Performance Analysis of MIMO-OFDM with Doubly Selective Zero Forcing Equalizer Technique

Owk Srinivasulu[1*], P. Rajesh Kumar[2]
[1]Research Scholar, Department of Electronics and Communication Engineering, Andhra University, Visakhapatnam, Andhra Pradesh
[2]Professor & Head, Department of Electronics and Communication Engineering, Andhra University, Visakhapatnam, Andhra Pradesh
Corresponding author: Owk Srinivasulu

Abstract

Multiple input multiple output (MIMO) is a technology that combines multiple antennas and orthogonal frequency division multiplexing (OFDM) modulation to increase the data rate and spectral efficiency of wireless communication systems. One of the key issues with MIMO-OFDM systems is the equalization problems, which are caused due to multiple antennas and subcarriers. To address equalization issues, the doubly selective zero forcing (DSZF) equalization is proposed for MIMO-OFDM systems. The DSZF equalization is a technique that extends the traditional ZF equalization to doubly selective channels. It involves using a time-domain equalizer to remove the effects of the time-varying channel in each MIMO-OFDM symbol, and a frequency-domain equalizer to remove the effects of the frequency-selective channel on each subcarrier. The time-domain equalizer uses a channel shortening filter to reduce the channel length, while the frequency-domain equalizer uses a diagonal loading technique to regularize the channel matrix and improve the equalization performance. So, DSZF equalization is an important technique for MIMO-OFDM systems in doubly selective channels. It helps to mitigate the impairments introduced by the time-frequency correlation of the channel, and thereby improves the system performance. The simulation results show that the proposed MIMO-OFDM-DSZF resulted in reduced bit error rate (BER), mean square error, transmitter power, increased energy efficiency, and increased capacity, as compared to state of art existing methods.

Keywords: Multiple input multiple output, orthogonal frequency division multiplexing, doubly selective zero forcing, equalization problems.

DOI Number: 10.48047/NQ.2022.20.7.NQ33512 **NeuroQuantology2022;20(7): 4200-4215**

1. Introduction

Advancement in science and technology plays a highly commendable role in the lives of human beings. Technological innovation and progress in communication system not only enhance the quality of life but also improve lives of human beings to be social and communicate with others. The progress in wireless technology has brought revolutionary changes in the lifestyle of people. The changes in signal characterization have brought a demand for the various innovations and developments in the wireless communication system [1]. The type and property of signals determine the wireless technology and lead to the improvement in the various performance parameters of the wireless system. The MIMO-OFDM is a wireless communication technology that combines multiple antennas and OFDM modulation to increase the data rate and spectral efficiency of the system. However, the use of multiple antennas and subcarriers can cause several equalization problems [2]. Interference between subcarriers, in an OFDM system, the signal is divided into multiple subcarriers, which are transmitted simultaneously. However, the subcarriers can experience interference due to channel dispersion, synchronization errors, and phase noise [3]. This can cause inter carrier interference (ICI) and inter symbol interference (ISI)to degrade the performance of the system. Interference between Antennas: MIMO systems use multiple antennas at the transmitter and receiver to transmit and receive data simultaneously. However, the signals from each antenna can interfere with each other due to the channel fading and the spatial correlation between the antennas. This can cause inter-antenna interference (IAI) [4] that degrades the performance of the system. Power estimation Errors, MIMO-OFDM systems require accurate CSI at the receiver to perform equalization. However, power estimation errors can occur due to channel fading, Doppler shift, and timing errors. These errors can cause the equalization to be inaccurate, resulting in ICI and ISI that degrade the performance of the system. Computational Complexity [5], MIMO-OFDM systems require significant computational complexity to perform equalization. This is particularly true in systems with many subcarriers and antennas. The high computational complexity can cause delays in the system and limit the achievable data rate.

To mitigate these equalization problems, various techniques have been proposed, including, channel Equalization: Channel equalization techniques, such as zero-forcing (ZF) [6] and minimum mean square error (MMSE) [7], can be used to mitigate ICI [8] and ISI [9] caused by interference between subcarriers and antennas. These techniques use CSI at the receiver to equalize the received signal and remove the interference. Pilot-Aided Power estimation [10], Pilot-aided power estimation techniques can be used to mitigate power estimation errors by inserting pilot symbols into the transmitted signal. The receiver can use the pilot symbols to estimate the channel response and perform accurate equalization. Precoding: Precoding techniques can be used to reduce IAI by pre-multiplying the transmitted signal with a matrix that cancels out the interference between antennas [11]. This technique requires accurate CSI at the transmitter and can significantly improve the performance of the system. Reduced-Complexity Equalization: Reduced-complexity equalization techniques, such as frequency-domain equalization (FDE), can be used to reduce the computational complexity of the equalization process [12]. FDE uses the FFT to convert the received signal from the time domain to the frequency domain, and then performs equalization in the frequency domain. So, MIMO-OFDM systems can experience equalization problems, such as interference between subcarriers and antennas, power estimation errors, and high computational complexity [13]. However, several techniques, including channel equalization, pilot-aided power estimation, precoding, and reduced-complexity equalization, have been proposed to mitigate these problems and improve the performance of the system.

The DSZF equalization is a computationally efficient technique that can achieve good equalization performance in doubly selective channels. It has been shown to outperform traditional ZF equalization techniques in simulations and experimental studies. So, DSZF equalization is an important technique for MIMO-OFDM systems in doubly selective channels. It helps to mitigate the impairments introduced by the time-frequency correlation of the channel, and thereby improves the system performance.

The rest of the paper is organized as follows: section 2 contains the literature survey with problem analysis. Section 3 contains the detailed analysis of the proposed MIMO-OFDM system. Section 4 discusses the detailed analysis of results and discussions. Section 5 contains the conclusion with future possibilities.

2. Literature survey

Shivaji, R., et al. (2022) [14] planned an efficient hybrid partial transmit system (EHPTS) to improve transmission performance. It has been proven to effectively reduce the PAPR in OFDM and is best used in conjunction with reconfigurable high-speed MIMO-OFDM. However, the PTS approach requires investigating every potential contributor to phase rotation. Yet the computational cost of the mathematical model increases as the number of subcarriers and subblocks expands. In [15] authors advocated merging PAPR reduction approaches with the SLM based PTS (SLM-PTS) method to further increase PAPR reduction and power amplifier efficacy in OFDM and MIMO (multiple inputs, multiple outputs)-OFDM systems. Jothi, S. et al. (2022) [16] suggest an energy-efficient multimedia paradigm called MIMO-OFDM. To improve QoS for multimedia transmission via wireless networks, MIMO is included into an OFDM technique. A technique called RSTBC (Rateless STBC) stays used in the proposed research towards improve the power constraint strategy while encoding video data for usage on mobile networks. Panda, Chinmayee, et al., 2022 [17] developed MIMO-OFDM, which improves transmission efficiency throughout the frequency spectrum, which is an abbreviation for combined code and frequency index modulation. They evaluate the performance of the traditional OFDM scheme, the Coded Frequency Division Multiplexing (CFIM) scheme with OFDM, as well as the MIMO-OFDM system in free space under circumstances of low turbulence and a set spectral efficiency. The "standard OFDM" system makes use of a frequency-division mechanism that has been validated after extensive testing. The BER of 50 is noticeably reduced when contrasted with that of conventional OFDM and CFIM-OFDM. There was more data to suggest that using the CFIM-MIMO-OFDM-FSO method might minimize PAPR in locations that are outside. In [18] authors developed the MIMO-OFDM approach based on mutable weight-based adaptive particle swarm optimization (MAPSO) was developed. The implementation of this strategy will take place in four stages: (1) signal detection; (2) OFDM with MIMO; (3) STBC-based OFDM coding; and (4) MC-CDMA for the evaluation of optimal channel estimate. During the process of implementing the MC-CDMA strategy, the MAPSO method is utilized to precisely adjust the parameters of each channel estimation procedure.

El-Khamy, Said E., et al. (2021) [19] observed that the orthogonality of the OFDM's subcarriers weakened with time, leading to a weaker signal. The purpose of this research was to provide criteria for evaluating the efficacy of the technique discussed; in particular, the MIMO-OFDM TSCE approach, which is based on CCs. Doppler dispersion and partial-band jamming contribute significantly to these findings. Among the several methods for MIMO-OFDM CE, TSCC-CE has shown to be the most successful due to its resistance to the effects of partial-band jamming on MIMO-OFDM CE accuracy. This enhancement in performance was seen in the presence of a partial-band jamming ratio and a Doppler spread with a very high value. Chen, Yixin, and coworkers (2021) [20] may be extended to function well with MIMO-OFDM networks. The outcomes of the simulation reveal that the recommended PFrFT-LDLH performs better than the other approaches when used to the SISO-OFDM scenario, and that its performance may be enhanced when it is applied to the MIMO-OFDM scenario. A Linear-Quadratic Estimation (LQE) approach was proposed by Reddy, Chetana, and colleagues (2021) [21] for the purpose of Channel Estimation in a MIMO-OFDM system. This is a system in which the noise covariance matrix, commonly known as Q, plays an essential role. The values of the states that came before Q are often used as a foundation for Q's value. The article [22] presents an implementation of low power, signal availability, network coverage, less latency, efficient bandwidth 5G technology communication system. The article proposes a new system architecture for 5G networks that addresses issues such as low power consumption and network coverage. The article [23] proposes a 5G adaptive communication channel modeling for the 75 GHz frequency spectrum. The article presents a new channel model for 5G networks that considers the frequency spectrum used for communication. The article [24] proposes an implementation of hybrid LTE and cognitive radio architectures based on traffic load and channel capacity. The article presents a new approach to implement LTE and cognitive radio architectures that optimizes traffic load and channel capacity.

In [25] authors described the time-domain synchronous OFDM as inherently compatible with ICI mitigation. This is because its receiver could produce rough estimations of linear channels that fluctuate with time. When simulating Time-Varying Channels in MIMOOFDM with 16QAM and QPSK modulation, BER and MSE were improved. Shahab, Maha Monther, et al. [26] analyze the effectiveness of the Low Complexity Zero Forcing (LCZF) equalizer in SISO-OFDM and SM-MIMO-OFDM systems with different quantized amplitude modulation (QAM) modulations. In the presence of "Additive White Gaussian Noise" and a multipath fading channel, it investigates a novel strategy to boost the BER, spectral efficiency, and power efficiency of an RF communication system while simultaneously decreasing its complexity. Girija, S. P., et al. [27] examine a method for dampening sudden noise using the fractional weighted zero-forcing (FWZF) equalizer. This equalizer is a variant of the Zero-Forcing equalizer that incorporates the concept of fractions. Due to the ZF equalizer's application of fractional theory in the interpretation of equalization values from earlier instances for the formulation of the effective equalization value in the present instance, noise effects in the MIMO-OFDM system are mitigated, and performance is enhanced. Liu, Jun, et al. [28] provide a fresh method of attaining high-precision synchronization in their paper. In this approach, machine learning is taken to extremes. (ELM). Both the residual symbol timing offset (RSTO) and the residual carrier frequency offset are estimated using ELMs in a typical MIMO-OFDM configuration. In [29] authors used the optimal equalization approach and modulation for MIMO OFDM systems, they have examined many detection methods with the aid. The purpose of this analysis was to choose the most efficient strategy. They have also compared the V-BLAST algorithm's BER/SNR results across different detection strategies. Zhao, Tianyu, et al. [30] proposed a deep learning (DL) based technique to signal identification in MIMO-OFDM-IM systems (multiple-input multiple-output orthogonal frequency division multiplexing with index modulation). This method makes use of variational autoencoder (VAE). Building a deep learning network with fully linked layers occurs simultaneously with the development of this variational optimization framework.

3. Proposed methodology

Both the hybrid beamforming transmitter (equalizer) design and the hybrid beamforming receiver (combiner) design are treated as two different sub-problems. Following the encoding of the incoming data input streams by the digital baseband precoder, the signal is then transformed into an RF signal by RF chains, which comprise of ADC/DAC, mixers, converters, and other components. Analog phase shifters then process RF signal's phase only and processed signal is further passed to transmitting antennas for transmission. Figure 1 presents the proposed DSZF equalizer-based MIMO-OFDM system. This architecture makes use of varying combinations of transmitting and receiving antennas, RF chains, and phase shifters. In addition, the minimum count of RF chains must be equal or greater than the count of data streams to be transmitted by the system. So, several formulations can be designed with different number of transmitting or receiving antennas, RF chains, phase shifters and way of connections. Two fundamental obstacles are presented using conventional ZF to enormous amounts of data. To begin, both the computational complexity and the iteration storage cost are rather high. Secondly, the single coefficient selection simultaneously requires the corresponding k iterations to estimate with k coefficient of q. Whenever the k iterations are increased, that leads to impracticably slow down its performance. The number of iterations in ZF-based methods is determined by the sparsity level of the channel; the suggested technique stops the iteration only when the residual is on the threshold of 0. Because of this, the precision of the recovery can be guaranteed. In addition, when correct partial common support information is gathered, the number of repetitions may be restricted, which results in a reduction in the computing cost of the proposed technique. However, in many traditional greedy algorithms, it is necessary to have priori knowledge on the receiver side. Additionally, greedy iteration algorithms are prone to inaccuracy and add an additional layer of complexity to the calculation.

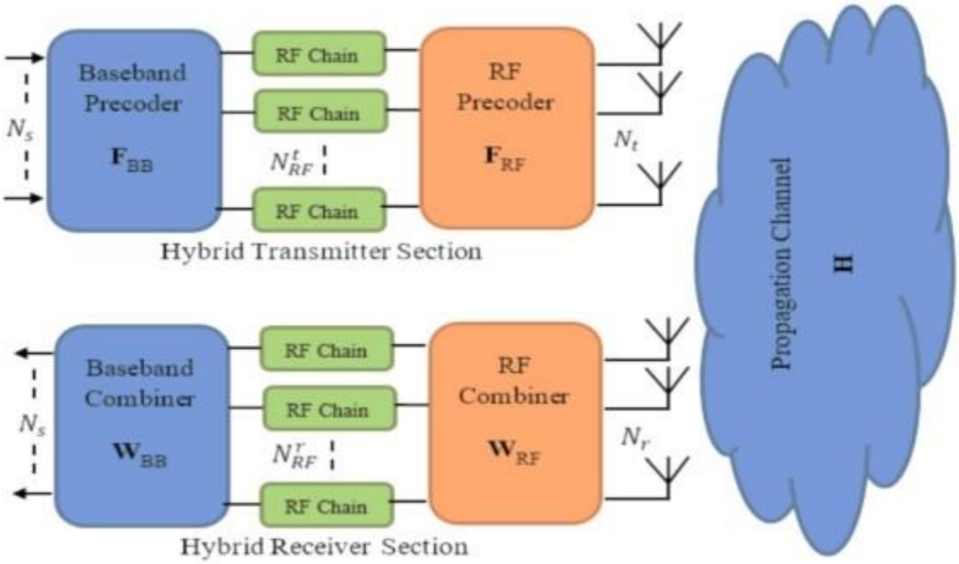

Figure 1: Proposed MIMO-OFDM with DSZF equalizers

The information on the fading channel has been effectively identified using any of these two different strategies. On the other hand, the channel level should not be considered previous information in the recovery method that has been provided. This iteration will follow the information from the partial common support and will rely on whether it has reached an iteration threshold. The DSZF algorithm is one of the most extensively applied hybrid-precoding algorithms with reasonably good performance. The DSZF based precoder design as sparsity constrained matrix reconstruction problem. The precoder design starts with discovering the array response vectors along which the fully digital precoder has the maximum projection. The columns of analog precoding matrix are appended from such array response vectors, then the least square solution for digital precoding matrix is calculated and the algorithm continues until all vectors are selected. The performance of Bayesian Gaussian mixture needs to be compared with other estimation schemes. DSZF is used as sparse recovery algorithms. The baseline schemes can be summed up as for Static LS: the first block value is considered. In Random LS, an orthonormal sequence is used for trained LS. In DSZF, a random Gaussian matrix × is selected, and the performance is poor with unit magnitudes. The DSZF algorithm gets back the channel initiated with the previous information, like the equalizer-aided scheme. Moreover, the DSZF algorithm is guaranteed only maximum posteriori estimation.

$$\varepsilon_i = z - \emptyset h_i \qquad (1)$$

Here, h_i is the sparse vector impulse of i^{th} case. Fundamentally, two strategies are involved in every iteration; firstly, a single delay of transmitting includes all the delays. This is the sum of accumulated delay. Secondly, to select uncovered paths that are required to estimate gains.

3.1 DSZF Equalizer

Consider a MIMO-OFDM network that has a BS with M antennas and K users, all of which have a single antenna system. Figure2 shows the block diagram of DSZF equalizer. It takes into consideration a scheduler as a means of maximizing the spectrum utilization of K users and a regularized zero-forcing pre-coder as a means of accommodating QoS requirements. It is believed that input is obtained from each one of the K users whenever the BS schedules users. Each of the K users choose $S\,[0]$ to quantize $Y\,[0]$ from a B-bit finite set, which is termed as a codebook and is known to both the BS and all of the users and feeds back the chosen codeword index. This process is repeated until all $Y\,[0]$ values have been quantized. Using an estimated SNR for each of the $(K\,M)$ possible combined channel matrices, the scheduler chooses M users from the pool of K users to achieve the maximum feasible sum rate. The *'S'* is the chosen user set, and it comprises information on power consumption that is tied to both UE and Small Cell Antenna (SCA) BSs.

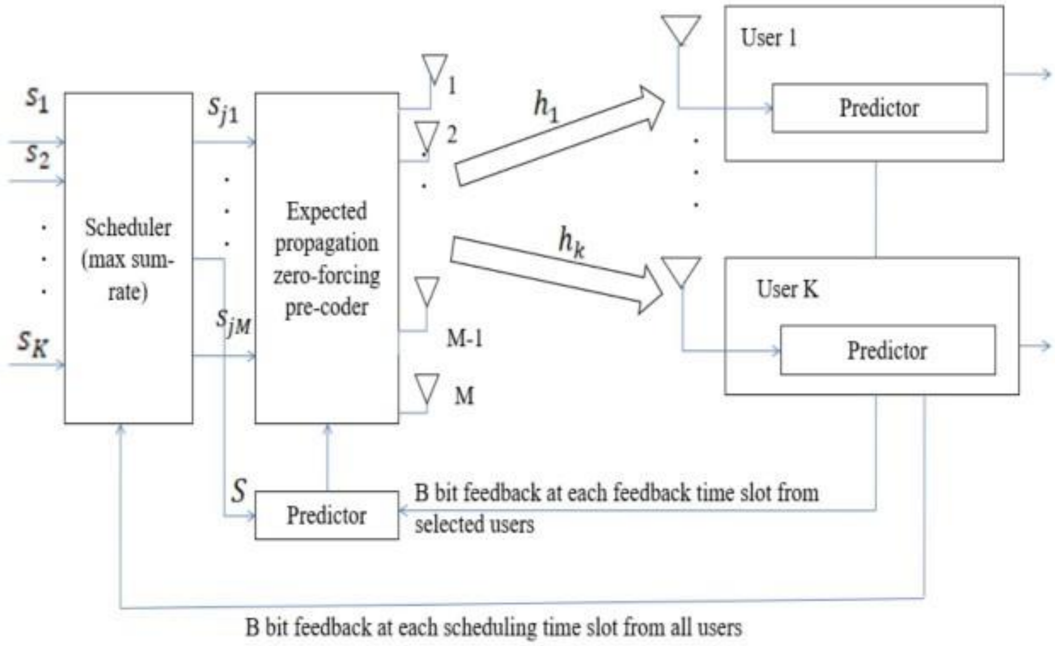

Figure 2. DSZF Equalizer

Doubly selective process: In a wireless communication system, the propagation environment is often characterized by a time-varying channel, where the channel parameters such as amplitude, phase, and delay, vary over time. In addition, the wireless channel can also exhibit frequency-selectivity, where different frequency components of the transmitted signal experience different channel gains and delays. When both time and frequency variations are present, the channel is said to be doubly selective.

Doubly selective channels are encountered in many wireless communication scenarios, such as high-speed mobile communication, wireless sensor networks, and satellite communication. The channel variations in doubly selective channels are caused by various factors such as multipath propagation, Doppler effect, and frequency-selective fading. In a doubly selective channel, the channel matrix that relates the transmitted and received signals is time-varying and frequency-selective. This means that the channel matrix changes with time and has different elements for each subcarrier in an OFDM system. Therefore, the traditional ZF equalization method may not be effective in removing the channel distortion in doubly selective channels. To mitigate the effects of doubly selective channels, various equalization techniques have been proposed, such as DSZF equalization, DFE (Decision

Feedback Equalization), and VBLAST (Vertical Bell Laboratories Layered Space-Time) equalization. These techniques are designed to remove the channel distortion in both the time and frequency domains, by using time-domain and frequency-domain equalizers. They also consider the time-frequency correlation of the channel to improve the equalization performance. One of the major challenges in dealing with doubly selective channels is the high computational complexity involved in the equalization process. The computational complexity increases with the number of subcarriers and the number of transmit and receive antennas. This complexity can be reduced by using low-complexity equalization techniques, such as linear equalization or subspace-based equalization. So, doubly selective channels are an important factor that affects the performance of wireless communication systems. The channel variations in doubly selective channels can cause severe distortion in the received signal, which can lead to poor system performance. Therefore, it is essential to use appropriate equalization techniques to mitigate the effects of doubly selective channels and improve the system performance. The algorithm for doubly selective process involves the use of equalization techniques to mitigate the effects of time and frequency variations in the wireless channel. In particular, the algorithm involves the following steps:

Step 1: Power estimation: To equalize the received signal, the channel parameters such as amplitude, phase, and delay need to be estimated. This can be done by transmitting known pilot symbols and using the received signal to estimate the channel response. Power estimation can be performed using various techniques such as Least Squares (LS), Minimum Mean Square Error (MMSE), and Maximum Likelihood (ML) estimation.

Step 2: Channel equalization: After the channel response is estimated, the equalization process can be performed. In doubly selective channels, the traditional ZF equalization technique may not be effective, and other techniques such as DSZF, DFE, or VBLAST equalization may be used. These techniques involve using time-domain and frequency-domain equalizers to remove the channel distortion in both time and frequency domains.

Step 3: Signal detection: After the equalization process is performed, the received signal is detected using a symbol detection algorithm. The detection algorithm can be based on maximum likelihood (ML), minimum mean square error (MMSE), or other techniques.

Step 4: Decoding: Finally, the detected symbols are decoded to obtain the transmitted information. This involves using a decoding algorithm such as the Viterbi algorithm or the Turbo decoding algorithm.

Step 5: It is important to note that the above steps are performed iteratively, as the channel parameters may change over time. Therefore, the power estimation and equalization process need to be performed periodically to track the time-varying channel.

Step 6: The computational complexity of the doubly selective process algorithm can be high, especially for systems with large numbers of subcarriers and antennas. Therefore, low-complexity techniques such as linear equalization or subspace-based equalization can be used to reduce computational complexity. So, the algorithm for doubly selective process involves power estimation, channel equalization, signal detection, and decoding. The equalization process is a key step in the algorithm, and various techniques such as DSZF equalization can be used to remove the effects of time and frequency variations in the wireless channel. The algorithm needs to be performed iteratively to track the time-varying channel, and low-complexity techniques can be used to reduce the computational complexity.

Zero forcing: The ZF is a linear equalization technique used to mitigate the effects of linear distortion in communication channels. The goal of the ZF equalizer is to remove the channel distortion by applying a linear filter to the received signal. The ZF equalizer works by inverting the channel response. In other words, the equalizer applies a filter that undoes the effect of the channel on the transmitted signal.

This is done by multiplying the received signal by the inverse of the channel response. Mathematically, the ZF equalizer can be represented as:

$$y_{eq} = H^{-1} * y \qquad (2)$$

where y is the received signal, H is the channel response, and y_{eq} is the equalized signal. The ZF equalizer assumes that the channel is a linear time-invariant system, which means that the channel response does not change over time. It also assumes that the channel is known at the receiver, which is often the case in systems where pilot symbols are transmitted periodically. One of the main advantages of the ZF equalizer is that it can provide optimal performance in ideal conditions, where there is no noise or other impairments in the channel. However, in practice, the ZF equalizer may not perform well in the presence of noise, interference, or other non-ideal conditions. This is because the equalizer may amplify the noise and interference along with the desired signal.

The ZF equalizer has a low computational complexity and is easy to implement, which makes it a popular choice for communication systems with limited computational resources. However, the performance of the ZF equalizer degrades rapidly as the channel becomes more frequency-selective or when the channel is time-varying. So, ZF equalizer is a linear equalization technique used to remove the effects of linear distortion in communication channels. It works by inverting the channel response and applying a linear filter to the received signal. While the ZF equalizer can provide optimal performance in ideal conditions, it may not perform well in the presence of noise and other impairments. The ZF equalizer has a low computational complexity and is easy to implement, but its performance degrades rapidly as the channel becomes more frequency-selective or when the channel is time-varying. The ZF equalizer algorithm can be summarized as follows:

Step 1: Receive the distorted signal y(n) at the receiver.

Step 2: Estimate the channel response H(n) using pilot symbols or other known symbols transmitted in the signal.

Step 3: Calculate the inverse of the channel response $H\^(-1)(n)$.

Step 4: Apply the inverse channel response to the received signal y(n) using the following equation:

$$y_{eq}(n) = H\^(-1)(n) * y(n) \qquad (3)$$

where$y_{eq}(n)$ is the equalized signal.

Step 5: Output the equalized signal $y_{eq}(n)$ for further processing or demodulation.

4.Results and discussion

This section gives a detailed analysis of simulation results of MIMO-OFDM systems using DSZF equalizer, which is implemented in MatlabR2018a software.

4.1 Simulation parameters

Table 1 presents the simulation parameters. The non-zero coefficients in channel generate a Gaussian compound distribution with zero mean and unit variance. Rician fading is a stochastic model for radio propagation anomaly caused by partial cancellation of an DSZF signal by itself. The signal arrives at the receiver by several different paths (hence exhibiting multipath interference), and at least one of the paths is changing.

Table 1. Simulation parameters

Parameters	Value
Number of BS Antennas	4, 8, 16
Number of Pilots	10000
Channel Sparsity	60
Channel Type	Rician
Signal to Noise Ratio Range	0-8 dB
FFT Size	128
System Bandwidth	20 MHz
Carrier Frequency	2.6 GHz

Rician fading is caused by partial cancellation of a DSZF signal by itself (lengthening or shortening). Rician fading happens when one of the pathways, often a signal traveling in a line-of-sight or some strong reflection signals. The amplitude gained in Rician fading may be thought of as having a Rician distribution as its defining feature.

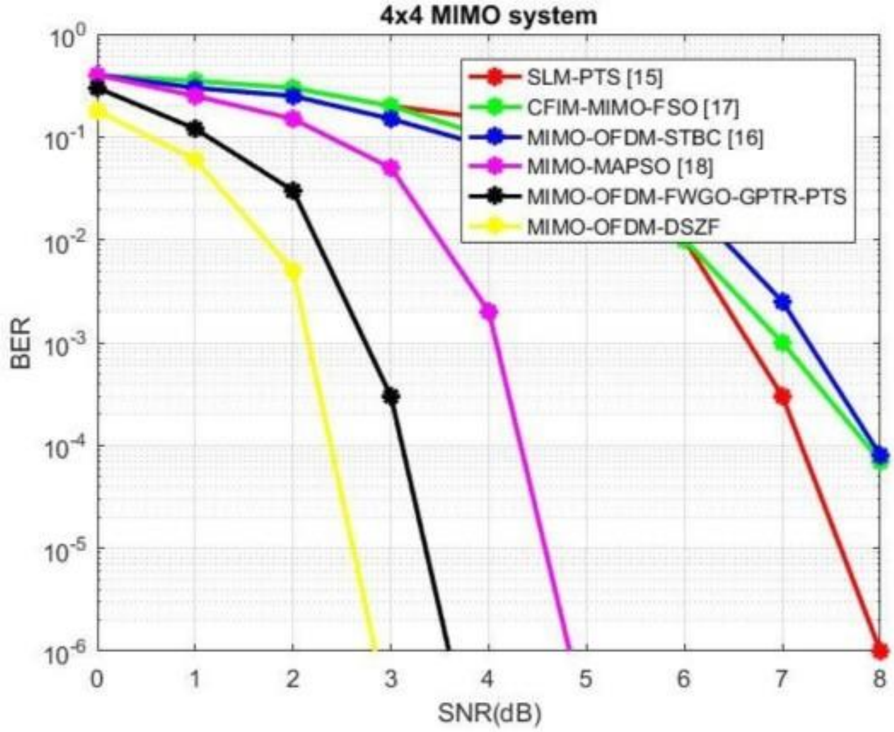

Figure 3. BER Performance of 4x4 MIMO-OFDM Systems.

4.2 BER performance evaluation

Figure 3, Figure 4, and Figure 5 present the BER performance of 4x4, 8x8, 16x16 MIMO systems. The BER values are measured in the range of 0-8 dB of SNR. The proposed MIMO-OFDM approach resulted in reduced BER performance as compared to conventional approaches such as SLM-PTS [15], CFIM-MIMO-FSO [17], MIMO-OFDM-STBC [16], MIMO-MAPSO [18], and FWGO-GPTR-PTS. From Figure 3, it is observed that the conventional MIMO-MAPSO[18] method resulted in BER of 10^{-6} at 5 dB, SLM-PTS [15] resulted in BER of 10^{-6} at 8 dB, CFIM-MIMO-FSO [17], MIMO-OFDM-STBC [16] resulted in BER of 10^{-4} at 8 dB, and FWGO-GPTR-PTS resulted in BER of 10^{-6} at 3.5 dB. Further, the proposed MIMO-OFDM resulted in reduced BER of 10^{-6} at 2.7 dB, which is less compared to existing approaches. From Figure 4, it is observed that the conventional SLM-PTS [15] method resulted in BER of 0.01 at 8 dB, CFIM-MIMO-FSO [17] method resulted in BER of $3 * 10^{-5}$ at 8 dB, MIMO-OFDM-STBC [16] method resulted in BER of 10^{-6} at 6.2 dB, MIMO-MAPSO[18] method resulted in BER of 10^{-6} at 5.5dB, and FWGO-GPTR-PTS resulted in BER of 10^{-6} at 4.95 dB. Further, the proposed MIMO-OFDM resulted in reduced BER of 10^{-6} at 3.8 dB, which is less compared to existing approaches. From Figure 5, it is observed that the conventional SLM-PTS [15] method resulted in BER of 0.03 at 8 dB, CFIM-MIMO-FSO [17] resulted in BER of $2 * 10^{-4}$ at 8 dB, MIMO-OFDM-STBC [16] resulted in BER of $3 * 10^{-5}$ at 8 dB, and MIMO-MAPSO[18] resulted in BER of 10^{-5} at 8dB, and FWGO-GPTR-PTS resulted in BER of 10^{-6} at 6.2 dB. Further, the proposed MIMO-OFDM resulted in reduced BER of 10^{-6} at 5.8 dB, which is less compared to existing approaches.

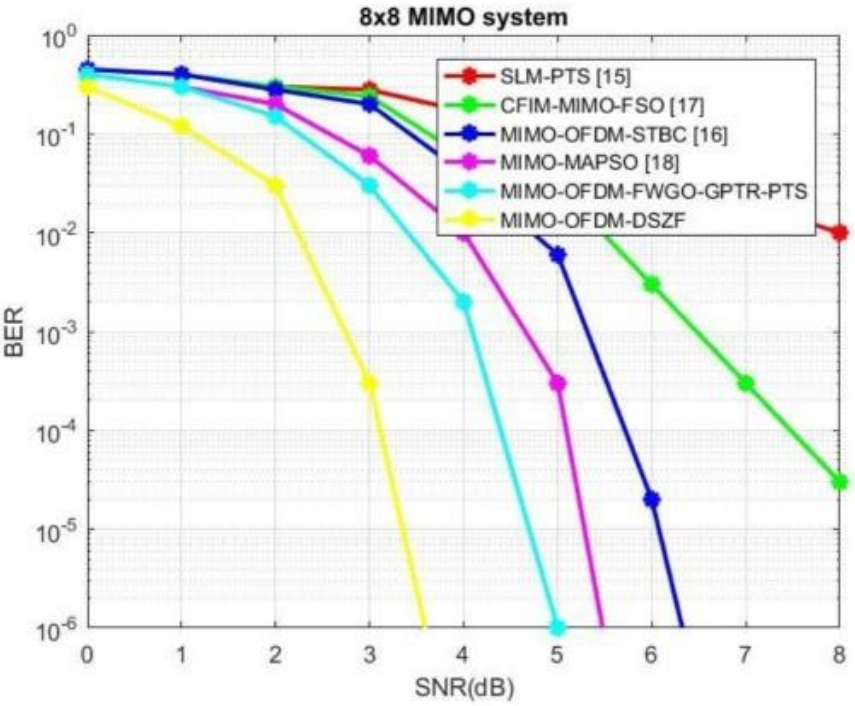

Figure 4. BER Performance of 8x8 MIMO-OFDM Systems.

4.3 MSE performance evaluation

Figure 6, Figure 7, and Figure 8 present the MSE performance of 4x4, 8x8, 16x16 MIMO-OFDM systems. The MSE values are measured in the range of 0-30 dB of SNR. The proposed MIMO-OFDM approach resulted in reduced MSE performance as compared to conventional approaches such as EHPTS [14], SLM-PTS [15], CFIM-MIMO-FSO [17], MIMO-OFDM-STBC [16], MIMO-MAPSO [18], and FWGO-GPTR-PTS. From Figure 6, it is observed that the conventional CFIM-MIMO-FSO [17] method resulted in MSE of 10^{-3} at 31dB, SLM-PTS [15] resulted in MSE of 10^{-3} at 30dB, MIMO-MAPSO [18] resulted in MSE of 10^{-3} at 32 dB, MIMO-OFDM-STBC [16] resulted in MSE of 10^{-3} at 27dB, EHPTS [14] resulted in MSE of 10^{-3} at 24 dB, and FWGO-GPTR-PTS resulted in MSE of 10^{-3} at 21 dB. Further, the proposed MIMO-OFDM resulted in reduced MSE of 10^{-3} at 18dB, which is less compared to existing approaches. From Figure 7, it is observed that the conventional CFIM-MIMO-FSO [17] method resulted in MSE of 10^{-3} at 35 dB, SLM-PTS [15] resulted in MSE of 10^{-3} at 28 dB, MIMO-MAPSO [18] resulted in MSE of 10^{-3} at 26 dB, MIMO-OFDM-STBC [16] resulted in MSE of 10^{-3} at 24 dB, EHPTS [14] resulted in MSE of 10^{-3} at 22 dB, and FWGO-GPTR-PTS resulted in MSE of 10^{-3} at 21 dB. Further, the proposed MIMO-OFDM resulted in reduced MSE of 10^{-3} at 19 dB, which is less compared to existing approaches. From Figure 8, it is observed that the conventional CFIM-MIMO-FSO [17] method resulted in MSE of 10^{-3} at 34 dB, SLM-PTS [15] resulted in MSE of 10^{-3} at 32 dB, MIMO-MAPSO [18] resulted in MSE of 10^{-3} at 32 dB, MIMO-OFDM-STBC [16] resulted in MSE of 10^{-3} at 32 dB, EHPTS [14] resulted in MSE of 10^{-3} at 29 dB, and FWGO-GPTR-PTS resulted in MSE of 10^{-3} at 27 dB. Further, the proposed MIMO-OFDM resulted in reduced MSE of 10^{-3} at 22dB, which is less compared to existing approaches.

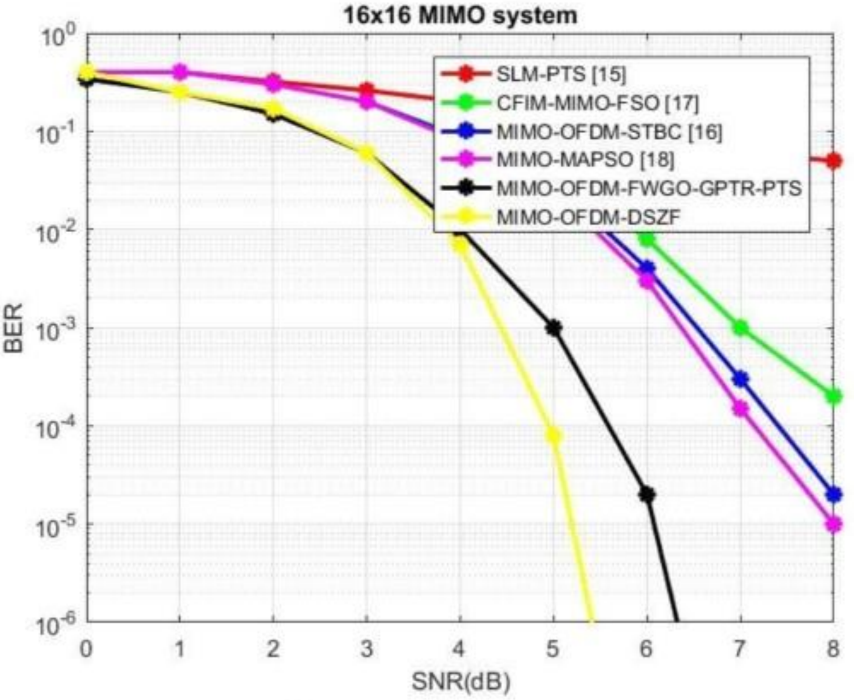

Figure 5. BER Performance of 16x16 MIMO-OFDM Systems.

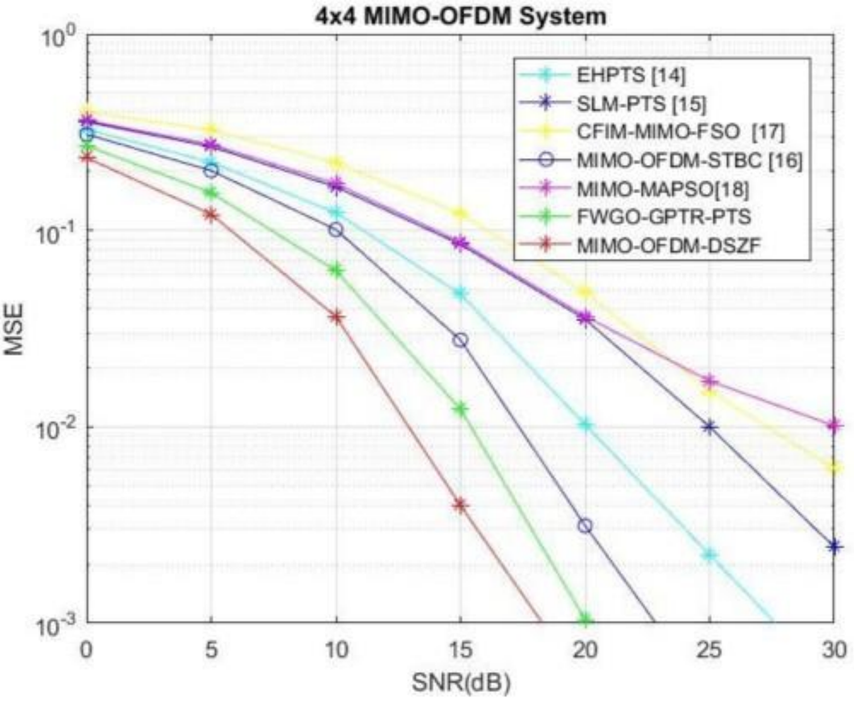

Figure 6. MSE Performance of 4x4 MIMO-OFDM Systems

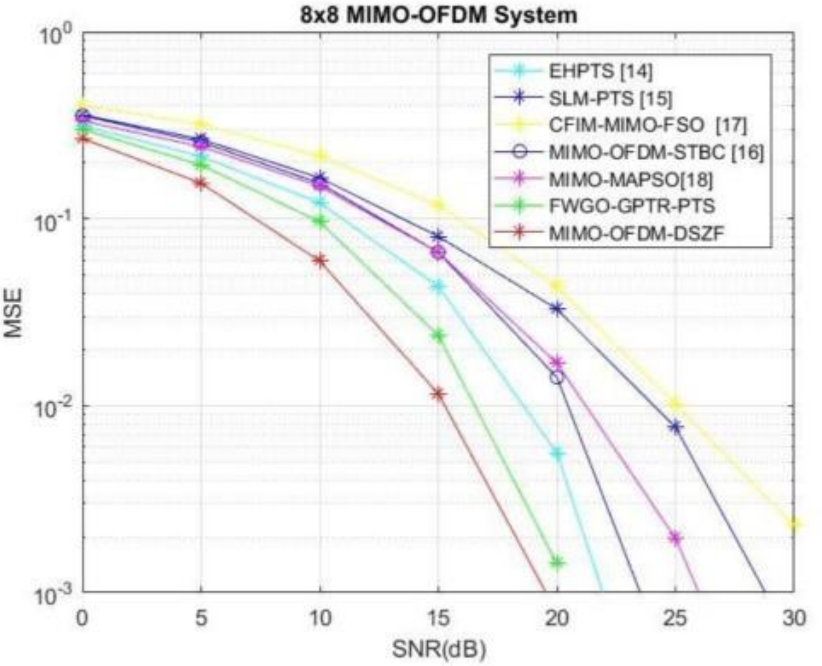

Figure 7. MSE Performance of 8x8 MIMO-OFDM Systems.

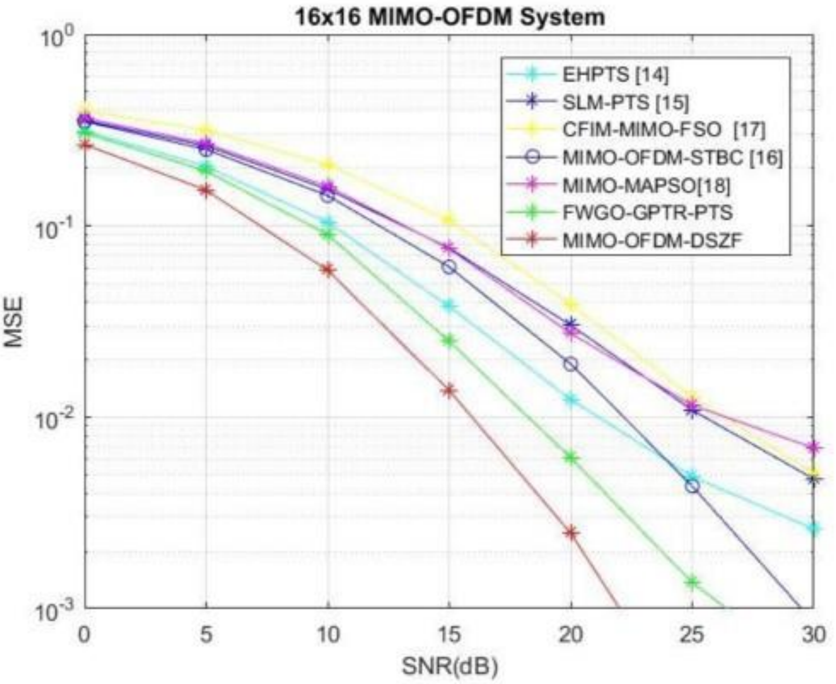

Figure 8. MSE Performance of 16x16 MIMO-OFDM Systems.

4.4 Energy efficiency performance evaluation

Figure 9 shows the energy efficiency performance of various MIMO-OFDM systems for 250 number of user equipment. Here, TSCE [19] resulted in 3.5MBPJ of energy efficiency, LDLH [20] resulted in 4.1 MBPJ, DMH-LQE [21] resulted in 4.5 MBPJ, and FWGO-GPTR-PTS resulted in 4.8 MBPJ. However, the proposed DSZF based MIMO-OFDM resulted in increased energy efficiency, i.e., 6 MBPJ, which is higher as compared to existing methods. Figure 10 shows the capacity performance of various MIMO-OFDM systems for 250 number of user equipment. Here, TSCE [19] resulted in 2.1MBPS of capacity, LDLH [20] resulted in 2.4 MBPS, DMH-LQE [21] resulted in 3.3 MBPS, and FWGO-GPTR-PTS resulted in 4.2 MBPS. However, the proposed DSZF based MIMO-OFDM resulted in increased channel capacity, i.e., 6 MBPS, which is higher as compared to existing methods. Figure 11 shows the transmitted power performance of various MIMO-OFDM systems for 250 number of user equipment. Here, TSCE [19] resulted in $10^{-1}\ uJ$, LDLH [20] resulted in in $2 * 10^{-2}\ uJ$, DMH-LQE [21] resulted in in $9 * 10^{-2}\ uJ$, and FWGO-GPTR-PTS resulted in in $10^{-3}\ uJ$ of transmitted. However, the proposed MIMO-OFDM resulted in reduced transmitted power, i.e., in $3 * 10^{-4}\ uJ$, which is lesser as compared to existing methods.

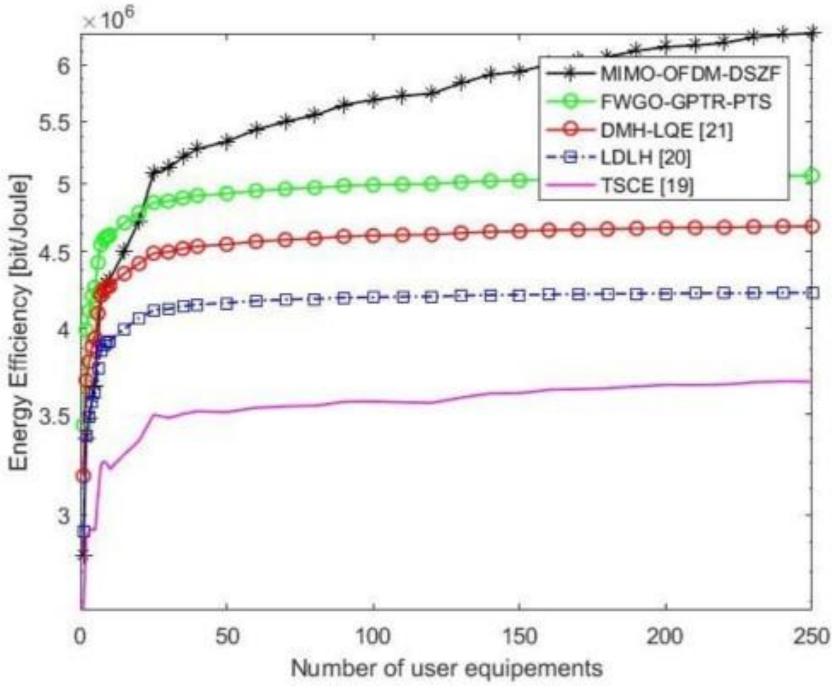

Figure 9. Energy efficiency performance of various MIMO-OFDM systems.

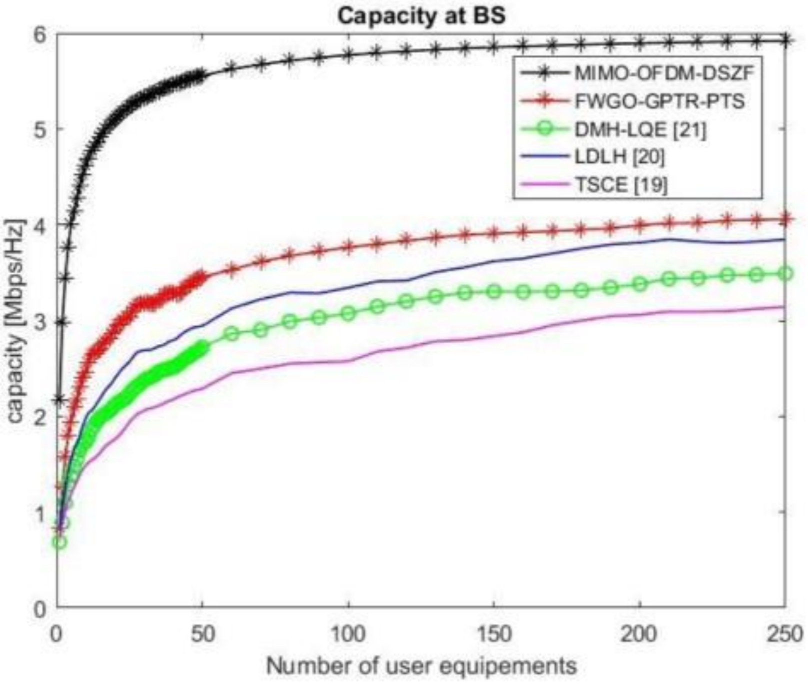

Figure 10. Capacity performance of various MIMO-OFDM systems.

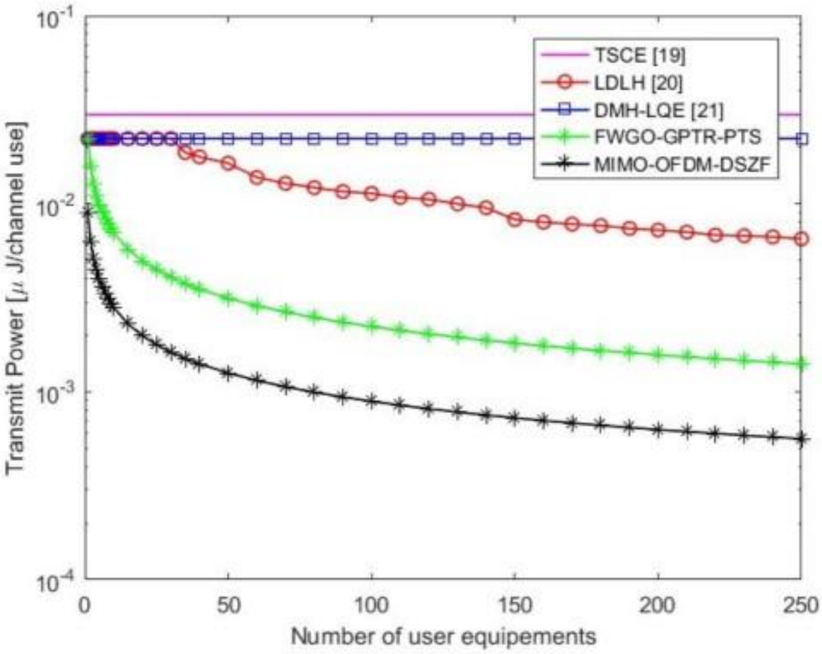

Figure 11. Transmit power performance of various MIMO-OFDM systems.

5. Conclusion

In this work, the DSZF channel equalize approach for MIMO-OFDM systems is presented as a potential solution. The DSZF is an algorithm that has a very low level of complexity and is based on the complicated oblique manifold of MIMO-OFDM channels. The algorithms that are based on matrix manifolds operations are carried out so that the ideal solution may be found for reaching near optimal performance. The DSZF can deliver near optimal performance with respect to capacity and energy efficiency. This reduces the heavy computational load that is placed on the system because of the Kronecker product and suffers from a slow convergence speed because of the nested loop structure. This makes it possible for the proposed method to achieve optimum performance with much quicker processing speed by decreasing transmitted power, BER, and MSE. This makes the proposed approach superior to other algorithms that are state-of-the-art. But optimal power allocation (OPA) in MIMO-OFDM is a critical component for achieving high spectral efficiency and improving the overall performance of the system. OPA refers to the process of allocating power to the different subcarriers and antennas in MIMO-OFDM systems in an optimal way.

References

[1] Lin, Bangjiang, et al. "Experimental demonstration of compressive sensing-based channel estimation for MIMO-OFDM VLC." IEEE Wireless Communications Letters 9.7 (2020): 1027-1030.

[2] Er, Madhuri Sonwane, and Madhavi Singh Bhawar. "Implementation of MIMO-OFDM with Zero Forcing Equalization." International Journal of Progressive Research in Science and Engineering 1.8 (2020): 1-7.

[3] El Ghzaoui, Mohammed, et al. "Compensation of non-linear distortion effects in MIMO-OFDM systems using constant envelope OFDM for 5G applications." Journal of Circuits, Systems and Computers 29.16 (2020): 2050257.

[4] Chen-Hu, Kun, Yong Liu, and Ana García Armada. "Non-coherent massive MIMO-OFDM down-link based on differential modulation." IEEE Transactions on Vehicular Technology 69.10 (2020): 11281-11294.

[5] Ramadan, K., Moawad I. Dessouky, and Fathi E. Abd El-Samie. "Modified OFDM

configurations with equalization and CFO compensation for performance enhancement of OFDM communication systems using symmetry of the Fourier transform." AEU-International Journal of Electronics and Communications 126 (2020): 153247.

[6] Mestoui, Jamal, et al. "Performance analysis of CE-OFDM-CPM Modulation using MIMO system over wireless channels." Journal of Ambient Intelligence and Humanized Computing 11 (2020): 3937-3945.

[7] Simon, Judy. "A Performance Analysis of Wavelet based LTE-OFDM with Multi-equalizers." Turkish Journal of Computer and Mathematics Education (TURCOMAT) 12.6 (2021): 108-116.

[8] Aldaya, Ivan, et al. "Compensation of nonlinear distortion in coherent optical OFDM systems using a MIMO deep neural network-based equalizer." Optics Letters 45.20 (2020): 5820-5823.

[9] Kapoor, Divneet Singh, and Amit Kumar Kohli. "Intelligence-based Channel Equalization for 4x1 SFBC-OFDM Receiver." Intelligent Automation & Soft Computing 26.3 (2020).

[10] Nandi, Shovon, Narendra Nath Pathak, and Arnab Nandi. "A novel adaptive optimized fast blind channel estimation for cyclic prefix assisted space–time block coded MIMO-OFDM systems." Wireless personal communications 115 (2020): 1317-1333.

[11] Kassam, Joumana, et al. "Two-step multiuser equalization for hybrid mmwave massive mimo gfdm systems." Electronics 9.8 (2020): 1220.

[12] Nandi, Shovon, Narendra Nath Pathak, and Arnab Nandi. "Avenues to improve channel estimation using optimized CP in STBC coded MIMO-OFDM systems—a global optimization approach." Proceeding of Fifth International Conference on Microelectronics, Computing and Communication Systems: MCCS 2020. Springer Singapore, 2021.

[13] Cheng, Nan-Hung, et al. "Maximum likelihood-based adaptive iteration algorithm design for joint CFO and channel estimation in MIMO-OFDM systems." EURASIP Journal on Advances in Signal Processing 2021 (2021): 1-21.

[14] Shivaji, R., et al. "Implementation of an Effective Hybrid PTS Model for PAPR in MIMO-OFDM System." ICDSMLA 2020: Proceedings of the 2nd International Conference on Data Science, Machine Learning and Applications. Springer Singapore, 2022.

[15] Ayeswarya, R., and N. Amutha Prabha. "Fractional wavelet transform based PAPR reduction schemes in multicarrier modulation system." *IETE Journal of Research* 68.1 (2022): 732-742.

[16] Jothi, S., and A. Chandrasekar. "An efficient modified dragonfly optimization based mimo-ofdm for enhancing qos in wireless multimedia communication." Wireless Personal Communications 122.2 (2022): 1043-1065.

[17] Panda, Chinmayee, and Urmila Bhanja. "Effect of Code and Frequency Index Modulation in MIMO-OFDM-FSO System." Optical and Wireless Technologies: Proceedings of OWT 2020. Springer Singapore, 2022.

[18] Ravi Kumar, P., P. V. Naganjaneyulu, and K. Satya Prasad. "Partial transmit sequence to improve OFDM using BFO & PSO algorithm." *International Journal of Wavelets, Multiresolution and Information Processing* 18.01 (2020): 1941018.

[19] El-Khamy, Said E., Noha O. Korany, and Hossam Hassan. "A New Efficient Two-Sided Complementary Code Based Channel Estimation Technique "TSCC-CE" for MIMO-OFDM Systems, Under the Effects of Partial-Band Jamming and Doppler Spread." IEEE Access 9 (2021): 155153-155160.

[20] Chen, Yixin, Carmine Clemente, and John J. Soraghan. "Partial fractional Fourier transform (PFrFT)-MIMO-OFDM for known underwater acoustic communication channels." Information 12.11 (2021): 469.

[21] Reddy, Chetana, and Virendra Shete. "A Hybrid Linear-Quadratic Estimation (LQE)

Technique for Channel Estimation in MIMO-OFDM System."

[22] Srinivasulu, Owk, and P. Rajesh Kumar., "Implementation of Low Power, Signal Avilability, Network Coverage, Less Latency, Efficient Bandwidth 5G Technology Communication System", International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 10 (2018) pp. 8272-8277

[23] Srinivasulu, Owk, and P. Rajesh Kumar., "5g Adaptive Communication Channel Modelling For 75 Ghz Frequency Spectrum", Jour of Adv Research in Dynamical & Control Systems, Vol. 10, 10-Special Issue, 2018, pp. (191-200)

[24] Srinivasulu, Owk, and P. Rajesh Kumar., "Implementation of Hybrid LTE and Cognitive Radio Architectures Based on Traffic Load and Channel Capacity", International Journal of Pure and Applied Mathematics Volume 119 No. 18 2018, 791-803.

[25] Muslim, Fahad Bin, et al. "Performance evaluation of a multicarrier MIMO system based on DFT-precoding and subcarrier mapping." *Facta Universitatis, Series: Electronics and Energetics* 35.2 (2022): 253-268.

[26] Shahab, Maha Monther, Saad Mshhain Hardan, and Asmaa Salih Hammoodi. "A new Transmission and Reception Algorithms for Improving the Performance of SISO/MIMO-OFDM Wireless Communication System." Tikrit Journal of Engineering Sciences 28.3 (2021): 146-158.

[27] Girija, S. P., and Rameshwar Rao. "Fractional weighted ZF equalizer: A novel approach for channel equalization in MIMO-OFDM system under impulse noise environment." Communications in Science and Technology 6.1 (2021): 1-10.

[28] Liu, Jun, et al. "Fine timing and frequency synchronization for MIMO-OFDM: An extreme learning approach." IEEE Transactions on Cognitive Communications and Networking 8.2 (2021): 720-732.

[29] Pyla, Srinu, Padma Raju K, and Bala Subrahmanyam N. "Capacity and BER performance improvement in integrated MIMO-OFDM system using optimal power allocation, channel estimation, and turbo coding." *International Journal of Communication Systems* 34.14 (2021): e4915.

[30] Zhao, Tianyu, and Feng Li. "Variational-autoencoder signal detection for MIMO-OFDM-IM." Digital Signal Processing 118 (2021): 103230.