World Applied Sciences Journal 17 (9): 1159-1166, 2012
ISSN 1818-4952

CDMA with Transmit Antenna Diversity Technique for Broadband Propagation Systems

Salim Abdelkareem Alkhawaldeh

Department of Electrical Engineering,
Faculty of Engineering Technology, Albalqa Applied University,
Amman, Jordan, P.O. Box: 15008 Amman 11134 Jordan

Abstract: The combination of CDMA and space time block coding (STBC) has been proposed for indoor environment where the delay spreads are very small and the channel is flat fading. However, these schemes are not valid for the outdoor situation where the delay spreads are significantly large and the channel is frequency selective fading. Therefore, in our paper, we propose CDMA with space-time block coding with three transmit antennas for frequency selective fading channels (outdoor situation) without loss of diversity order. In the proposed scheme, Orthogonal Frequency Division Multiplexing (OFDM) technique is used to mathematically change the frequency selective fading channel to multi flat fading channels. It is worthy of noting that our scheme provides very low decoding complexity compared to CDMA with space time trellis coding. Also, the proposed scheme provides high performance and high bandwidth efficiency. Simulation results are provided to show the significant improvement in the performance achieved by the proposed scheme.

Key words: Antennas · Diversity · CDMA · STBC · OFDM · Fading

INTRODUCTION

Multimedia and cellular systems suffer from the problem of time-varying multipath fading and the great demand of users. These problems can be overcome by using multiple input and multiple output (MIMO) wireless systems [1-2]. The use of MIMO technology increases the diversity and spatial multiplexing gains which leads to high performance and high data rate of the system. The third generation of cellular systems is based on the code division multiple access (CDMA) technique. This generation suffers from some limitations in the bandwidth efficiency and inter-symbol interference (ISI) [3]. To solve these problems, CDMA in conjunction with OFDM technology is proposed for the fourth generation of cellular systems. In CDMA systems, as the number of users increases the performance decreases. The combination of space time coding and CDMA technique is very promising solution for future cellular communications. Space time coding has taken a lot of attention as a suitable technique to eliminate the effects of fading channels and to maintain high bandwidth efficiency. A number of space-time coded systems have been proposed [4-9] for wireless flat-fading channels. However, the performance of these algorithms is degraded by multipath fading. For frequency selective fading channels, several space-time trellis and block codes in conjunction with OFDM have been proposed [10-13] for high data-rate wireless communications. The schemes in [10, 11] are based on space-time trellis codes whereas the schemes in [12, 13] are based on space-time block codes with two transmit antennas [8].

The combination of CDMA and space time trellis codes have been presented for frequency selective fading channels [14-17]. The efficiency of these codes is high compared to old conventional schemes. Prominent drawback of these approaches is that they suffer from high decoding complexity. To overcome this problem, CDMA with space time block codes have been proposed for flat fading channels [18,19]. However, in the outdoor environments, the channel is frequency selective fading and the schemes in [18,19]

Corresponding Author: Salim Abdelkareem Alkhawaldeh, Department of Electrical Engineering,
Faculty of Engineering Technology, Albalqa Applied University, Amman, Jordan,
P.O. Box: 15008 Amman 11134 Jordan.

are not valid. Therefore, in this paper, we propose a combination of CDMA and space time block coding scheme for frequency selective fading channels. The proposed scheme uses the space time block coding with three transmit antennas in conjunction with OFDM technology [20] and two users CDMA technique. In this scheme, for *n* receive antennas, a diversity gain of 3*n* is achieved. It is worth of noting that the maximal-ratio receiver combining (MRRC) scheme achieves the same diversity gain compared to the proposed scheme. The proposed scheme uses a maximum-likelihood detector with linear processing which results in low computational complexity. Also, it is straightforward to extend this scheme to multiuser CDMA system. To show the comparison of the proposed scheme and the conventional schemes, simulation results are provided.

CDMA with Space Time Block Coding for Flat Fading Channels: In this section, CDMA system with two users and space-time block coding with three transmit antennas are used. Figure 1 shows the CDMA combined with space-time block coded system with three transmit antennas at the base station and one receive antenna for the two users under the assumption of flat-fading channel [9]. Let the coefficients $h_{ij}(k)$ be the channel gain from transmit antenna i to the receive antenna of user j at time k where $i = 1, 2, 3$ and $j = 1, 2$. The channel gains are assumed to be samples of independent complex Gaussian random variables with variance 0.5 per one dimension.

It is assumed that the CDMA technique with two users uses two orthogonal spreading codes c_1 and c_2. The spreading code c_1 related to user 1 is represented as 1 1 whereas the spreading code c_2 related to user 2 is represented as 1-1. Consider the noise at the receive antenna of user j at time k $n_j(k)$ be independent zero-mean complex Gaussian random variable. In [9], it is also assumed that the channel doesn't change over four symbol periods. In the transmitter, let us take four symbol periods and in every period, symbols related to user 1 and user 2 are spread corresponding to spreading codes c_1 and c_2, respectively, then, they are encoded and transmitted according to Table 1. In Table 1, the superscript * is the complex conjugate. Now, let u_1, u_2 and u_3 be given as

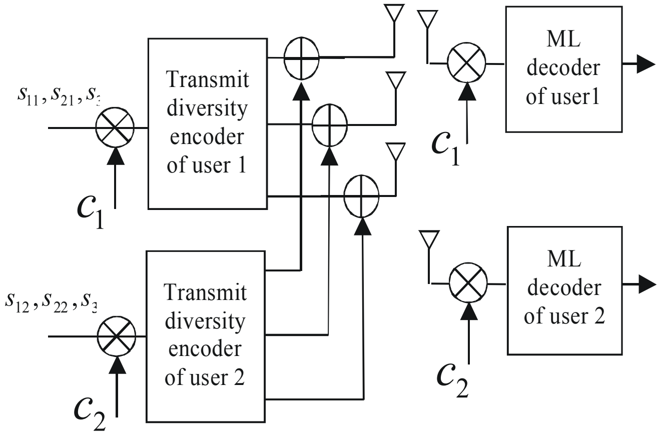

Fig. 1: CDMA/STBC system for flat fading channels

Table 1: Spreading, encoding and transmission for flat fading channels

k	Antenna 1	Antenna 2	Antenna 3
1	$s_{11}c_1 + s_{12}c_2$	$s_{21}c_1 + s_{22}c_2$	$\frac{s_{31}c_1 + s_{32}c_2}{\sqrt{2}}$
2	$-s_{21}^*c_1 - s_{22}^*c_2$	$s_{11}^*c_1 + s_{12}^*c_2$	$\frac{s_{31}c_1 + s_{32}c_2}{\sqrt{2}}$
3	$\frac{s_{31}^*c_1 + s_{32}^*c_2}{\sqrt{2}}$	$\frac{s_{31}^*c_1 + s_{32}^*c_2}{\sqrt{2}}$	$\frac{(-s_{11} - s_{11}^* + s_{21} - s_{21}^*)c_1}{2} + \frac{(-s_{12} - s_{12}^* + s_{22} - s_{22}^*)c_2}{2}$
4	$\frac{s_{31}^*c_1 + s_{32}^*c_2}{\sqrt{2}}$	$\frac{-s_{31}^*c_1 - s_{32}^*c_2}{\sqrt{2}}$	$\frac{(s_{11} - s_{11}^* + s_{21} + s_{21}^*)c_1}{2} + \frac{(s_{12} - s_{12}^* + s_{22} + s_{22}^*)c_2}{2}$

$$u_1 = s_{11}c_1 + s_{12}c_2 \tag{1}$$

$$u_2 = s_{21}c_1 + s_{22}c_2 \tag{2}$$

$$u_3 = s_{31}c_1 + s_{32}c_2 \tag{3}$$

The received signal of user *j* can be written as

$$\begin{bmatrix} y_j(1) \\ y_j(2) \\ y_j(3) \\ y_j(4) \end{bmatrix} = \begin{bmatrix} u_1 & u_2 & \frac{u_3}{\sqrt{2}} \\ -u_2^* & u_1^* & \frac{u_3}{\sqrt{2}} \\ \frac{u_3^*}{\sqrt{2}} & \frac{u_3^*}{\sqrt{2}} & \frac{-u_1 - u_1^* + u_2 - u_2^*}{2} \\ \frac{u_3^*}{\sqrt{2}} & \frac{-u_3^*}{\sqrt{2}} & \frac{u_1 - u_1^* + u_2 + u_2^*}{2} \end{bmatrix} \begin{bmatrix} h_{1j} \\ h_{2j} \\ h_{3j} \end{bmatrix} + \begin{bmatrix} n_j(1) \\ n_j(2) \\ n_j(3) \\ n_j(4) \end{bmatrix} \tag{4}$$

With some manipulations, we can write the received signal of user *j* as:

$$\begin{bmatrix} y_{jr}(1) \\ y_{jim}(1) \\ y_{jr}(2) \\ y_{jim}(2) \\ y_{jr}(3) \\ y_{jim}(3) \\ y_{jr}(4) \\ y_{jim}(4) \end{bmatrix} = \breve{H}_j \begin{bmatrix} u_{1r} \\ u_{1im} \\ u_{2r} \\ u_{2im} \\ u_{3r} \\ u_{3im} \end{bmatrix} + \begin{bmatrix} n_{jr}(1) \\ n_{jim}(1) \\ n_{jr}(2) \\ n_{jim}(2) \\ n_{jr}(3) \\ n_{jim}(3) \\ n_{jr}(4) \\ n_{jim}(4) \end{bmatrix} \tag{5}$$

Where the subscripts *r* and *im* denote the real and imaginary parts, respectively. $\breve{H}_j$ is defined as:

$$\breve{H}_j = \begin{bmatrix} h_{1jr} & -h_{1jim} & h_{2jr} & -h_{2jim} & \frac{h_{3jr}}{\sqrt{2}} & \frac{-h_{3jim}}{\sqrt{2}} \\ h_{1jim} & h_{1jr} & h_{2jim} & h_{2jr} & \frac{h_{3jim}}{\sqrt{2}} & \frac{h_{3jr}}{\sqrt{2}} \\ h_{2jr} & h_{2jim} & -h_{1jr} & -h_{1jim} & \frac{h_{3jr}}{\sqrt{2}} & \frac{-h_{3jim}}{\sqrt{2}} \\ h_{2jim} & -h_{2jr} & -h_{1jim} & h_{1jr} & \frac{h_{3jim}}{\sqrt{2}} & \frac{h_{3jr}}{\sqrt{2}} \\ -h_{3jr} & 0 & 0 & -h_{3jim} & \frac{h_{1jr} + h_{2jr}}{\sqrt{2}} & \frac{h_{1jim} + h_{2jim}}{\sqrt{2}} \\ -h_{3jim} & 0 & 0 & h_{3jr} & \frac{h_{1jim} + h_{2jim}}{\sqrt{2}} & \frac{-h_{1jr} - h_{2jr}}{\sqrt{2}} \\ 0 & -h_{3jim} & h_{3jr} & 0 & \frac{h_{1jr} - h_{2jr}}{\sqrt{2}} & \frac{h_{1jim} - h_{2jim}}{\sqrt{2}} \\ 0 & h_{3jr} & h_{3jim} & 0 & \frac{h_{1jim} - h_{2jim}}{\sqrt{2}} & \frac{-h_{1jr} + h_{2jr}}{\sqrt{2}} \end{bmatrix}. \tag{6}$$

At the receiver of user *j*, the above signal is multiplied by the spreading code c_j as

$$\begin{bmatrix} v_{jr}(1) \\ v_{jim}(1) \\ v_{jr}(2) \\ v_{jim}(2) \\ v_{jr}(3) \\ v_{jim}(3) \\ v_{jr}(4) \\ v_{jim}(4) \end{bmatrix} = \begin{bmatrix} y_{jr}(1)c_j \\ y_{jim}(1)c_j \\ y_{jr}(2)c_j \\ y_{jim}(2)c_j \\ y_{jr}(3)c_j \\ y_{jim}(3)c_j \\ y_{jr}(4)c_j \\ y_{jim}(4)c_j \end{bmatrix} \tag{7}$$

It is assumed that the receiver has perfect knowledge of the channel. Hence, from (6) the estimates $\hat{s}_{1j}, \hat{s}_{2j}$ and $\hat{s}_{3j}$ related to user *j* can be evaluated as:

$$\begin{bmatrix} \hat{s}_{1jr} \\ \hat{s}_{1jim} \\ \hat{s}_{2jr} \\ \hat{s}_{2jim} \\ \hat{s}_{3jr} \\ \hat{s}_{3jim} \end{bmatrix} = H_j^H \begin{bmatrix} v_{jr}(1) \\ v_{jim}(1) \\ v_{jr}(2) \\ v_{jim}(2) \\ v_{jr}(3) \\ v_{jim}(3) \\ v_{jr}(4) \\ v_{jim}(4) \end{bmatrix} \tag{8}$$

Where the superscript *H* denotes the complex conjugate. These estimates are sent to the optimum detector where the maximum likelihood decision rule is applied.

The scheme presented in this section has been proposed for indoor environment where the channel is flat fading. Unfortunately, this scheme is not suitable for the outdoor environment where the channel is frequency selective fading. To overcome this problem, we propose CDMA with transmit diversity scheme equipped with three transmit antennas for frequency selective fading channels (outdoor situation) in the next section.

Proposed CDMA with Transmit Diversity Scheme for Frequency Selective Fading Channels: Consider the system shown in Fig. 1 under the assumption of frequency selective fading channel (delay spread in the channel). At a given time *k*, signal $x_i(k)$ is transmitted from antenna *i* and signal $y_j(k)$ is received, where $i = 1, 2, 3$, $j = 1, 2$, $k = 0, 1, \dots, K-1$ and *K* is the size of data block. We can model the delay spread channel between antenna *i* and the receive antenna of user *j* by

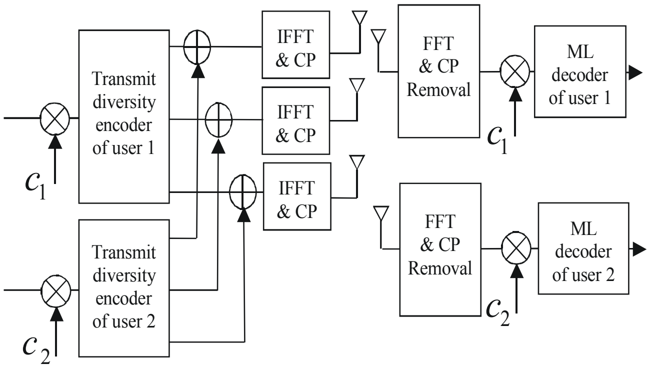

Fig. 2: Proposed CDMA/STBC-OFDM scheme for frequency selective fading channels

Table 2: Spreading, encoding and transmission of the proposed scheme

m	Antenna 1 $\bar{\boldsymbol{x}}_1^{(m)}$	Antenna 2 $\bar{\boldsymbol{x}}_2^{(m)}$	Antenna 3 $\bar{\boldsymbol{x}}_3^{(m)}$
1	$\mathbf{s}_{11}c_1+\mathbf{s}_{12}c_2$	$\mathbf{s}_{21}c_1+\mathbf{s}_{22}c_2$	$\frac{\mathbf{s}_{31}c_1+\mathbf{s}_{32}c_2}{\sqrt{2}}$
2	$-\mathbf{s}_{21}^{*}c_1-\mathbf{s}_{22}^{*}c_2$	$\mathbf{s}_{11}^{*}c_1+\mathbf{s}_{12}^{*}c_2$	$\frac{\mathbf{s}_{31}c_1+\mathbf{s}_{32}c_2}{\sqrt{2}}$
3	$\frac{\mathbf{s}_{31}^{*}c_1+\mathbf{s}_{32}^{*}c_2}{\sqrt{2}}$	$\frac{\mathbf{s}_{31}^{*}c_1+\mathbf{s}_{32}^{*}c_2}{\sqrt{2}}$	$\frac{(-\mathbf{s}_{11}-\mathbf{s}_{11}^{*}+\mathbf{s}_{21}-\mathbf{s}_{21}^{*})c_1}{2}+\frac{(-\mathbf{s}_{12}-\mathbf{s}_{12}^{*}+\mathbf{s}_{22}-\mathbf{s}_{22}^{*})c_2}{2}$
4	$\frac{\mathbf{s}_{31}^{*}c_1+\mathbf{s}_{32}^{*}c_2}{\sqrt{2}}$	$\frac{-\mathbf{s}_{31}^{*}c_1-\mathbf{s}_{32}^{*}c_2}{\sqrt{2}}$	$\frac{(\mathbf{s}_{11}-\mathbf{s}_{11}^{*}+\mathbf{s}_{21}+\mathbf{s}_{21}^{*})c_1}{2}+\frac{(\mathbf{s}_{12}-\mathbf{s}_{12}^{*}+\mathbf{s}_{22}+\mathbf{s}_{22}^{*})c_2}{2}$

$$H_{ij}=\begin{bmatrix} h_{ij}(0) & & & 0 \\ \vdots & \ddots & & \\ h_{ij}(L) & & & \\ & & & h_{ij}(0) \\ & & \ddots & \vdots \\ 0 & & & h_{ij}(L) \end{bmatrix} \tag{9}$$

The received vector y_j related to user j can be written as:

$$\boldsymbol{y_j}=\begin{bmatrix} y_j(0) \\ \vdots \\ y_j(K+L-1) \end{bmatrix}=\sum_{i=1}^{3} H_{ij}\begin{bmatrix} x_i(0) \\ \vdots \\ x_i(K-1) \end{bmatrix}+\boldsymbol{n_j} \tag{10}$$

Where L is the delay spread in the channel and vector $\boldsymbol{n}_j$ is complex white Gaussian noise at the receive antenna of user j.

Figure 2 shows the baseband representation of the proposed scheme which uses CDMA with two users and space-time block code combined with OFDM technique. OFDM technique is used to solve the problem of ISI in the frequency selective fading systems [21-23]. Every block of data is spread and encoded by the STBC, then, a cyclic prefix (CP) of length L is added to the encoded block $\bar{x}_i^{(m)}=\left[x_i^{(m)}(0),\ \dots\ ,x_i^{(m)}(K-1)\right]^T$ which results in $x_i^{(m)}=\left[x_i^{(m)}(K-L),\ \dots\ ,x_i^{(m)}(K-1),\ \bar{\mathbf{x}}_i^{(m)T}\right]^T$ where $m = 1, 2, 3, 4$ is the data block index. The Inverse Fast Fourier Transform (IFFT) of this block is transmitted.

By employing Fast Fourier Transform (FFT) at the receiver of user j and canceling the first L entries of the received signal, the vector $y_j^{(m)}$ can be written as:

$$\boldsymbol{y}_j^{(m)}=\sum_{i=1}^{3}\tilde{H}_{ij}\bar{\boldsymbol{x}}_i^{(m)}+\bar{\boldsymbol{n}}_j^{(m)} \tag{11}$$

Where $\tilde{H}_{ij}$ is a block circulant matrix and vector $\bar{n}_j^{m}$ is the discrete Fourier transform of the channel noise at the receive antenna of user j.

Now consider a block of symbols related to user j as $\mathbf{s}_{pj}=\left[s_{pj}(0),\cdots,s_{pj}(K-1)\right]^T$ and choose $\bar{x}_i^{(m)}$ according to Table 2.

Let the vectors $\boldsymbol{u}_1$, $\boldsymbol{u}_2$ and $\boldsymbol{u}_3$ be given as

$$\boldsymbol{u}_1 = \boldsymbol{s}_{11}c_1 + \boldsymbol{s}_{12}c_2 \tag{12}$$

$$\boldsymbol{u}_2 = \boldsymbol{s}_{21}c_1 + \boldsymbol{s}_{22}c_2 \tag{13}$$

$$\boldsymbol{u}_3 = \boldsymbol{s}_{31}c_1 + \boldsymbol{s}_{32}c_2 \tag{14}$$

$$\begin{bmatrix} \boldsymbol{y}_j^{(1)} \\ \boldsymbol{y}_j^{(2)} \\ \boldsymbol{y}_j^{(3)} \\ \boldsymbol{y}_j^{(4)} \end{bmatrix} = \begin{bmatrix} \Lambda_{1j} \\ \Lambda_{2j} \\ \Lambda_{3j} \end{bmatrix}^T \begin{bmatrix} \boldsymbol{u}_1 & \boldsymbol{u}_2 & \frac{\boldsymbol{u}_3}{\sqrt{2}} \\ -\mathbf{u}_2^* & \boldsymbol{u}_1^* & \frac{\boldsymbol{u}_3}{\sqrt{2}} \\ \frac{\boldsymbol{u}_3^*}{\sqrt{2}} & \frac{\boldsymbol{u}_3^*}{\sqrt{2}} & \frac{-\boldsymbol{u}_1 - \boldsymbol{u}_1^* + \boldsymbol{u}_2 - \boldsymbol{u}_2^*}{2} \\ \frac{\boldsymbol{u}_3^*}{\sqrt{2}} & \frac{-\boldsymbol{u}_3^*}{\sqrt{2}} & \frac{\boldsymbol{u}_1 - \boldsymbol{u}_1^* + \boldsymbol{u}_2 + \boldsymbol{u}_2^*}{2} \end{bmatrix}^T + \begin{bmatrix} \overline{\boldsymbol{n}}_j^{(1)} \\ \overline{\boldsymbol{n}}_j^{(2)} \\ \overline{\boldsymbol{n}}_j^{(3)} \\ \overline{\boldsymbol{n}}_j^{(4)} \end{bmatrix}. \tag{15}$$

In (15), A_{ij} is diagonal matrix where its diagonal elements are DFT of the channel impulse response $h_{ij}(k)$. With some manipulations, (15) can be written as:

$$\begin{bmatrix} \boldsymbol{y}_{jr}^{(1)} \\ \boldsymbol{y}_{jim}^{(1)} \\ \boldsymbol{y}_{jr}^{(2)} \\ \boldsymbol{y}_{jim}^{(2)} \\ \boldsymbol{y}_{jr}^{(3)} \\ \boldsymbol{y}_{jim}^{(3)} \\ \boldsymbol{y}_{jr}^{(4)} \\ \boldsymbol{y}_{jim}^{(4)} \end{bmatrix} = \Lambda_j \begin{bmatrix} \boldsymbol{u}_{1r} \\ \boldsymbol{u}_{1im} \\ \boldsymbol{u}_{2r} \\ \boldsymbol{u}_{2im} \\ \boldsymbol{u}_{3r} \\ \boldsymbol{u}_{3im} \end{bmatrix} + \begin{bmatrix} \overline{\boldsymbol{n}}_{jr}^{(1)} \\ \overline{\boldsymbol{n}}_{jim}^{(1)} \\ \overline{\boldsymbol{n}}_{jr}^{(2)} \\ \overline{\boldsymbol{n}}_{jim}^{(2)} \\ \overline{\boldsymbol{n}}_{jr}^{(3)} \\ \overline{\boldsymbol{n}}_{jim}^{(3)} \\ \overline{\boldsymbol{n}}_{jr}^{(4)} \\ \overline{\boldsymbol{n}}_{jim}^{(4)} \end{bmatrix} \tag{16}$$

$$\Lambda_j = \begin{bmatrix} \Lambda_{1jr} & -\Lambda_{1jim} & \Lambda_{2jr} & -\Lambda_{2jim} & \frac{\Lambda_{3jr}}{\sqrt{2}} & \frac{-\Lambda_{3jim}}{\sqrt{2}} \\ \Lambda_{1jim} & \Lambda_{1jr} & \Lambda_{2jim} & \Lambda_{2jr} & \frac{\Lambda_{3jim}}{\sqrt{2}} & \frac{-\Lambda_{3jr}}{\sqrt{2}} \\ \Lambda_{2jr} & \Lambda_{2jim} & -\Lambda_{1jr} & -\Lambda_{1jim} & \frac{\Lambda_{3jr}}{\sqrt{2}} & \frac{-\Lambda_{3jim}}{\sqrt{2}} \\ \Lambda_{2jim} & -\Lambda_{2jr} & -\Lambda_{1jim} & \Lambda_{1jr} & \frac{\Lambda_{3jim}}{\sqrt{2}} & \frac{-\Lambda_{3jr}}{\sqrt{2}} \\ -\Lambda_{3jr} & 0 & 0 & -\Lambda_{3jim} & \frac{\Lambda_{1jr}+\Lambda_{2jr}}{\sqrt{2}} & \frac{\Lambda_{1jim}+\Lambda_{2jim}}{\sqrt{2}} \\ -\Lambda_{3jim} & 0 & 0 & \Lambda_{3jr} & \frac{\Lambda_{1jim}+\Lambda_{2jim}}{\sqrt{2}} & \frac{-\Lambda_{1jim}+\Lambda_{2jim}}{\sqrt{2}} \\ 0 & -\Lambda_{3jim} & \Lambda_{3jr} & 0 & \frac{\Lambda_{1jr}-\Lambda_{2jr}}{\sqrt{2}} & \frac{\Lambda_{1jim}-\Lambda_{2jim}}{\sqrt{2}} \\ -\Lambda_{3jim} & 0 & 0 & \Lambda_{3jr} & \frac{\Lambda_{1jim}-\Lambda_{2jim}}{\sqrt{2}} & \frac{-\Lambda_{1jim}-\Lambda_{2jim}}{\sqrt{2}} \end{bmatrix}. \tag{17}$$

At the receiver of user j, the received signal is multiplied by the spreading code c_j as

$$\begin{bmatrix} \boldsymbol{v}_{jr}^{(1)} \\ \boldsymbol{v}_{jim}^{(1)} \\ \boldsymbol{v}_{jr}^{(2)} \\ \boldsymbol{v}_{jim}^{(2)} \\ \boldsymbol{v}_{jr}^{(3)} \\ \boldsymbol{v}_{jim}^{(3)} \\ \boldsymbol{v}_{jr}^{(4)} \\ \boldsymbol{v}_{jim}^{(4)} \end{bmatrix} = \begin{bmatrix} \boldsymbol{y}_{jr}^{(1)}c_j \\ \boldsymbol{y}_{jim}^{(1)}c_j \\ \boldsymbol{y}_{jr}^{(2)}c_j \\ \boldsymbol{y}_{jim}^{(2)}c_j \\ \boldsymbol{y}_{jr}^{(3)}c_j \\ \boldsymbol{y}_{jim}^{(3)}c_j \\ \boldsymbol{y}_{jr}^{(4)}c_j \\ \boldsymbol{y}_{jim}^{(4)}c_j \end{bmatrix} \tag{18}$$

Estimated blocks $\hat{s}_{1j}, \hat{s}_{2j}$ and $\hat{s}_{3j}$ related to user j can be evaluated as:

$$\begin{bmatrix} \hat{s}_{1jr} \\ \hat{s}_{1jim} \\ \hat{s}_{2jr} \\ \hat{s}_{2jim} \\ \hat{s}_{3jr} \\ \hat{s}_{3jim} \end{bmatrix} = \Lambda_j^H \begin{bmatrix} \boldsymbol{v}_{jr}^{(1)} \\ \boldsymbol{v}_{jim}^{(1)} \\ \boldsymbol{v}_{jr}^{(2)} \\ \boldsymbol{v}_{jim}^{(2)} \\ \boldsymbol{v}_{jr}^{(3)} \\ \boldsymbol{v}_{jim}^{(3)} \\ \boldsymbol{v}_{jr}^{(4)} \\ \boldsymbol{v}_{jim}^{(4)} \end{bmatrix}. \tag{19}$$

These estimates are sent to the optimum detector where the maximum likelihood decision rule is applied. It is straightforward to extend this scheme to multiuser CDMA. Note that this scheme provides a diversity order as the MRRC scheme. It achieves diversity of $3n$ for n receive antennas. On the other hand, this code exploits ¾ of the maximum transmission rate and uses maximum-likelihood decoder with linear processing. Using OFDM technique with cyclic prefix causes a reduction in the bandwidth proportional to $L/(K+L)$. This fraction can be reduced by increasing the block size K if it is guaranteed that the channel doesn't change over four block periods.

Simulation Results: In this section, numerical results of the proposed scheme and conventional schemes are demonstrated. In all simulations, we use 3 transmit antennas at the base station and 1 receive antenna at the mobile of users. Also, it is assumed that the channel is

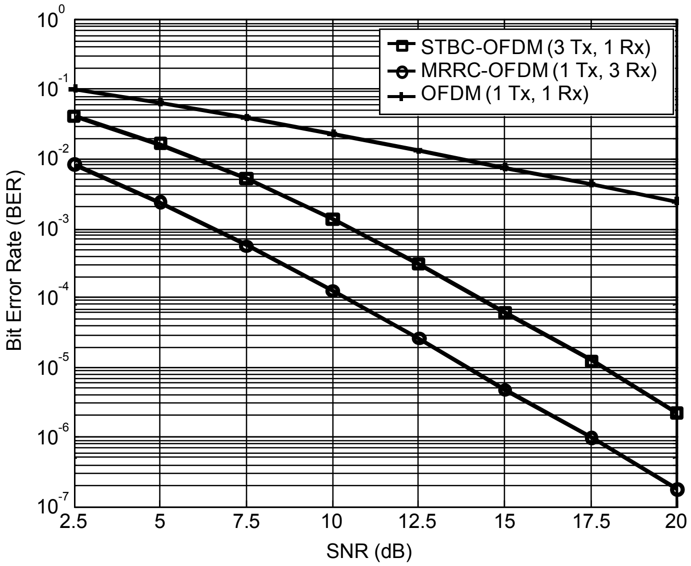

Fig. 3: BER of MRRC-OFDM and STBC-OFDM schemes for frequency selective fading channels

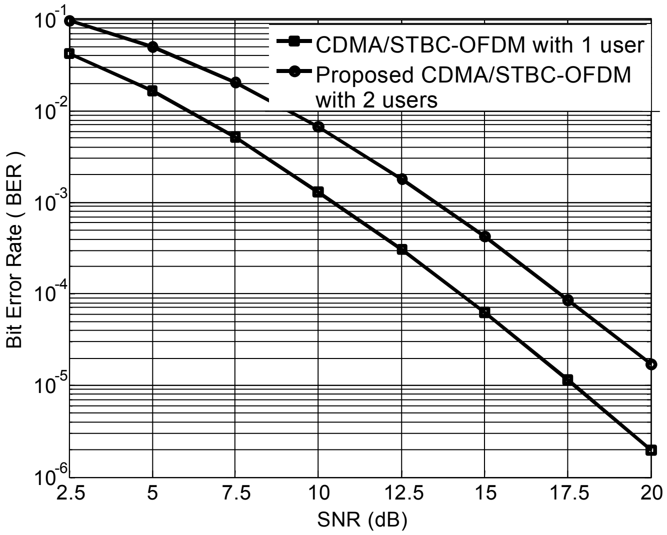

Fig. 4: BER of CDMA/STBC-OFDM scheme with 1 user and the proposed CDMA/STBC with 2 users for frequency selective fading channels

frequency selective fading with delay spread of 4 bits and the size of the transmitted block equals 128. Furthermore, the channel path gains are assumed as samples of independent complex Gaussian random variables with variance 0.5 per one dimension (Rayleigh fading) and the noise is considered to be complex white Gaussian.

Figure 3 shows the bit error probability with respect to signal to noise ratio of the STBC-OFDM scheme compared to the MRRC-OFDM scheme. In this example, binary PSK modulation is used. It is noted that the performance of the STBC-OFDM is 4 dB worse than the MRRC because, the total transmit power of our scheme equals to the transmitted power from the single transmit antenna for MRRC. If we make the power of each block of s_1, s_2, and s_3 in STBC-OFDM scheme equals to the transmitted power from the single transmit antenna for MRRC, the bit error rate (BER) of the two schemes will be the same and the curves will overlap with each other. Also, it is worthy of noting that the two schemes have the same slopes which means that the STBC-OFDM achieves diversity gain similar to the diversity gain of the MRRC-OFDM scheme. As a result, STBC-OFDM can be used as an efficient coding scheme to improve the performance of the wireless system.

In Fig. 4, we present the performance of the proposed CDMA/STBC-OFDM scheme with two users compared to CDMA/STBC-OFDM scheme with one user. It is assumed that the transmitted power in the two cases is the same and binary PSK modulation is used. As expected, the CDMA/STBC-OFDM scheme with one user has approximately 3 dB performance gain over the CDMA/STBC-OFDM scheme with two users. This is due to the fact that when the number of users doubles, the performance gain decreases by 3 dB. Also, it is interesting to note that the two curves have the same slopes. This means that the proposed CDMA/STBC-OFDM scheme with two users has the same diversity order as the diversity order of the CDMA/STBC-OFDM scheme with one user. In addition, this diversity order doesn't change for the proposed CDMA/STBC-OFDM with any number of users.

CONCLUSIONS

A CDMA/STBC-OFDM scheme for frequency selective fading channels has been presented. It is shown that this scheme is efficient for frequency selective fading channels with low decoding complexity and good performance. It provides a diversity order of $3n$ for n receive antennas as the MRRC scheme. The extension of this scheme to multiuser CDMA is straightforward.

REFERENCES

1. Theodore S. Rappaport, 2002. Wireless communications: principles and practice. Prentice Hall PTR, NJ.
2. Wang, X., Salim Alkhawaldeh and Y. Shayan, 2007. A New approach to diversity and multiplexing gains for wideband MIMO channels. IEEE Transaction on Wireless Communications, USA, 6(1): 90-100.
3. Bansal, L.K. and A. Trivedi, 2010. Comparative Study of Different Space-Time Coding Schemes for MC-CDMA Systems, Int. J. Communications, Network and System Sci., 3: 418-424.
4. Tarokh, V., N. Sheshadri and A.R. Calderbank, 1998. Space-time codes for high data rate wireless communication: performance criterion and code construction. IEEE Trans. Inform. Theory, 44(2): 744-765.
5. Tarokh, V., H. Jafarkhani and A.R. Calderbank, 1999. Space-time block coding for wireless communications: performance results. IEEE JSAC, 17(3): 451-460.
6. Tarokh, V., A. Naguib, N. Sheshadri and A.R. Calderbank, 1999. Combined array processing and space-time coding. IEEE Trans. Inform. Theory, 45: 1121-1128.
7. Alkhawaldeh, S., X. Wang and Y.R. Shayan, 2008. Multilayered linear dispersion codes for flat multiple-input multiple-output channels. IET Communications, 2(9): 1149-1158.
8. Alamouti, S.M., 1998. A simple transmit diversity technique for wireless communications. IEEE JSAC, 16(8): 1451-1458.
9. Tarokh, V., H. Jafarkhani and A.R. Calderbank, 1999. Space-time block codes from orthogonal designs. IEEE Trans. Inform. Theory, 45: 1456-1467.
10. Agrawal, D., V. Tarokh, A. Naguib and N. Sheshadri, 1998. Space-time coded OFDM for high data-rate wireless communication over wideband channels. IEEE Vehicular Technology Conference, VTC'98., pp: 1000-1004.
11. Blum, R., Y. Geoffrey, J. Li Winters and Q. Yan, 2001. Improved Space-time coding for MIMO-OFDM wireless communications. IEEE Trans. on Communications, 49(11): 1873-1878.
12. Mudulodu, S. and A. Paulraj, 2000. A transmit diversity scheme for frequency selective fading channels. IEEE Globecom.
13. Lee, K.F. and D.B. Williams, 2000. A space-frequency transmitter diversity technique for OFDM systems. IEEE Globecom.
14. Ostuni, F.S., M.R. Nakhai and H. Aghvami, 2003. Iterative Multi-User MMSE Receiver for Space-Time Trellis Co- ded CDMA over Frequency Selective channels, IEEE 14th International Symposium on Personal, Indore and Mobile Radio communication Proceedings, Chennai, pp: 1968-1972.
15. Trivedi, A. and M. Bansal, 2007. Adaptive Equalization of Space-Time Coded MC-CDMA Systems, Communica-tion, Computers and Signal Processing, IEEE Pacific Rim, 22-24 August 2007, pp: 186-189.
16. Trivedi, A. and L.K. Bansal, 2008. Performance Study of Space-Time Trellis Coded MC-CDMA System Employ-ing Different Detection Techniques, IEEE Proceedings, World Championship Sports Network, Conducted by Indian Institute of Information Technology, Allahabad, December 27-29, 2008, pp: 137-140.

17. Trivedi, A. and L.K. Bansal, 2009. Comparative Study of Space-Time Trellis Code Concatenated with Space-Time Block Code MC-CDMA System, IEEE Proceedings, International Anti Corruption Conference, Conducted by Thapar University, Patiala, March 6-7, 2009, pp: 1099-1102.
18. Geng, J., U. Mitra and M. Fitz, 2000. Optimal space-time block codes for CDMA," systems," MILCOM 2000. 21st Century Military Communications Conference Proceedings, 1: 387-391.
19. Sreesudha, P. and M. Lakshmi, 2011. Ber enhancement of MIMO-CDMA based on Space-time block codes. AIAA 2011, CS and IT, 3: 21-26.
20. Alkhawaldeh, S. and Y. Shayan, 2003. An extended space-time transmit diversity scheme for frequency selective fading channels, IEEE' CCECE Conf., 2003, Montreal, pp: 1663-1666, May, 2003.
21. Matarneh, A.M. and N.A. Al-Dmour, 2011. Transmission Performance of Coded Orthogonal Frequency Division Multiplexing for Radio over Multimode Fibre Systems, World Applied Sciences Journal, 13(6): 1302-1309.
22. Kadhim, M.A. and W. Ismail, 2011. Implementation Transmitter Diversity with Tomlinson-Harashima Precoding for WIMAX IEEE802.16d OSTBC-OFDM Baseband Transceiver on a Multi-Core Software Defined Radio Platform, World Applied Sciences Journal, 12(9): 1482-1491.
23. Sharma, P.K., R.K. Nagaria and T.N. Sharma, 2009. Power Efficiency Improvement in OFDM System using SLM with Adaptive Nonlinear Estimator, World Applied Sciences Journal, 7(Special Issue of Computer and IT): 145-151.