PERFORMANCE IMPROVEMENT OF MC-CDMA SYSTEM THROUGH DSTBC SITE DIVERSITY

N.KUMARATHARAN, P.DANANJAYAN, AND M.PADMAVATHY

1 Research Scholar, 2 Professor and Head, 3 P.G. Student
Department of Electronics and Communication Engineering
Pondicherry Engineering College, Pondicherry-605014, India
E-mail: pdananjayan@hotmail.com

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

\[
x_1 = S_j(t = t_j); S_{j+1}(t = t_{j+1})
\]

\[
x_2 = -S_{j+1}^*(t = t_j); S_j^*(t = t_{j+1})
\]

(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,

\[
r_j = \alpha_a S_j - \alpha_b S_{j+1}^* + n_j(t = t_j)
\]

\[
r_{j+1} = \alpha_a S_{j+1}^* + \alpha_b S_j + n_{j+1}(t = t_{j+1})
\]

(2)

where \(\alpha_a\) and \(\alpha_b\) 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].

The multi-user matrix is denoted as \(\mathbf{x} = [x_1, \ldots, x_n, \ldots, x_N]\) and includes the information of all the users, where \(x_n = [x_{1,n}, \ldots, x_{j,n}, \ldots, x_{N,n}]^T\) is a vector of length \(N_u\), \(N_u\) is the number of users, \(N\) is the number of transmitted symbol vectors, \(\mathbf{L}^T\) 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

\[
G_2^* = \begin{pmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{pmatrix}
\]

(3)

\[
G_3^* = \begin{pmatrix} x_1 & -x_2 & -x_3 & x_4 & x_1^* & -x_2^* & -x_3^* & x_4^* \\ x_2 & x_1 & -x_3 & x_4 & x_2^* & x_1^* & -x_3^* & -x_4^* \\ x_3 & -x_1 & x_2 & -x_3 & x_4 & -x_1^* & x_2^* & -x_3^* \\ x_4 & x_2 & x_1 & -x_3 & x_4 & -x_1^* & x_2^* & -x_3^* \end{pmatrix}
\]

(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 \(1/2\). The \(L\)th column of \(G_{N_t}^*\) represents the transmitted symbols at time slot 1 while the \(t\)th row of \(G_{N_t}^*\) 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 \(G_{N_t}^*\) 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 \(Lc \leq N_c\), 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 despread. 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

$$R_r = H_r C G_r^* + N_r$$

(5)

where $R_r = [r_{r1}, \ldots, r_{rL}]$ is a $N_t L_c \times L$ matrix of the $L$ received signals $r_{r}$ at the $r$th antenna, with $r_{r}$ is the vector of the $L_c$ sub-carriers received at time $l$.

$C$ is the spreading code

$H_r = \text{diag}(H_{r1}, \ldots, H_{rL})$ is the diagonal channel matrix with $L$ received signals of length $N_t L_c \times N_t L_c$.

$G_r^*$ 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,

$$G_{2r_{1st\, row}}$$

with $N_r = 2, 3$

For instance with $N_r = 2$,

$$G_{2r_{1st\, row}} = \begin{pmatrix} r_{r1}^* \\ r_{2r}^* \end{pmatrix}$$

(6)

This process should be performed on each receiving antenna $r = 1, 2, \ldots, N_r$. Then $N_{Nu} \times LL_c$ equalization matrix $G_{Nr}$ is obtained for each receive antenna by applying equalization coefficients matrices $G_r$ and $G_{Nr}$ which are used at the transmitter. $G_r$ 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.

![Figure 1](image1.png)

**Figure 1** Block diagram of STBC diversity for MC-CDMA transmitter

![Figure 2](image2.png)

**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

\[
G_t^T G_t = G, \quad G_t^T = I
\]

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

\[
R = \frac{1}{t} \log_2(N) \quad b/s \; Hz
\]

where, \( N \) is the number of elements in \( \zeta \).

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

\[
C_k = C_{k-1} G_k
\]

where, \( k = 1, 2, \ldots, K \), \( G_k \) 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 \( C_0 C_0^T = I \). Fig.3 shows how the elements of the encoded blocks \( C_k \) are interpreted in space and time.

\[
\begin{bmatrix}
1 & -j \\
j & 1 \\
1 & 2
\end{bmatrix}
\]

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

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

\[
Y_k = HC_k a_k + w_k
\]

where, \( k = 1, 2, \ldots, K \)

\( H \) 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 processes

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

\( w_{2k-1}, w_{2k} \) 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

\[
\hat{G}_k = \arg \max_{G_k} Re \; Tr \{G Y_k^T Y_{k-1}\}
\]

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. Figure 4 clearly indicates the improvement in performance with the use of diversity technique under Rayleigh fading channel.

![Figure 4 Performance of the system with and without diversity](image)

![Figure 5 Performance of the system using STBC with selective combining technique](image)

Table 1. Simulation parameters

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

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 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
5. CONCLUSION

In this paper, site diversity scheme for MIMO 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.

6. REFERENCES


