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BER performance analysis of OFDM-MIMO system using GNU Radio

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Abstract: **Multiple Input Multiple Output (MIMO) channels have been one of the most recent techniques employed in wireless communication system to increase data rate as well as capacity of a channel. It is accomplished by multiple transmitting and receiving antennas at both the ends of a wireless communication system. Orthogonal Frequency Division Multiplexing (OFDM) exploits the idea of employing multiple separate antennas at both the end systems to support MIMO configuration. However, the ultimate goals for any communication system do not lie in obtaining high data rate and high channel capacity. The reliability of the wireless radio system under different environmental conditions is one of the factors that decide the performance of the system. The performance of wireless digital systems is often measure in Bit Error Rate (BER) in the presence of noise, i.e. Signal to Quantization Noise Ratio (SQNR) which means corruption in any Bit position will cause the whole packet lost. It is well known that old traditional wireless systems are oftentimes degraded due to multipath fading and several transmission impairments that include interference, distortion, noise etc. This paper demonstrates design of a reconfigurable MIMO-OFDM system using GNU radio which is fast evolving radio software that implements Software Defined Radio (SDRs). Performance of the designed system is also assessed based on Bit Error rate generated for various modulation techniques. Further, this paper draws the importance of BER and Signal to Noise ratio (SNR).**

***Keywords* —BER, GNU radio, LTE, MIMO, OFDM, SNR, WiMAX**

I. INTRODUCTION

Due to rapid increase in demand for wireless transmission during the last two decades, the performance assessment of wireless communication systems has become current area of research. Some of the challenges that the wireless technology has faced include signal fading, multipath propagation, limited frequency spectrum etc. [1,3]. As the number of users is increasing with time and the service providers have limited bands at the same time, there are still wasted and unused frequencies due to different factors and parameters. The wireless communication systems are not as reliable as guided medium communication mainly due to fading [10] and other propagation effects and accordingly, techniques to improve its capacity and reliability has become one of the most important areas of current research. It is shown that by using the technique of multiple antennas at both the transmitting and receiving ends, the high performance 4G [2,23] broadband wireless is enabled and such wireless set up is known as Multiple Input Multiple Output (MIMO) [3,5] technology. MIMO systems are enabled by Orthogonal Frequency Division Multiplexing (OFDM) [2] to achieve higher throughput without the extension of the bandwidth available. This kind of set up increases the data transfer rate and the main reason of OFDM in MIMO systems is that the actual information is modulated into a number of independent sub-carrier signals which are orthogonal to each other instead of a single carrier which is commonly used in traditional wireless systems [21]. So the next generation wireless technology such as Worldwide Interoperability for Microwave Access (WiMAX) [20], Long Term Evolution (LTE) [3], Wireless Local Area Network (WLAN), Wireless Metropolitan Area Network (WMAN) [21] standards, which provide many users in the same channel, the MIMO-OFDM technique is considered as one of the best techniques that overtake many challenges of today's wireless technology and it is highlighted as a solution for the future broadband wireless communication systems. MIMO based 4G wireless systems are based on IEEE 802.16 which provides a data rate of 75 mbps for static users in cell radii up to 75 km [20] and 15 mbps in cell radii up to 2-4 km cell radii for mobile users [20]. The 4G technology WiMAX or LTE has 10-16 GHz and 2-11 GHz bandwidth for line of sight and non-line of sight environments respectively [20]. Further, the MIMO-OFDM technique provides the requirements of high throughput and high channel capacity without the extending the available bandwidth of spectrum [2,3]. While studying MIMO technology and OFDM technique, this paper sets up a MIMO-OFDM wireless communication

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system and the performance is examined by comparing Bit Error Rate (BER) for different modulation schemes using the GNU radio.

This paper is managed as follows: Section II introduces the GNU radio software used. Section III describes fundamentals of MIMO system and OFDM techniques. Section IV discusses the designed system. Section V analyses results and its discussion. Finally, the paper concludes in Section VI with a conclusion on the topic.

II. GNU RADIO

The system demonstrated in this paper is set up using GNU radio [15] which is evolving free and open source software that consists of blocks and flow graphs to complete the designing process. It is a powerful Software Defined Radio (SDR) that provides set of easily reconfigurable blocks and can be easily adaptable to different network architectures and protocols. In addition to this, it provides a number of easily reconfigurable blocks with different parameters that can be adjusted to suit for different projects and are used in most of the recent wireless communication systems in which when connected together forms transceiver chains. The GNU radio applications are primarily written using python while performance critical signal processing blocks are implemented in C++. It furnishes a library of signal processing blocks written in C++ which implements various functionalities of transceiver architectures. These C++ blocks can be used and combined by the final user through appropriate Python code. GNU radio ensures a Python interface for each C++ blocks as well as tools required to connect various blocks. In this way, the simplified wrapper and interface generation allows C++ code to be used from Python. GNU radio is built on two important concepts of "blocks" and "flow graphs". Blocks are basic operation units that process continuous data streams and each block has a number of input and output ports.

III. MIMO AND OFDM

A. *MIMO Technology and system model*

A Multiple Input Multiple Output (MIMO) system employs multiple antennas in the transmitter and receiver at the same time of a communication system and uses the random fading and multipath propagation to increase its transmission rate. MIMO provides transmit diversity and receiver diversity. It can be used in different kinds of networks like PAN, MAN, WAN, WLAN, LAN and can receive either a diversity gain, capacity gain and to overcome signal fading. A MIMO system consists of three main parts i.e. transmitter, channel and receiver. The function of the transmitter is to send multiple data such as $X_1,X_2,X_3,\ldots,X_N$ using different transmit antennas, N_t and the signals $R_1,R_2,R_3,\ldots,R_N$ are received by each receive antennas, Nr simultaneously at the receiver. If at any instance of time, the complex signals $X_1,X_2,X_3,X_4,\ldots,X_{N-1},X_N$ are transmitted through N_t transmit antennas, then the received data $R_1,R_2,R_3,R_4,\ldots,R_{N-1},R_N$ received by N_r receive antennas can be expressed as[13]

$$
\begin{aligned}
R_1 &= h_{11} X_1 + h_{12} X_2 + \ldots + h_{1N} X_N \\
R_2 &= h_{21} X_1 + h_{22} X_2 + \ldots + h_{2N} X_N \\
&\;\;\cdots\cdots \\
R_N &= h_{N1} X_1 + h_{N2} X_2 + \ldots + h_{NN} X_N
\end{aligned}
\qquad (1)
$$

By combining all the received signals in a vector R, the MIMO signal model is described as

$$R = H X + n \qquad (2)$$

Where R is $N_r\times1$ received signal vector, H is $N_t\times1$ transmitted vector and n is $N_r\times1$ Gaussian noise vector.
With N_t inputs and N_r outputs the channel can be expressed as $N_r\times N_t$ MIMO channel transfer matrix H, given by [13]

$$H=\begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1Nt} \\ h_{21} & h_{22} & \cdots & h_{2Nt} \\ \vdots & \vdots & \vdots & \vdots \\ h_{N1} & h_{N2} & \cdots & h_{NrNt} \end{bmatrix} \qquad (3)$$

where h_{ij} is the attenuation and phase shift between the j^{th} transmitter and i^{th} receiver.

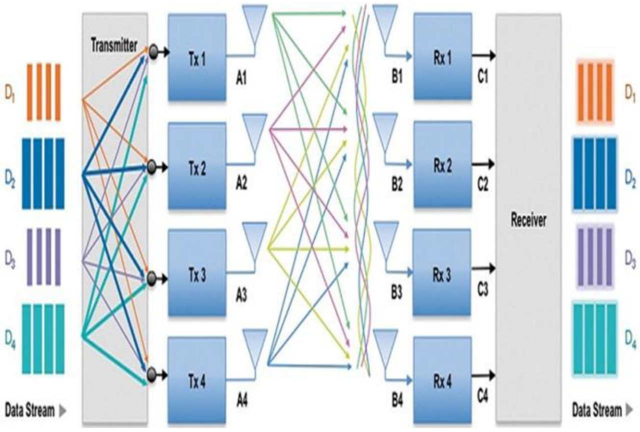

Figure 1.Block diagram of multiple input multiple output (MIMO) system [13].

B. *OFDM technique and system model*

Orthogonal Frequency Division Multiplexing (OFDM) is a class of signal modulation that splits a high data rate signal stream into a number of slowly modulated and narrowly separated narrowband subcarriers and this makes OFDM systems less susceptible to frequency selective fading. It is also known as multicarrier modulation technique. The OFDM system carries the message data on orthogonal subcarriers for parallel transmission, eliminating the distortion caused by the frequency selective channel or equivalently, the inter-symbol-interference in the multi-path fading channel. If the orthogonality is not adequately maintained, its functioning may be cheapened due to inter symbol interference as well as inter channel interference. An OFDM signal comprises of multiple number of closely separated modulated carriers which are orthogonal to each

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other in order to avoid signal interference between them. When the modulation of any form of information –video, voice, data, etc. is employed into a carrier, the sidebands disperse in either side. Although overlapping of each sideband, the receiver can still able to receive signal without interference if the orthogonality of the signals are maintained. This is attained by maintaining the carrier spacing equal to the reciprocal of the symbol period.

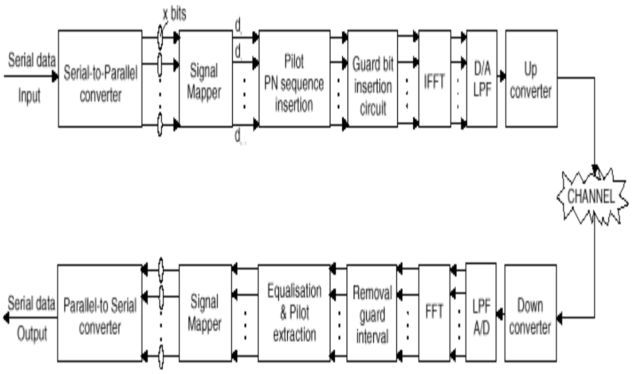

Figure 2.An OFDM system configuration [8]

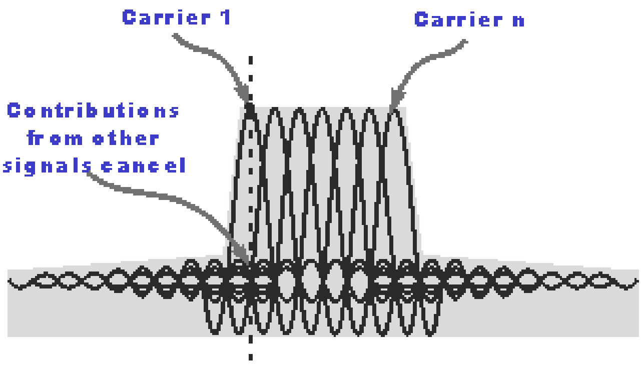

Figure 3.OFDM spectrum [8]

The high speed serial data stream is converted to low speed parallel data streams that can be transmitted in multiple N sub-channels. For this, N different sub-carriers which are orthogonal to each other are used to modulate the signals and the modulated signals are transmitted together. Linearity of OFDM transmitting and receiving system is one of the requirements to be maintained at both ends. The transmitted and received signals will suffer from interference as a result of inter-modulation distortion between them if linearity is not maintained. This will produce undesirable signals that would result in interference and break the orthogonality of the signals. At the receiver, the received signals are reconstructed to the form of original high speed data by using parallel to serial data converter. A typical OFDM system configuration is shown in fig.2. Fig. 3 represents an OFDM signal spectrum where multiple orthogonal signals are transmitted within the available bandwidth without interference between them.

IV. WORKING METHODOLOGY OF THE DESIGNED OFDM-MIMO SYSTEM

By directly connecting blocks available and providing appropriate parameters, this paper presents simulation process of designing a MIMO-OFDM system shown in fig. 4 below and its performance evaluation based on BER vs SNR using GNU radio. The proposed system consists of block of random source that generates random signals which are sampled into number of samples and are packetized for further process. This is done by assigning fix packet length to the input stream. The packet length used in this work is 96. The packetized data are trailed with error checking codes. The packets are converted to symbols after adding header information and assign with different sub-carriers, insert pilot signals. With the help of OFDM modulator block, the generated signal is modulated to produce orthogonal signals. An inverse Fourier transform (IIFT) is performed after the carrier allocation to convert the signal from frequency domain to time domain ready for transmission. Primary aim is given to corrupt the signal so that the system portrays as practical one. So a random noise source is used to infiltrate into the channel model to interrupt and corrupt the signal transmitted.

Table 1. Parameters used in the proposed work.

Parameters	Values
Sampling rate	10M
FFT length	256
Packet length	96
Occupied tones	200
Bandwidth	4.5MHz
Cyclic prefix length	64
Modulation schemes	BPSK, QPSK, QAM16, QAM64, 8PSK

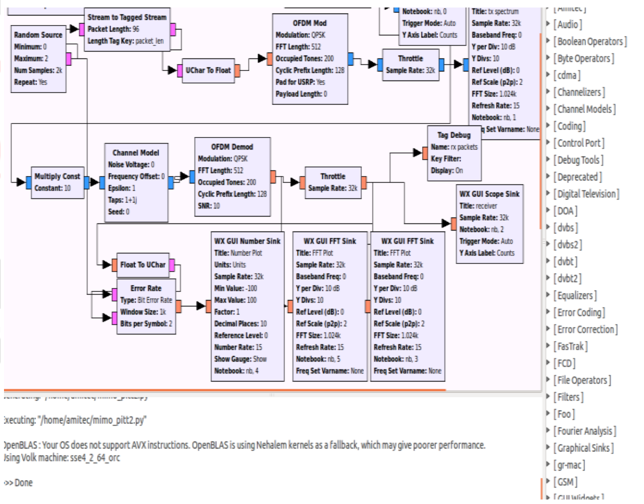

Figure 4.Designed GNU schematic for the OFDM MIMO system

The channel model block in this work acts as a basic model that can simulate to evaluate, design, and help test various signals, waveforms and algorithms. It provides users to re-assign the voltage of an AWGN noise source to produce the AWGN noise. At the receiver end, OFDM demodulator block is used to demodulate the modulated signals. And the received signal is passed through a synchronizer that performs the frame synchronization. The header/payload demux is used to separate the header information. Payload

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data is converted back to frequency domain by Fourier Transform (DFT) for further analysis.

After proper transmission and reception of the system is tested, the main focus is given on assessing and evaluating the Bit Error Rate value (BER) for different types of modulation techniques. BER is defined as a parameter that corresponds to the number of received bits that have been altered because of transmission impairments such as the interference, noise, distortion etc. It measures the whole end to end performance of the given system that includes the transmitter, receiver and the medium. In this work, the Error Rate block is used to compute the Bit Error Rate (BER) or the Symbol Error Rate (SER) that compares the received byte streams with the reference byte streams. Each byte in the incoming stream represents one symbol. The bits per symbol parameter are useful for measuring the BER.

V. RESULT ANALYSIS AND DISCUSSIONS

The performance of the system described in this paper is evaluated by determining the data error rate during transmit and receive process. Bit error rate parameter is frequently used to determine the performance of digital communication system in the presence of noise, i.e. SQNR (signal to quantization noise ratio). The transmitted signal waveform and received data streams are obtained. Fig. 5 shows the transmitted signal waveform and fig. 7 shows the received data streams at the transmitter and receiver side respectively. Table 2 shows the BER performance of the system with different modulation techniques.

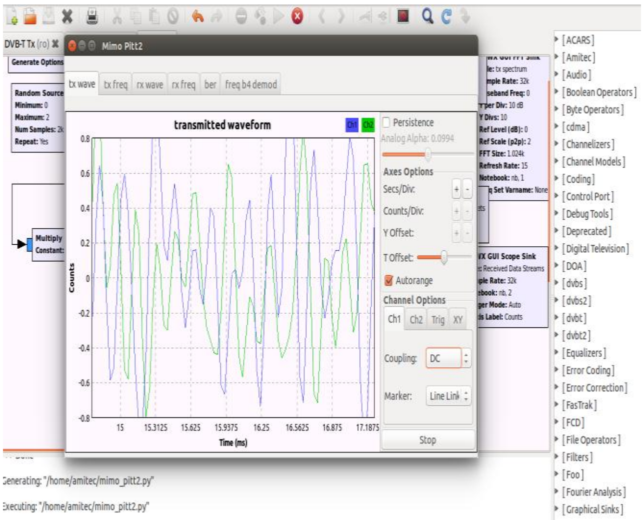

Figure 5.Transmitted waveform at the transmitter

Figure 5 represents the OFDM signal waveforms that represent encoded signal ready for transmission. These signals represent slow parallel data streams which are obtained from fast serial input signal. It is accomplished by serial to parallel converter in the transmitter system. Each parallel data stream is assigned to different and unique carrier signals. Ultimately, OFDM modulator generates the OFDM signals which are orthogonal to each other. The frequency spectrum representation of this OFDM is shown in fig. 6.

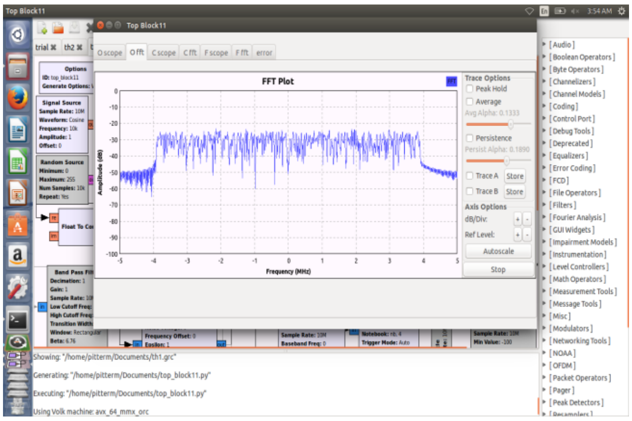

Figure 6.OFDM Signal spectrum at the transmitter side

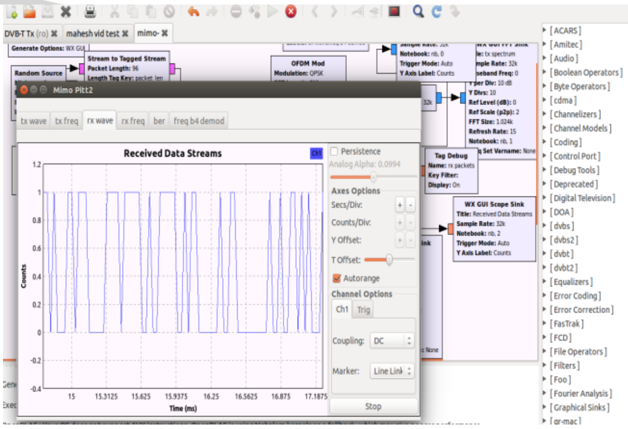

Figure 7.Received data streams at the receiver side

Figure 7 shows the received data streams at the receiver end abstracted from the received OFDM signal. The signal processing at the receiver side is opposite to that of step by step process at the transmitter. Obviously, the received data stream represents corrupted data flow as it is affected by random source of noise provided at the channel model of the designed system. The amplitude of noise is varied to different values 0.707, 0.562, 0.446, 0.354, 0.282, 0.224 to make SQNR values equal to 0dB, 2dB, 4dB, 6dB, 8dB, 10dB respectively. Bit Error Rate (BER) values are measured for these noise amplitudes and SNR values using Error Rate block. Further, this noise amplitude can also be changed to appropriate values for different SNQR and calculate BER.

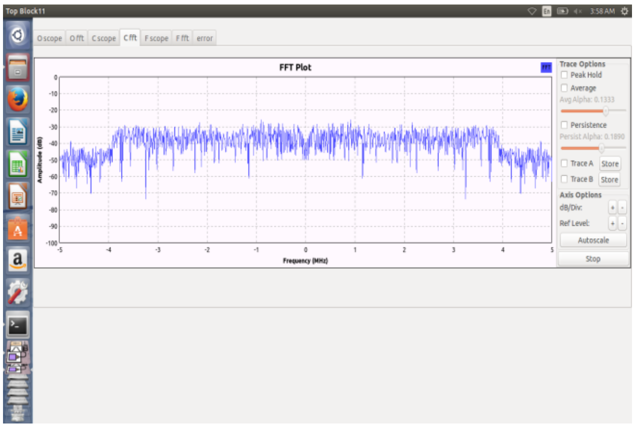

Figure 8.Received spectrum at receiver

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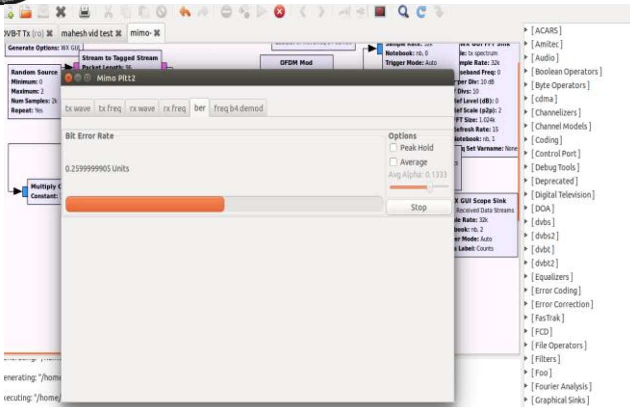

Figure 9.BER value generated

Table 2. BER for different modulation schemes.

SNR (dB)	BPSK	QPSK	QAM 16	QAM 64	8PSK
0	0.7960	0.8015	0.8125	0.8080	0.7977
2	0.7723	0.7839	0.8060	0.8059	0.7913
4	0.7458	0.7635	0.7995	0.7910	0.7655
6	0.7367	0.7543	0.7888	0.7893	0.7599
8	0.7117	0.7488	0.7718	0.7825	0.7441
10	0.6901	0.7312	0.7460	0.7825	0.7380

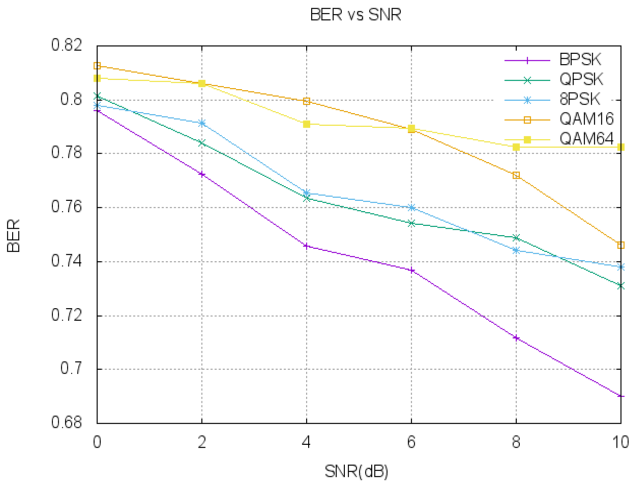

Figure 10.BER vs SNR curve of the MIMO-OFDM system

Table 2 highlights the measured value of Bit Error Rate (BER) obtained from the design MIMO system as a function of varying Signal to Quantization Noise Ratio (SQNR) for various modulation techniques i.e. BPSK, QPSK, 8PSK, QAM16 and QAM64. Figure 10 depicts the plot between BER and SNR. After analyzing the results obtained and from the graph, it is obvious that BER values greatly depend on the number of bits to represent a symbol. It is seen that the value of BER is low for BPSK which suggest that it can be the best modulation technique suitable for signals in the OFDM-MIMO. Higher order modulation schemes such as Quadrature Amplitude Modulation (QAM) in this simulation have high BER which indicates that they are less robust to the noise effect. It is because of the fact that they represent more number of bits per symbol compare to the lower level modulation schemes. The difference in the corresponding values of BER performance is that they are exposed to different tolerance margin to noise. In terms of SNR, it is seen that the BER value greatly depends on SNR as with the increase of SNR, the BER decreases because a stronger noise increases BER and a stronger signal power decreases the BER. So, it is clearly seen that there is trade-off between BER and SQNR with the order of modulation schemes such that for poor SQNR systems, employing BPSK would be a wise selection as it is robust to noise. And for better SQNR systems, employing higher order modulation schemes can be a noble approach which leads to better bandwidth efficiency and high data rates.

VI. Conclusion

This paper presents a MIMO-OFDM system and assesses its performance by measuring the BER vs SNR for different modulation schemes. This paper evaluates the BER value as a result of varying Signal to Noise Ratio (SNR) by setting different noise levels in the channel model. And it is found that out of the modulation schemes used, BPSK scheme turns out to be the best scheme followed by QPSK scheme. Further, it can be concluded that lower order modulation techniques decrease BER that provides better and improved results. However, higher level modulation schemes are more bandwidth efficient but they are less robust. The trade-off between BER and SQNR with different orders of modulation schemes has also been highlighted in this paper. Further works can be expanded to some real time implementation of MIMO-OFDM systems using USRPs in different environmental conditions using different coding schemes that will further reduce the BER to some minimum value.

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