

## **A Proposed Improvement Model for MC-CDMA in Selective Fading Channel**

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**Abstract**—In this paper, a proposed model based on phase matrix rotation was suggested to improve the performance of Multicarrier-Code Division Multiple Access (MC-CDMA) lies in Fast Fourier Transform (FFT) algorithm under the Additive White Gaussian Noise (AWGN) and frequency selective fading channel. This model is used to reduce the effect of multipath fading. The results extracted by a computer simulation for a single user, then it compared with the original technique for MC-CDMA based on FFT for both systems. As a result, it can be seen from the proposed technique that a high performance improvement was obtained over the conventional MC-CDMA, where the Bit Error Rate (BER) is widely reduced under different channel characteristics for frequency selective fading and the AWGN channel.

**Key Words**—MC-CDMA, AWGN, BER, Phase Matrix, Selective Fading

### **1. Introduction**

The most important objectives on the 4G wireless systems are to take care of the severe Inter-Symbol Interference (ISI) resulting from the high data rates, and to utilize the available limited bandwidth in a spectrally efficient manner. To achieve these objectives, there are two principle contending technologies, Orthogonal Frequency Division Multiplexing (OFDM) and Code Division Multiple Access (CDMA). CDMA is a well-known standard and has been used for several years. The MC-CDMA scheme spreads the original data stream using spreading code and then modulates different carriers with each chip, i.e. spreading the chips in frequency domain [1]. The second type spreads the serial to parallel converted streams using a spreading code and then modulates different carrier with each data stream, i.e., spreading in time domain [2].

The input data stream is spread using the spreading sequence which could be a Walsh-Hadamard code or a PN sequence, and the resultant chips after spreading the symbols are modulated into different subcarriers using the Inverse Fast Fourier Transform (IFFT) operator [3, 4]. The end few symbols are appended at the beginning of the frame to act as the cyclic prefix. The cyclic prefix maintains orthogonality between the subcarriers in a multipath channel [5]. Firstly, at the receiver removes the cyclic prefix and then performs a Fast Fourier Transform (FFT) operation of the received symbols and brings them back to the frequency domain. Then de-spreading and decoding of the chips in frequency domain are performed for the traditional MC-CDMA. To further enhancement the spectral efficiency of the OFDM-CDMA, the proposed MC-CDMA based FFT and the traditional OFDM-CDMA are discussed with their main blocks and the analysis are given to simplify the comparison between them.

## 2. Simulation Model

OFDM-CDMA transmitter spreads the original signal using a given spreading code in the frequency domain. In other words, a fraction of the symbol corresponding to a chip of the spreading code is transmitted through different subcarriers. For multicarrier transmissions, it is essential to have frequency nonselective fading over each subcarrier. Therefore, if the original symbol rate is high enough to become subjects to frequency selective fading, the signal needs to first be converted from serial to parallel before spreading over the frequency domain [6, 7].

The relative motion between receiver and transmitter, or mobile medium among them, would result in the Doppler effect. For example, the Doppler effect would influence the quality of a cell phone conversation in a moving car. On the other word, the path delay causes a fluctuation in the received signal and leads to an inter-symbol interference. The block diagram of the traditional OFDM-CDMA is shown in **fig. 1**.

At the receiver of OFDM-CDMA, if there is an error occurred due to multipath or noise in one bit (for example), then, at the output of the FFT there will be a high error occurred at the other bits due to mixing of phases and values of signal by FFT. So, if there is an algorithm that be able to inhibits the error in this bit from spreading or affecting on the other bits at the output of the FFT at the receiver then, the BER will reduce, such algorithm can be done by multiplying the transmitted signal by a Phase Matrix (PM) at the transmitter side and the Inverse of Phase Matrix (IPM) at the receiver side. This property can be verifying because the same bits are modulated on different subcarriers. So, it is possible to transmit each bit on different ordered phase. In the same time if the output of IFFT vectors are directly multiplied by a phase vector (not phase matrix), then it is impossible to arrange the output phases of transmitted vector in a constant increasing or decreasing order, because every bit out of IFFT at the transmitter side has a related phase value and the multiplication of this vector by an ordered vector will not be able to arrange the phase values. Another advantages of phase matrix related with the power of the transmitted signal via the channel, the output signal power from the IFFT will be reduced to a very low level compared with the input value to it, the phase matrix will be able to retrieve the signal power to its normal level as the same input mean value to the IFFT.

The transmitted symbol which consist of N-IFFT bins can be multiplied by a Phase Matrix (PM) which can be simply generated as in Eq. (1) and Eq. (2)

$$x(n, i) = \sum_{v=0}^{N-1} x(n * N - (N - 1) + v, i) e^{-j(2\pi / N).i.v} \quad (1)$$

Where;

n: data bit stream number.

I: frequency bin of the FFT or IFFT (from 1 to N)

N: the window size of FFT.

It can be seen that the Phase Matrix in equation (1) is a square matrix with a dimension of N\*N points. The phase of this matrix is changed as the frequency bin of the FFT is changed. If the FFT has 64 points, then the Phase Matrix in Eq. (1) can be formulated in the form:

$$P.M. = \begin{bmatrix} e^{-j(2\pi/64)*0} & e^{-j(2\pi/64)*1} & e^{-j(2\pi/64)*2} & \dots & e^{-j(2\pi/64)*63} \\ e^{-j(2\pi/64)*0} & e^{-j(2\pi/64)*2} & e^{-j(2\pi/64)*4} & \dots & e^{-j(2\pi/64)*126} \\ e^{-j(2\pi/64)*0} & e^{-j(2\pi/64)*3} & e^{-j(2\pi/64)*6} & \dots & e^{-j(2\pi/64)*189} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ e^{-j(2\pi/64)*0} & e^{-j(2\pi/64)*64} & e^{-j(2\pi/64)*128} & \dots & e^{-j(2\pi/64)*4032} \end{bmatrix} \quad (2)$$

If the signal is multiplied by this PM at the transmitter side then it must be multiplied by the Inverse of Phase Matrix (IPM) at the receiver side in order to retrieve it, or in other form:

$$y_{receiver-side} = y_{received} * IPM \quad (3)$$

Note that the last equation is a general equation, which means it depends on the location of the received signal that must be processed, and this location dependent on the transmitter side, because at the receiver the inverse procedure will be done to process the signal.

The proposed modulator and demodulator are shown in **fig.2**. By comparing the new model shown in **fig. 2** with the original model, it can be seen that there are a new four blocks are added to this model, namely PM block, FFT block, PM block, and the IFFT block at the transmitter and the other four blocks at the receiver in reverse form. Even the new model is more complex than the original model but, it is expected that the improvement will be increased due to increasing the orthogonality significantly in this case due to the use of IFFT twice [8], also due to the use of efficient algorithm related with a phase matrix model.

### 3. Phase Matrix Performance Analysis

For illustrating the effect of phase matrix on the performance of suggested model, let us consider a simple circuit shown in **fig. 3**. Assume that the input data is logic '1' with a Walsh-Hadamard spreading code number 20 for this simulation. The spreading signal is processed by the IFFT (N=32) and the output vector are multiplied by PM with a dimension (32\*32). The transmitted signal over the channel is assumed to be subjected to a phase variation 45° at bit 14 and 15 respectively, **Fig. 4** describes these steps. The subplot (a) represents the input signal to the IFFT which it has zero phases shift and the second subplot (b) represents the phase values for the signal out from IFFT. Now, the signal transmitted over the channel to the receiver with phase values shown in subplot (c). Note that there is a phase difference between subplots (c) and (d) by the value of 45° at bits 14 and 15, the phase angle about -150° at these bits is decreased to about 105° after the channel. The IPM redistributes the phases before convert the signal to frequency domain by the FFT block. The important thing here, that the random phase generated by the channel is only appeared at the output of the FFT block compared with the phases of the input signal to the IFFT. While, if the PM was not used, then any variation in any bit will lead to loss the most of bits, as in **fig. 5**, subplot (d).

### 4. Performance Analysis of the Proposed Model

The signal firstly are processed by the IFFT block for both data and training, then it multiplied by the phase matrix of size (N\*N). The multiplication is done for both data and training as *Row Vector (data or training)\*column of Phase Matrix*. The output phase of signal from phase matrix stay has the same values in spite of changing the user code, namely if the user code are changed from code 20 to any other code number then the same sign of phase values can be obtained, or in other fashion the phase values are always start from negative half and converted

to positive half at the end of data vector. This property was not kept in the FFT block at the transmitter where the phase values are changed randomly according to the user code number between  $-180^\circ$  to  $180^\circ$ . After the FFT block the signal and training sequence are multiplied again by the same phase matrix before it converted to the time domain by the IFFT block. The multiplication at the second phase matrix is done as *Row Vector (data or training)\*column of Phase Matrix*. The block of FFT is used at the transmitter side in order to make the phases and values of signal in the span area between bit 17 to 48 has a values out of zeros., because if the IFFT is used alone with PM, then this span area will stay has zero values as in the subplot I, this is not a good case, because it leads to increase the BER in the multipath fading channel. The transmitted signal (subplot (f)) has an amplitude shape is matched with that in subplot (d) in the period existing input signal to the IFFT, while it has the mirror amplitude at the period of zero padding (bit 17 to bit 48). The description of these steps for the modulator is shown in **fig. 6**.

For any suggested model there are many important points that can play an important role for improving the performance of MC-CDMA in selective fading channel, where as the transmitted signal shape be more approaches to the received signal shape that fluctuated by the multipath then the system performance will be improved, so the transmitted signal must has the following properties:

- 1) Each bit in the transmitted data vector must contain the information for the other (N-1) bits. Where N is the total number of FFT transform points or number of subcarriers. This property exists by using the mixing property of FFT, wavelet transform and the phase matrix.
- 2) The transmitted data vector must has different amplitudes and phase values.
- 3) The transmitted vector must contain one or more dominant points, such that this dominant point is less affected by the noise.

These properties can be done by multiplying the transmitted symbols by a phase matrix in the transmitter side and the inverse of phase matrix at the receiver side, but it is easily to note that the phase matrix uses the same phase values for the inverse fast Fourier transform but the distribution is different to the phase values of them. For his reason the fast Fourier transform is used at the transmitter side after the phase matrix block to verify these points.

*Hint:* since the using of phase matrix with FFT at the transmitter side will cause an increasing in the amplitude of the transmitted signal to be more than the level of the random noise generated by matlab tool as in the subplot (d) and (e), so the mean value is set at 0.5 or less. The output absolute mean value of signal is about 2.5111, this signal is scaled to be 0.5 by dividing it on its (absolute mean value\*2). The output mean value of the transmitted signal or training is normalized to 0.5 as given by Eqs. (4) and (5).

$$AbsoluteMeanValue_{Data\ or\ Training}(k) = \left( Real_k^2 + Imag_k^2 \right)^{1/2}, \quad k = 1, 2, 3, \dots, N \quad (4)$$

$$Transmittd\ Symbols_{Data\ and\ Training} = Transmittd\ Signal\ and\ Data / (2 * mean(Eq.(4))) \quad (5)$$

At the receiver the signal and training are multiplied by (2\*mean value) that are divided by it at the transmitter side. The first procedure at the receiver is to process the signal and training by the FFT block and then multiplied it by the IPM (*the multiplication here is done according to transmitter side*) which simply can be obtained by the matlab tools, then processes it by IFFT that represents the inverse of the FFT at the transmitter side, multiply it again by the IPM which matches the first phase matrix at the transmitter side, and finally convert it to frequency domain and do the channel estimation and compensation on it.

The training sequence will be used to estimate the channel frequency response as follows [4, 8]:

$$H(k) = \frac{\text{Received Training Sample}(k)}{\text{Transmitted Training Sample}(k)} \quad (6)$$

The channel frequency response will be used to compensate the channel effects on the data, and the estimated data can be found using the following equation:

$$\text{Estimate. data} = H^{-1}_{\text{estimate}}(k) * \text{Received.data}(k) \quad (7)$$

Finally the signal is Exclusive Ored (XOR) with a Walsh-Hadamard of the same user at the transmitter side, and the detection threshold decision is used to decide the value of signal.

## 5. Simulation Results

In this section, the combination of conventional MC-CDMA with the proposed MC-CDMA will be studied, in this research the Walsh-Hadamard (code 20) has been used with 32 bits of zeros are added. A simulation of the two systems has been made using MATLAB 7. And the BER performance of the two systems will be studied in different channel models which are AWGN, and AWGN+frequency selective fading channel, with a bit rate of 5 Mbps and 64 subcarriers are used in this simulation.

### 5.1 Performance of the Proposed System in AWGN Channel

The channel here is modeled as an Additive White Gaussian Noise for wide range of SNR from 0dB to 40dB, from **Fig. 6**, it is found that the proposed system MC-CDMA does worked with SNR=4dB at BER=10<sup>-4</sup>, while in the traditional MC-CDMA the bit error rate of 10<sup>-4</sup> at SNR=23dB, which means a gain of 19dB was obtained by the proposed model. Also the error is started to be appeared less than 10<sup>-2</sup> when SNR is started at 1dB.

### 5.2 Performance of the Proposed System in Selective Fading Channel

In this type of channel, the frequency components of the transmitted signal are affected by uncorrelated changes, where the parameters of the channel in this case corresponding to multipath, the two paths are chosen, the line of sight and second path which is the reflected path. In selective fading channel many models have been taken into consideration to compare the BER performance of the systems, the influence of the attenuation, delay and maximum Doppler shift of the echo is successfully discussed. First, the Doppler shift parameter has been taken in interest; set the Doppler shift to 5 Hz, and 1100 Hz. The path delay has been set to 1 sample and the path gain to -8dB.

It is seen that from **Fig. 7**, at Doppler frequency=5 Hz, the proposed MC-CDMA has SNS=18dB at BER=10<sup>-4</sup> in comparing with 37dB for the original MC-CDMA, this means a gain of about 19dB was obtained by the new way over the original system. As the Doppler frequency increases, the BER will increase for both systems and the same value of gain can be obtained by the proposed model as shown in the same figure.

Now, the path delay has been depicted, for the reflected path at a maximum Doppler shift 5 Hz. At this case a path delay vector is assumed to be  $= [0 \ 0.1 \ 0.5 \ 1 \ 1.5 \ 2] / (\text{bit rate})$  for each one. The results are shown in **Fig.8**. From this figure it is obvious that the proposed MC-CDMA is still more active under this variations and the BER is decreased for both systems at a BER= $10^{-4}$ . With a gain of 19dB was obtained from the proposed model compared with the original MC-CDMA.

Another parameter can be checked, which is the path gain for the reflected path. Let us consider at a Doppler frequency=5 Hz there are 5 paths, each has one sample delay with a path gain=  $[0 \ -1 \ -5 \ -10 \ -15 \ -20]$  dB for each one, the value 0 represents the line of sight. The results are shown in **Fig.9**. It is clear from these results the effect of changing the path gain for the reflected path on the performance of both systems. The SNR required achieving a BER at  $10^{-4}$  is decreased by about 2.5dB for the proposed system as the path gain was changed according to the vector values, while it is increased for the conventional one.

## 6. Conclusions

The simulation of the proposed and traditional OFDM-CDMA systems has been investigated. It has been shown that the new algorithm is more active to work under some different channel characteristics. Approximately a gain of 18dB or more was obtained for frequency selective channel at different Doppler frequency shift. A gain of 19dB appeared at the AWGN channel at BER= $10^{-4}$  from the proposed OFDM-CDMA. The proposed OFDM-CDMA is less affected by changing the path gain and the path delay.

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## Symbols

$i$	The frequency bin of the FFT or IFFT (from 1 to $N$ )
$n$	Data bit stream number.
$N$	The window size of FFT.
$R$	Zeros padding bits.
$y$	Received Signal

## Abbreviations

AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
CDMA	Code Division Multiple Access
FFT	Fast Fourier Transform
IFFT	Inverse Fast Fourier Transform
IPM	Inverse of Phase Matrix
ISI	Inter-Symbol Interference
MC-CDMA	Multicarrier- Code Division Multiple Access
OFDM	Orthogonal Frequency Division Multiplexing
OFDM-CDMA	Orthogonal Frequency Division Multiplexing-Code Division Multiple Access
PM	Phase Matrix
PN	Pseudo Noise

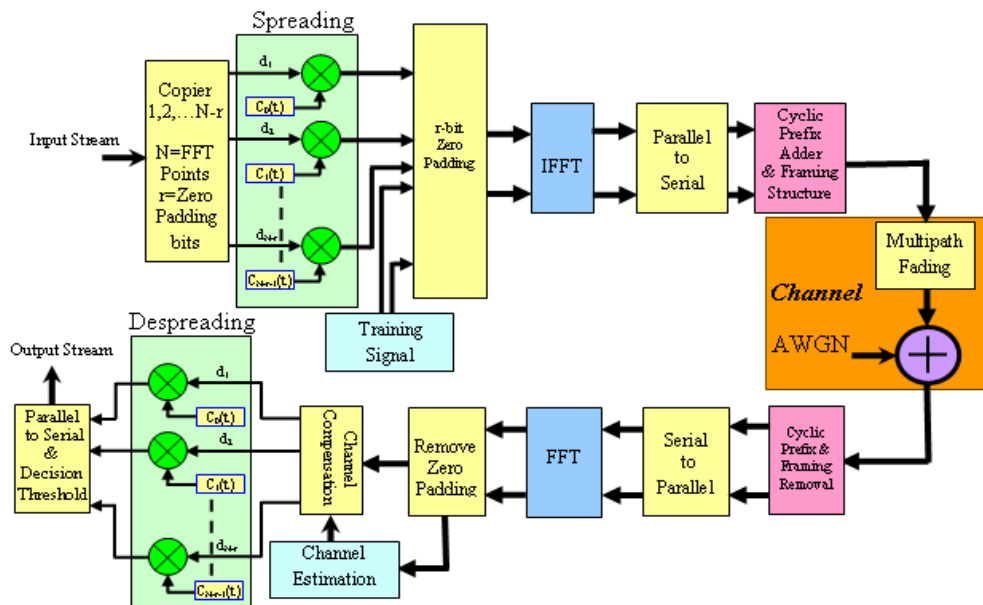


Figure (1): Block diagram for the traditional OFDM-CDMA [9].

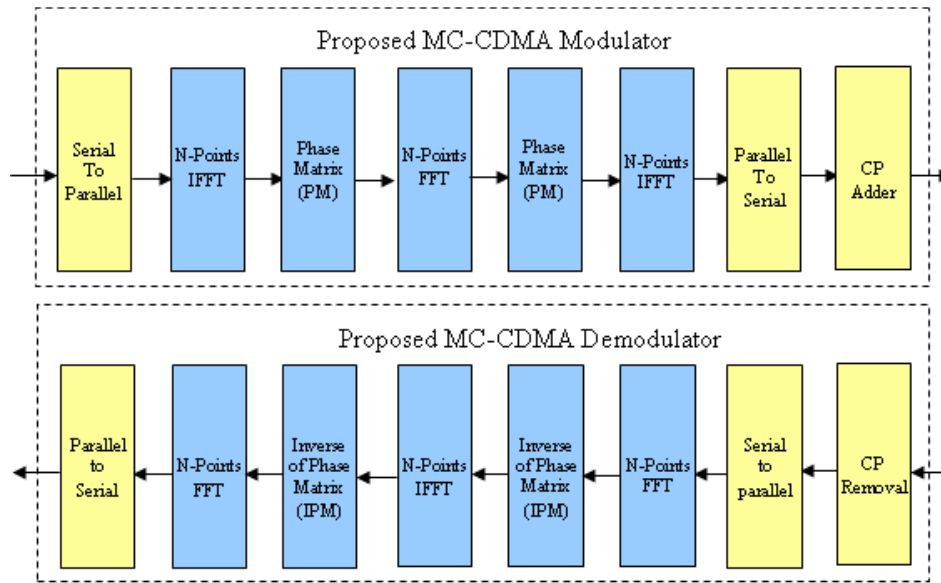


Figure (2): A proposed Model for OFDM-CDMA.

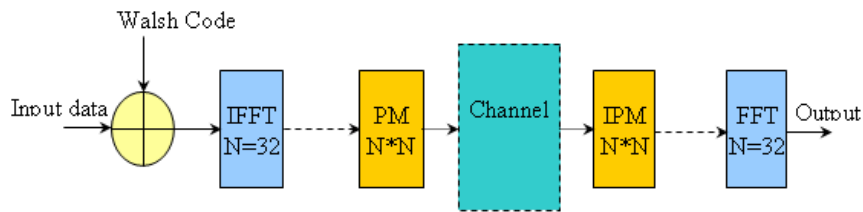


Figure (3): A demonstration circuit for Phase Matrix model

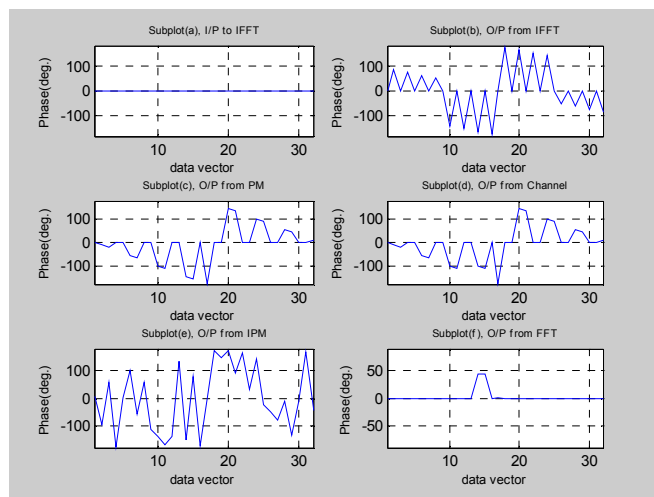


Figure (4): Phase values for a demonstration circuit with a phase matrix.



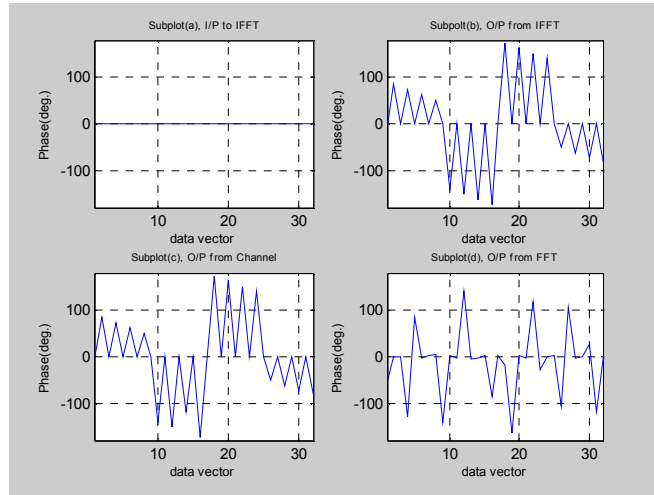


Figure (5): Phase values for a demonstration circuit without phase matrix

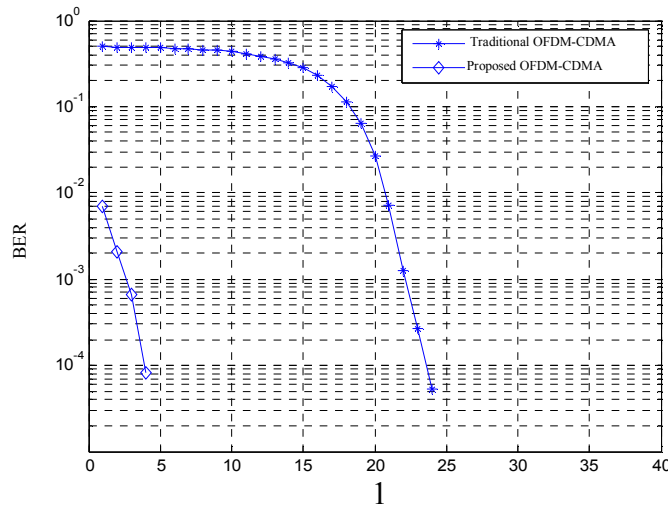


Figure (6): Performance of both systems in AWGN channel

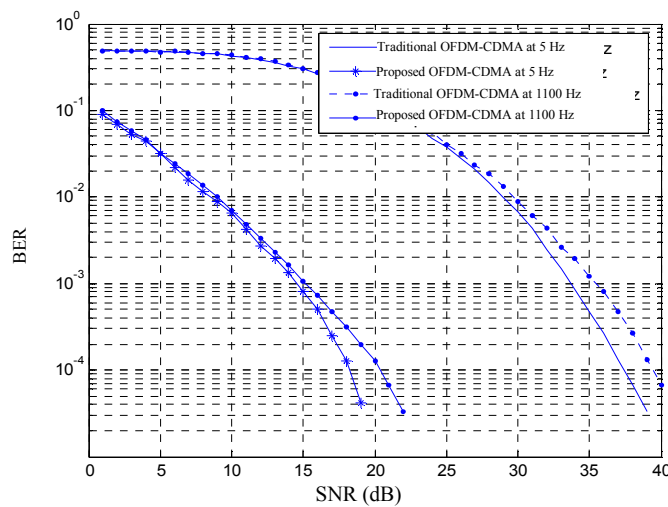


Figure (7): Performance of the proposed and traditional OFDM-CDMA in frequency selective fading channel at maximum Doppler shift=5, 1100 Hz, path gain=-8dB, 1 sample delay.

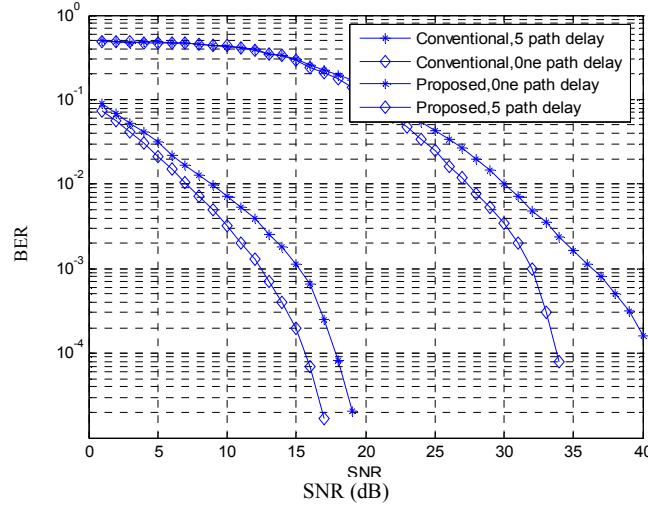


Figure (8): Performance of the proposed and conventional ODFM-CDMA in frequency selective fading channel at maximum Doppler shift=5 Hz, and different path delay.

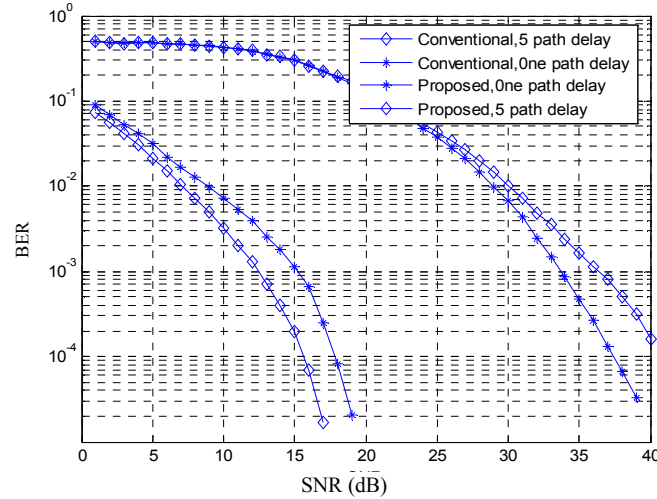


Figure (9): Performance of the proposed and traditional OFDM-CDMA in frequency selective fading channel at maximum Doppler shift=5 Hz, and different path gain

### نموذج مقترح لتحسين اداء الحاملات المتعددة-الوصول المتعدد المقسم بالترميز بقناة الخبو الانتقائي

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**الخلاصة-** في هذا البحث، تم اقتراح نموذج جديد لتحسين اداء الحاملات المتعددة-الوصول المتعدد المقسم بالترميز (MC-CDMA) بالاعتماد على مصفوفة الفيز الدوار للنموذج المعتمد على تحويل الفورير بقناة الضوضاء الابيض المضافة لكاوز (AWGN) وقناة الخبو الانتقائي للترددات. ويستخدم هذا النموذج لتقليل تاثير الخبو الناتج من الانعكاسات المختلفة للاشارة اللاسلكية. النتائج تم استخراجها رياضيا باستخدام الحاسبة الالكترونية لمستخدم واحد فقط، وتمت مقارنتها مع اداء النموذج الاصلي المعتمد على تحويل الفورير السريع. النتائج بينت وجود كسب كبير بالاشارة تم الحصول عليه من النموذج المقترح مقارنة بالنموذج الاصلي، حيث ان نسبة الخطا بالبتات (BER) قلت بشكل كبير تحت تاثير مختلف البارامترات للقنوات اللاسلكية عند قنوات الخبو الانتقائي وقناة الضوضاء الابيض المضافة لكاوز.

