 11. It is vivid that B-STTC based site diversity outperforms STTC based site diversity as it achieves better coding rate compared to STTC since they use points of the constellation with equal probability. STBC based STTC site diversity outperforms B-STTC site diversity as it gains additional diversity gain. It clearly highlights that the STTC based STBC site diversity is provides better performance and is best opted for the system.

V. CONCLUSION

In this paper, site diversity scheme for MC-CDMA system is proposed using B-STTC and STTC based STBC with MIMO technique to improve the performance of mobile terminals in the downlink. These methods considerably minimise multi-cell interference by jointly consuming the diversity gain and coding gain. Coding gain was further improved in B-STTC as they use points of constellation with equal probability. With STBC based STTC site diversity technique, the performance of MC-CDMA system achieves better reduction in error rates with additional diversity gain. Simulation results shows that STTC based STBC site diversity outperforms B-STTC based site diversity in terms of SER and is best opted for MC-CDMA system.

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