APPLYING CHANNEL EQUALIZATION TECHNIQUES TO STBC OFDM – CDMA SYSTEM IN THE PRESENCE OF MULTI-PATH FREQUENCY SELECTIVE CHANNEL FADING

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ABSTRACT

In this paper three systems are joined together in order to mitigate distortion effect caused by multipath fading. Those systems are; space time block coding (STBC), code division multiple access (CDMA), and orthogonal frequency division multiplexing (OFDM). The proposed STBC OFDM-CDMA system has been simulated in the presence of frequency selective fast multipath fading channel which is considered the worst form of channel fading. Therefore, system performance depends mainly on channel equalization technique applied at the receiver. In this paper, a comparison among three channel equalization schemes was introduced, those schemes are; phase equalizer (PE), maximal ratio (MR), and minimum mean square error equalizer (MMSE). Those equalization schemes have been compared under various system conditions and using different modulation techniques. The main problem of OFDM system is the relative high peak-to-average power ratio (PAR). Therefore, three techniques for reducing the PAR have been applied into the proposed STBC OFDM-CDMA transmitter. Channel coding is essential for any wireless communication system especially in the presence of this bad fading form. This is coming from its ability of error detection and correction at the receiver. Two types of channel coding, Hamming and convolutional coding, have been introduced into the proposed system in order to enhance its performance.

Keywords: Orthogonal Frequency Division Multiplexing (OFDM), Code Division Multiple Access (CDMA), Space Time Block Coding (STBC), and Peak- to- Average Power Ratio (PAR)

1. INTRODUCTION

Multi-path channel fading is the main enemy for any wireless communications system. Therefore, for any novel approach applied at any wireless communication system, its efficiency is measured according to its ability of mitigating the distortion caused by fading. The worst fading types is frequency – selective fast fading type since it results in two forms of distortion. First it causes time dispersion to the transmitted symbols resulting in inter symbol interference (ISI). The second effect is the distortion in the spectrum of the transmitted signal.

In the proposed system, two systems have been joined together to mitigate distortion appears in both time and frequency domains. Those two systems are OFDM and DS-CDMA systems. DS-CDMA mechanism can convert fast fading into slow fading channel where, the symbol duration is divided into much smaller chip duration after spreading [5]. This chip duration will be smaller than coherence time of the channel of course resulting in slow fading form. OFDM system will convert frequency selective fading into flat fading. Where instead of modulating all data symbols using the same carrier and over one frequency band, each symbol (or a group of symbols) modulates different carriers so that the total band is divided into smaller adjacent non-interfered sub-bands. Therefore, the resultant sub-bands will be of smaller width than channel coherence bandwidth resulting in frequency nonselective (or flat) fading form.

The main performance limitation in the OFDM system is that the transmitted signal has high peak-to-average power ration (PAR) which may cause the receiver amplifiers to be saturated leading to degradation in the receiver performance that appears in the rising of bit error rate level. In order to reduce the PAR, three techniques have been used in the proposed system to reduce the PAR of transmitted OFDM signal. Those techniques are; simplified symbol formatting, modified selective mapping approach (SLM) [1] and modified partial transmit sequence approach (PTS) [2] that are to be described in details in the coming subsections.

Multiple transmitting – receiving antennas are applied into the OFDM – CDMA system in order to provide many versions of transmitted symbol at the receiver so the possibility of having deep fading over all transmitting – receiving path will be very rare. This is done by using STBC system which arranges symbol transmission through each transmitting antenna in a certain way [4]. In order to help the receiver in making channel estimation, preamble vectors are transmitted by each antenna before real data transmission [3]. Those preambles should be designed in a certain way in order to be orthogonal to each other. At the receiver only a rough estimate for the channel coefficients could be obtained by the help of those preambles but additional channel equalization is necessary. In the proposed receiver, three channel equalizers have been introduced; phase equalizer (PE), maximal ratio equalizer (MRE) and minimum mean square error equalizer (MMSE) [6].

In order to reduce the BER level, one of the channel coding schemes could be used such as Hamming or convolutional coding which have the ability of making error detection and correction at the receiver. By applying any of the previous channel coding techniques very low BER value was obtained at relatively small SNR.

The contents of the coming sections are arranged as follows: Section 3 describes the STBC OFDM-CDMA transmitter model with the aid of channel coding. At section 4, the design of the preamble vectors is described and how they could be used in channel equalization stage using any of channel equalization schemes described before. STBC OFDM-CDMA receiver will be described at section 5. Section 6 displays the simulation results using computer software which are displayed in form of set of curves and tables.

2. STBC OFDM – CDMA TRANSMITTER MODEL DESCRIPTION

There are K users each transmits binary data sequence. Then one of shift keying techniques is applied as modulation scheme to the input data sequence of each user. The modulated symbol of user *k* is denoted by D_k^t where *t* is the signaling time instant. In case of BPSK and DBPSK $D_k^t = \{\pm 1\}$ whereas, in QPSK modulation case, $D_k^t = \{\pm 1 , \pm j\}$. Each modulated symbol is spreaded using Walsh code with length *M* chips. The symbol after spreading could be expressed as follows:

$$\underline{S}_k^t = D_k^t \, \underline{W}_k \qquad \ldots \quad (1)$$

Where $\underline{W}_k$ is the PN code of the user *k*. The Walsh code could be obtained by many methods but the simplest way is by using Hadamard matrix. The Hadamard matrix is a square matrix of elements $\{\pm 1\}$ and the cross-correlation between each two rows equals to zero therefore, each row can be a perfect PN code in DS-CDMA system with the guarantee of no multiple access interference among users.

Another advantage of the Walsh code is that, when all transmitted symbols by the K users are summated, it will be destructive summation which means the PAR of the superimposed signal will be reduced [1]. The proposed model of the STBC ODFM – CDMA is displayed in figure 1.

Beginning from this point and forward, the parameter *t* will be omitted for simplicity and because transmission and reception process will be done over symbol-by-symbol.

As mentioned before, the main problem in the OFDM system is the relatively high PAR of the OFDM signal. Before displaying the proposed methods for reducing the PAR, let's define the PAR first:

$$PAR = \frac{\max\limits_{0 \le n \le N-1} \left\{ \left| s_{k,n} \right|^2 \right\}}{E\left[\left| s_{k,n} \right|^2 \right]} \qquad \ldots \quad (2)$$

Where; s_k is the time domain sequence constructed from S_k by evaluating N-point inverse fast Fourier transform IFFT for S_k.

2.1. SIMPLIFIED SYMBOL FORMATTING

In that scheme, the sequence denoted by $\underline{S}_k$ is divided into two halves; $\underline{S}_k[1]$ and $\underline{S}_k[2]$ where, the first halve is transmitted as it is whereas, the conjugate of the second halve will be transmitted. The previous steps could be summarized in the coming equation:

$$\underline{S}_k^f = [\underline{S}_k[1] \;\; \underline{S}_k^*[2]] \qquad \ldots \qquad (3)$$

After that the vectors of all the K users will be summated as follows

$$\underline{S}^f = \sum_{k=1}^{K} \underline{S}_k^f \qquad \ldots \qquad (4)$$

When calculating the PAR for the resultant vector, it was found that the PAR is smaller than the PAR of resultant vector without symbol formatting and simulation result has proved that.

2.2. SELECTIVE MAPPING (SLM) ALGORITHM

In the traditional SLM scheme [1] , [9] a set of complex vectors $P^{(g)}$ are first randomly generated each with size *N* and the total number of vectors is *G*. The elements of those vectors are described as: $P^{(g)} = \{\pm 1 , \pm j\}$ and $1 \le g \le G$. Each vector is multiplied by the vector $\underline{S}^f$ resulting in a group of vectors $\{\underline{S}^f(g) \quad , 1 \le g \le G\}$ which could be represented as follows:

$$S_n^f(g) = S_n^f \,.\, P_n^{(g)} \quad \ldots \quad (5)$$
$$0 \le n \le N-1 \quad , \quad 1 \le g \le G$$

Then the PAR is calculated for all obtained vectors and the one with the lowest PAR denoted by $\underline{S}'^f$ is the selected vector to be transmitted. In the proposed system, modified SLM scheme is applied which is more effective and simpler than the ordinary one. In the modified SLM, the length of the vectors $\{P^{(g)}\}$ is reduced to be N/F_d where $F_d = 2^j \in \{2, 4, 8, 16, \ldots$ etc $\}$ then only certain elements of $\underline{S}^f$ are selected to be multiplied by those vectors elements whereas, the rest items remain unchanged as follows:

$$S_i^f(g) = S_i^f \,.\, P_j^{(g)} \qquad \ldots \quad (6)$$

Where, $i = 0 , \frac{N}{F_d} - 1 , \frac{2N}{F_d} - 1 , \quad \ldots \quad N-1$

$j = 1 , 2 , \quad \ldots \quad F_d$

Here, the number of multiplications will be smaller than in the ordinary SLM technique.

2.3. PARTIAL TRANSMIT SEQUENCE (PTS) ALGORITHM

The PTS scheme is very similar to the SLM technique. In the traditional PTS scheme [7], a group of complex exponential vectors $\{b^{(v)}\}$ are randomly generated with length *N* given by: $b^{(v)} = e^{j\theta_v}$, $1 \le v \le V$. The set of phases $\{\theta_v\}$ are randomly selected from the range [0 , 2π [. Each vector is multiplied by the vector $\underline{S}^f$ resulting in a group of vectors $\{\underline{S}^f(v) \quad , 1 \le v \le V\}$ which could be represented as follows:

$$S_n^f(v) = S_n^f \,.\, b_n^{(v)} \;, 0 \le n \le N-1 \qquad \ldots \quad (7)$$

And similarly, the PAR is calculated for all obtained vectors and the one with the lowest PAR denoted by $\underline{S}'^f$ is the selected vector to be transmitted. But in this paper, a modified PTS technique [4] is applied in which the vector length of $\{b^{(v)}\}$ is reduced to be of only *N/C* items where $C = 2^j \in \{2, 4, 8, 16, \ldots$ *etc* $\}$. The difference between ordinary and modified PTS scheme is exactly as in the case of SLM approach, where certain elements of $\underline{S}^f$ is multiplied by those vectors elements whereas, the rest items remain unchanged as follows:

$$S_i^f(v) = S_i^f \,.\, b_j^{(v)} \qquad \ldots \quad (8)$$

Where, $i = 0 , \frac{N}{c} - 1 , \frac{2N}{c} - 1 , \quad \ldots \quad N-1$

$j = 1 , 2 , \quad \ldots \quad C$

2.4. SPACE TIME BLOCK CODER (STBC)

In multi-transmitting antennas system, instead of emitting the same symbol by all antennas at the same time, *L* successive symbols (over *L* signaling intervals) are stored and arranged to be transmitted through N_t transmitting antennas in permutation manner at each signaling interval and this is the main concept of STBC system[8]. In the proposed system, two cases are considered; two transmitting and four transmitting antennas cases ($N_t = 2$ and $N_t = 4$ respectively).

Two transmitting antennas:

In this case two successive symbols S_1 and S_2 are stored then at first signaling interval, antenna1 emits symbol S_1 and antenna2 emits symbol S_2. At second signaling interval, antenna1 emits $-S_2^*$ whereas, antenna2 emits S_1^*. This can be expressed in matrix form as follows:

$$\begin{bmatrix} S_1 & -S_2^* \\ S_2 & S_1^* \end{bmatrix} \quad \ldots \quad (9)$$

Four transmitting antennas:

The symbol transmission arrangement could be expressed in matrix form as follows:

$$\begin{bmatrix} S_1 & -S_2 & -S_3^* & -S_4^* \\ S_2 & S_1 & S_4^* & -S_3^* \\ S_3 & -S_4 & S_1^* & S_2^* \\ S_4 & S_3 & -S_2^* & S_1^* \end{bmatrix} \quad \ldots \quad (10)$$

In this case there are four symbols to be transmitted in four successive signaling intervals using four transmitting antennas. In the matrix given in (10) the column number denotes the antenna number whereas; the row number denotes the signaling time interval number.

3. PREAMBLE DESIGN FOR MULTIPLE – ANTENNA OFDM- CDMA

The preamble is a complex vector $\{X_i \;\; , 1 \le i \le N_t\}$ added at each transmitting antenna before real transmission of data which acts as a pilot sequence helping the receiver in channel estimation process. Those vectors are designed to be orthogonal in order not to have interference between those vectors at each receiving antenna, and they should be independent in order to monitor fading channel parameters at the receiver in efficient way. The selected phases for the preambles depend on two things; the number of transmitting antennas N_t and the number of IFFT points. The preamble vector can be displayed in matrix notation as follows:

$$\underline{X} = \begin{bmatrix} \underline{X}_1 \\ \underline{X}_2 \\ . \\ . \\ . \\ \underline{X}_{N_t} \end{bmatrix} = \begin{bmatrix} e_1 \underline{X}_1 \\ e_2 \underline{X}_1 \\ . \\ . \\ . \\ e_{N_t} \underline{X}_1 \end{bmatrix} \quad \ldots \quad (11)$$

Where; $\underline{X}_1 = [1 \;\; 1 \;\; 1 \;\; \ldots \;\; 1]$ $\longleftarrow N \longrightarrow$

$$e_i = \exp\left(j \frac{2\pi \, n p_i}{N} \right)$$

$n = 0, 1, 2, \ldots, N-1$ $\qquad p_i = \frac{(i-1)N}{N_t}$

and $i = 1, 2, \ldots, N_t$

Fig.2 displays an example of frequency domain preamble vectors with $N_t = 4$ and $N = 8$.

The channel between each pair of transmitting and receiving antennas is a multipath fading channel. The maximum number of paths between any transmitting and receiving antennas pair is denoted by N_P each path contains N coefficients with complex Gaussian distribution (Rayleigh envelope). The fading is assumed to be of frequency selective fast type. The impulse response of the channel between the transmitting antenna i and the receiving antenna j for the N_P paths could be expressed as follows:

$$h_{ij} = [\, h_{ij}(1) \;\; h_{ij}(2) \;\; \ldots \;\; h_{ij}(N_P)\,] \quad \ldots \quad (12)$$

By evaluating N-point FFT for the channel impulse response given in equation (12), we will get the channel frequency response as follows:

$$H_{ij} = [\, H_{ij}(0) \;\; H_{ij}(1) \;\; H_{ij}(2) \;\; \ldots \;\; H_{ij}(N-1)\,] \quad \ldots \quad (13)$$

4. STBC OFDM – CDMA RECEIVER MODEL

The receiver model is illustrated at figure 3 and the stages of reception process will be displayed in the coming subsections.

4.1. CHANNEL ESTIMATION

Preambles are transmitted by each antenna before real data transmission so the received vector, in frequency domain could be expressed as follows:

$$R_{ij} = X_i \,.H_{ij} + N_{ij} \quad \ldots \quad (14)$$

Where; R_{ij} is a square matrix of diagonal = $[R_1 \; R_2 \; \ldots \; R_N]$ representing the received vector from transmitting antenna *i* to receiving antenna *j*. And H_{ij} is a square matrix of diagonal given in equation (13). N_{ij} is a square matrix of diagonal = $[N_1 \; N_2 \; \ldots \; N_N]$ representing the AWGN vector in the path between transmitting antenna *i* to receiving antenna *j*.

By dividing the received matrix by the preamble matrix X_i, a rough estimate for the channel frequency response matrix denoted $\hat{H}_{ij}$ could be obtained as follows:

$$\hat{H}_{ij} = \frac{R_{ij}}{X_i} \quad \ldots \quad (15)$$

4.2. REAL DATA TRANSMISSION

The frequency domain vector received by receiving antenna j (obtained after N – point FFT operation) can be described as follows:

$$R_j = S'^f \sum_{i=1}^{N_t} H_{ij} + N_{ij} \quad \ldots \quad (19)$$

Where; S'^f is the frequency domain transmitted data vector in the final form (after symbol formatting and applying PAR reduction scheme). We have now rough estimate for channel parameters which could be used in channel equalization stage. In the proposed receiver, three channel equalization schemes are compared:

A. Phase Equalization:

In which, the received vector R is multiplied by the conjugate of the estimated channel matrix normalized to its absolute values of the same matrix follows:

$$\tilde{S} = R.\frac{\hat{H}^*}{\left|\hat{H}\right|} \quad \ldots \quad (20)$$

The numerator of the equalization term given in the equation above is for compensating the phase effect of fading channel coefficients whereas the denominator is for eliminating the amplitude of channel coefficient. This scheme is very powerful in deep fading environment.

B. Maximal Ratio Equalization

In this case, the received matrix R is multiplied by the conjugate of the estimated channel matrix as follows:

$$\tilde{S} = R.\hat{H}^* \quad \ldots \quad (21)$$

The operation is simpler than phase equalization process but could be effective only in case when all channel coefficients are close in amplitude to each other (i.e. no deep fading at any sample).

C. Minimum Mean Square Error Equalization

In this case, noise dimension is considered where the signal-to-noise is inserted into the channel equalization term as follows:

$$\tilde{S} = R.\left(\frac{\hat{H}^*}{\left|\hat{H}\right|^2 + B}\right) \quad \ldots \quad (23)$$

Where; $B = \dfrac{M}{K.SNR}$

After that, the vector $\tilde{S}$ is applied into the dispreading process to give a set of observation items denoted by $\{Z_k \,, 1 \le k \le K\}$ from which the transmitted symbols by each user can be estimated by making threshold detection. The dispreading process could be expressed as follows:

$$Z_k = \sum_{n=1}^{N} \tilde{S}(n)\,.\,W_k(n) \quad \ldots \quad (24)$$

5. PERFORMANCE EVALUATION AND SIMULATION RESULTS

The STBC OFDM – CDMA system has been simulated using computer software. In the coming set of curves, we concentrate on four points: comparison between the three equalization schemes mentioned before, system performance using various modulation techniques, the effect of applying channel coding on the receiver performance, and the effect of channel coder design on the receiver performance.

The first set of curves shown in figure (4) represents BER performance versus variation in SNR with following system parameters; the number of users K = 10, Walsh code length M = 32, the number of paths N_P = 3, using Hamming coding, and QPSK as modulation technique. All those parameters are repeated in two cases; in case of two transmitting antennas N_t = 2 and in case of single transmitting antenna N_t = 1. Simulation results have shown that the PE technique results in the lowest BER when compared to both MR and MMSE equalizers. Take for example the BER at SNR = 6 dB; in case of MMSE equalization the BER = 0.09, at MR equalization the BER = 0.008, and at PE the BER = 3.5×10^{-4}.

The next set of curves shown in figure 5 represents the BER performance versus variation in the SNR using the same parameters settings as in figure 4 but with BPSK as modulation technique. In this case also, the PE has shown the best performance with respect to the two other equalization schemes; MMSE and MR.

Figure 6 displays a comparison between BPSK and QPSK modulation techniques according to the BER level versus variation in the number of users K. The system parameters adjusted in this case are as follows: SNR = 4 dB, M = 32, and using Hamming coding. This is in case of three paths and two paths frequency selective fast fading channel (N_p = 3 and N_p = 2 respectively). As expected, the BER obtained by using BPSK is lower than QPSK because the QPSK results in more phase ambiguity between received signal constellations resulting in higher probability of error.

In figure 7, two channel coding techniques are compared Hamming coding and convolutional coding. In that set of curves, the BER performance versus change in the users' number is displayed for both coding techniques with SNR = 6 dB, M = 32, N_p = 3, and PE. As shown in that figure, by applying convolutional coding, lower BER could be obtained more than Hamming coding case. In case of convolutional coding, Viterbi algorithm has been applied for decoding purpose which is characterized by its ability of obtaining low error probability of the decoded data. At the same set of curves, two different designs for both Hamming and convolutional coders are given represented in form of solid and dashed lines for each couple of curves.

For Hamming coding; coder1 represents encoder with 11 bits input data word length and 15 bits output code word length or by another word (15 , 11) Hamming code. Whereas, code2 is (7 , 4) Hamming code and simulation results showed that code2 results in lower BER level. In case of convolutional coding two designs are assigned; coder1 and coder2 displayed in figures 8 and 9.

Simulation results have shown that coder2 can give lower BER level at the receiving end but it has more complicated design with respect to coder1. Table1 displays BER obtained at K = 14 for all cases shown in figure 6.

TABLE 1:

Convolutional Coding	*Coder1*	2.8×10^{-3}
	Coder2	1.2×10^{-3}
Hamming Coding	*Coder1*	3.5×10^{-5}
	Coder2	1.8×10^{-6}

The last set of curves, given in figure 10, displays the effect of the number of transmitting antennas N_t on the system performance. Where, that figure represents BER performance versus variation in SNR with following system parameters; K = 10, N_p = 3, convolutional coding, and PE. This is in two cases; with M = 16 and with M = 32. In table2, we will display an example of the obtained BER at SNR = 4 dB in each case.

TABLE II:

Nt = 1	*M = 16*	0.12
	M = 32	3.5×10^{-3}
Nt = 2	*M = 16*	0.019
	M = 32	1.2×10^{-4}
Nt = 4	*M = 16*	1.8×10^{-4}
	M = 32	4.5×10^{-7}

6. CONCLUSIONS

Wireless transmission of digital signals though multi-path frequency selective fast fading will be done in perfect way by applying multicarrier CDMA technique or OFDM – CDMA. Those two techniques when combined can mitigate distortion caused by both frequency selective and fast fading. Multi-transmitting multi-receiving antenna, denoted by STBC, is joined to the OFDM – CDMA system. Through that scheme, many versions of the same data message can be obtained at the receiving end each experiences different fading conditions (impossible to have deep fading at all links) so the reception process can be performed in better manner by using such diversity scheme. Simulation of the proposed system using computer software has shown that the BER level obtained at the receiver has reached order of 10^{-7} at SNR = 6 dB. But actually the performance of the STBC OFDM-CDMA receiver depends mainly on the channel equalization stage. In that paper, three different equalization schemes have been compared; PE, MR, and MMSE equalization and simulation results have sown that the PE results in the lowest BER level when compared with the two other techniques.

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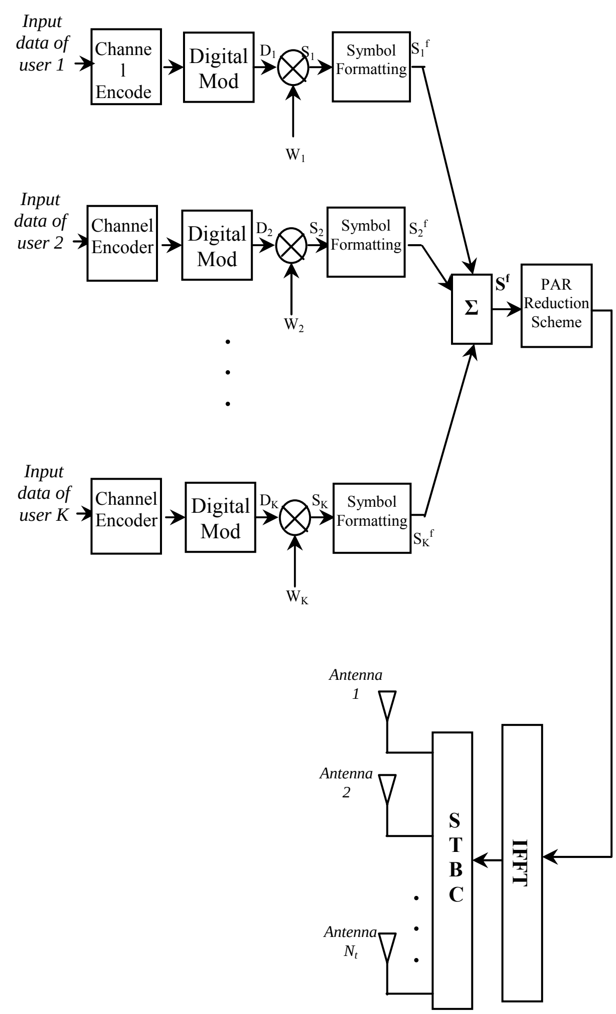

Fig. 1 "STBC OFDM – CDMA Transmitter Model"

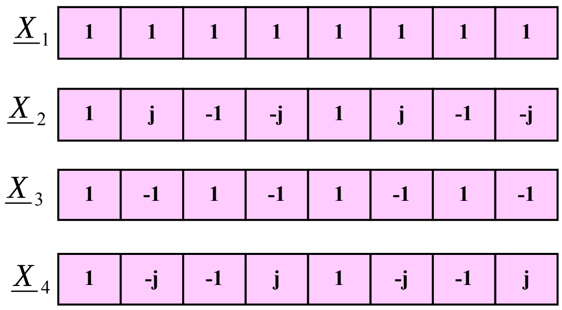

Fig.2 "Preamble Vectors in Frequency Domain with $N_t = 4$ and N = 8"

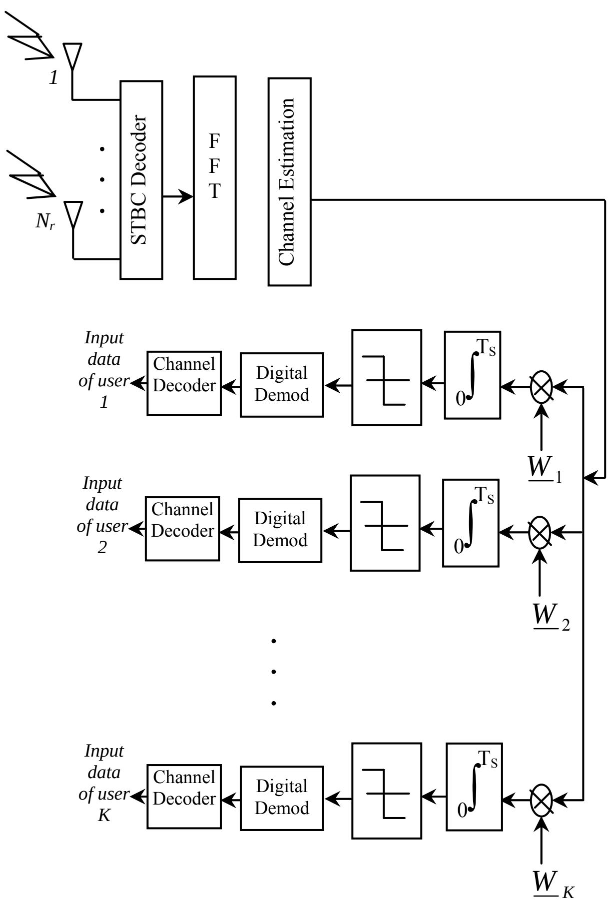

Fig. 3 "STBC OFDM – CDMA Receiver Model"

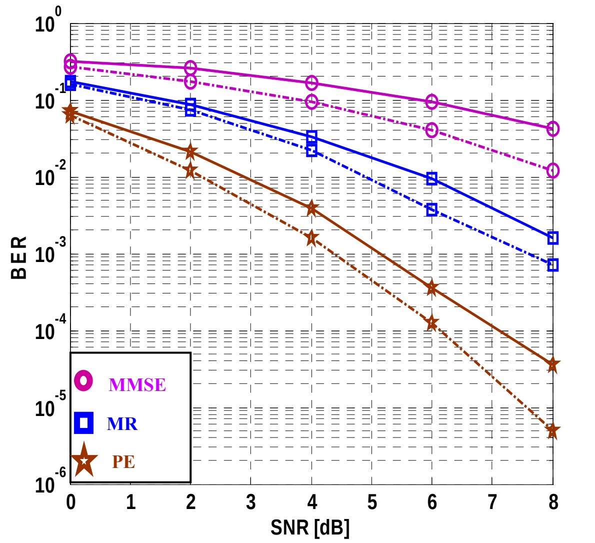

Fig. 4 "BER performance versus SNR assuming equal SNR for all K users with following system parameters; K = 10, Np = 3, G = 30, Fd = 8, M = 32, Hamming coding and QPSK modulation technique where, the solid line represents Nt = 1 and the dashed one is for Nt = 2"

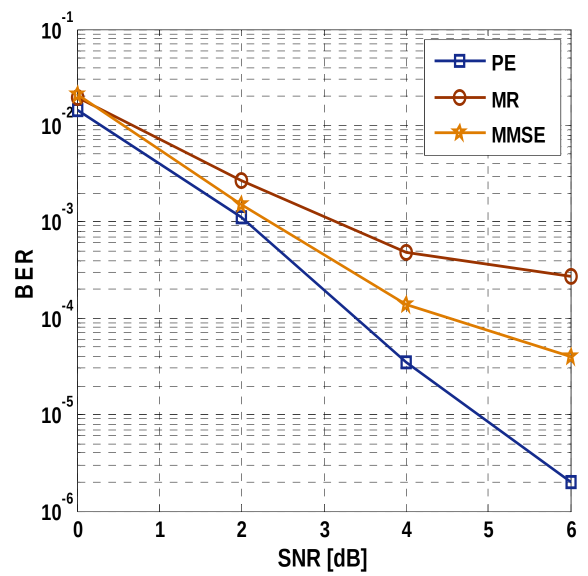

Fig. 5 "BER performance versus SNR assuming equal SNR for all K users with following system parameters; K = 10, Np = 3, G = 30, Fd = 8, M = 32, Hamming coding and BPSK modulation technique"

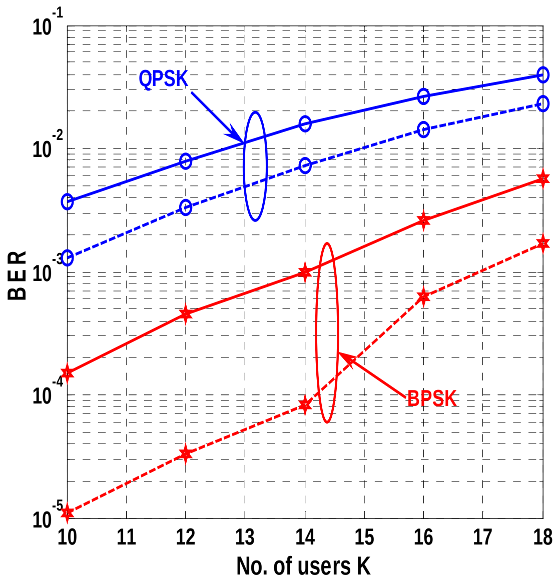

Fig. 6 "BER performance versus no. of users K assuming equal SNR for all users with following system parameters; SNR = 4dB, G = 30, Fd = 8, M = 32, using PE, and using Hamming coding where, the solid line is for Np = 3 and the dashed one is for Np = 2"

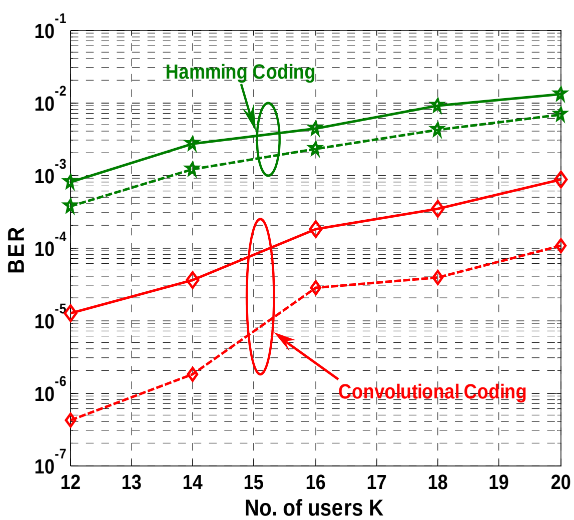

Fig. 7 "BER performance versus no. of users K assuming equal SNR for all users with following system parameters; SNR = 6dB, Np = 3, G = 30, Fd = 8, M = 32, for both Hamming and convolutional coding where, the solid line is for first code design and the dashed one is for second code design"

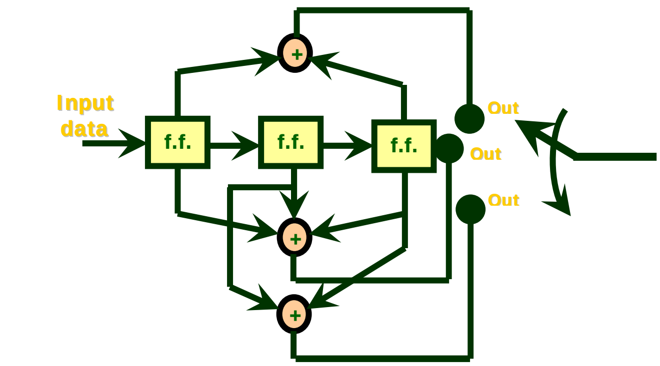

Fig. 8 "Convolutional Coder1"

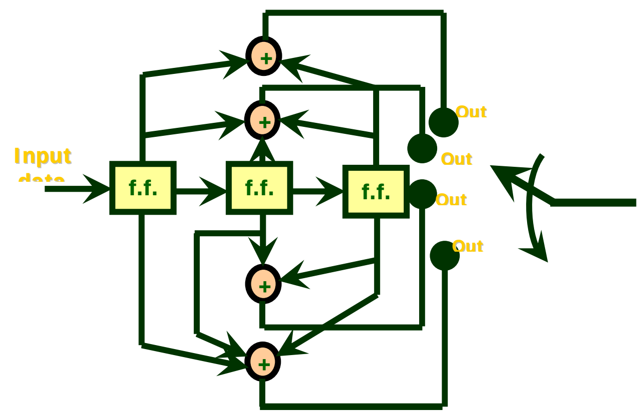

Fig. 9 "Convolutional Coder2"

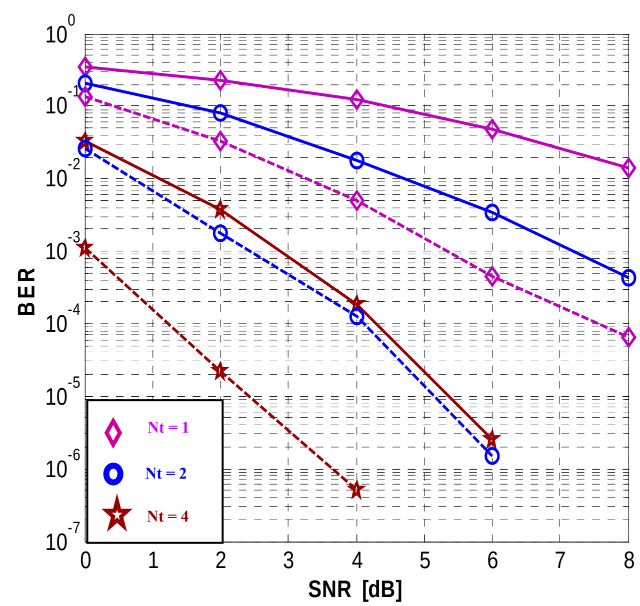

Fig. 10 "BER performance versus SNR assuming equal SNR for all K users with following system parameters; K = 10, Np = 3, G = 30, Fd = 8, PE, and convolutional coding where, the solid line is for M = 16 and the dashed one is for M =32"