LTE SYSTEM PERFORMANCE IN FREQUENCY SELECTIVE FADING CHANNEL WITH AID OF STBC TECHNOLOGY

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Abstract: Multipath fading is the major problem facing any wireless communications system. Orthogonal frequency division multiplexing (OFDM) is considered efficient solution for mitigating fading distortion especially frequency selective type. LTE and WiMAx families are based on OFDM technology which is the main reason for those systems high efficiency. In this paper two techniques will be joined in order to mitigate distortion caused by multipath frequency selective fading channel. Channel estimation and equalization are necessary processes when the channel is time variant, as usual for most wireless channels. System performance has been analyzed based on BER level obtained at the receiving end versus variation in SNR at different system situations. Simulation of the proposed system has been done using computer software and results will be displayed in form of set of curves and tables.

Key words: OFDM – STBC – SLM

1. INTRODUCTION

In wireless communication field, any novel technology is focusing on one target which is to allow flexible system expansion for more subscribers with acceptable service quality. The first challenge for this target is the complicated characteristics for wireless channel mainly the multipath fading effect which requires special improvement applied to both transmitter and receiver. In the recent ten years, the fourth generation for mobile communication system (denoted by 4G) has been appeared with many candidate technologies. LTE system belongs to this generation which is based on OFDM technique and this is the proposed system in our paper. In OFDM technique transmitted data are distributed over N_c orthogonal sub- bands with spectral spacing inversely proportional to data symbol duration. The main target of this technique is to make data transmission distributed over multi frequency bands so that when one of those bands is subjected to channel fading distortion (even deep fading) only part of data will be affected not all transmitted data. Another benefit of OFDM technology is to reduce data transmission rate over each sub-channel to be slower than channel coherence time so slow fading situation will be guaranteed. [1]. As usual there is no perfect system therefore we have to be honest and display the main problems facing OFDM. The first problem is the high peak – to – average power ratio (PAR) which in most cases leads receiver amplifier to be saturated and that causes distortion in detected signal. In order to mitigate that problem there should PAR reduction technique applied in transmission process. Many types of PAR reduction techniques were tested since appearance of OFDM in early 90's such as clipping and peak windowing, peak cancellation, PAR reduction codes and symbol scrambling. In this paper one PAR reduction scheme will be applied in OFDM transmitter which is selective mapping (SLM) that belongs to symbol scrambling category and it will be described in details in the coming subsections. [2] , [3]. Recently MIMO technology became vital addition in wireless communication systems especially after the appearance of 3G and 4G mobile systems family. One special form of MIMO system known by Space time block coding (STBC) will be considered in this paper. In STBC transmitted symbols are emitted from transmitting antennas in a certain arrangement and that arrangement is changed at each signaling interval. In order to help the receiver in making channel estimation, preamble vector is emitted from each antenna before real data transmission [6]. Those preambles should be designed in a certain way in order to be orthogonal to each other. At the receiver an estimate for the channel coefficients could be obtained by the help of those preambles based on which channel equalization process will be performed [7]. In this paper we will handle special modified STBC LTE communication system with subsections arranged as follows: subsection 3 describes STBC LTE transmitter model whereas receiver and multi- path fading models will be described in subsection 4. In subsection 5 results obtained from proposed system simulation will be displayed and analyzed in details. In the last subsection conclusions for proposed system will be handled.

2. TRANSMITTER MODEL

All stages of proposed system transmitter are illustrated in the block diagram shown in figure 1. The first stage in the transmitter is the data source which is assumed to be binary data source with output vector denoted by $\underline{b} \in \{0, 1\}$ .Channel coding process has become vital stage at any wireless communication system. In this paper we will examine the effect of two different channel coding technique; hamming code and convolution code. After that digital mapping (or base band digital modulation) takes place in which the mathematical forms for amplitude and phase of data symbol can be determined. For example when considering BPSK modulation technique, then modulated symbols will be as follows: $\underline{S} \in \{\pm 1\}$ whereas when considering QPSK modulation, then Following to this step, parallel- to- serial conversion takes place that delivers a finite length symbols vector to the IFFT operator which is considered the basic operation in OFDM transmitter. Elements of time domain vector (OFDM symbol) obtained after IFFT operation could be described as follows:

$$s_n = \frac{1}{N}\sum_{k=1}^{N} S_k \exp\left(j\frac{2\pi k n}{N}\right)$$

$$0 \le n \le N-1 \quad \ldots \quad (1)$$

Where; N is the number of data symbols applied to the IFFT operation and also is the length of OFDM symbol vector obtained at the output of the IFFT operator or by another word it is the number of subcarriers used per OFDM symbol.

2.1. MODIFIED SELECTIVE MAPPING

One of PAR reduction techniques known by selective mapping (SLM) is applied in the proposed system transmitter and that will be applied before IFFT operation which means that the length of input vector to SLM algorithm is N. In the coming paragraph, steps of SLM algorithm will be described in brief.

In the traditional SLM scheme [8] , [9] a set of G complex vectors $P^{(g)}$ are first randomly generated each with size N where those vectors described as: $P^{(g)} = \{\pm 1, \pm j\}$ and $1 \le g \le G$. Each vector will be multiplied by the vector $\underline{S}$ (obtained at the digital modulator output) giving a group of vectors $\{\underline{S}^{SL}(g) \quad ,1 \le g \le G\}$ which could be represented as follows:

$$S_n^{SL}(g) = S_n^{f} \,.\, P_n^{(g)} \qquad ,$$

$$0 \le n \le N-1 \quad \ldots \quad (2)$$

Then the PAR is calculated for all obtained vectors and the one with the lowest PAR denoted by $\underline{S'}^{SL}$ is the selected vector to be transmitted.

Note: Remember that the PAR for a time domain vector is calculated as follows:

$$PAR = \frac{\max\left\{ |s_n|^2 \,, 0 \le n \le N-1\right\}}{1/N \sum_{n=0}^{N-1} |s_n|^2} \quad \ldots \quad (3)$$

In the proposed system, modified SLM scheme is applied which is more effective than the ordinary one in which the length of generated vectors $\{P^{(g)}\}$ are reduced to be N/F_d where $F_d = 2^{j} \in \{2, 4, 8, 16, \ldots$ modulated

Symbols will be $\underline{S} \in \{\pm 1 \pm j\}$.

etc }which means that some elements of $\underline{S}$ are selected to be multiplied by those vectors elements (elements number 0 , $\frac{N}{F_d} - 1$, $\frac{2N}{F_d} - 1$, . . . , $N - 1$.

Whereas , the rest items remain unchanged which means that the number of multiplications will be smaller than in the ordinary SLM technique.

2.2. SPACE TIME BLOCK CODING

The last stage in the transmitter is STBC operator representing MIMO technology realization in the proposed system. The main difference between traditional MIMO system and STBC systems is that in MIMO system the same symbol is emitted from all transmitting antennas at the same time whereas in STBC system L successive symbols (over L signaling intervals) are stored to be transmitted through transmitting antennas by a certain order which is changed at each signaling interval [10]. The optimum performance for STBC system is obtained when the stored symbols length L equals to the number of transmitting antennas N_t. In the proposed system, two cases are considered; two transmitting ($N_t = 2$) and four transmitting antennas $(N_t = 4)$. Arrangement of symbols transmission is represented by the aid of transmission matrix. Let's display two examples of transmission matrices:

Two transmitting antennas:

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

$$\begin{bmatrix} S_1 & -S_2^* \\ S_2 & S_1^* \end{bmatrix} \qquad \ldots \quad (4)$$

Four transmitting antennas:

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

$$\begin{bmatrix} S_1 & -S_2 & -S_3^* & -S_4^* \\ S_2 & S_1 & S_4^* & -S_3^* \\ S_3 & -S_4 & S_1^* & S_2^* \\ S_4 & S_3 & -S_2^* & S_1^* \end{bmatrix} \quad \ldots \quad (5)$$

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

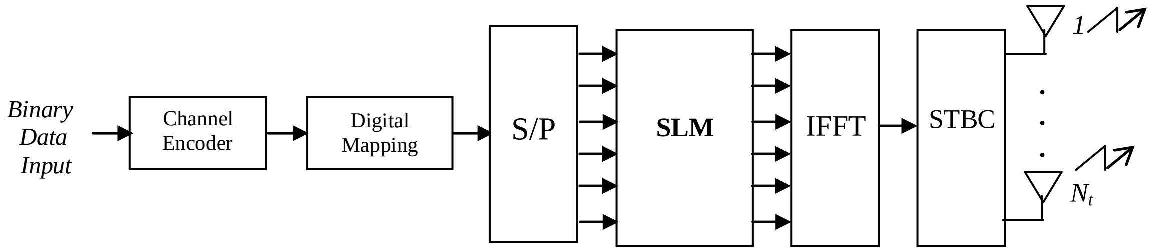

Fig.1 "STBC OFDM Transmitter Model"

2.3. PREAMBLE DESIGN FOR MULTIPLE – ANTENNA SYSTEM

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 helps 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. The selected phases for the preambles depend on two things; the number of transmitting antennas N_t and the number of IFFT points N. The preamble vector can be displayed in matrix notation as follows:

$$\underline{X} = \begin{bmatrix} \underline{X}_1 \\ \underline{X}_2 \\ \cdot \\ \cdot \\ \cdot \\ \underline{X}_{N_t} \end{bmatrix} = \begin{bmatrix} e_1 \underline{X}_1 \\ e_2 \underline{X}_1 \\ \cdot \\ \cdot \\ \cdot \\ e_{N_t} \underline{X}_1 \end{bmatrix} \quad \ldots \quad (6)$$

Where; $\underline{X}_1 = [1 \;\; 1 \;\; 1 \;\; .. \;\; 1]$ (length N)

$$e_i = \exp\left(j \frac{2\pi \, n p_i}{N} \right) n = 0 , 1 , 2 , \ldots , N-1 \qquad p_i = \frac{(i-1)N}{N_t}$$

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

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

$\underline{X}_{P1}$	1	1	1	1	1	1	1	1
$\underline{X}_{P2}$	1	i	-1	-i	1	i	-1	-i
$\underline{X}_{P3}$	1	-1	1	-1	1	-1	1	-1
$\underline{X}_{P4}$	1	-i	-1	i	1	-i	-1	i

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

Following to those preambles transmission there should be interval of no signaling, called guard interval (GI), in order to mitigate any interference that may happen between two successive signaling intervals. Therefore the GI is chosen to be greater than or equal the coherence time of the fading channel or by another word $N_{GI} \geq N_P$ where; N_{GI} is the number of bits equivalent to the guard interval and N_P is the maximum number of paths between any pair of transmitting and receiving antennas.

3. RECEIVER MODEL

Stages of proposed receiver model are simply performing reverse operation of corresponding stages in the transmitter model as illustrated in figure 3. Therefore we will discuss each stage briefly.

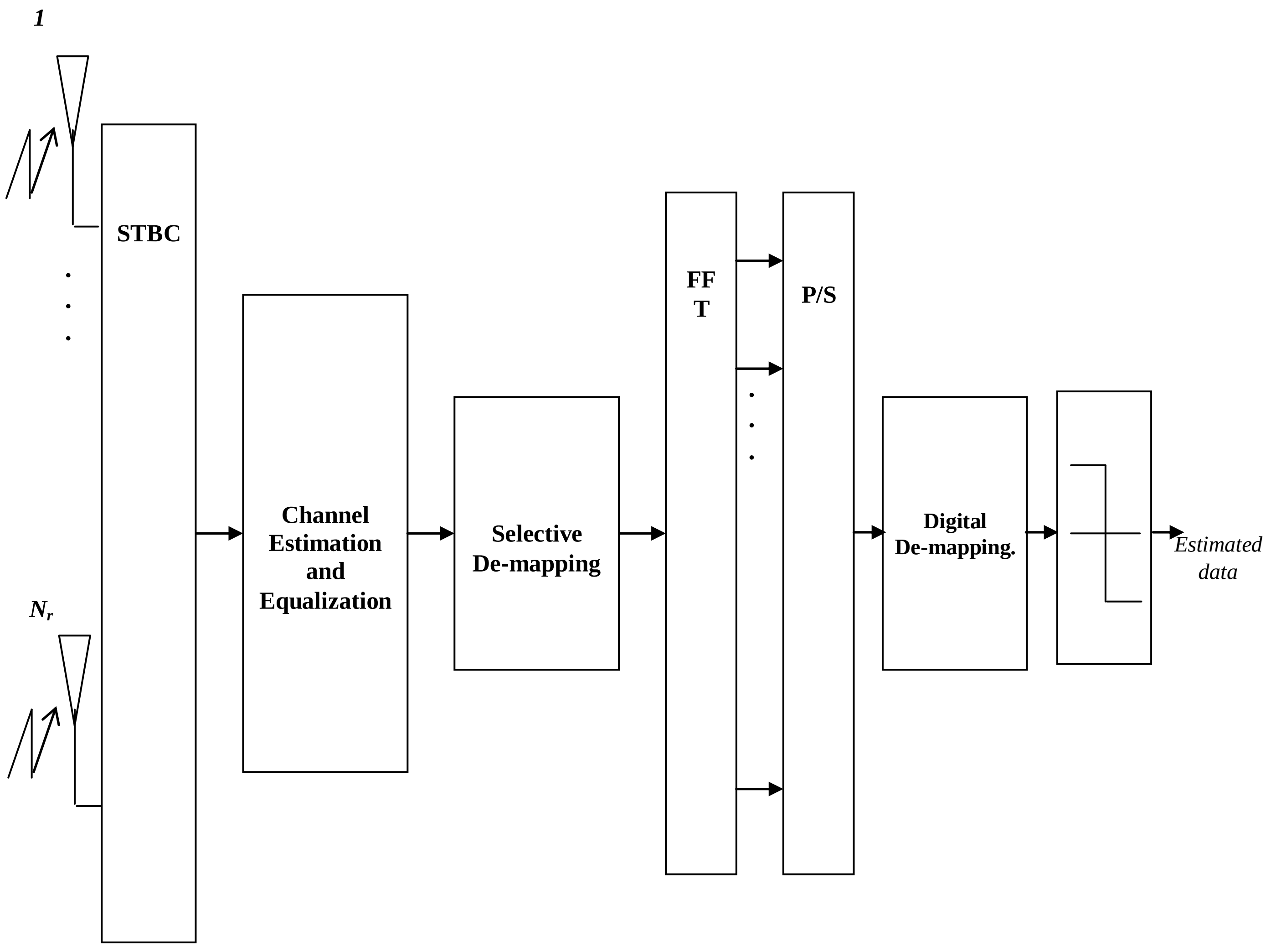

Fig.3: "STBC OFDM Receiver Model"

At each signaling interval there are N_t data symbols delivered at each receiving antenna (we have N_r receiving antennas). As shown in figure 3, the first stage in the receiver is STBC decoder which store received symbols vector in its original order and phase. There are N_t versions for transmitted data symbol each experiences different channel characteristics. Actually there are many techniques for combining those versions ate each receiving terminal such as maximal ratio combining (MRC) and equal gain combining (EGC) which is the selected combining technology in this paper [11].

3.1. CHANNEL ESTIMATION PROCESS

As mentioned before, preamble vectors are transmitted at the beginning of every signaling interval in order to enable the receiving end in channel estimation process. When transmitting preamble vector number i (i = 1 , 2 , . . . , N_t) denoted by X_i, then received vector could be defined as follows:

$$R_{ij} = diag(\underline{X}_i).\underline{C}_{ij} + \underline{N}_{ij} \quad ... \quad (7)$$

Where:

- R_{ij} is the received vector by receiving antenna j corresponding to emitted preamble vector X_i from transmitting antenna i.
- C_{ij} is channel frequency response coefficients of the link between transmitting antenna i and receiving antenna j with length equals to OFDM symbol length = N. But in time domain, channel coefficients vector could be described as follows:

$$\underline{c}_{ij} = \left[c_{ij}^{(1)} \; c_{ij}^{(2)} \; \cdots \; c_{ij}^{(Np)}\right] \quad ... \quad (8)$$

Where: N_p is the maximum number of paths in the link between any pair of transmitting and receiving antennas.

As mentioned before, preamble vectors are known at the receiving end to be used for estimating channel frequency response coefficients as follows:

$$\left(C_{ij}\right)_{est} = \frac{R_{ij}}{diag(X_i)} \quad ... \quad (9)$$

3.2. CHANNEL EQUALIZATION PROCESS

After emitting preamble vectors, real data vector $\underline{S}_i$ is transmitted from transmitting antenna i. ($1 \le i \le N_t$). When this vector is received by receiving antenna j, that received vector could be described as follows:

$$\underline{Z}_{ij} = diag(\underline{S}_i).\underline{C}_{ij} + \underline{N}_{ij} \quad ... \quad (10)$$

As well known, channel equalization process means to compensate channel distortion by multiplying received vector (in frequency domain) by inverse version of estimated channel matrix. In the proposed receiver, phase equalization will be applied in which, the received vector $\underline{Z}_{ij}$ is multiplied by the conjugate of the estimated channel matrix normalized to its absolute values of the same matrix follows:

$$\tilde{S}_{ij} = \underline{Z}_{ij} \cdot \frac{\left(C_{ij}\right)^{*}_{est}}{\left|\left(C_{ij}\right)_{est}\right|} \quad ... \quad (11)$$

In order to have one version for estimated data symbols vector at any time instant, combination process takes place. In the proposed system equal gain combining is applied resulting in estimated symbols vector as follows:

$$\tilde{S} = \frac{1}{N_t \; N_r} \sum_{i=1}^{Nt} \sum_{j=1}^{Nr} \tilde{S}_{ij} \quad ... \quad (12)$$

4. SYSTEM SIMULATION

In this subsection, proposed system simulation results will be displayed and analyzed in details. Simulation has been performed using MATLAB 10 code for STBC LTE transmitter and receiver block diagrams shown in figures 1 and 3 respectively. When evaluating system performance, we should study the effect of many parameters on performance efficiency. Let's display the effect of special effective parameters on proposed system performance efficiency. The first set of curves shown in figure 4 displays BER performance versus SNR variation in threes different situations; without channel coding, with hamming code (7 , 4) and with convolutional code. It is well known that convolutional code enhances system performance in remarkable way since it results in acceptable BER at lower SNR when compared with another forward error correcting codes. The applied convolution encoder here is with code rate = 1/3. In order to compare between hamming and convolutional codes with respect to non- channel coding case, let's pick one BER level from figure 4 in the mentioned three cases. Where in order to have BER = 10^{-3}, it is required to adjust SNR to be more than 10 dB in non- channel coding case whereas in hamming coding case required SNR of 8.5 dB. When convolutional code is applied only 6.5 dB is required to achieve the same BER level. In those set of curves, system parameters are set as follows: the number of subcarriers N_c = 32, selective mapping (SLM) population size G = 30, SLM step size F_d = 8, the number of transmitting antennas N_t = 2, the number of receiving antennas N_r = 1, the channel is multi-path frequency selective fading with Rayleigh distribution, Doppler shift = 50 Hz, and maximum number of paths = 3.

In the next set of curves shown in figure 5 we will study the effect of convolutional encoder design on system performance based on BER behavior versus SNR variation. In convolution encoder design, there are three parameters to be considered; number of shift registers (constellation length), outputs number and outputs polynomials (code generators).

Four convolutional encoder designs are compared in figure 5 with parameters displayed in table1. The major parameter effecting on error correcting capability of the convolutional code is the constellation length where the BER will be lowered when the constellation length is increased. For example at SNR = 7 dB, obtained BER = 0.01 when encoder 1 is applied. Whereas when encoder 2 is applied, obtained BER = 1.1176 x 10^{-4} at the same value for SNR. When considering encoders 3 and 4 obtained BERs will be 7.8162 x 10^{-5} and 3.9075 x 10^{-5} respectively.

In figure 5, system parameters are set as follows: the number of subcarriers N_c = 32, selective mapping population size G = 30, SLM step size F_d = 8, the number of transmitting antennas N_t = 2, the number of receiving antennas N_r = 1, the channel is multi-path frequency selective fading with Rayleigh distribution, Doppler shift = 50 Hz, and maximum number of paths N_p = 3.
The main conclusion observed from previous set of curves is that when the number of encoder outputs is increased, smaller level of BER could be obtained at the receiver bust that is conditioned on selected polynomials. Whereas, the number of shift registers has less effect on the BER value. For example, BER is changed from 7.8 x 10^{-5} to 3.9075 x 10^{-5} when the encoder length is increased from 3 to 4 shift registers.

The main factor used in this paper for performance enhancement is STBC. Therefore simulation results should include the effect of transmitting – receiving antennas combination. As well known, increment in both number of transmitting and receiving antennas will result in BER decreasing and the reason is that there will be more versions of the same data symbols each experiences different channel characteristics which are all obtained at the receiving end. In figure 6 four different cases for transmitting – receiving antennas combinations; (1 x 1), (2 x 1), (2 x 2), and (4 x 2) with following system parameters; the number of subcarriers N_c = 32, selective mapping population size G = 30, SLM step size F_d = 8, convolutional coder 2, the channel is multi-path frequency selective fading with Rayleigh distribution, Doppler shift = 50 Hz, and maximum number of paths = 3.

As illustrated in this figure, the lowest BER level is obtained in case of applying four transmitting antennas and two receiving antennas when compared with the other three considered cases. In table 2 we have picked obtained BER at SNR = 5dB:

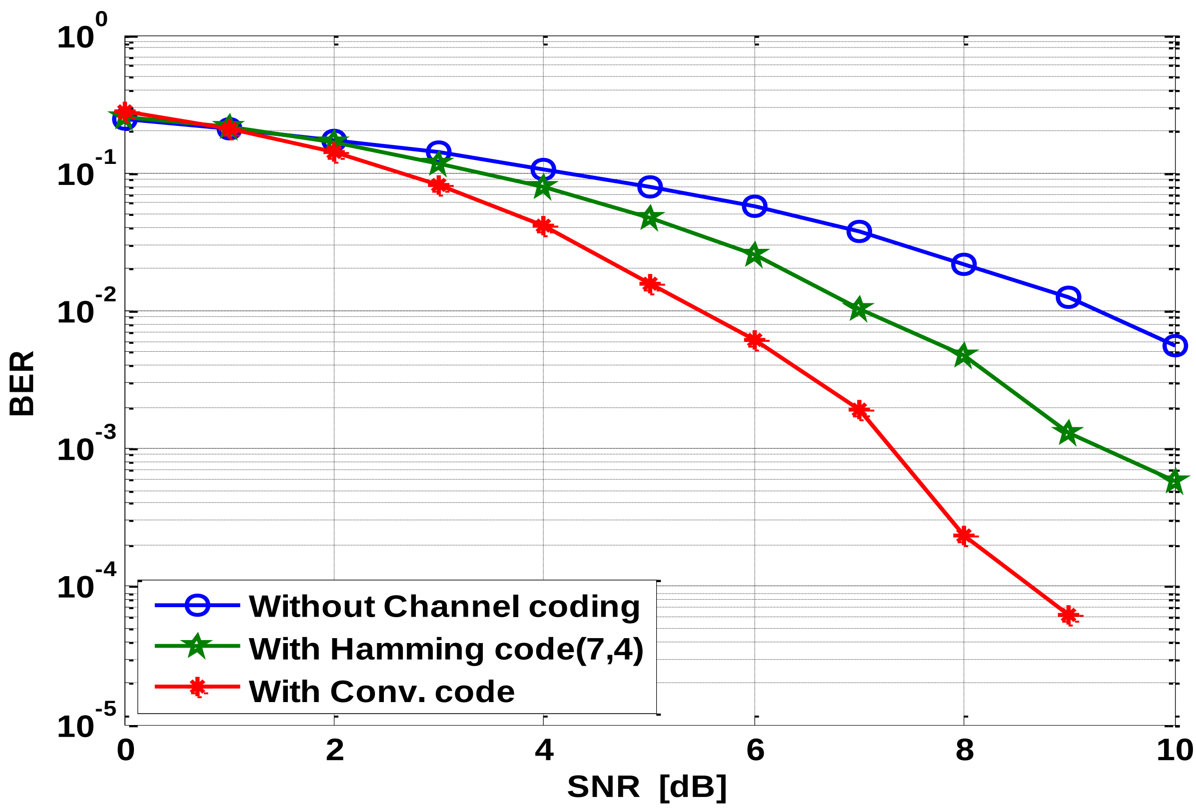

Fig. 4 **"BER performance vs SNR variation in three channel coding situations using *(N_t x N_r)* = (2 x 1), N_c = 32, G = 30, F_d = 8, Doppler shift = 50 Hz, N_p = 3"**

Table 1: Convolutional encoders parameters used in figure 5

	Number of S.R.	*Number of outputs*	*Outputs Polynomials*
Encoder 1	*3*	*2*	$Out_1 = 1 + x + x^2$ $Out_2 = 1 + x^2$
Encoder 2	*3*	*3*	$Out_1 = 1 + x + x^2$ $Out_2 = 1 + x^2$ $Out_3 = 1 + x$
Encoder 3	*3*	*4*	$Out_1 = 1 + x + x^2$ $Out_2 = 1 + x^2$ $Out_3 = 1 + x$ $Out_4 = 1 + x + x^2$
Encoder 4	*4*	*4*	$Out_1 = x^3$ $Out_2 = x + x^2 + x^3$ $Out_3 = 1 + x + x^2 + x^3$ $Out_4 = x^2 + x^3$

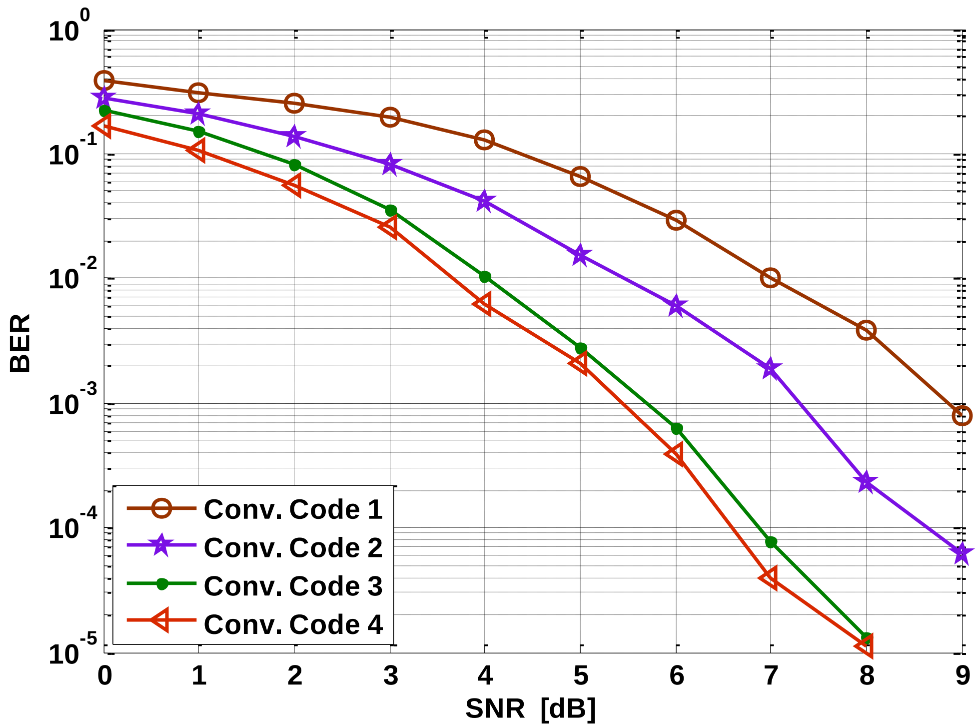

Fig. 5 "BER performance vs SNR variation using N_t x N_r = 2 x 1, N_C = 32, G = 30, F_d = 8, Doppler shift = 50 Hz, convolutional coding, and number of paths = 3"

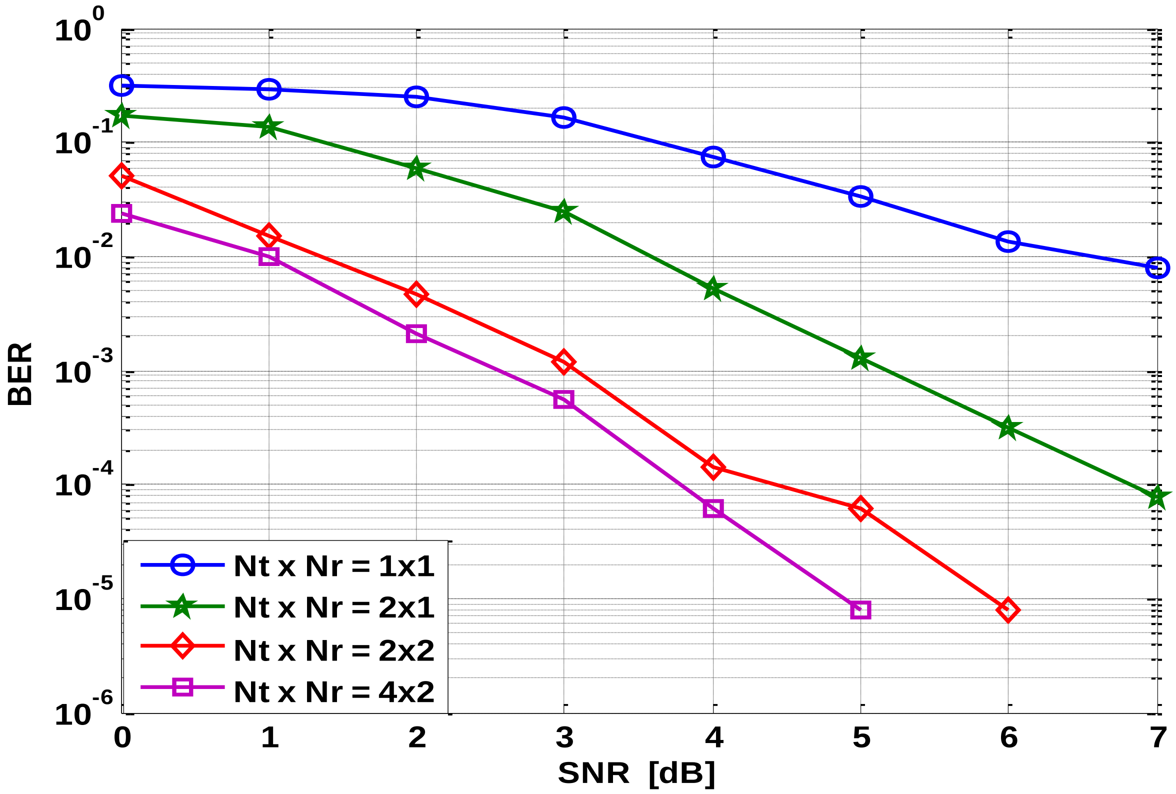

Fig. 6 "BER performance vs SNR variation with $N_C = 32$, $G = 30$, $F_d = 8$, Doppler shift = 50 Hz, convolutional cod 2, and number of paths = 3"

Table 2: "BER at SNR = 5 dB obtained using different STBC configurations"

(Nt x Nr)	*BER*
1 x 1	*0.0333*
2 x 1	*0.0034*
2 x 2	6.2512×10^{-5}
4 x 2	7.8140×10^{-6}

5. CONCLUSION

Orthogonal frequency division multiplexing has shown efficient performance enhancement when inserted into any wireless communication system and it is the secret of LTE family efficiency. Space time block coding is considered special case for MIMO technology that can mitigate fading distortion in its worst form. In addition to OFDM combined with STBC techniques, there are traditional stages should be inserted into any wireless communication system which are channel coding and channel equalization in order to make error correction and channel compensation respectively at the receiving end. All those combined techniques have resulted in acceptable BER obtained at the receiver (e.g. BER is order of 10^{-5} when 2 x 2 STBC is applied at SNR =5 dB). But actually there is one shortage in the proposed system is the necessity of preamble vectors transmission before every OFDM symbol transmission in order to enable the receiver in channel estimation process which makes that system unsuitable for real time communication applications.

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