Performance Analysis of MIMO-OFDM System on Different Digital Modulation Schemes

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ABSTRACT

The main basic components for selecting modulation technique are Bit Error Rate (BER) and Signal to Noise Ratio (SNR). This paper examined the performance of different modulation in Multiple Input and Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) system. A model of 2×2 MIMO-OFDM has been developed utilizing the communication tools of MATLAB/Simulink. The model was used to carry out comprehensive analyzed the performance of different digital modulation techniques namely, 8-PSK, 16-PSK, 32-PSK, 64-PSK, 8-QAM, 16-QAM, 32-QAM, 64-QAM and QPSK in terms of BER with respect to SNR over Additive White Gaussian Noise (AGWN) and Rayleigh fading channels. Having conducted extensive simulation and performance evaluation, results indicated that lower order modulation techniques outperform the higher order schemes for transmission of data over both AGWN and Rayleigh fading channels such that for M-PSK modulation, 8-PSK offered the lowest BER of (0.0010 and 0.0333) while 16-PSK, 32-PSk, and 64-PSK showed BER of (0.0202 and 0.0792), (0.061 and 0.1317), and (0.116 and 0.1832) against increasing SNR at 10dB in AGWN and Rayleigh channels respectively. Similarly, for QAM modulation, 8-QAM provided the finest BER with value of (0.000652 and 0.0231), while 16-QAM, 32-QAM, and 64-QAM yielded BER performance of (0.017 and 0.0301), (0.0161 and 0.0665), (0.0265 and 0.0792) with respect to increasing SNR at 10 dB in AGWN and Rayleigh channel. However, this comes at the cost of the data rate since lower order techniques have lower data rates than their higher order counterpart. Furthermore, it was found that the performance over AGWN channel was better than the performance over Rayleigh fading channel for all considered modulation schemes. On which modulation technique provided the best BER performance, it was observed that QPSK modulation technique outperformed other modulation schemes with BER of 3.8×10^{-6} in AGWN channel and 0.0010 in Rayleigh fading channel at SNR of 10 dB. Generally, the simulation results showed that the BER performance improves as the SNR increases.

Keywords: Additive White Gaussian Noise, Bit Error Rate, MIMO-OFDM, Signal to Noise Ratio, Digital Modulation

1.0 INTRODUCTION

MIMO technology is one of the major attracting techniques in wireless communications due to the fact that it provides significant increases in data throughput and coverage without additional bandwidth or transmitter power. It also provides high spectral efficiency and link reliability. Due to these properties, MIMO is an essential part of modern wireless communication standards such as IEEE 802.11n (Wi-Fi), 4G, 3GPPLTE, WiMAX and HSPA+ (Venkateswarlu and Nagendra, 2014).

On the other hand, OFDM is one of the emerging transmitting techniques at higher data rates (Aziz et al., 2012). Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation technique that offers high bandwidth efficiency because the carriers are orthogonal to each other and multiple carriers share the data among themselves. The main advantage of this transmission technique is its robustness to channel fading in wireless communication environment. OFDM can be seen as either a modulation technique or a multiplexing technique (Samuel et al, 2012; Alade, 2014).

Obviously, with the advancing technology in wireless network in terms of higher data rates, the expectation for high spectral efficiency has increased. Of course achieving these data rates requires cautious selection of multicarrier

modulation scheme available. Hence, this necessitates the study focusing on investigating the performance of the MIMO-OFDM system in different modulation schemes. Modulation is the process of varying one or more properties of a periodic waveform, called the carrier signal, with a modulating signal that typically contains information to be transmitted. The analysis is done based on simulations using Simulink simulation tool in MATLAB.

2.0 DIGITAL MODULATION SCHEMES
This section presents the mathematic expression for the digital modulation schemes considered in this work.

2.1 Quadrature Phase Shift Keying
The quadrature phase-shift keying (QPSK) modulation scheme is like the binary phase shift keying (BPSK), which is characterized by the fact that the information carried by the transmitted wave is contained in phase. The QPSK system has two successive bits in a bit stream which is combined together to form a message and each message is represented by a distinct value of phase shift of the carrier. In particular, in QPSK, the phase of the carrier takes on one of four equally spaced values, such as $\pi/4$, $3\pi/4$, $5\pi/4$ and $7\pi/4$. A block diagram of QPSK modulator is shown in Figure 1. A QPSK signal is produced when the baseband signals I (In-phase baseband signal) and Q (Quadrature phase base band signal) take on

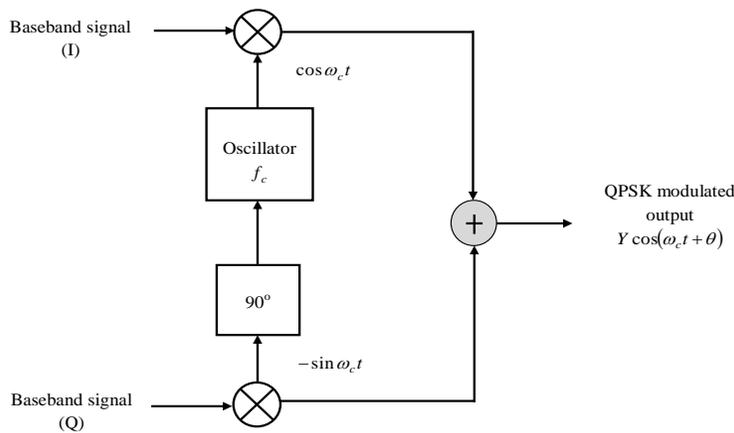values of $\pm A/\sqrt{2}$. where A is the amplitude of baseband signal.

Figure 1: Structure of QPSK modulator

Trigonometric identity can be applied to the structure in Figure 1 such that:
$$I \cos\omega_c t + Q \sin\omega_c t = Y \cos(\omega_c t + \theta) \tag{1}$$

where $Y = \sqrt{I^2 + Q^2}$, the carrier frequency in rads^{-1} ω_c is expressed in terms of carrier wave frequency f_c as $\omega_c = 2\pi f_c$

Hence, the carrier wave is given by:
$$s_i(t) = \sqrt{\frac{2E}{T}} \cos[2\pi f_c t + (2i - 1)\pi/4] \tag{2}$$

where i = 1, 2, 3, 4 and E is the transmitted signal energy per symbol, T is the symbol duration, and $Y = \sqrt{2E/T}$.

So the average probability of error is represented in terms of ratio E_b/N_0 and bit error probability is given by:
$$P_b = \frac{1}{2}\text{erfc}\sqrt{\frac{E_n}{N_0}} \tag{3}$$

For QPSK modulation scheme there are two normal orthonormal basic functions, $\varphi_1(t)$, $\varphi_2(t)$ contained in the expression of $s_i(t)$. In a QPSK system, the transmission rate is two bits per symbol. This means that twice the signal energy per bit is equal to the transmitted signal energy per symbol. The expressions in Equations (2) and (3) are coded in MATLAB/Simulink QPSK modulator block function which is used for simulation.

The diagram of a QPSK demodulator is shown in Figure 2. The received QPSK modulated signal (input) is directed by the power splitter to the I and Q product detectors and the carrier recovery circuit, which reproduces the original transmit carrier wave signal. This recovered signal must be frequency and phase coherent with the transmit reference carrier.
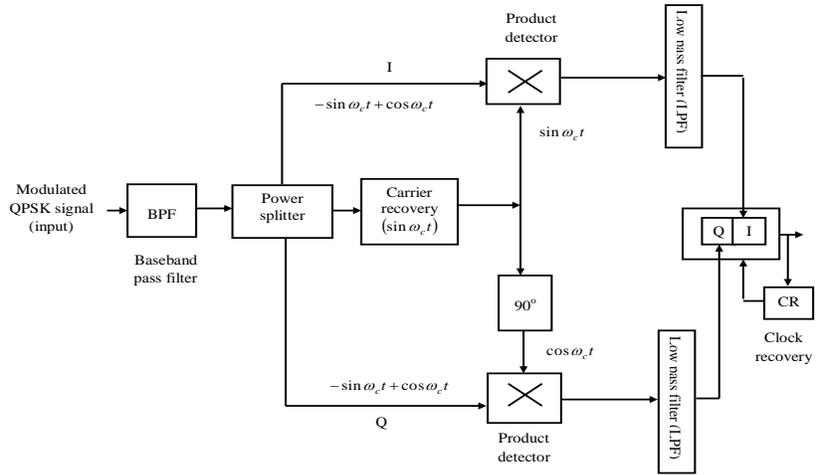

Figure 2: Block diagram of QPSK demodulation

Demodulation of the modulated QPSK signal takes place in the product detectors of the I and Q that generate the original I and Q data bits. The bit combining circuit is fed with the outputs of the product detectors and where the data bits are converted from parallel I and Q data channels to single binary output data stream, y. The demodulation process is represented considering Figure 2 as follows:

The I baseband product detector output is given by:

$$I = \underbrace{(-\sin\omega_c t + \cos\omega_c t)}_{\text{modulated QPSK signal (input)}} \times \underbrace{(\sin\omega_c t)}_{\text{carrier}}$$

$$= (-\sin\omega_c t) \times (\sin\omega_c t) + (\cos\omega_c t) \times (\sin\omega_c t)$$

$$= -\sin^2\omega_c t + (\cos\omega_c t) \times (\sin\omega_c t)$$

$$= -\frac{1}{2}(1 - \cos 2\omega_c t) + \frac{1}{2}\sin(\omega_c + \omega_c)t + \frac{1}{2}\sin(\omega_c - \omega_c)t$$

$$I = -\frac{1}{2} + \frac{1}{2}\cos 2\omega_c t + \frac{1}{2}\sin 2\omega_c t + \frac{1}{2}\sin 0 = -\frac{1}{2}\text{ V (logic 0)} \tag{4}$$

Also, the second input is the recovered carrier shifted 90º in phase $(\cos\omega_c t)$. Hence, the mathematical expression for Q product detector is given by:

$$Q = \underbrace{(-\sin\omega_c t + \cos\omega_c t)}_{\text{modulated QPSK signal (input)}} \times \underbrace{(\cos\omega_c t)}_{\text{carrier}}$$

$$= \cos^2\omega_c t - (\sin\omega_c t) \times (\cos\omega_c t)$$

$$= \frac{1}{2}(1 + \cos 2\omega_c t) - \frac{1}{2}\sin(\omega_c + \omega_c)t - \frac{1}{2}\sin(\omega_c - \omega_c)t$$

$$Q = \frac{1}{2} + \frac{1}{2}\cos 2\omega_c t - \frac{1}{2}\sin 2\omega_c t - \frac{1}{2}\sin 0 = \frac{1}{2}\text{ V (logic 1)} \tag{5}$$

where the $1/2\cos 2\omega_c t$ is filtered out by the LPF and $1/2\sin 2\omega_c t$ is equal to zero. This mathematical expression is used by the QPSK demodulator block of MATLAB/Simulink.

3.0 QUADRATURE AMPLITUDE MODULATION

Quadrature Amplitude Modulation (QAM) is a method of combining two amplitude-modulated (AM) signals into a single channel, thereby doubling the effective bandwidth. The structure of a QAM modulation is shown in Figure 3. A binary data stream m(t), which is input of 2-bit is fed into a serial-to-parallel (S/P) converter with k bps data rate.
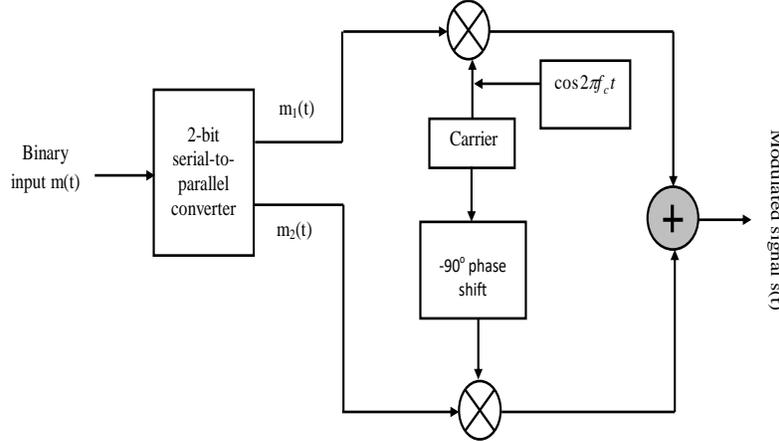

Figure 3: Structure of QAM modulator

A mathematical expression can be derived for the QAM modulation process considering Figure 3. The 2-bit S/P converter produces two level of k/2 data rate bit stream, $m_1(t)$ and $m_2(t)$. At the upper level of the modulation scheme, $m_1(t)$ is multiplied by the carrier signal generated by oscillator. For the modulation at the lower portion of the modulation scheme, the carrier signal is first shifted by 90° and this shifted signal is used to multiply the lower bit stream data, $m_2(t)$.

Generally, the mathematical expression for QAM modulated signal is (Zhang et al., 2020):

$$s(t) = \sum_n A_n g(t - nT_s)\cos(2\pi f_c t + \theta_n) \tag{6}$$

where A_n is the baseband signal amplitude, $g(t - nT_s)$ is the waveform of a single baseband signal, T_s is the width. Equation (6) can be represented orthogonally (Zhang et al., 2020) given by:

$$s(t) = \left[\sum_n A_n g(t - nT_s)\cos\theta_n\right]\cos 2\pi f_c t - \left[\sum_n A_n g(t - nT_s)\sin\theta_n\right]\sin 2\pi f_c t \tag{7}$$

Considering Figure 3 and applying the trigonometric theorem in Equation (7), the following can be written:

$$\left.\begin{array}{l} m_1 = A_1 g(t - T_s), \quad n = 1 \\ m_2 = A_2 g(t - T_s), \quad n = 2 \end{array}\right\} \tag{8}$$

The amplitude can be fixed such that $A = A_1 = A_2$. Thus, the results of the upper and lower portion of the multiplied signals are added together and the modulated QAM signal is given by:

$$s(t) = m_1(t)\cos(2\pi f_c t) - m_2(t)\sin(2\pi f_c t) \tag{9}$$

where $m_1(t)$ and $m_2(t)$ are the two message signals. The symbol error probability of M-ary QAM is given by:

$$p_b \leq 4\,\text{erfc}\left(\sqrt{\frac{3kE_b}{(M-1)N_0}}\right) \quad (\text{for } M = 2^k) \tag{10}$$

where k is the number of bits transmitted by each symbol. The Expressions in Equations (9) and (10) are coded in MATLAB/Simulink block of QAM modulator used in the Simulink modeling in this paper.

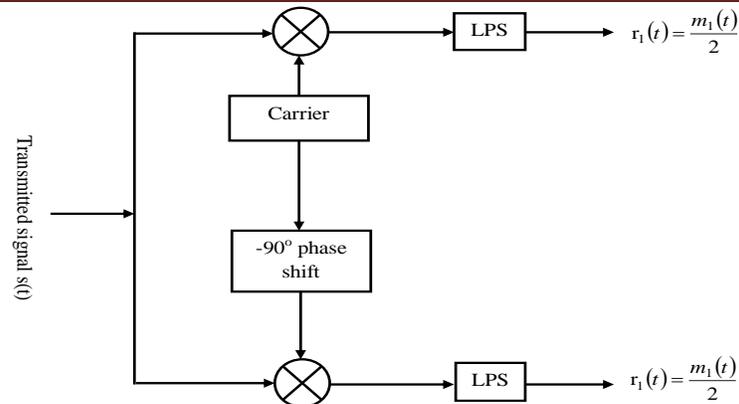Figure 4 is the structure of a QAM demodulator.

Figure 4: Structure of QAM demodulator

At the receiver, a QAM demodulator local oscillator (carrier) generates a function given by:

$$e^{j2\pi f_c t} = \cos 2\pi f_c t + j \sin 2\pi f_c t \qquad (11)$$

For the expression in Equation (11) is generated by local oscillator (carrier) which must be exactly in phase with local oscillator (carrier) that generate the $\cos 2\pi f_c t$ and $\sin 2\pi f_c t$ function at the transmitter. This entire process is a complex implementation of a synchronous demodulator QAM signal at the receiver (Real-time DSP laboratory 7, sourced 2021). Hence, the entire process of the complex implementation of QAM is coded in the MATLAB/Simulink QAM demodulation block used in this paper.

4.0 MODULATION PHASE SHIFT KEYING

Phase-Shift Keying (PSK) is a digital modulation technique that transmits data by changing, or modulating, the phase of a reference signal. The term *M-ary* is derived from the word binary. *M* simply represents a digit that corresponds to the number of conditions, levels, or combinations possible for a given number of binary variables.

The number of bits necessary to produce a given number of conditions is expressed mathematically given by:

$$N = \log_2 M \qquad (11)$$

where N is the number of bits necessary, M is the number of conditions, levels, or combinations. For N = 3, M = 2^3 = 8 and this gives 8-PSK, and so on. The block diagram of M-PSK modulator is shown in Figure 5.
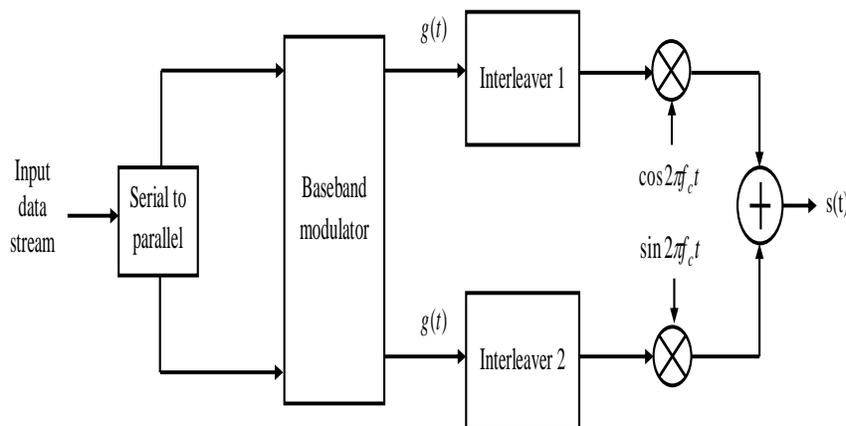

Figure 5: Block diagram of PSK modulator

Considering the block diagram of the M-PSK modulator, the baseband modulator generates the quadrature components such that at the upper link and lower link the expression for the interleavers can be written as $g(t)\cos\theta_m$ and $g(t)\sin\theta_m$. The outcome of the detectors at upper portion and lower portion of the modulator product of the output of the interleavers and the carrier wave written as:

$$\left.\begin{array}{l} D_1 = \left(g(t)\cos\theta_m\right)\left(\cos 2\pi f_c t\right) \\ D_2 = \left(g(t)\sin\theta_m\right)\left(\sin 2\pi f_c t\right) \end{array}\right\} \tag{12}$$

where D_1 and D_2 stands for output of detector 1 and 2 respectively. The *M* signal waveform for PSK modulated can be written (Proakis, 2007) as:

$$s(t) = g(t)\cos\theta_m \cos 2\pi f_c t - g(t)\sin\theta_m \sin 2\pi f_c t \tag{13}$$

where $g(t)$ is the signal pulse phase shape and $\theta_m = 2\pi(m-1)/M$, $m = 1, 2, \cdots, M$, are the *M* possible phase of the carrier that transmit the modulated signal. The expression in Equation (13) is represented by a MATLAB/Simulink model of M-PSK modulator in this work. The PSK demodulator block diagram is shown in Figure 6.
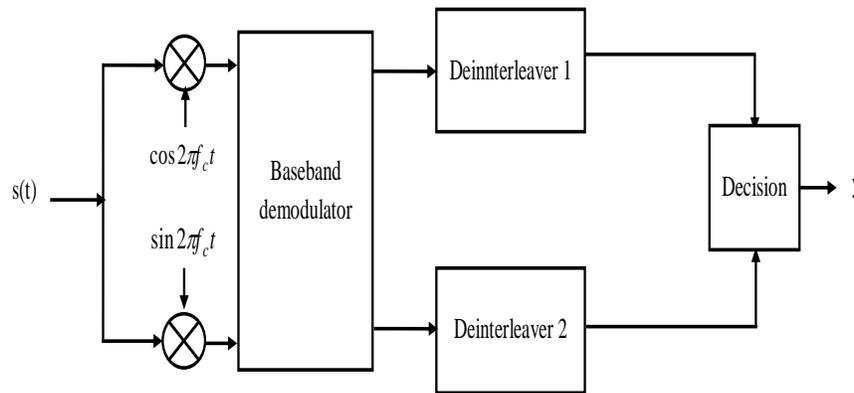

Figure 6: Block diagram of PSK demodulator

The mathematical expression of the MPSK output is complex equation containing the complex white Gaussian noise, $z(t)$, the fading amplitude, a_n, the phase shift due to fading channel, ϕ_n and $s_l(t)$ is the equivalent low pass of the transmitted signal s(t) and is given by (Slimane, 1998):

$$y = a_n e^{-j\phi_n} s_l(t) + z(t) \tag{14}$$

5.0 MIMO-OFDM SYSTEM SIMULINK MODEL
The developed block diagram model of MIMO-OFDM system implemented in MATLAB/Simulink environment is shown in Figure 7. The basic concept of MIMO-OFDM is to improve the data rate (bits/sec) and/or quality (BER) by using multiple antennas in the transmitter and receiver of the communication system. The MIMO system employs spatial diversity and uses Orthogonal Space Time Block Coding (OSTBC) as the core technique. The subsystem of the proposed MATLAB/Simulink model for the OFDM transmitter, Receiver and the 2Tx and 2Rx fading channel in Simulink are shown in Figures 8a, b and c.

Figure 7: Block diagram of MIMO-OFDM system

Figure 8a: Susbystem of OFDM transmitter

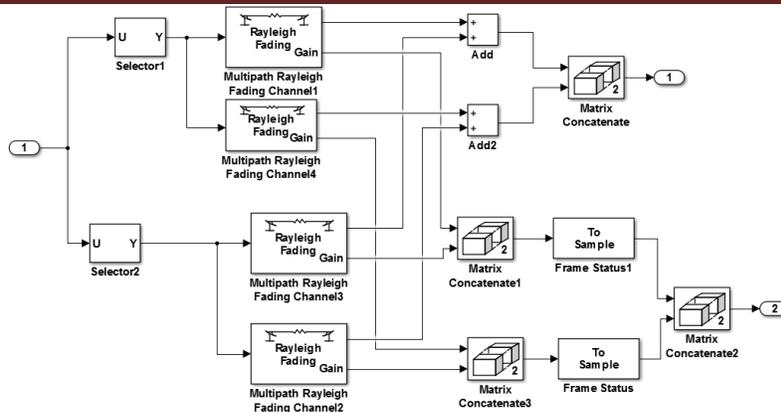Figure 8b: Subsystem of OFDM receiver

Figure 8c: Subsystem of 2x2 fading channel

The different components of the Simulink model of the system are explained, while table 1 shows the simulation parameters.

- Data Source: This block is used to generate frame based input data. It is represented by the random integer generator.
- Modulator: This block is used to modulate the input data stream using QAM or any other modulation scheme. For example, if the M in M-ary of QAM is chosen as 16 (that is 16-QAM), this value determines the number of bits on each subcarrier
- OFDM Modulator: This block basically consists of IFFT block that computes inverse Fast Fourier Transform (FFT) of the input data. The IFFT operation is mathematically identical to OFDM operation. Hence it can be said that this is the block that actually implements OFDM.
- PN Sequence Generator: This block generates a sequence of pseudo random binary numbers. These sequences are used for modulating the data sequences. For multiuser system, different set of pseudo random sequences are generated which are orthogonal to one another.
- Unipolar to Bipolar Converter: This block converts the unipolar input signal to bipolar output signal. That means if the input consists of integers from 0 to M-1, then the output of this block will consist of integers from (M-1) to (M-1).
- Alamouti Code: According to ASTE, each group of n information bits is first modulated and then encoding takes place for the two symbols and are transmitted at time t_1 and t_2.
- Transmission Channel: In order to model the actual transmission channel (represented as subsystem1), both the AWGN and Rayleigh fading channels are connected in series. The signal to noise ratio of the AWGN channel can be adjusted by varying the SNR parameter value. The Rayleigh fading block provides additional parameters like Doppler shift, path delay gain and so on to make the channel resemble the actual channel as closely as possible.
- OFDM Demodulator: The operations performed by this block are basically opposite to that performed by the OFDM modulator block. At first the cyclic prefix is removed by using a remove cyclic prefix block and then FFT block is used to find the FFT of the data samples. Finally select rows block is once again used to remove the pilot samples added and output the exact data samples.
- Demodulation: This block demodulates the input data using quadrature amplitude demodulation method. The constellation for this block was set to [0.7071 + 0.7071i 0.7071 - 0.7071i -0.7071+ 0.7071i -0.7071 - 0.7071i]. Finally the output integer samples are converted to bits using an integer to bit converter block to facilitate the computation of BER.
- Output: This computes the BER and displays them. It also displays the time domain signal and frequency domain signal of OFDM through vector scope and spectrum scope respectively.
- Error Rate Calculation: This block calculates the BER. The receive delay of this block is set to 1. The output is displayed using a display block. For implementing a multiuser system, the same transmitter and receiver arrangement is used with the same generating polynomial but each of the users should be assigned different set of initial state.

Table 1: Simulation Parameter (Ajose et al., 2018)

System Parameter	Value
System	MIMO-OFDM
Modulation Techniques	MPSK/16QAM/64QAM/ QPSK

Antenna Configuration	$2T_X$ and $2R_X$
Channel	AWGN and Rayleigh Fading
FFT/IFFT Points	256
Symbol Period	192e-6s
Maximum Doppler Frequency	0.01Hz
Guard type	Cyclic prefix
Channel input signal power	1 W

6.0   SIMULATION RESULTS

In this section the results obtained using the bertool of MATLAB to analyze the bit error rate (BER) performance of the M-PSK, QAM and QPSK modulation schemes in the developed 2x2 MIMO-OFDM system in Simulink are presented. The simulations were conducted considering AGWN channel and Rayleigh fading channel for M-PSK (8, 16, 32, and 64), QAM (8, 16, 32, and 64) and QPSK. The maximum bit error is placed at 100 and the maximum number of bits taken as 1e7. The objective is to evaluate each modulation technique with respect to BER against signal to noise ratio (SNR). The graphical representations of the simulation results are shown from Figures 9 to 16. The Performance analyses of each graphical representation are shown in Table 2 to 9.
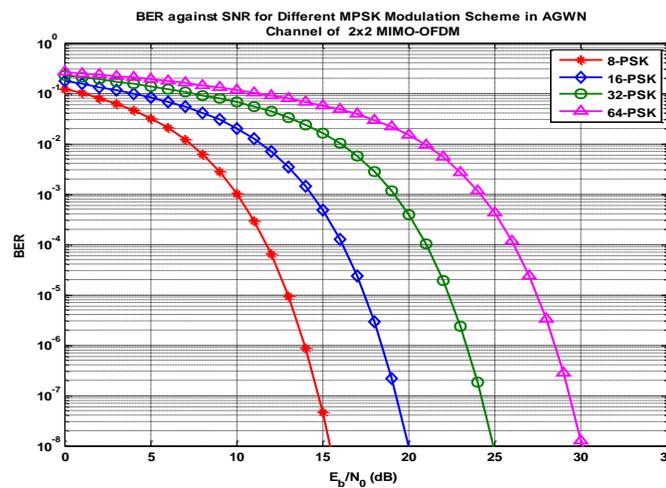

Figure 9: BER against SNR for different M-PSK modulation scheme in AGWN channel

Table 2: Performance analysis for BER vs SNR for differennt M-PSK modulation scheme in AWGN channel

SNR(dB)	BER (8-PSK)	BER (16-PSK)	BER (32-PSK)	BER (64-PSK)
0	0.1226	0.1744	0.2256	0.2649
1	0.1007	0.1534	0.2673	0.2497
2	0.0806	0.1338	0.1892	0.2345
3	0.0622	0.1155	0.1713	0.2193
4	0.0458	0.0986	0.1538	0.2043
5	0.0318	0.0829	0.1368	0.1894
6	0.0204	0.0681	0.1206	0.1746
7	0.0119	0.0542	0.1055	0.1599
8	0.0061	0.0414	0.0914	0.1452
9	0.0027	0.0299	0.0784	0.1306
10	0.0010	0.0202	0.0661	0.1164

Figure 9 and Table 2 are the graphical representation and the performance analysis of the simulation results for BER against SNR for different M-PSK modulation technique in a 2-transmit antenna and 2-receive antenna (2x2 MIMO-OFDM) in AGWN channel. It can be seen from the graph that the performance of the MIMO-OFDM system in AGWN channel improves in terms of BER with increasing SNR (Eb/No). From the performance table, it is clear that 8-PSK has the most effective performance.
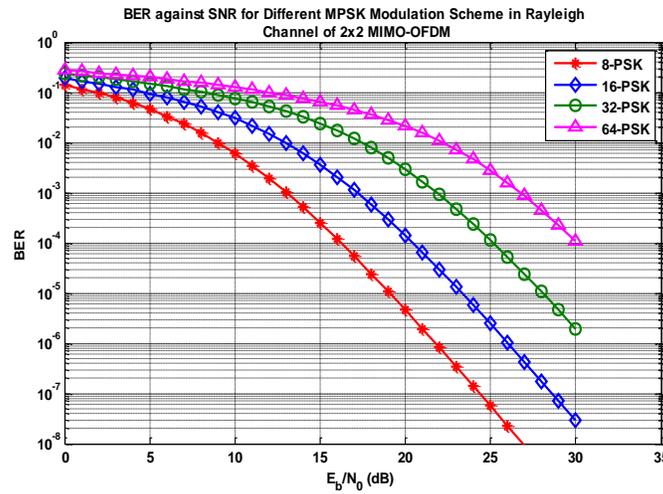

Figure10: BER against SNR for different M-PSK modulation scheme in Rayleigh channel

Table 3: Performance analysis for BER vs SNR for differennt M-PSK modulation scheme in Rayleigh fading channel

SNR(dB)	BER (8-PSK)	BER (16-PSK)	BER (32-PSK)	BER (64-PSK)
0	0.1386	0.1884	0.2363	0.2735
1	0.1167	0.1676	0.2180	0.2583
2	0.0961	0.1477	0.2000	0.2432
3	0.0773	0.1289	0.1822	0.2281
4	0.0604	0.1112	0.1648	0.2130
5	0.0457	0.0946	0.1479	0.1981
6	0.0333	0.0792	0.1317	0.1832
7	0.0232	0.0649	0.1163	0.1635
8	0.0155	0.0518	0.1017	0.1539
9	0.0099	0.0401	0.0880	0.1395
10	0.0060	0.0300	0.0751	0.1256

The performance characteristics of different M-PSK modulation scheme in Rayleigh fading channel of 2x2 MIMO-OFDM is shown in Figure 10, while the performance evaluation of the graphical result is presented in Table 3. The simulation result reveals similar trend as in AGWN channel with 8-PSK offering the best performance in terms of BER with increasing SNR.
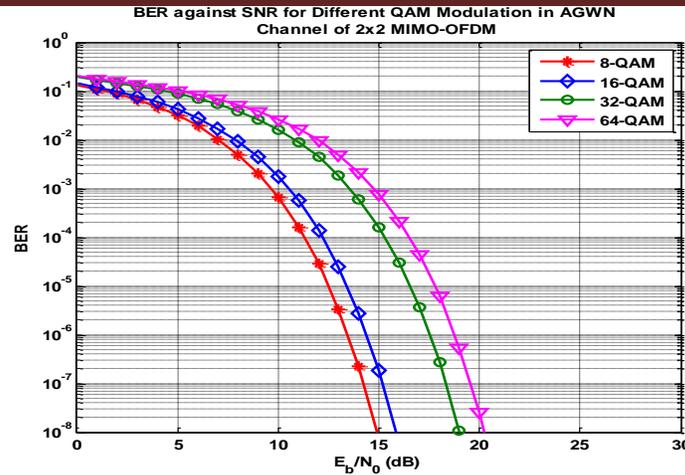
Figure 11: BER against SNR for different QAM modulation in AGWN channel

Table 4 Performance analysis for BER vs SNR for differennt QAM modulation scheme in AGWN channel

SNR(dB)	BER (8-QAM)	BER (16-QAM)	BER (32-QAM)	BER (64-QAM)
0	0.1326	0.1409	0.1894	0.1998
1	0.1092	0.1189	0.1672	0.1779
2	0.0867	0.0977	0.1461	0.1569
3	0.0657	0.0774	0.1259	0.1371
4	0.0470	0.0586	0.0906	0.1185
5	0.0313	0.0418	0.0880	0.1007
6	0.0191	0.0278	0.0702	0.0838
7	0.0104	0.0169	0.0536	0.0675
8	0.0050	0.0092	0.0387	0.0523
9	0.0020	0.0043	0.0261	0.0384
10	0.000652	0.0017	0.0161	0.0265

The performance of different QAM modulation schemes is shown in Figure 11 and it can be seen that as the BER decreases the SNR (dB) increases with better modulation achieved in terms of BER against SNR as the order of QAM reduces as can be deduced from Table 4.
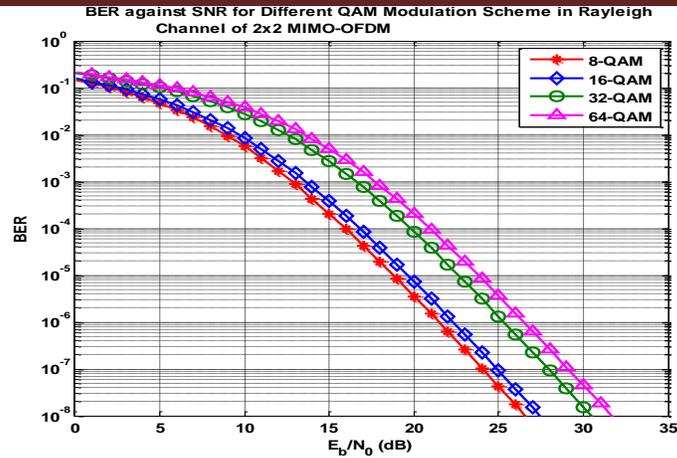
Figure 12: BER against SNR for different QAM modulation scheme in Rayleigh channel

Table 5: Performance analysis for BER vs SNR for differennt QAM modulation scheme in Rayleigh fading channel

SNR(dB)	BER (8-QAM)	BER (16-QAM)	BER (32-QAM)	BER (64-QAM)
0	0.1471	0.1556	0.2034	0.2129
1	0.1242	0.1334	0.1814	0.1916
2	0.1023	0.1121	0.1601	0.1708
3	0.0819	0.0921	0.1395	0.1507
4	0.0634	0.0734	0.1197	0.1314
5	0.0473	0.0567	0.1008	0.1131
6	0.0338	0.0422	0.0830	0.0956
7	0.0231	0.0301	0.0665	0.0792
8	0.0151	0.0206	0.0517	0.0640
9	0.0094	0.0134	0.0387	0.0501
10	0.0055	0.0083	0.0278	0.0379

Figure 12 shows the performance of different orders of QAM modulation scheme in Rayleigh fading channel for 2x2 MIMO-OFDM in terms of BER against SNR (dB). It can be seen that the BER for both 8-QAM and 16-QAM is very close for SNR less than 9dB. Also, the BER performance of both 32-QAM and 64-QAM seems to be very close for SNR less than 9dB. The performance analysis of the graph is shown in Table 5.
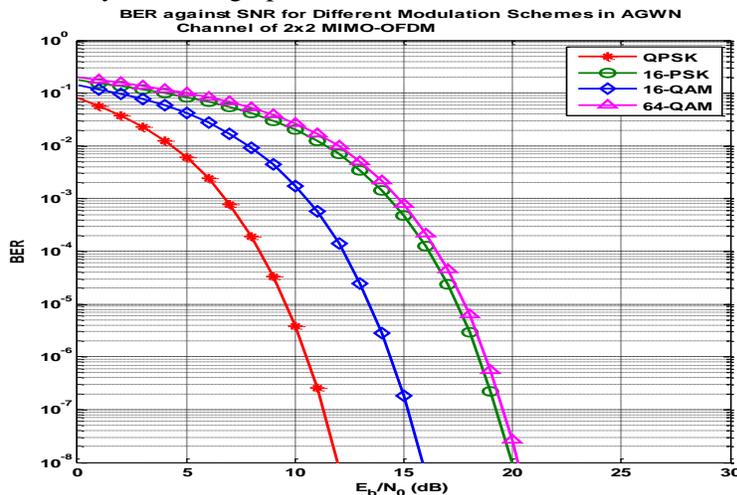
Figure 13: BER against SNR for different modulation schemes in AGWN channel

Table 6: Performance analysis for BER vs SNR for differennt modulation
schemes in AWGN channel

SNR(dB)	BER (QPSK)	BER (16-PSK)	BER (16-QAM)	BER (64-QAM)
0	0.0786	0.1744	0.1409	0.1998
1	0.0562	0.1534	0.1189	0.1779
2	0.0375	0.1338	0.0977	0.1569
3	0.0228	0.1155	0.0774	0.1371
4	0.0125	0.0986	0.0584	0.1185
5	0.0059	0.0829	0.0418	0.1007
6	0.0023	0.0681	0.0278	0.0836
7	0.00077	0.0542	0.0169	0.0675
8	0.00019	0.0414	0.0092	0.0523
9	0.000033	0.0299	0.0043	0.0384
10	0.0000038	0.0202	0.0017	0.0265

From Figure 13 and Table 6, it can be seen that the QPSK modulation has the best BER performance followed by the 16-QAM. Also, both the 16-PSK and the 64-QAM modulations seem to have very closed performance BER as the SNR increases.
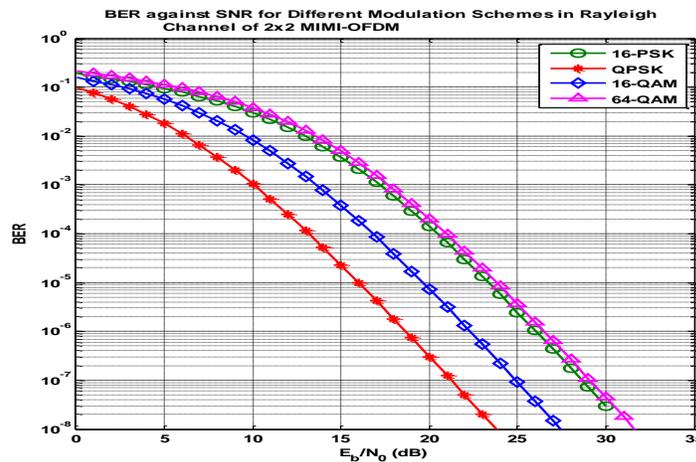

Figure 14 BER against SNR for different modulation schemes in Rayleigh channel

Table 7 Performance analysis for BER vs SNR for differennt modulation
schemes in Rayleigh fading channel

SNR(dB)	BER (QPSK)	BER (16-PSK)	BER (16-QAM)	BER (64-QAM)
0	0.0975	0.1884	0.1556	0.2129
1	0.0756	0.1676	0.1334	0.1916
2	0.0564	0.1477	0.1121	0.1708
3	0.0404	0.1289	0.0920	0.1507
4	0.0276	0.1112	0.0734	0.1314
5	0.0180	0.0946	0.0567	0.1131
6	0.0112	0.0792	0.0422	0.0956
7	0.0066	0.0649	0.0301	0.0792
8	0.0037	0.0518	0.0206	0.0640

9	0.0020	0.0401	0.0134	0.0501
10	0.0010	0.0300	0.0083	0.0379

Figure 14 shows the graphical representation of the performance analysis of different modulation schemes in Rayleigh fading channel of 2x2 MIMO-OFDM system. It can be seen that with QPSK modulation having best performance in terms of BER, the 16-PSK and the 64-QAM modulation have very close BER as the SNR (dB) increases. Table 8 shows the performance analysis.
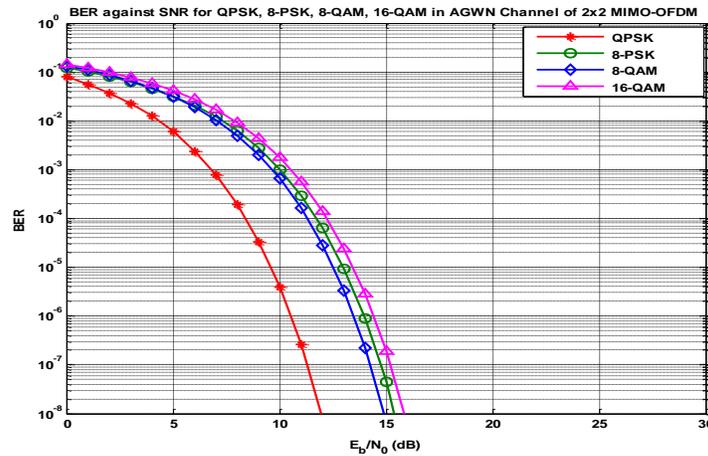

Figure 15 BER against SNR for QPSK, 8-PSK, 8-QAM, 16-QAM

Table 8 Performance analysis for BER vs SNR for QPSK, 8-PSK, 8- QAM and 16-QAM modulation schemes in AGWN channel

SNR(dB)	BER (8-QAM)	BER (16-QAM)	BER (QPSK)	BER (8-PSK)
0	0.1326	0.1409	0.0786	0.1226
1	0.1092	0.1189	0.0562	0.1007
2	0.0867	0.0977	0.0375	0.0806
3	0.0657	0.0774	0.0228	0.0622
4	0.0470	0.0586	0.0125	0.0458
5	0.0313	0.0418	0.0059	0.0318
6	0.0191	0.0278	0.0023	0.0204
7	0.0104	0.0169	0.00077	0.0119
8	0.0050	0.0092	0.00019	0.0061
9	0.0020	0.0043	0.000033	0.0027
10	0.000652	0.0017	0.0000038	0.0010

With the performances of QPSK, 8-PSK, 8-QAM and 16-QAM modulation schemes in terms of BER in AGWN channel of 2x2 MIMO-OFDM shown in Figure 15 and tabulated in Table 8, it can be seen that QPSK outperformed the others. The 8-PSK, 8-QAM, and 16-QAM show very close BER performance. A look at Table 8 revealed that the 8-PSK has better BER performance than the 8-QAM at less than SNR of 5dB, nevertheless the 8-QAM outperformed the 8-PSK at SNR beyond 5dB.
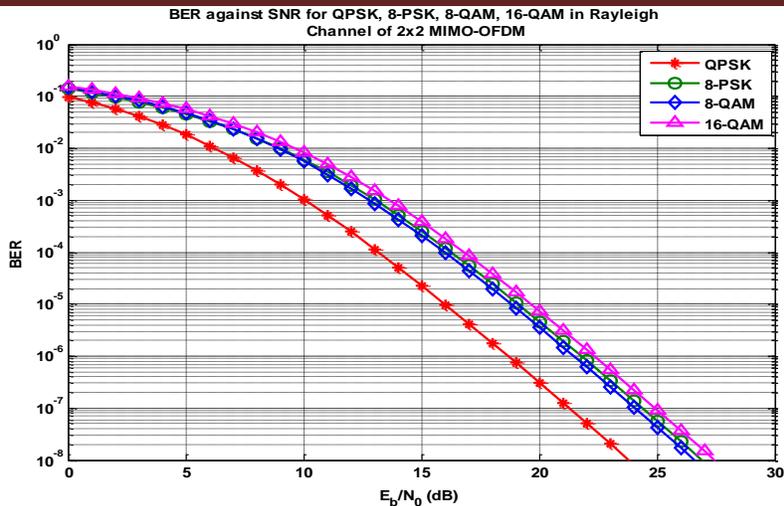
Figure 16: BER against SNR for QPSK, 8-PSK, 8-QAM AND 16-QAM in Rayleigh fading channel

Table 9: Performance analysis for BER vs SNR for QPSK, 8-PSK, 8-QAM, and 16-QAM modulation scheme in Rayleigh fading channel

SNR(dB)	BER (8-QAM)	BER (16-QAM)	BER (QPSK)	BER (8-PSK)
0	0.1471	0.1556	0.0975	0.1386
1	0.1242	0.1334	0.0756	0.1167
2	0.1023	0.1121	0.0564	0.0961
3	0.0819	0.0921	0.0404	0.0773
4	0.0634	0.0734	0.0276	0.0604
5	0.0473	0.0567	0.0180	0.0457
6	0.0338	0.0422	0.0112	0.0333
7	0.0231	0.0301	0.0066	0.0232
8	0.0151	0.0206	0.0037	0.0155
9	0.0094	0.0134	0.0020	0.0099
10	0.0055	0.0083	0.0010	0.0060

In Figure 16, it can be seen that 8-PSK, 8-QAM, and 16-QAM show very closed BER in Rayleigh channel. The 8-PSK modulation scheme offers better performance than the 8-QAM modulation at BER less than 7dB, after which 8-QAM outperforms 8-PSK in Rayleigh fading channel for the 2x2 MIMO-OFDM configurations considered. The performance analysis is presented in Table 9.

Figure 9 through Figure 16 have shown the BER performance of the various modulation schemes considered in this work. Whereas the BER against SNR (dB) performance analysis of the various schemes are presented in Tables 2 through 9. In Figures 9 and 10, the simulation show that 8-PSK outperformed all the other sets of the MPSK modulation scheme in both AGWN channel and Rayleigh channel of the 2x2 MIMO-OFDM system as the SNR (dB) increases from 0 to 30dB. The BER performance of the different orders of QAM modulation scheme shown in Figures 11 and 12 for both AGWN channel and Rayleigh channel showed that 8-QAM provided the best results in terms of BER. However, the performances of the 8-QAM and 16-QAM seem very closed in the Rayleigh fading channel, and the same holds for 32-QAM and 64-QAM. For the comparison of the BER performances of QPSK, 16-PSK, 16-QAM and 64-QAM in AGWN channel and Rayleigh channel with respect to SNR (dB) as shown in Figures 13 and 14, it can be seen that the QPSK modulation outperformed all the other modulation schemes followed by 16-QAM. Also the performance of the 16-PSK and 64-QAM seems to be very close in both channels. As shown in Figures 15 and 16, 8-PSK, 8-QAM and 16-QAM have very close BER performance with increasing SNR in both channels.

Generally, the performance of the various modulation schemes in terms of BER with respect to SNR at constant maximum number of bit for the developed 2x2 MIMO-OFDM configuration shows that QPSK modulation scheme offered the best minimum BER of 3.8×10^{-6} in AGWN channel and 0.0010 in Rayleigh fading channel at SNR of 10 dB respectively while 64-PSK provided the worst perforamce with BER of 0.1164 in AGWN channel and 0.1256 in Rayleigh fading channels at SNR of 10 dB respectively. The simulation plots show that the various orders of the QAM modulation scheme outperforms equivalent orders of the M-PSK modulation schemes for the MIMO-OFDM configuration. Also, the results obtained show that in both AGWN and Rayleigh fading channels, lower order modulation schemes provided better BER performance than higher order schemes with respect to SNR (dB) as can be seen in Tables 4.1 through 4.8. Furthermore, from the figures and tables, it can be seen that all the modulation schemes perform better in AGWN channel than Rayleigh fading channel.

CONCLUSION

This paper has investigated the performance of MIMO-OFDM system in different modulation techniques. In order to meet the objectives of the work, the scope was limited to modeling a 2x2 MIMO-OFDM system with modulation carried out over two channels. The performance of the 2x2 MIMO-OFDM system developed in MATLAB/Simulink over two channels namely, AWGN and Rayleigh fading channels, using various modulation techniques such as 8-PSK, 16-PSK, 32-PSK, 64-PSK, 8-QAM, 16-QAM, 32-QAM, 64-QAM, and QPSK was evaluated. The performance of the system was compared for all the modulation techniques employed over both channels. Generally, it can be concluded that over both AGWN and Rayleigh channels, lower modulation techniques performed better than the higher order schemes but this comes at the cost of the data rate, since lower order techniques have lower data rates than their higher order counterpart. Furthermore, performance of all the modulation techniques was better in AWGN channel than Rayleigh fading channel. Hence, through all the simulation graphs, it is evaluated that the QPSK modulation scheme provided the least (most improved) BER, which means it is the most effective method for data transmission in comparison to other methods of modulations considered in terms of BER.

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