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Performance of OFDM- CDMA System using Modified Space- Shift Keying Technique

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ABSTRACT

Many reasons cause multi- carrier CDMA to be the best technology in the latest mobile generations known by fourth generation for mobile. As well known, the greatest enemy for any wireless communication is multi- path fading which usually result in distortion in time- domain, or in frequency domain or even in both. Therefore any new technique applied into mobile communication system is concerning with mitigating multi-path fading distortion which appears in form of reducing BER level. In this paper three techniques have been combined in order to enhance mobile system performance in the presence of multipath fading channel. These techniques are, orthogonal frequency division multiplexing (OFDM), code division multiple access (CDMA), and modified space shift keying (SSK). The last technique is considered special case for MIMO technology. By the aid of MATLAB code, proposes system was simulated in order to display BER performance versus variation in the SNR at many various system conditions.

Keywords: *OFDM, CDMA, MIMO, and SSK*

I. INTRODUCTION

Since the introduction of OFDM, there are many researches that have been focus to fully exploit the benefits of OFDM either in improving the data rate, the capacity or achieve better spectrum efficiency with the technique. Many researchers have proposed combination between OFDM and CDMA systems to achieve better spectrum efficiency and also increase the system capacity. [1 - 3] This system is also known as the MC-CDMA (Multi-carrier CDMA) system. MCCDMA system achieves comparable performance of DS-CDMA, however, the benefits of the MC-CDMA system lies within its flexibility and the relatively simple receiver design. The core difference between MC-CDMA and DS-CDMA is that the codes that identify different users are modulated in the frequency domain instead of in the time domain. Since the codes are introduced in the frequency domain, there is no need for a rake receiver that complicates the whole system.

An MC– CDMA system has no major advantage over a DS – CDMA system in terms of required bandwidth. Also in terms of performance, the Bit Error Ratio (BER) lower bound of an MC – CDMA system is same as that of a DS – CDMA system. But actually the major benefit of MC- CDMA over DS-CDMA is the acceptable BER in the presence of frequency selective fading channel which can't be reached using DS-CDMA technology. As well known, the optimum spreading code could be used in DS- CDMA is based on the Walsh-Hadamard coding which ensures minimum cross- correlation between different codes, as the rows are mutually orthogonal. Therefore, Walsh code is selected to be the spreading code the proposed MC- CDMA system.

MC – CDMA system includes two forms of diversity; time and frequency diversity therefore all the scattered received signal energy can be effectively combined in both frequency and time domains. [4] OFDMA is one of the most promising solutions to provide a high performance physical layer in emerging Point to Multipoint (PMP) networks. It is based on OFDM immunity to Intersymbol Interference (ISI) and frequency selective fading. [5 – 11]

Orthogonal Frequency Division Multiplexing (OFDM) is a popular multicarrier transmission technique that has recently seen rapid growth and is recognized as an excellent method for high bit rate wireless data communication. The OFDM scheme has the following key advantages:

- OFDM is an efficient way to deal with multipath fading, especially frequency selective fading form, where fading channel over every sub- channel is converted from frequency selective fading into flat fading from [3].
- Concerning with mitigating distortion caused by multi-path fading, the implementation complexity is significantly lower than that for a single carrier system with an equalizer.
- In relatively slow time – varying channels, it is possible to significantly enhance the capacity by varying the data rate per subcarrier according to signal – to – noise ratio for that particular subcarrier.
- OFDM is robust against narrowband interference, because such interference affects only small percentage of the subcarriers.
- OFDM makes single – frequency networks possible, which is especially attractive for broadcasting applications. [4].

OFDM supports multiusers with popular multiple access schemes, these schemes are Multicarrier Code Division Multiple Access (MC– CDMA) and Orthogonal Frequency Division Multiple Access (OFDMA). MC–CDMA has gained much attention because the signal can be easily transmitted and received using Inverse Fast Fourier Transform (IFFT) and (FFT) processors without increasing the transmitter and receiver complexities. Therefore, upgrading from third generation (3G) to fourth generation (4G) will be simple matter.

Impressive improvements in capacity and bit error rates (BERs) have motivated the recent interest in multiple-antenna radio systems, also known as multiple-input multiple-output (MIMO) systems. Along with the gains, however, comes a price in hardware complexity. The radio terminals, at both transmitter and receiver, have complexity, size, and price that scale with the number of antennas. MIMO signaling can improve wireless communication in two different ways: diversity methods and spatial multiplexing. Diversity methods improve the robustness of the communication system in terms of BER by exploiting the multiple paths between transmit and receive antennas. On the receive side, this diversity is similar to that provided by the RAKE receiver. Diversity can also be obtained with multiple transmit antennas, but then one must address the mutual interference of simultaneously transmitting antennas. This leads to a body of work known as *space-time coding*. Defining *diversity order* as the slope of the BER–signal-to-noise ratio (SNR) curve, space time codes are capable of delivering diversity order of *NrNt*, where *Nr* and *Nt* are the number of receive and transmit antennas, respectively. [12]

Although MIMO systems provide dramatic capacity gain through an increased spatial dimension, the capacity gain is reduced if the channel state information (CSI) is not perfect. Since perfect CSI is difficult to be obtained in MIMO systems due to an increased number of channel parameters to estimate at the receiver, the channel capacity with imperfect CSI is an important problem to investigate. [13], [14]. There have been several approaches in this area. In [15], [16], Lapidoth, *et al.* show that in the absence of CSI the MIMO capacity only grows double-logarithmically as a function of signal-to-noise ratio (SNR), and we do not benefit from the increased spatial dimensions. However, under certain conditions, MIMO systems with reasonable channel estimation accuracy can achieve linear increase of capacity at practical SNR values [17].

It is important to specify the channel fading condition since it affects the accuracy of CSI and the way CSI could be obtained. CSI at the receiver (CSIR) is typically obtained via channel estimation. Pilot or training based channel estimation schemes are studied in [18 – 20] for block fading channels and channels with a band-limited Doppler spectrum, respectively, and their achievable rates are derived.

Space modulation is a novel digital modulation concept for (MIMO) wireless systems, which is receiving a growing attention due to the possibility of realizing low–complexity and spectrally–efficient MIMO implementations [21 – 24]. The space modulation principle is known in the literature in different forms, such as Information– Guided Channel Hopping (IGCH) [21], Spatial Modulation (SM) [22], and Space Shift Keying (SSK) modulation [23]. Although different from one another, all these transmission technologies share the same fundamental working principle, which makes them different from conventional modulation schemes: they encode part of the information bits into the spatial position of the antenna–array, which plays the role of a constellation diagram (the so–called "spatial–constellation diagram") for data modulation [24].

II. SYSTEM MODEL

Consider K users transmitting data symbols in synchronous manner where data symbol of user k denoted by D_k is with form depend on digital mapping type. For example in case of BPSK $D_k \in \{\pm 1\}$ whereas in case of QPSK $D_k \in \{\pm 1, \pm j\}$. Spreading process is applied after that over each data symbol belong to each user (i.e D_k , $1 \le k \le K$). As well known, Walsh code is the optimum PN used in DS- CDMA technique since obtained codes from this method have perfect orthogonality. The simplest way of Walsh code generation is by using Hadamard matrix where every row (or column) in this matrix could be used as single user PN code excluding first row or first column since it contains all ones. Hadamard matrix is simply generated using software codes. The simplicity of Walsh codes generation is considered another advantage for such kind of PN code. Let's display an example of Hadamard matrix valid to be used as PN cods for 7 users which is generated using MATLAB command:

$$C = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{bmatrix} \begin{array}{l} \\ \rightarrow \underline{C}_1 \\ \rightarrow \underline{C}_2 \\ \rightarrow \underline{C}_3 \\ \rightarrow \underline{C}_4 \\ \rightarrow \underline{C}_5 \\ \rightarrow \underline{C}_6 \\ \rightarrow \underline{C}_7 \end{array}$$

Data symbol of user k after being spread is denoted by $\underline{S}_k$ given as follows:

$$\underline{S}_k = D_k.\underline{C}_k = [S_k^0 \ S_k^1 \dots S_k^{M-1}] \quad \dots \quad (1)$$

In particular, SSK modulation exploits only the spatial–constellation diagram for data modulation, which results in a very low–complexity modulation concept for MIMO systems [23]. In SSK modulation, blocks of information bits are mapped into the index of a single transmit–antenna, which is switched on for data transmission while all the other antennas radiate no power. The messages sent by the transmitter can be decoded at the destination what ever was channel impulse response for transmit–to– receive wireless link assigned for time interval of interest. Regardless of the information message to be transmitted and, thus, the active transmitting antenna in SSK modulation exploits the location–specific property of the wireless channel assigned for data modulation [24]. In [23] and [24], it has been shown that the achievable performance of SSK modulation depends on how different the conditions of channel impulse responses are. In other words, the channel impulse responses are the points of the

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spatial– constellation diagram, therefore the space modulation concept is more sensitive to channel estimation errors.

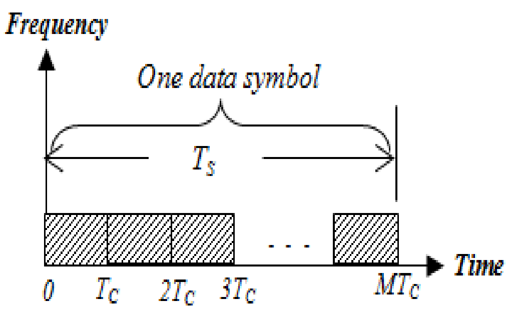
Where; $\underline{C}_k$ is PN code of user k of length M chips and chip duration T_c so that $T_S = M.T_C$. T_S is defined as symbol duration. The sum of K spread vectors denoted by $\underline{S}$ could be described as follows:

$$\underline{S} = \sum_{k=1}^{K} \underline{S}_k = \sum_{k=1}^{K} D_k . \underline{C}_k \quad \cdots \quad (2)$$

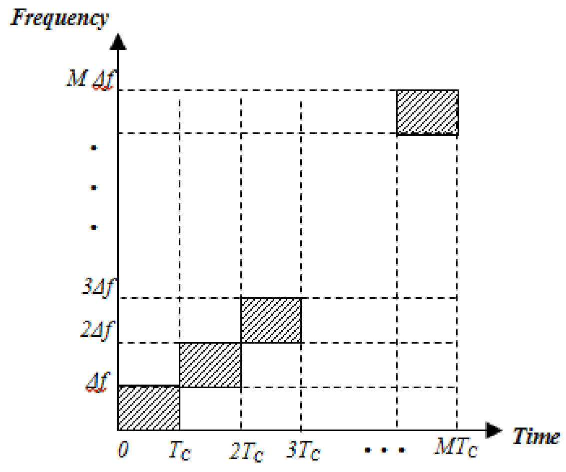
It is required after that to make those chips, defined in equation (2), modulating group of subcarriers with frequency spacing = Δf with a certain condition in order to be orthogonal in frequency domain. [3] This process could be achieved using bank of modulator or by simpler way using Inverses Fast Fourier Transform (IFFT) processor which is executed in software manner. As well known, IFFT process is considered the main stage in OFDM modulator. If we consider spread data vector $\underline{S}$ representing frequency domain vector, then data vector after IFFT operation will represent time domain vector obtained as follows:

$$\underline{s} = \frac{1}{M} \sum_{m=0}^{M-1} S(m)\, e^{jim\left(\frac{2\pi}{M}\right)} \quad , i = 0 , 1 , \ldots , M - 1$$
$$= \begin{bmatrix} s_0 & s_1 & \cdots & s_{M-1} \end{bmatrix} \quad \cdots \quad (3)$$

As mentioned before, by combining OFDM and DS- CDMA technologies we have two forms of diversity; frequency and time diversity respectively. Figure (1) displays relationship between time and frequency for single data symbol before and after IFFT process.



(a) Spread data symbol before IFFT operation



(b) Spread data symbol after IFFT operation

Fig. 1: "Effect of IFFT Operation on Time- Frequency Characteristics of CDMA Symbol"

Before emitting the time- domain vector $\underline{S}$ through transmitting antennas, RF modulation stage is applied. There are N_t transmitting antennas but not activated together where some antennas will be selected at every signal interval (i.e. symbol duration). Modified space shift keying SSK is the proposed algorithm used for selecting transmitting antenna which will be explained in the coming subsection. Figure (2) illustrates stages of MIMO OFDM- CDMA transmitter.

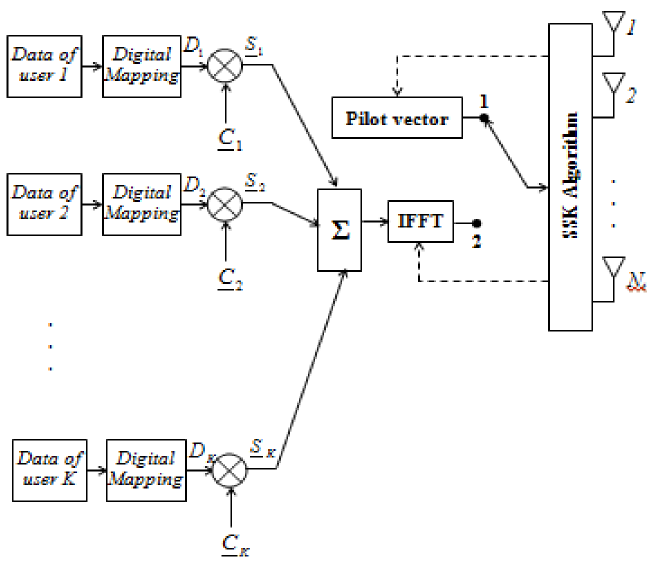


Fig. 2 "Transmitter Model for MIMO OFDM- CDMA System"

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Before real data transmission, preamble (pilot) vector is emitted through selected antennas in order to enable receiver to estimate present channel impulse response. After transmission of preamble vector, time domain data vector denoted by $\underline{S}$ given in equation (3) will be emitted through the same group of selected antennas.

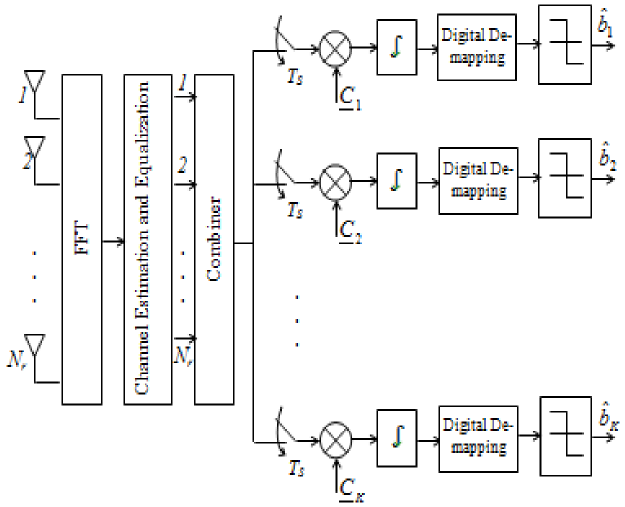

Fig. 3 "Receiver Model for MIMO OFDM- CDMA System"

Receiver stages are simply reverse ordered operations of transmitter model therefore we are not going to explain stages of receiver except in two positions channel estimation and equalization which are going to be explained in details in the coming subsection. Receiver stages of proposed MIMO OFDM- CDMA system is illustrated in figure (3). Proposed receiver uses N_r receiving antennas in order to introduce space diversity at receiving end as well as in transmitter. As mentioned before, there are N_t transmitting antennas which means that each spread OFDM will experience (N_t x N_r) different channel impulse responses. Actually this is the secret of MIMO technology efficient performance especially in bad fading channel conditions. In SSK algorithm, not all transmitting antennas are activated at each signaling interval whereas all receiving antennas are activated all the time.

MODIFIED SSK ALGORITHM

A. Traditional SSK Algorithm*:*

Considering a generic Nt × Nr MIMO system, then we can display basic steps of SSK algorithm as follows:

i. The transmitter encodes blocks of log2(Nt) data bits into the index of a single transmit–antenna, which is switched on for data transmission while all the other antennas are kept idle.
ii. The receiver solves a Nt–hypothesis detection problem to estimate the transmit–antenna that is activated, which results in the estimation of the unique sequence of bits emitted by the encoder.

In table (1) an example of 8 transmitting antenna assigned with 3 data bits used for encoding process.

Table -1: "Traditional SSK No.1"

Encoding Bits	Selected Antenna
0 0 0	1
0 0 1	2
0 1 0	3
0 1 1	4
1 0 0	5
1 0 1	6
1 1 0	7
1 1 1	8

Another SSK algorithm was introduced in which more than one transmitting antenna could be used at every signaling interval but requires data bits with length = N_t in order to select activated transmitting antenna. Table (2) displays an example of 4 transmitting antennas selection.

Table -2: "Traditional SSK No.2"

Encoding Bits	Selected Antenna
0 0 0 1	(4)
0 0 1 0	(3)
0 0 1 1	(3 , 4)
0 1 0 0	(2)
0 1 0 1	(2 , 4)
0 1 1 0	(2 , 3)

In SSK algorithms mentioned before, there are many drawbacks that can cause system performance degradation. Those problems are given as follows:

1. The main target of space diversity is to introduce various channel conditions by using many transmitting antenna at the same time. When selecting single antenna to be used in transmission process this means that space diversity technique will not be efficient as needed.
2. In the second SSK algorithm, the number of selected antenna i could be $1 \le i \le N_t$ which result in more

possible channel frequency responses to be estimated at the receiver. In order to avoid disadvantages of traditional SSK algorithms, modified SSK algorithm will be introduced in this paper.

B. Modified SSK Algorithm:

Modified SSK algorithm differs from traditional SSK algorithms in many points. You can notice that clearly when reading steps of modified SSK algorithm displayed as follows:

Step 1: Select an integer L so that L < 2Nt.

Step 2: Put integers serial [0 , 2Nt – 1] then convert these integers to binary form with length Nt bits per code.

Step 3: Invert the first bit at every vector obtained in step 2.

Step 4: Sort binary vectors in descending order based on the number of ones at every vector (code).

Step 5: Select first L vectors from sorted vectors obtained in step 4 then put them in another pool. Those vectors contain the highest number of ones.

Step 6: Every vector in the selected pool, with size L vectors, will determine selected antennas to be used for emitting one data symbol at each signaling interval.

Let's display an example for modified SSK algorithm results using Nt = 3 , L = 5 in table (3).

Table -3: "Modified SSK Algorithm"

Step"1"	Step"2"	Step"3"	Step"4"	Step"5"	Step"6" "Selected antennas"
$N_t = 3$ $L = 5$	0 0 0 0 0 1 0 1 0 0 1 1 1 0 0 1 0 1 1 1 0 1 1 1	1 0 0 1 0 1 1 1 0 1 1 1 0 0 0 0 0 1 0 1 0 0 1 1	1 1 1 1 0 1 1 1 0 0 1 1 1 0 0 0 1 0 0 0 1 0 0 0	1 1 1 1 0 1 1 1 0 0 1 1 1 0 0	(1 , 2 ,3) (1 , 3) (1, 2) (2 , 3) (1)

CHANNEL ESTIMATION AND EQUALIZATION

As mentioned in previous subsection describing modified SSK algorithm, at each signaling interval there are different group of transmitting antennas selected to emit the same data OFDM- CDMA symbol. Now let's denote number of selected transmitting antennas by n where $n \le N_t$. In order to enable receiving end to estimate channel frequency response, pilot signal is usually transmitted before real data transmission. Similar to pilot signal preamble vectors can perform the same target. Preamble vector are unit vectors (i.e. all ones) with length = M to be emitted in successive manner from n transmitting antennas selected at each signaling interval. Duration of each preamble vector = TS denoted before as data symbol duration. Actually preamble vectors are not emitted directly but first subjected to IFFT process exactly like data. Transmitted preamble vector from transmitting antennas number i is given as follows:

$$P_i = [\underbrace{1 \quad 1 \quad \cdots \quad 1}_{\leftarrow M \rightarrow}] \quad 1 \le i \le n \qquad \ldots \quad (4)$$

After IFFT:

$$p_i = [\underbrace{1 \quad 0 \quad \cdots \quad 0}_{\leftarrow M \rightarrow}] \quad 1 \le i \le n \qquad \ldots \quad (5)$$

Received preamble by receiving antenna j is considered estimated version for channel impulse response expressed as follows:

$$\tilde{c}_{ij} = \underline{p}_i \otimes c_{ij} + n_{ij} \qquad \ldots \quad (6)$$

Where:

$\tilde{c}_{ij}$ is estimated channel impulse response of the link between transmitting antenna i and receiving antenna j.

n_{ij} is AWGN of the link between transmitting antenna i and receiving antenna j with unity variance and power spectral density = No.

c_{ij} is the actual channel impulse response of the link between transmitting antenna i and receiving antenna j expressed as follows:

$$\underline{c}_{ij} = [A_{ij}^{(1)} \exp(j\theta_{ij}^{(1)}) \;\; A_{ij}^{(2)} \exp(j\theta_{ij}^{(2)}) \;\cdots\; A_{ij}^{(Np)} \exp(j\theta_{ij}^{(Np)})] \qquad \ldots \quad (7)$$

Where:

$A_{ij}^{(l)}$ and $\theta_{ij}^{(l)}$ are amplitude and phase of channel impulse response in the link between transmitting antenna i and receiving antenna j of path number l. (amplitudes have Rayleigh distribution)

NP is the maximum number of paths in fading channel.

After applying M-point FFT operation for estimated channel impulse given in equations (6) and (7) we can obtain estimated version for channel frequency response described as follows:

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$$\tilde{C}_{ij} = diag\left([\tilde{C}_{ij}^{(0)}\ \tilde{C}_{ij}^{(1)} \cdots \tilde{C}_{ij}^{(M-1)}]\right) \quad \ldots\ (8)$$

When all transmitting antennas are used together to emit preamble vector in successive manner, estimated channel frequency response seen by receiving antenna number j could be described as follows:

$$\underline{\tilde{C}}_j = [\underline{\tilde{C}}_{1j}\ \underline{\tilde{C}}_{2j} \cdots \underline{\tilde{C}}_{nj}] \quad \ldots\ (9)$$

By applying windowing process, we can separate frequency response for every single link $\{1 \le i \le n\}$. Now real data will be emitted from the same set of selected antennas (n antennas) and it is assumed that channel characteristics are remain unchanged. Received vector by receiving antenna j when OFDM- CDMA symbol is emitted from transmitting antenna i could be expressed as follows

$$r_{ij} = \underline{s} \otimes c_{ij} + n_{ij} \quad \ldots\ (10)$$

In order to compensate distortion caused by multi- path fading channel, channel equalization should take place. Actually channel equalization became essential stage at any wireless receiver. In this paper maximal ratio equalizer is selected since it is known by its efficient performance.

After applying FFT process on received vector given in equation (10), then channel equalization stage could be applied described as follows:

$$\left(R_{ij}\right)_{eq} = R_{ij} \cdot conj\left(\tilde{C}_{ij}\right) \quad \ldots\ (10)$$

Where; R_{ij} is received vector after FFT process with length M.

SIMULATION RESULTS

In the coming subsection, proposed system has been simulated using MATLAB code. The target of system simulation is to analyze the effect of many parameters on the proposed system performance.

The first set of curves shown in figure (4) represents BER performance versus variation in the SNR for proposed MIMO OFDM- CDMA system using following parameters; N_t = 2, N_r = 1, and N_P = 3. Three values of subcarriers number denoted by M have been used; 16, 32, and 64. Remember that M also represents PN code length used in MC- CDMA spreading process. For each value of M, two cases have been considered; solid curve represents case of 10 users (i.e. K = 10), whereas dashed curve represents case of 15 users (i.e. K = 15). Actually figure (4) studies effect of two parameters; PN code length M and the number of multiplexing users K in the proposed system. As expected, increment in the PN code length has positive effect on BER level where this will cause degradation in BER. The opposite will happen when the number of users increases where BER will increase if the number of users increases.

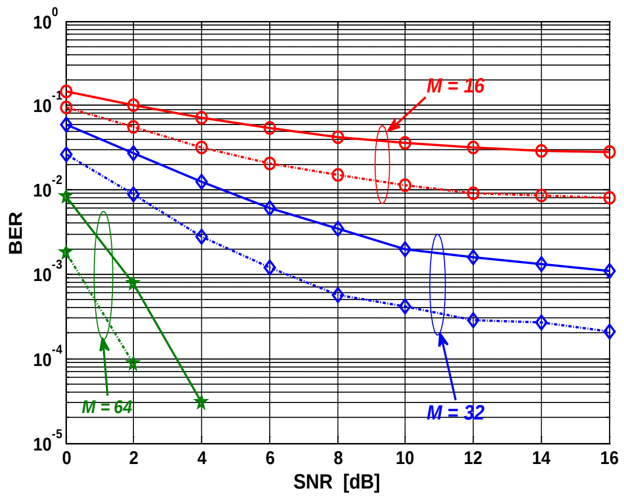

Fig. 4: "BER performance for MIMO OFDM- CDMA System in Rayleigh fading channel with N_P = 3, N_t = 2, and N_r = 1 using M = 16, 32, and 64. Solid line for K = 15 and dashed line for K = 10"

When talking about CDMA technology we should focus on multiple access interference MAI as the major problem which causes degradation in the system performance. MAI increases with increment in the number of users whereas MAI decreases when the length of PN code increases. Table (4) gives an example for BER obtained at SNR = 2 dB for all cases mentioned in figure (4).

Table -4: "BER at SNR = 2dB for curves in figure 4"

K = 10	M = 16	0.056
	M = 32	0.0089
	M = 64	8.7×10^{-5}
K = 15	M = 16	0.1023
	M = 32	0.0272
	M = 64	7.8×10^{-4}

When concerning with any MIMO communication system, then simulation results should include different combinations of transmitting – receiving antennas number. Increment in both number of transmitting and receiving antennas will cause decreasing in the BER obtained at receiver. Although in SSK algorithm not all N_t transmitting antennas are used for emitting the same data symbol, also increment in the number of transmitting antennas, as well as in the receiving antennas, will result in BER reduction.

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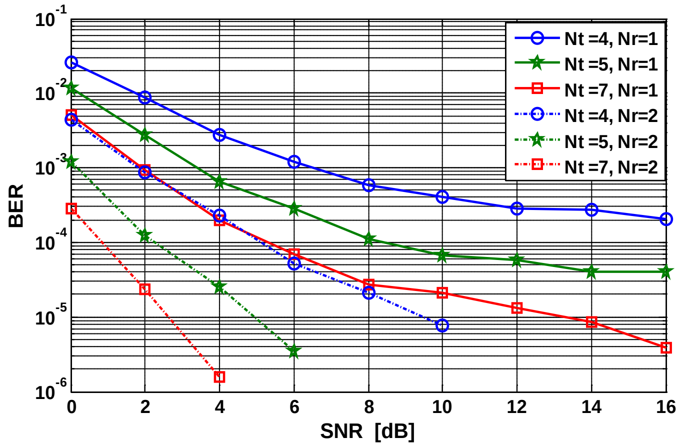

Fig. 5: "BER performance for MIMO OFDM- CDMA System in Rayleigh fading channel with N_P = 3, M = 32, K = 10 using different combinations of Nt x Nr"

The reason for is that when more transmitting and receiving antennas are provided, more variety of fading channels will be provided which means data symbol will experience different channel conditions. When any of those channels contains deep fading conditions, it will be impossible to have deep fading over all provided links. Figure (5) illustrates 6 combinations of N_t x N_r using M = 32, K = 10, and N_P = 3. In the coming table we have peaked an example for BER obtained at receiver for SNR = 4dB for cases illustrated in figure (5) in order to display the effect of increasing the number of both transmitting and receiving antennas on the BER level.

Table -5: "BER at SNR = 5dB for curves in figure 5"

N_r = 1	**N_t = 4**	0.0028
	N_t = 5	6.51 x 10-^{4}
	N_t = 7	1.98 x 10^{-4}
N_r = 2	**N_t = 4**	2.25 x 10^{-4}
	N_t = 5	2.5 x 10^{-5}
	N_t = 7	1.56 x 10^{-6}

The last set of curves shown in figure (6) displays how the number of fading channel paths denoted by N_P affects on the proposed system performance. Four cases are displayed in figure (6) considering N_P= 3, 5, 7, and 10. In this case more channel paths means more scattering in the transmitted signal power and more time dispersion in the received symbols which increases the probability of ISI observed at receiving end. In brief more channel paths will increase BER obtained at receiver. Considering the worst fading conditions among considered cases (i.e. N_P = 10 paths) obtained BER reaches order of 10^{-4} at SNR = 6dB which is considered acceptable performance in such bad conditions. This confirms what is mentioned before at introduction of this paper which is the effect of combining OFDM, CDMA, and MIMO technologies on performance enhancement especially in bad multi- path fading channel conditions (i.e. frequency selective – fast – many paths)

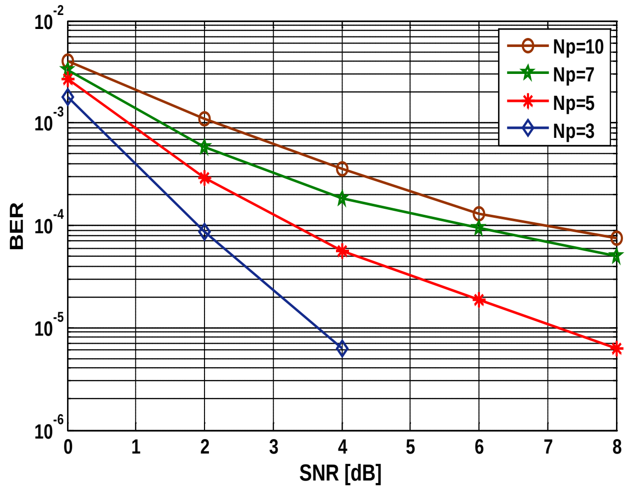

Fig. 6: "BER performance for MIMO OFDM- CDMA System in Rayleigh fading channel with N_t = 4, N_r = 1, M = 64, K = 10 for different number of channel paths N_P"

CONCLUSIONS

Fourth generation of mobile has introduced many different families one of those families uses both OFDM and CDMA techniques together in order to join benefits of frequency and time diversity. But in spite of the efficient performance of all families of the 4G, it faces great challenge because of required services. Modern applications for digital communication systems such as video calls, internet services, mobile live entertainments, ..., etc all those applications need higher transmission data rates and high quality of services. We have recommended in this paper, novel technique for MIMO technology denoted by modified SSK has been inserted into OFDM- CDMA system. This modified algorithm provides efficient selection for transmitting antennas instead of using all transmitting antennas as in case of traditional MIMO technology. Simulation results for proposed system showed acceptable BER level at small value of SNR and also at bad fading channel condition. For example at only SNR = 4dB, BER is order of 10^{-6} using 7 transmitting antennas and 2 receiving antennas in presence of multi- path Rayleigh fading channel.

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