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A new Transmission and Reception Algorithms for Improving the Performance of SISO/MIMO- OFDM Wireless Communication System

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ABSTRACT

The future wireless communication requires a reliable transmission at high data rates, so the transmission over frequency-selective fading Multiple-Input–Multiple-Output MIMO channels become interesting since the capacity of "MIMO" channels expressions enormous gains above that of their essential single-input–single-output "SISO" channels. This paper examines the performance of the Low Complexity Zero Forcing "LCZF" equalizer for both systems single-input–single-output-Orthogonal Frequency Division Multiplexing" SISO-OFDM" and spatially multiplexed-Multiple-Input–Multiple-Output "SM-MIMO-OFDM" with different "QAM" modulations. It is exploring a new algorithm to improve the performance of the "BER", spectral efficiency, and power efficiency and to reduce the complexity of the "RF" communication system under the effect of the Additive White Gaussian Noise "AWGN" and multipath fading channel. It is also improves an efficient channel by developing a Low Complexity Zero Forcing "LCZF" equalizer for both "SISO-OFDM" and "SM-MIMO-OFDM" wireless Communication systems. This is done by proposing a new algorithm at the receiver side to covert the Linear Convolution in to Cyclic Convolution by adding Zero Padding "ZP" to the channel impulse response in such a way to be the same length to the transmitted signal in the time domain which is of length N, where N is the length of "IFFT".

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خوارزميات جديدة للإرسال والاستقبال لتحسين أداء أنظمة الاتصالات اللاسلكية الراديوية (أحادي الإدخال – أحادي الإخراج \ متعددة المدخلات – متعددة الإخراج- التعدد في قسم الترددات المتعامدة)

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الخلاصة
يتطلب نظام الاتصال اللاسلكي المستقبلي الى إرسال موثوقًا به للبيانات و بمعدلات نقل بيانات عالية ،وبالتالي فان الارسال عبر قنوات التلاشي المتعدد المسارات والتردد باستخدام نظام متعدد الادخالات والاخراجات (MIMO) اصبح مثيرا للاهتمام نظرا لان سعة قنوات mimo تظهر مكاسب هائلة في الطاقه مقارنه مع استخدام نظام ذات مداخل ومخارج فردية(SISO). يتناول هذا البحث اداء نظام معادلة القسر الصفرية والقليل التعقيد (LCZF) والمستخدم لكلا النظامين SISO-OFDM/ SM-MIMO-OFDM مع عدة تشكيلات مختلفة من التغير في طبقة الصوت نوع (QAM) . كما يضم هذا البحث استخدام خورازمية جديدة لتحسين اداء خواص BER والكفاءة الطيفية وكفاءة الطاقة لكلا النظامين SISO-OFDM/ MIMO-OFDM وتقليل تعقيد نظام الاتصالات اللاسلكية (RF) تحت تاثير قناة ال AWGN و القنوات المتعددة المسارات (Multi-Path Fading channel) ويتم ذلك عن طريق اقتراح خوارزمية جديدة في جانب المستلم لتحويل عملية ال(Linear Convolution) الى عملية ال(Cyclic Convolution) عن طريق إضافة صفر الحشو (ZP) إلى القناة لتكون نفس الطول للإشارة المرسلة (في المجال الزمني) الذي هو بطول N، حيث N هو طول IFFT للنظام المطور
.

الكلمات الدالة: نظام متعددة المدخلات – متعددة الإخراج،نظام ذات مداخل ومخارج فردية، نظام معادلة القسر الصفرية والقليل التعقيد،نظام التعدد في قسم الترددات المتعامدة، صفر الحشو.

1. INTRODUCTION

The rapidly growing demand for reliability and high-speed data transmission in recent years imperative existence a fast and spectrally efficient wireless communication system.The goal of Zero-Forcing (ZF) is to force the removal of ISI. The ZF algorithm is simple as compared to the Maximum likelihood (ML) algorithm, but its performance debilitated at the similar time [1]. Based on the ZP-OFDM encoding system, [2] a two-stage decoder is proposed which attains the maximum multipath diversity with minor computational complexity, as compared to a ZF ZP-OFDM. It is similarly analytically showed that the projected decoder is diversity-multiplexing tradeoff (DMT) optimal. It has also been exposed that by location the decoder parameters, it can attain any subjective diversity gain smaller than the maximum multipath diversity. Also, when the diversity gain is lessened the other computational complexity is decreased. The ZP-OFDM is another encoding system, which achieves a maximum multipath diversity with the ZF equalizer in [3]. Conflicting the CP-OFDM, a ZP-OFDM due to transmitting zeros at the guard period has the computational complexity of inverting a $K \times K$ matrix for its linear equalization. To reduce the complexity of a ZP-OFDM, a two approaches (ZP-OFDM-FAST and ZP-OFDM overlap-add (ZP-OFDM-OLA) are suggested in [3]. Though these two approaches are computationally efficient, none of them achieved the maximum obtainable diversity of the channel. To improve the bandwidth efficiency in the multicarrier systems, the ZP-OFDM (AZP-OFDM) is suggested in [4]. AZP-OFDM offers performance similar to that of CP-OFDM, complexity similar that of the ZP-OFDM, with bandwidth efficiency more than of both CP-OFDM and ZP-OFDM. In coherent demodulation schemes, the calculation of Zero-Forcing ZF detections can be very complex, when the number of subcarriers and antennas is large. In [5] the LC systems are projected to calculate the ZF equalizer for the massive MIMO-OFDM, which included of the efficient arrangement of computing the matrix inversions using Neumann series (NS) as a small-complexity approximation with the interpolation of these inverted matrices. In [6] the FPGA application advanced and analyzed for Maximum likelihood (ML), Zero Forcing (ZF), and Minimum Mean Square Error (MMSE) related to multiple-input wireless multi-input (MIMO) schemes with fewer response than transmitting antennas. In [7] studied and analyzed the performance of different channel equalizer techniques in wireless communication systems using SISO and MIMO systems. In [8] proposed a low-complexity MMSE and ZF detections for the orthogonal time-frequency space OTFS signal detection. The proposed approach attained exact MMSE and ZF solutions with lesser complexity as compared to the matrix inversion method. Though a Zero-Forcing ZF equalizer is low computational complexity in Multiple-Input Multiple-Output (MIMO) communication systems, it suffered from a meaningfully poor performance. The sphere decoder (SD) system, attains the maximum likelihood (ML) performance yet imposes a great computational complexity. In [9] proposed a low-complexity detection system with the sphere decoder (SD) scheme, which confirms the reliability of the ZF equalized observations via some predefined regions and thresholds attained by the channel realization. [10] studied the performance evaluation and implementation complexity analysis framework for ZF based linear massive MIMO detection. A framework for algorithm-architecture synergy for the performance scheming and FPGA application complexity analysis of linear massive MIMO detection systems are discussed with three low complexity implementation systems of the Zero-Forcing ZF based linear detection. This research deals with several systems, to make correct decisions. Its surveys the performance of LCZF equalizer for SISO/SM-MIMO-OFDM systems. Although the channel impulse response has a finite length, the impulse response of the conventional equalizer needs to be infinitely length [11]. The constraints caused by these limiting conditions have been solved by proposing a new algorithm which comprises converting the linear convolution into cyclic convolution by adding Zero Padding(ZP) to the channel impulse response in such a way to be the same length to the transmitted signal (in the time domain) which is of length $\boldsymbol{N}$, Where $\boldsymbol{N}$ is the length of IFFT. This new technique is applied in both SISO/MIMO-OFDM systems to remove ISI. The rest of the paper is prearranged as follows: Section 2 gives an insight into system description. The block diagrams of the proposed ZF equalizer schemes for both SISO-OFDM and MIMO-OFDM are explained in detail. In Section 3, the calculation for the theoretical bit error rate for the proposed OFDM systems is presented. The complexity enhancement of the proposed system and simulation results are discussed in Section 4. The conclusion is drawn in Section 5.

2.Modeling of SISO/SM-MIMO-OFDM system with ZF-equalizer

The Single Input Single Output SISO system is a low complexity scheme that is suitable for a wireless communication system. For increasing the speed and the reliability of wireless communication links, the MIMO systems are needed [12,13]. The OFDM technique combined with MIMO techniques is used to increasing spectral efficiency and increasing throughput. The idea of combining the two techniques (MIMO and OFDM) enables the communication to transmit independent OFDM modulated data from multiple antennas concurrently. At the receiver, OFDM symbols are demodulated, and MIMO decoding on each sub-channel is done to extract the information from all transmitting antennas. The Zero forcing ZF detection systems at the receiver can be used to equalize the received signal. Though, in practice, attaining this equalization at some megabits per second with compact and small-cost hardware is quite problematic. A Spatially Multiplexed MIMO (SM-MIMO) schemes can transmit information at a better speed than MIMO systems using antenna diversity methods. Though, spatial demultiplexing or signal detection at the receiver side is the interesting routine for SM-MIMO schemes. Consider the $\boldsymbol{N_R} \times \boldsymbol{N_T}$ MIMO system in Fig. 1. Let $\boldsymbol{H}$ represent the channel matrix by it $(\boldsymbol{j}, \boldsymbol{i})$ th pass $\boldsymbol{h_{ji}}$ for the channel gain between the $\boldsymbol{i_{th}}$ transmit antenna and the $\boldsymbol{j_{th}}$ receive antenna, $\boldsymbol{j} = \boldsymbol{1, 2, \ldots, NR}$ and $\boldsymbol{i} = \boldsymbol{1, 2, \ldots, NT}$. A spatially-multiplexed(SM) user data and the reliably received signals are presented with $\boldsymbol{x} = [\boldsymbol{x_1}, \boldsymbol{x_2}, \ldots \ldots \boldsymbol{x_{NT}}]^T$and $\boldsymbol{y} = [\boldsymbol{y_1}, \boldsymbol{y_2}, \ldots \ldots \boldsymbol{y_{NR}}]^T$, correspondingly, where $\boldsymbol{x_i}$ and $\boldsymbol{y_j}$ describe the transmit signal from $\boldsymbol{i_{th}}$ transmit antenna and the received signal at the $\boldsymbol{j_{th}}$ receive antenna, correspondingly. Let $\boldsymbol{z_j}$ deal to the white Gaussian noise with an alteration of $\propto_z^2$ at the $\boldsymbol{j_{th}}$ receive antenna, and $\boldsymbol{h_i}$ specify the $\boldsymbol{i_{th}}$ column vector of the channel matrix $\boldsymbol{H}$. Now, the $\boldsymbol{N_R} \times \boldsymbol{N_T}$ MIMO scheme is represented in equation 1 [14].

$$y = H.x + z = h_1x_1 + h_2x_2 + \cdots h_{NT}x_{NT} + z \quad \ldots 1$$

Where $z = [z_1, z_2, \ldots \ldots z_{NR}]^T$

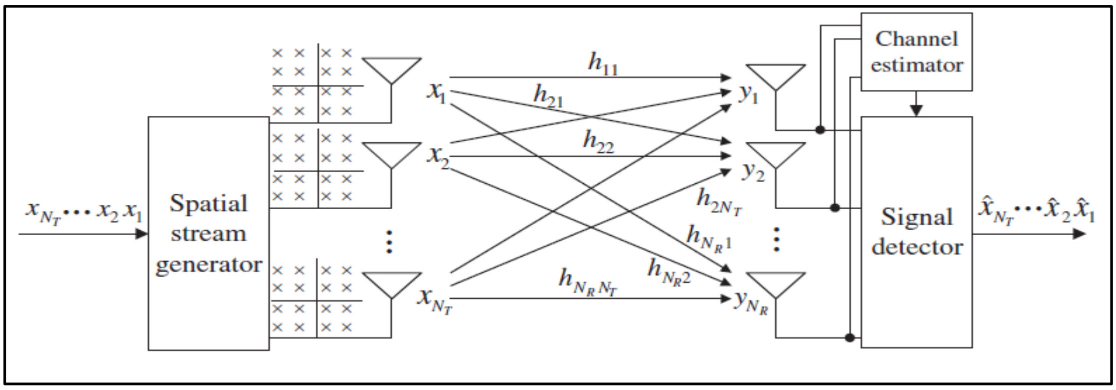

Fig.1 The spatially multiplexed SM- MIMO systems [14].

The Zero-Forcing ZF means that the goal is to force the remaining ISI to zero. ZF algorithm uses the inverse matrix of the channel matrix $\boldsymbol{H}$ as a vector, and then we discovery the output before the decision exposed in equation (3). A ZF equalizer algorithm presented the idea of the pseudo-inverse matrix to abridge the algorithm, and the channel matrix $\boldsymbol{H}$ is changed into $\boldsymbol{NT}$ parallel scalar channels composed with the noise. The noise division is improved due to the left multiplication. Therefore, a ZF algorithm decreases the complexity of the Maximum Likelihood ML algorithm, but its performance debilitated at the similar time [15]. The estimator of the vector transmitted by ZF is got at the receiver using the following procedure:

$$G = H^{+} = (H^{H}\, H)^{-1}\, H^{H} \quad \dots (2)$$

Where $\boldsymbol{H}^{+}$ is a pseudo inverse matrix of $\boldsymbol{H}$.

$$G = H^{+}\, y = (H^{H}\, H)^{-1}\, H^{H} y = x + \widehat{w} \quad \dots (3)$$

Where $\widehat{w} = H^{+} w \quad \dots (4)$ modifier noise.

3. The Proposal Zero-Forcing Equalizer based SISO/MIMO-OFDM RF Communication System

The proposal consists of two methods firstly, a zero-forcing equalizer at receiver in SISO-OFDM, secondly a zero-forcing equalizer at receiver in SM-MIMO-OFDM. Figure (3) and figure (4) represent the block diagrams of SISO and SM-MIMO-OFDM systems respectively. The process starts via data stream which is a vector in SISO-OFDM and matrix in MIMO-OFDM system to QAM modulation block for converting it to a complex number and passing it to S/P (conversion block) for converting it to parallel state. Next, applying $\boldsymbol{N}$ - IFFT processing to data $\boldsymbol{X}$ to convert it to time-domain $\boldsymbol{x}$. The other step is adding Cyclic Prefix CP to the parallel data stream $\boldsymbol{x}$ to obtain the $\boldsymbol{x_t}$ data as shown in figure (2.a). Then the transmitted data pass-through the channel, where a linear convolution process is done between the data $\boldsymbol{x_t}$ and the impulse response of the channel $\boldsymbol{h}$ (that is also (N/4) vector in SISO-OFDM and ($\boldsymbol{n_T} \times \boldsymbol{n_R} \times \boldsymbol{N/4}$) 3D matrix in MIMO-OFDM system), finally the AWGN is added. A received signal $\boldsymbol{y}$ that is the sum of the signal $\boldsymbol{x}$ with noise $\boldsymbol{w}$ at discrete time. The noise is measured as independent and identically distributed which is exposed to the normal distribution (zero-mean and variance)

$$y = x + w \quad \dots 5$$

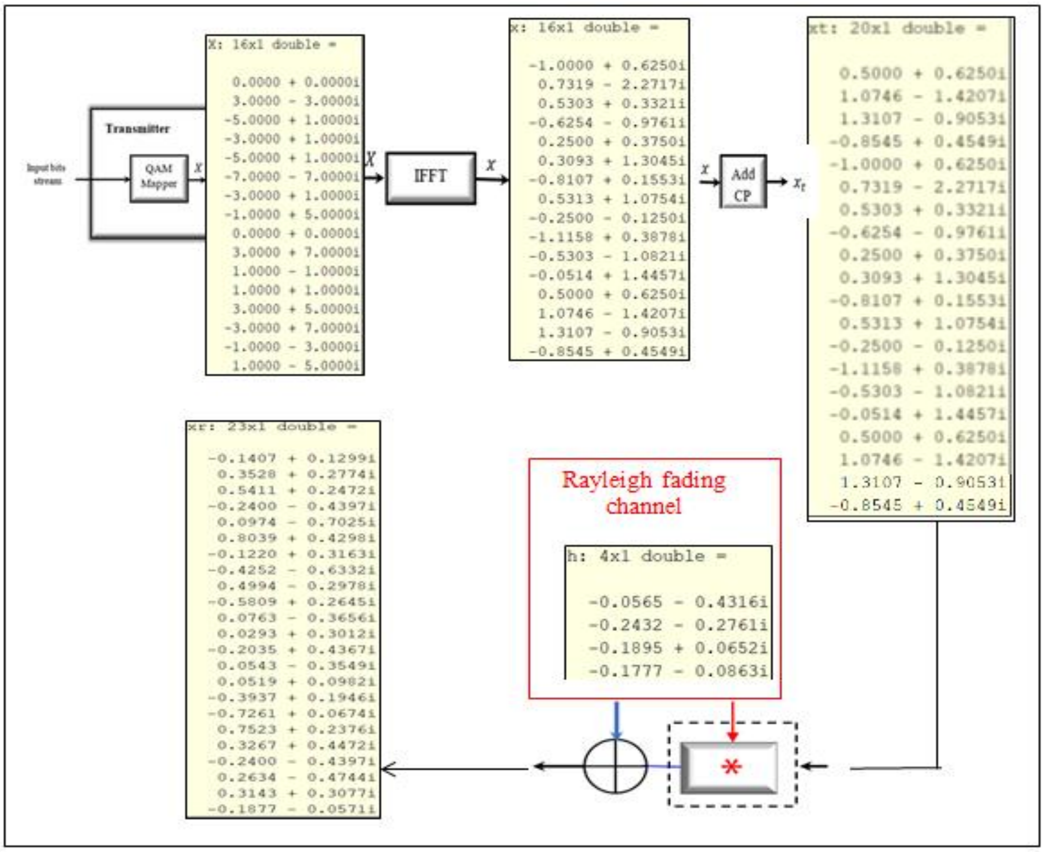

Fig.(2,a): Transmitter processing.

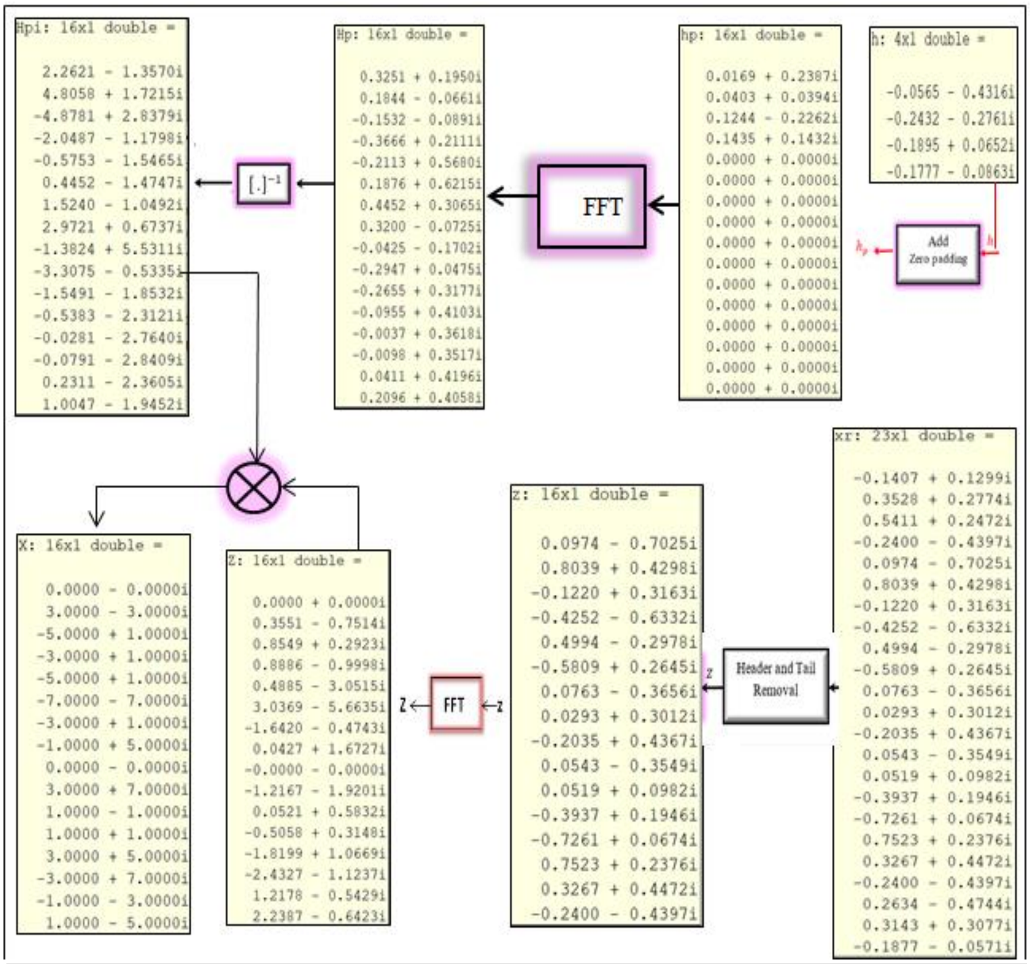

Fig.(2,b): Receiver processing.

At the receiver, a Zero Padding ZP is added to the estimated channel $\boldsymbol{h}$ to convert the linear convolution to circular convolution due to the properties of circular convolution (the length of the transmitted data $\boldsymbol{x_t}$ must be equivalent to the length of channel impulse response $\boldsymbol{h}$ in a time domain, and the circular convolution is equivalent to the inverse discrete Fourier Transform(DFT) of the product of the $\boldsymbol{x_t}$ and $\boldsymbol{h}$ information or the circular convolution of a Zero-Padded ZP for channel impulse response $\boldsymbol{hp}$ and $\boldsymbol{z}$ data, is equal to the linear convolution of $\boldsymbol{x_t}$ and $\boldsymbol{h}$ data) as shown in figure (2.b)

$$y(n) = x(n) \circledast h(n) \leftrightarrow Y(K) = X(K)H(K) \quad \dots 6$$

Next step is to enter both $\boldsymbol{hp}$ and $\boldsymbol{z}$ which is a subset circular data from $\boldsymbol{x_r}$, and after removing the Cyclic Prefix (CP) from data $\boldsymbol{x_r}$ by Head and Tail Removal block in FFT block to convert them from the time domain to frequency domain. Later, passing the data stream $\boldsymbol{Z}$ in (LCZF) equalizer to multiply by the proposed $\boldsymbol{Hp^{-1}}$. The $\boldsymbol{Hp^{-1}}$ is extracted from channel impulse response that has predefined dimensions then the Zero Padding(ZP) is added to the estimation channel to get $\boldsymbol{hp}$ as shown in figures (3,4,5) for changing the linear convolution to circular convolution due to its properties, the $\boldsymbol{hp}$ data is entered to FFT processor for converting it to the frequency domain and getting the proposed $\boldsymbol{Hp^{-1}}$, which is multiplied by received data $\boldsymbol{Z}$ to apply the circular convolution processes and to retrieve the originally transmitted data $\boldsymbol{\hat{X}}$. Where the data $\boldsymbol{\hat{X}}$ is obtained after converting it from parallel to serial by P/S block and after passing it to the QAM de-mapper.

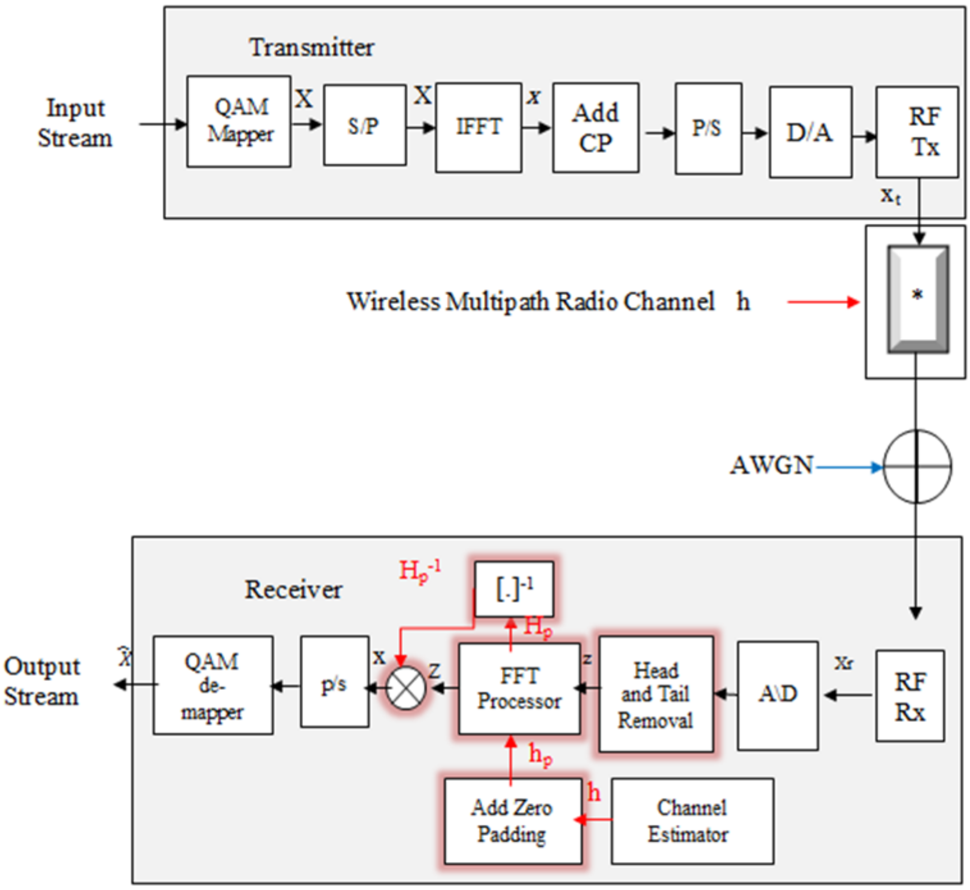

Fig. 3: Block diagram of the low complexity ZF- Equalizer based SISO-OFDM.

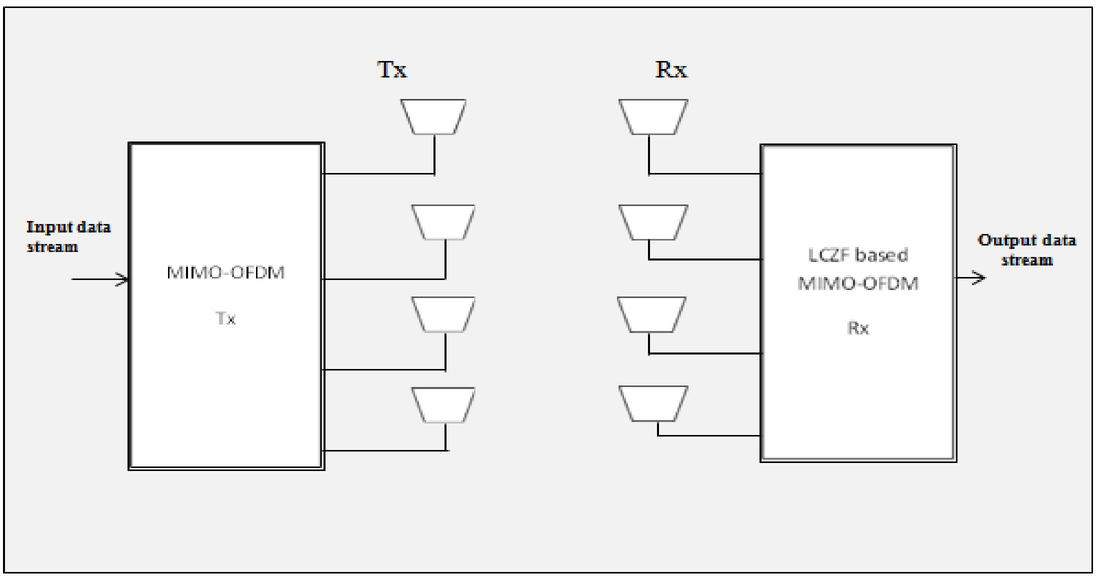

Fig. 4: Block diagram of the low complexity ZF- Equalizer based MIMO-OFDM.

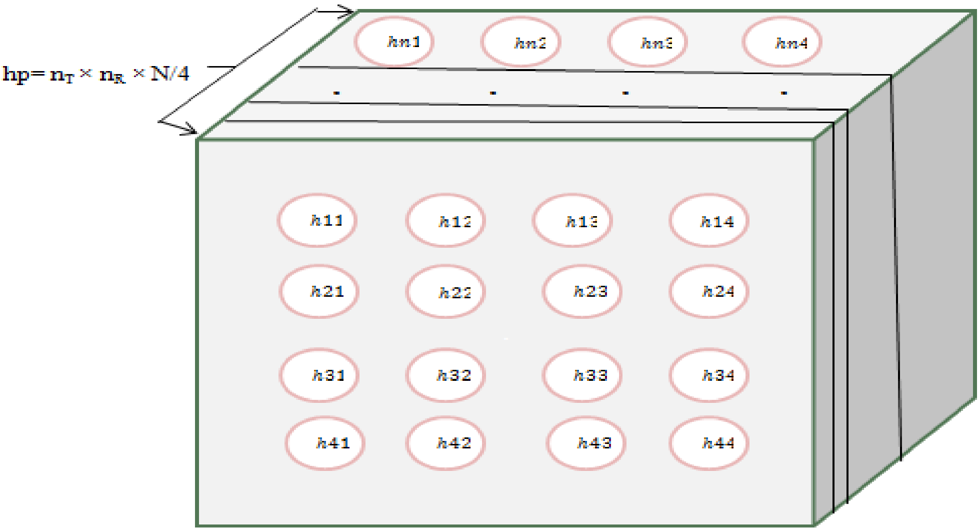

Fig. 5 Block diagram of proposed $\boldsymbol{h_p}$.

This is a distinctive feature of our proposed system that makes it different from previous conventional systems because circular data $\boldsymbol{z}$ is cutback from the transmitted data $\boldsymbol{x_r}$ after receiving and removing the Head and Tail Removal block from it,and adding a Zero Paddings(ZP) to impulse response of the channel in such a way to be the alike length to the transmitted data which is of length N to convert the Linear convolution process to circular convolution process. This is unlike conventional systems in which only Linear convolution process was used between the transmitted data and the impulse response data of the channel.

All processing steps in the proposal shown in previous figures (2.a,2.b) for transmitter and receiver processing, and figures (3,4) for the block diagram of the low complexity LCZF-Equalizer based SISO and MIMO-OFDM respectively with adding the Zero-Forcing(ZF) equalizer in the receiver to prevent all ISI.

The result for this system in both cases line of site only with AWGN and multipath fading channel can be explained in mathematic model **1** for the SISO-OFDM system and model **2** for MIMO-OFDM system as follow:

Mathematical Model **1**

The received signal is represented using equation 7:

$$y(n) = \sum_{n=1}^{n} x(n) * h(n) + w \ldots .7$$

Where $h(n) = 0,1,2, \ldots n$ is a channel impulse response,$x(n) = 0,1,2, \ldots n$ is the parallel data stream and (w) is a AWGN

$$y(n) = x(n) * h(n) + w \ldots \ldots 8$$

The output signal after passing through ZF equalizer H^{-1} is written as :

$$Y = (XH + W)H^{-1} \quad \ldots . 9$$

After demodulation , the output signal is :

$$\hat{X} = YH^{-1} = X + WH^{-1} \ldots . 10$$

The BER theoretical expressions for M-ray QAM gesturing in AWGN and Rayleigh channels are congruently assumed by equation (11) & equation (12) as:

$$P_e = \frac{2(M-1)}{M \log_2 M}\left(\sqrt{\frac{6E_b \log_2 M}{N_\circ (M^2-1)}}\right) \ldots 11$$

$$P_e = \frac{2(M-1)}{M \log_2 M}\left(1 - \sqrt{\frac{3\gamma \log_2 M/(M^2-1)}{3\gamma \log_2 M/(M^2-1)+1}}\right) \ldots 12$$

Where, γ and M denote Eb/No and the modulation order, correspondingly, Note that if nosed subcarriers out of total N (FFT size) subcarriers (except N_{vc}=N/N_{used} practical subcarriers) are used for transport information, the time-domain SNR, SNR_f, varies from the frequency-domain SNR, SNRf, as shadows[14]:

$$SNR = SNR_f + 10 \log \frac{N_{used}}{N} \; [dB] \ldots 13$$

The same procedure applied to parallel transmission (MIMO) and the theoretical proposal explain in mathematical model **2**.

Mathematical Model **2**

$$\underline{R} = \underline{H}.\underline{S} + \underline{n} \quad \ldots 14$$

Where $\underline{H}$ is the channel mixing matrix, $\underline{S}$ is signal and $\underline{n}$ is noise.

$$\underline{H} = \begin{matrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{21} & h_{22} & h_{23} & h_{24} \\ h_{31} & h_{32} & h_{33} & h_{34} \\ h_{41} & h_{41} & h_{43} & h_{44} \end{matrix}$$

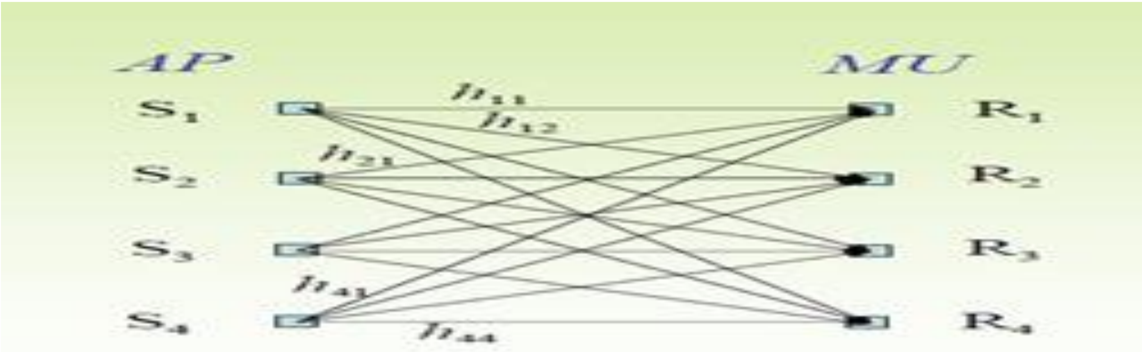

Fig. 6 MIMO system.

The receiver signals are in the example:

$$R_i = \begin{Bmatrix} R_1 = h_{11}S_1 + h_{12}S_2 + h_{13}S_3 + h_{14}S_4 + n \\ R_2 = h_{21}S_1 + h_{22}S_2 + h_{23}S_3 + h_{24}S_4 + n \\ R_3 = h_{31}S_1 + h_{32}S_2 + h_{33}S_3 + h_{34}S_4 + n \\ R_4 = h_{41}S_1 + h_{42}S_2 + h_{43}S_3 + h_{44}S_4 + n \end{Bmatrix}$$
...15

$$\hat{\underline{S}} = \underline{H}^{-1}.\underline{R} \approx \underbrace{\underline{H}^{-1}.\underline{R}}_{\underline{Y}} .\underline{S} \ldots 16$$

If H is ill-condition (close to singular), Y will be distant from the identity matrix following in co-channel interference .

The mathematical model is applied in the receiver site as explain in detail in algorithm 1 for transmission data.

Algorithm 1: Algorithm for Propped ZF-equalizer for SISO-OFDM

Input: Xr// received **data**

h //estimated channel

Output: $\hat{X}$ // bit stream

Begin

Step 1: z← AnalougToDigital(Xr)

Step 2: zd←RemoveHeadAndTail(z)

Step 3: Z←FastFourierTransform(zd)

Step 4: hp←ZeroPadding(h)

Step 5: Hp←FastFouriertransform(hp)

Step 6: Hpi ←InverseElement (Hp) // invert each element in Hp vector

Step 7: Xi←Product (Z, Hpi) //Eliminate the effect of multipath fading using ZF equalizer

Step 8: Xc←SerialToParallel (Xi)

Step 9: $\hat{X}$ ←QamDeModulation (Xc)

End Algorithm

4. SISO/SM-MIMO-OFDM Systems Simulation based on LCZF equalizer

This section delivers the simulation results to assess the performance of SISO/SM-MIMO-OFDM systems based on the proposed Low Complexity Zero Forcing (LCZF) equalizer and compare them with the conventional systems. We study the assessment of the spectral efficiency, power efficiency and the performance of the BER according to the SNR, while modifying a new algorithms for equalizer to reduce the complexity of the RF communication system. To compare the performance of BER rendering to the SNR under the effect of the multipath fading (Rayleigh fading channel) and AWGN for both systems (SISO and SM-MIMO-OFDM) based on the proposed (LCZF) equalizer. The QAM modulation (4,16, 64, and 128) for the SISO-OFDM and SM-MIMO-OFDM systems are used with 128 length FFT and IFFT in the transmitter and receiver respectively. The simulation of signal processing at the transmitter side is represented by several processing steps as follow: firstly, the information entered to QAM block for transforming them to complex form. Secondly, the modulated data is prepared for orthogonal carrier transmission using an inverse IFFT processor to convert the frequency domain of the $\boldsymbol{X}$ shape signal to the time domain signal $\boldsymbol{x}$. Thirdly, adding CP to the data (head and tail block) to get $\boldsymbol{x_t}$ that will convoluted using linear convolution in channel $\boldsymbol{h}$ which is also **(N/4)** vector in SISO-OFDM and ($\mathbf{n_T} \times \mathbf{n_R} \times$ **N/4**) 3D matrix in MIMO-OFDM system.Where $\mathbf{n_T}$ is the number of transmitted antennae and $\mathbf{n_R}$ is the number of received antenna to get $\boldsymbol{x_r}$ information. At the receiver the signal $\boldsymbol{x_r}$ (that is got from the liner convolution between the data $\boldsymbol{x_t}$ and the channel impulse response $\boldsymbol{h}$) is received and removed CP (head and tail) from this signal and getting $\boldsymbol{z}$ data, after that, the signal $\boldsymbol{z}$ which is a sub-set circular data from the $\boldsymbol{x_r}$ information will input to FFT processor for converting it to frequency domain $\boldsymbol{Z}$, in the other side the Zero-Padding added to the estimation channel $\boldsymbol{h}$ for changing the linear convolution to circular convolution due to its properties .The $\boldsymbol{hp}$ will converting to the frequency domain $\boldsymbol{H_P}$ using the FFT processor. The $\boldsymbol{Z}$ and $\boldsymbol{H_P}$ data entered to (LCZF) equalizer to multiply the information by inverse $\boldsymbol{H_P}$ proposed to retrieve the original signal $\boldsymbol{X}$. The simulation and theoretical results of the performances for both SISO-OFDM and MIMO-OFDM systems based on the proposed LCZF equalizer are represented in figures (7) and (8) respectively for 4,16,64, and 128-QAM.

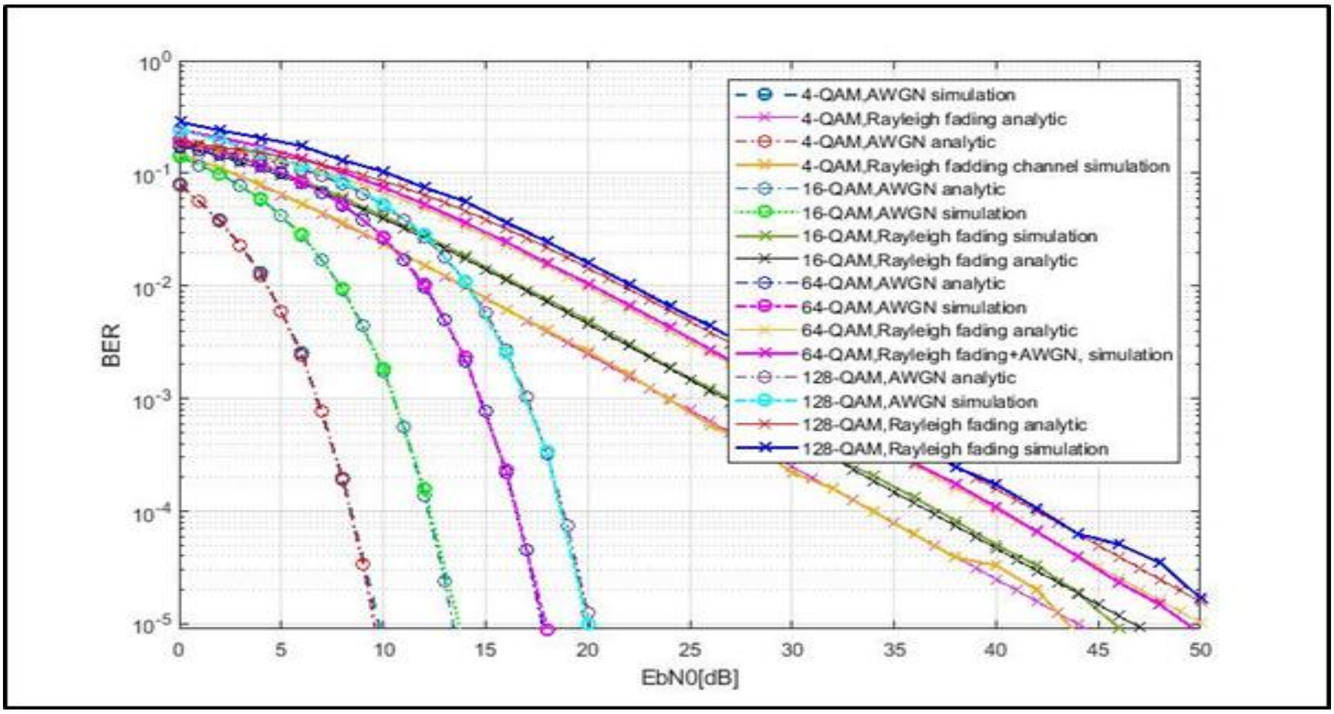

Fig.7 Performance of the proposed Low Complexity LCZF equalizer with (4,16,64, and 128-QAM) in SISO –OFDM system.

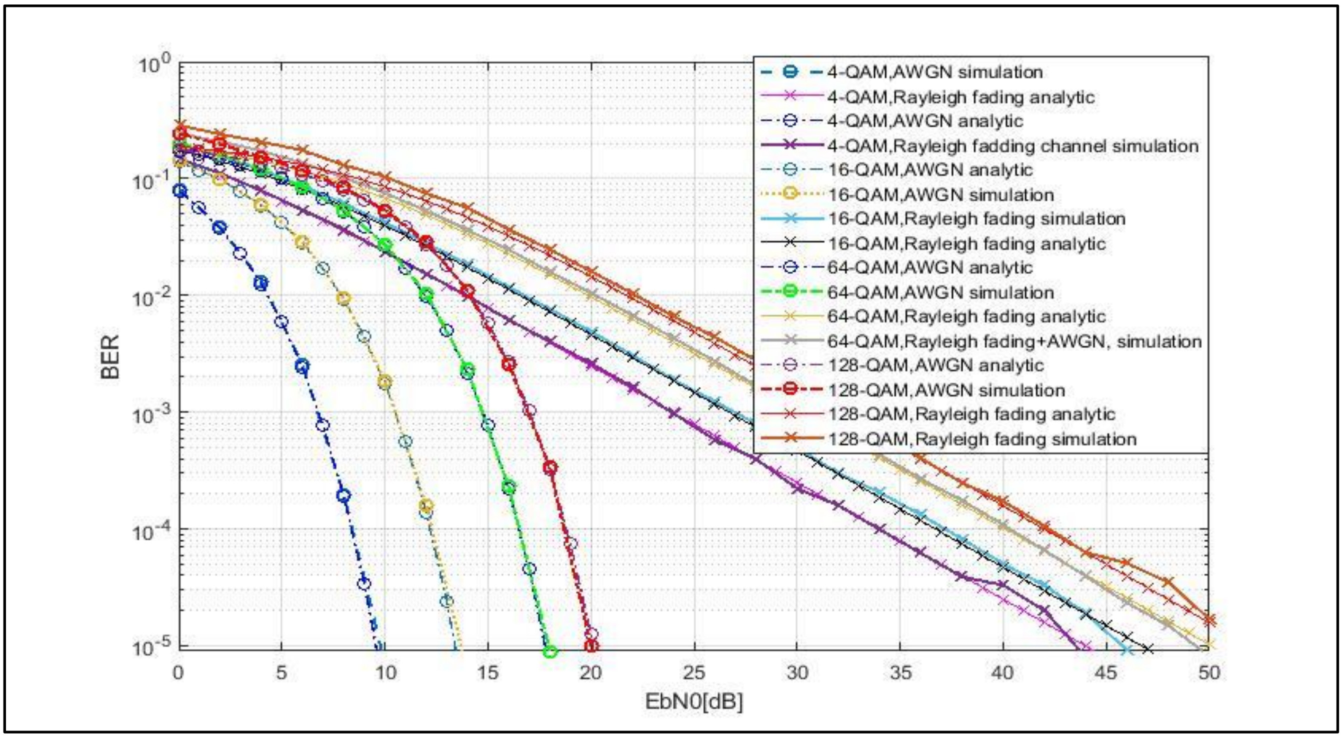

Fig.8 Performance of the proposed Low Complexity LCZF equalizer with (4,16,64, and 128-QAM) in SM-MIMO –OFDM system.

From the previous figures(7,8), we observe a similarity between the simulated and theoretical curves for both proposed systems under the effect of the multipath fading and AWGN.

To compare the performances of SISO-OFDM and MIMO-OFDM based on the proposed LCZF equalizer for the same spectral efficiency equal to 8 bit/s/Hz, it is clear from figure 9 that the LCZF based MIMO-OFDM outperform LCZF based SISO-OFDM by 10 dB SNR within forward error correction coding (FEC) threshold 3.8e-3 which means a valuable saving in power.

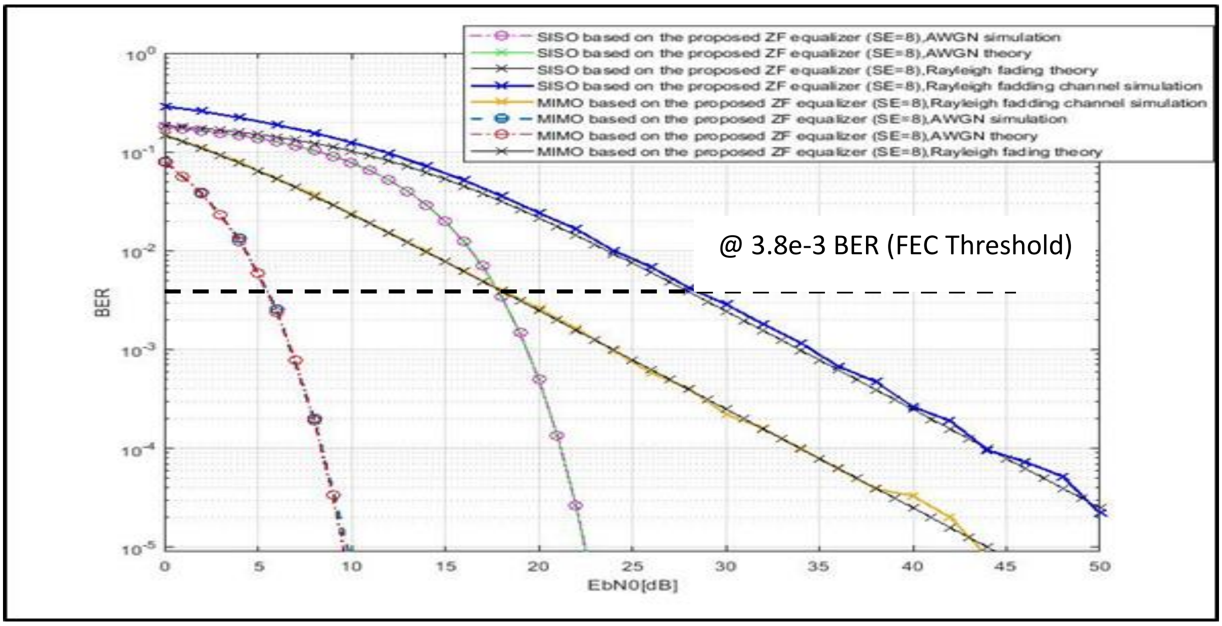

Fig.9 Performance of the proposed LCZF equalizer for 4-QAM in the MIMO-OFDM system and 256–QAM in the SISO-OFDM system.

It is clear from figure10 that the LCZF based MIMO-OFDM system can give the same performance of LCZF based SISO-OFDM system with spectral efficiencies equal to 2 and 8 bit/s/Hz respectively using the same constellation order (4 QAM) which means 400 % spectral efficiency gain in case of using LCZF based MIMO-OFDM instead of LCZF based SISO-OFDM system.

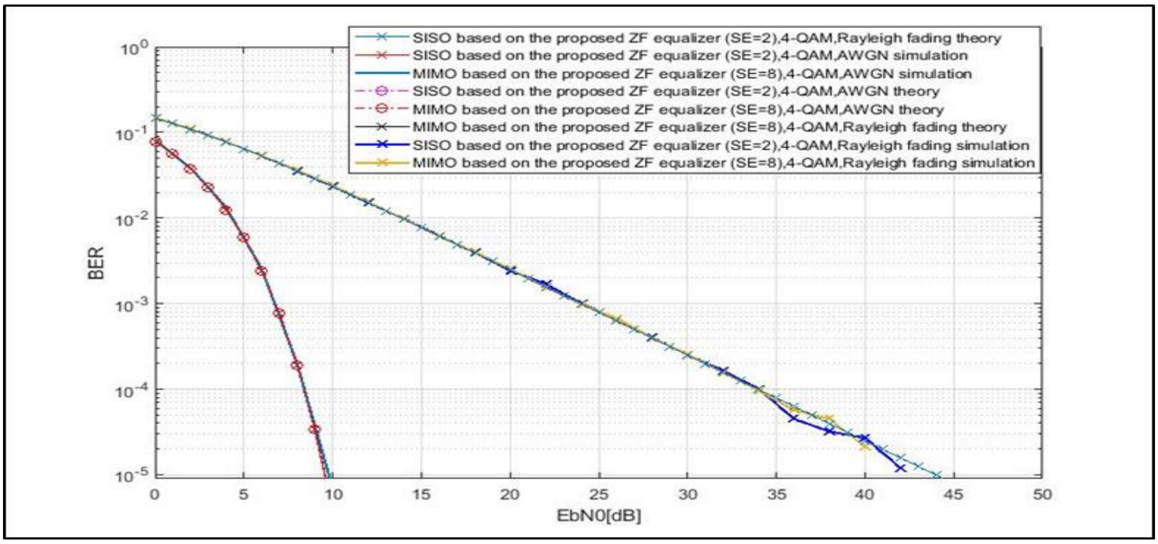

Fig.10: Performance of the proposed LCZF equalizer for 4-QAM in both MIMO and SISO-OFDM systems.

To ensure a fair comparison between the performance of the proposed system and other works(conventional systems) under the effect of Rayleigh fading channel, the performance of the proposed LCZF based MIMO-OFDM is compared with the performances of C- ZP-OFDM-OLA and C-RCZF d= L systems which proposed in in last research [2]. Figure 11 demonstrates this comparison. Its clear that the proposed system outperform both C-RCZF d= L and C- ZP- OFDM-OLA systems by 8 and 12.5 dB respectively within forward error correction coding (FEC) threshold $3.8e^{-3}$

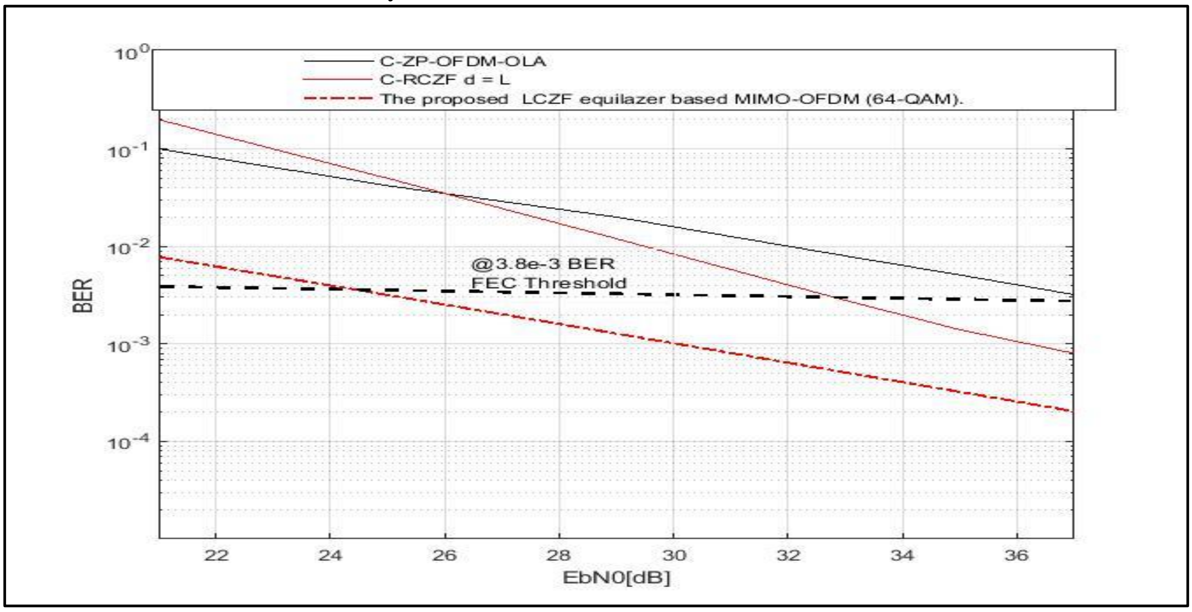

Fig.11 Comparison between the performance of the SM-MIMO-OFDM proposed system based on LCZF equalizer for 64-QAM and the performance for ZF equalizer with C-ZP- OFDM-OLA conventional system for 64-QAM in the last research [2] .

5. Conclusion

The conclusion of this work is represented via the mathematical modeling , computer simulation and performance analysis for both systems SISO-OFDM and SM-MIMO-OFDM based on LCZF equalizer that are useful for designing as compare to the other conventional systems. From analysis results and simulation there are approximations between theoretical and simulation results under the effect of AWGN and Rayleigh fading channel. From the comparison between both systems in the same spectral efficiency equal to 8 bit/s/Hz, the performance of proposed LCZF based MIMO-OFDM is outperform the performance of proposed LCZF based SISO-OFDM by 10 dB SNR within forward error correction coding (FEC) threshold $3.8e^{-3}$ .This leads to get a gain in the power efficiency.

In proposed LCZF equalizer for SISO\MIMO-OFDM systems, there is about 400 % spectral efficiency gain in case of using LCZF based MIMO-OFDM instead of LCZF based SISO-OFDM system.

6. Future work

1. The performance of OFDM based RF systems is significantly influenced by nonlinear characteristic of the power amplifier. This is due to the fact of high peak-to average power ratio (PAPR) of the OFDM signal. Due to the high PAPR, a system with a limited linear dynamic range results in clipping of the peak amplitudes of the OFDM signal, which introduces additional clipping noise. Reducing the PAPR of the proposed schemes can be involved in the proposed approaches for better system's performance. PAPR reduction methods will reduce the power requirements and reduce the BER of the proposed system, which are set aside as another future suggestion.
2. Calculation of the bit-error rate (BER) is of fundamental interest in digital communications. It is recommended to derive an exact expressions for the BER of the proposed systems using various modulation schemes under AWGN and multipath fading channel.

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