Bit Error Rate and Signal to Noise Ratio Performance Evaluation of OFDM System with QPSK and QAM M-array Modulation Scheme in Rayleigh, Rician and AWGN Channel Using MATLAB/Simulink

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Abstract

The Orthogonal Frequency Division Multiplexing (OFDM) is a practical application of both amplitude and phase modulation scheme and has taking its place in Multiplexing Techniques where a number of independent message signal are at the same time transmitted over a single channel. OFDM is beneficial in transmission with high data rate and better performance. High data rates are achieved by the use of multiple carriers and performance improvement. This paper is based on the QPSK and QAM of Different Modulation order. The performance Evaluation is done using the Bit Error Rate (BER) Against the Signal to Noise Ratio (SNR) parameters which shows a low BER to High SNR. At the end of the work, it was found out that the QPSK has more better performance in OFDM system than the QAM. QPSK has lower BER than the QAM in AWGN, Rayleigh and Rician channel. The performance of QPSK in OFDM is better than the QAM in the OFDM system. The simulation was done using MATLAB/SIMULINK.

Keywords: Orthogonal Frequency Division Multiplexing, Quadrature Phase Shift Keying, Quadrature Amplitude Modulation, Bit Error Rate, Signal to Noise Ratio.

1. Introduction

All electrical signals exist in continuous wave nature at a given time. Analog communication was the order of the day until recently, a digital form of communication has replaced it due to significant advantages over the analog means of communication. The most important features are the digital modulation techniques adopted by the digital communication systems. Some of the advantages of the techniques includes greater noise immunity and its robust channel impairment, easier multiplexing of various forms of information, accommodation of larger amount of digital error control codes with detection and correction transmission errors and implementation of digital modulation and demodulation scheme and techniques. The type of MODEM adopted depends largely on quality factors such as provision of low bit error rate at low received signal to noise ratio, good performance in an interference, multipath and fading environments, minimum bandwidth occupation and lastly easy and probably cost effective in implementation. This paper in based on BER and SNR analysis using the Digital Communication M-array Modulation Scheme such as PSK and QAM. The binary scheme of a digital data consists of only two symbols i.e. 1 and 0. The distinct waveform known as pulse is assign to these two symbols and transmitted over a channel and detected at the receiving end after converting it back to binary data. In an M-array scheme, a symbol consists of more than one binary digits of either 0 and 1 or both.

OFDM as a transmission scheme is adopted by the broadband radio systems and its current used in a well-known standard IEEE 802.16 hence the part which determines the performance in a combination of the dynamic sub-carrier allocation, transmission power allotment, and adaptive modulation (Sivanagaruju & Siddiah, 2014). OFDM is beneficial in transmission with high data rate and better performance. High data rates are achieved by the use of multiple carriers and performance improvement caused by interference ISI which disports the expected signal (Mousumi et al. 2014). Other benefits include increase in spectral efficiency and also minimizes multipath distortion. In this paper, a total number of 128 subcarriers is used at a cyclic prefix of 32. The Maximum bit error is at 100 at 1e7 maximum number of errors.

OFDM baseband signal is typically the sum of number of orthogonal sub-carriers, of which each subcarrier is modulated independently by its own data either QAM or PSK. As the name implies, simultaneous transmission is allowed without interference on a lot of sub-carrier from each other. The simplest form of PSK in the binary scheme BPSK. Though the QPSK will be used in this evaluation in detail. The BPSK like QAM overlap without interference other form of PSK is QPSK (Quadrature phase shift keying). QPSK is often used in the evaluation of the Bit Error rate (BER) due to its improved spectral efficiency requirement and for a given bit rate $1/T_{b,}$ a QPSK system requires just half the bandwidth required for a BPSK system. Hence, QPSK is bandwidth efficient. The QPSK uses the points constellation diagram. QPSK encodes two bits per symbol. In this paper, QAM and PSK will be used in the analysis of the BER as they modulate both phase modulation and the amplitude modulation at the same time in the process. The OFDM is a practical application of both amplitude and phase modulation scheme.

Three channels are used as a medium of transmission in this paper, namely Additive White Gaussian Noise (AWGN) Channel, Rayleigh fading channel also known as Non-Line of Sight (Non-Los) and Rician fading channel also known as Line of sight (Los). The three channels have its peculiarities and technicality in its usage in digital communication system.

MIMO (Multiple input Multiple output) system is an integration of a spatial dimension that represent a good solution to improve the rate and the robustness of transmission system without increasing the bandwidth. Hence using OFDM with MIMO allows simplifying the equalization at the receiver. Introduced in 2005 by IEEE 802.16e. specification to improving the quality of service (QoS). The two known techniques used in MIMO channel is the MIMO diversity (MD) and spatial multiplexing (SM). Practically, the MD uses more antennas in the transmitter and receiver, aiming at improving wireless link quality and are not designed to increase the peak rate of the system (Yosra et al 2010). In the MIMO system, a transmit diversity scheme known as Space Time Block Coding (STBC) in used. It basic function is to encodes the signal through two transmit and in time to enhance the BERV- while preserving the unit code rate. However, the SM offers high peak throughput by transmitting independently and separately encoded data signal from each of the case may be. An example of an effective and simple transmit diversity scheme is the STBC. It encodes the signal through two transmit antennas and in time to enhance significantly the BER while preserving the unit code rate (Yosra et al 2010). Specifically, MIMO is a diversity schemes I which two antenna transmitters and single receiver antenna can provide the same diversity of a single antenna transmitter and two receiving antennas unlike the SISO employs the antenna diversity and cooperative diversity techniques to reduce the multipath effects and improve the performance of wireless communication (Saif & Alnawayseh 2015).

2. OFDM System Design

The OFDM is similar to the CDMA as if also adopts a spread – spectrum in that energy generated at a particular bandwidth is spread across a wider bandwidth making it durable to intrusion and jamming. Occupied bandwidth is directly related to the data to be transmitted (Makarand et al 2016). It means that wider bandwidth requires much transmitting power. OFDM is also termed as a special form of multicarrier modulation (MCM) with closely spaced subcarriers overlapping spectra – it works on the principles of transmitting data by dividing the stream into several bit streams, each of which has a much lower bit rate and uses the sub-streams to modulation several carriers. MIMO – OFDM is considered as a potential technology for high speed data wireless transmission networks as WLAN, 3GPP, LTE and WiMAX. MIMO – OFDM spatial multiplexing in a promising solution to achieve high rates and robust communication for future wireless systems (Namrata et al 2015).

In 1960, the concept of using parallel – data transmission and FDM was first published, it idea was to use parallel – data and FDM with overlapping sub-carrier channels to avoid the use of high speed equalization to combat impulsive noise and multipath distortion and fully utilize bandwidth. The advent of FFT facilitated the realization of OFDM in the 1960, hence FFE/IFFT makes of possible to generate OFDM using the digital domain for orthogonality of sub-carrier. System model of OFDM using FFT/IFFT OFDM structures basically relies on the three principles namely, IFFT/FFT, cyclic prefix (CP) and interleaving application (Sai & Chaparala 2013; Usha & Nataraj 2014).

2.1 Rayleigh Channel (Non-LOS), Rician Channel (LOS) and AWGN Model

The fading that occurs in the channels are of different types ranging from Large scale fading and Small scale fading in a multipath system. In the large-scale fading, the received signal power varies gradually as a result of signal attenuation determined by the geometry of the path profile while small scale fading leads to rapid fluctuation of phase and amplitude of the signal. In flat fading, it is clear that the bandwidth of the mobile channel is greater than the bandwidth of the transmitted channel either all frequency components of a received radio signal vary in the same proportion simultaneously (Ojasvi et al 2014; Usha & Nataraj 2014). In this paper, the small-scale fading (SSF) is discussed. The SSF, the three models namely Rayleigh fading (Non–Los), Rician fading (LOS) and Additive White Gaussian Noise (AWGN) typical example.

2.2 Rayleigh fading Channel.

Rayleigh fading model is a statistical model for the effect of a propagation environment on a radio signal (Ojasvi et al 2014). In order words, it a rational model when there are many objects in the environment that scatter the transmitted signal to arrival at the receiver antenna. Basically, when large number of paths, applying central limit theorem, each path can be modelled as circularly symmetric complex Gaussian random variable with time as the variable. It uses the Rayleigh distribution to complement it methods – laving zero mean and phase evenly distributed between 0 and 2π radians. (Sai & Suman 2013; Ojasvi et al 2014).

The form of the circularly symmetric complex Gaussian random variable is

$$Z = X + jY \tag{1}$$

Where X is real and Y is imaginary parts and zero mean independent and identically distributed Gaussian random variables.

For a circularly symmetric complex random variable

$$E[Z] = E\left[e^{j\theta}Z\right] = e^{j\theta}[Z] \tag{2}$$

And the statistics of a circularly symmetric complex Gaussian random variable is completely specified by the variance.

$$\delta^2 = E[Z^2] \tag{3}$$

The magnitude [z] which has a probability Density function (PDF), [8] [9].

$$P(z) = \frac{z}{\delta^2} e^{\frac{-z^2}{2\delta^2}}, z > o \tag{4}$$

That is called Rayleigh random variable.

The Rayleigh fading channel model also known as Non-line of sight (Non-LOS) is good in a complex environment where there is no Line of Sigh (LoS) between the transmitter and the receiver. Possibly, reflection, diffraction and scattering is bound to happen.

Also, the impulse is

$$h(t) = \frac{1}{\sqrt{n}}[h_1(t - t_1) + \cdots . + hn(t - t_n)] \tag{5}$$

$h_1(t\text{-}t_1)$ is the channel coefficient of the first tap

$h_2(t\text{-}t_2)$ is the channel coefficient of the second tap

$h_3(t\text{-}t_3)$ is the channel coefficient of the third tap and so on. However, the real and imaginary part of each tap is an independent Gaussian random variable with mean 0 and variance ½. The term ${}^{1}/_{\sqrt{n}}$ is for normalizing the average channel power over multiple channel realization to 1.

2.3 Rician Fading Model

It is a non-deterministic model for a line of sight (LoS) system. It is for the miss-normal that occurs when signals transmitted accidentally cancels itself, hence causing fading or attenuation at the receiver. In furtherance, when one of the paths either LoS is stronger than the others, it means that Rician fading has occur in the environment. Like the Rayleigh fading mentioned earlier which is characterized by Rayleigh distribution, the Rician fading model is characterize by Rician distribution. In summary, when there is LoS between the OFDM transmitter and receiver, then it is characterized by Rician fading (Ojasvi et al 2014; Omijeh 2015).

Practically, two parameters like the Rice Factor (*K*) and the total power from both paths and acts as a scaling factor to the distribution.

The received signal amplitude is Rice distributed with parameters.

$$V^2 = \frac{K}{1+K^2}\Omega \tag{6}$$

And

$$\sigma^2 = \frac{\Omega}{2(1+k)} \tag{7}$$

Then the PDF is

$$f(x) = \frac{2(1+k)}{\Omega}\exp\left(-k - \frac{(1+k)x^2}{\Omega}\right) I_0\left(2\sqrt{\frac{K(k+1)}{\Omega}}\,x\right) \tag{8}$$

where I_o is the 0^{th} order modified Bessel function of the first kind. If the Rice factor (*K*) is 0 then the Rician faded Envelope reduces down to Rayleigh faded Envelope. Hence the Rayleigh faded model and Rician fading Model are closely related under such condition (Sai & Chaparala 2013).

2.4 AWGN Model

AWGN is the simplest model of all channels. It is well suited for wired communication. It takes place with well-mannered mathematical models of communication system without fading and distortions (Sutanu 2014). The AWGN channel adds white Gaussian noise to the signal when it is passed through the channel, either the values at any pair of times are identically distributed and statistically independent on each other (Sai & Chaparala 2013). In this AWGN, it is not associated to either fading or any other system parameters. The noise is only added to the OFDM modulated signal when it is traveling through the channel.

$$C = \frac{1}{2}\log\left(1 + {}^{P}/_{n}\right) \tag{9}$$

Where C = channel capacity

The fading channel output received a signal is given by

$$r(t) = c(t)s(t) + n(t) \tag{10}$$

when *n*(t) is the AWGN with power spectral density η in both real and imaginary components, *c*(t) is the zero-mean complex gain of the channel and *s*(t) is the transmitted signal (Sutanu 2014).

c(t) can be given as

$$c(t) = \exp(j\omega ct)\, m(t) \tag{11}$$

And

m(t) is the complex Gaussian fading process with variance σm^2.

2.5 BER and SNR

An acronym for Bit Error Rate (BER) and Signal to Noise Ratio (SNR) is an important parameter and taken very serious mostly when carrying out evaluation and analysis of a system be it electronics or any other system – involving transfer of signal through a medium i.e. from transmitter to Receiver and vice-visa. In this paper, a critical analysis is done just by understanding what it actually means.

2.5.1 BER

It is used to measure the difference among original transmitted signal and received signal at the receiving end (Meenakhsi, 2016).

$$BER(t) = abs(x(t) - y(t)) \tag{12}$$

Where,

x(t) is the originally generated signal at transmitter and

y(t) is the received signal at the receiver end at time (t)

In short, the Bit Error Rate (BER) is the number of bit error per unit time. The Bit Error Ratio (BER) is the number of bit error divided by the total number of transferred bit during a studied time interval (Arokia & Maran 2016).

$$BER = \frac{Number\ of\ errors}{Total\ number\ of\ bits\ transmitted}$$

A situation where the transmission speed and medium are good at a particular time but the SNR is high then BER becomes very low (Arokia & Maran 2016)..

2.5.2 Signal-to-Noise Ratio, SNR

The ratio of the signal power to the noise power in decibel (dB) is commonly known as the signal to Noise ratio.

$$SNR = 10log\frac{Signal\ power}{Noise\ power}dB$$

It is an indicator used to evaluate the quality of a communication link. It means a communication link is in good condition when the SNR is higher (Arokia & Maran 2016)..

2.6 QUADRATURE PHASE SHIFT KEYING (QPSK)

The two main resources of a communication system are defined by the transmission power and channel bandwidth. The channel bandwidth depends on the bit rates (signaling rate (fb)). The most prominent parameter in digital communication is the carrier signal.

However, the carrier signal is transmitted over a channel together with the baseband signal after it has been modulated. It implies that if two or more bits are combined as a symbol, the fb is reduced, thereby reducing the carrier frequency. The grouping of bits in symbols, also reduces the transmission channels bandwidth.

In the QPSK, two successive bits in the data sequence are grouped together.

S/No	**Input**	**Successive Bits**	**Symbol**	**Phase shift in the Carrier**
1	1(IV)	0(-IV)	S_1	$^{\pi}/_{4}$
2	0(-IV)	0(-IV)	S_2	$3\,^{\pi}/_{4}$
3	0(-IV)	1(IV)	S_3	$^{5\pi}/_{4}$
4	1(IV)	1(IV)	S_4	$^{7\pi}/_{4}$

Table 1. Show four symbols and phase shift by $^{\pi}/_{4}$ per symbol.

The table shows combination of two successive bits and formation of four distinct symbols. When any change in symbol occurs, the phase of the carrier is changed by 45^0 $^{\pi}/_{4}$ radians.

Practically, in QPSK, m =4, each of the four levels can be represented by a di-bit (pair of bits): 00,01, 10, or 11. At each signally symbol period

$$T_s = 2T_b \tag{13}$$

i.e.

$$s(t) = \sqrt{2E_s/T_s}\, Cos\left[\left(2\pi_{fc}t + (i-1\right)\pi/2\right]\ 0 \le t \le T_s\ and\ i = 0,1,2,3,4. \tag{14}$$

$$\text{SQPSK(t)} = \begin{cases} S_0(t) = \sqrt{2E_s/T_s}\, Cos\,[2\pi_{fc}t + 0]\; for\ dibit\ 00 \\ S_1(t) = \sqrt{2E_s/T_s}\, Cos\,[2\pi_{fc}t + \pi/2]\; for\ dibit\ 01 \\ S_2(t) = \sqrt{2E_s/T_s}\, Cos\,[2\pi_{fc}t + \pi]\; for\ dibit 10 \\ S_3(t) = \sqrt{2E_s/T_s}\, Cos\,[2\pi_{fc}t + {}^{3\pi}/_{2}]\; for\ dibit\ 11 \end{cases} \qquad (15)$$

where $0 \leq + \leq Ts$, Hence the carrier is transmitted after modulation with one of the four possible phases: 0, ${}^{\pi}/_{2}$, π, or ${}^{3\pi}/_{2}$ each phase corresponding to a unique di-bit.

2.7 QAM (Quadrature Amplitude Modulation)

The M-ray QAM signal can be represented as follows

$$S_1(t) = \sqrt{\frac{2E_{min}}{T_s}}\, ai\ Cos(2\pi_{fc}t) - \sqrt{\frac{2E_{min}}{T_s}}\ bisin(2\pi_{fc}t) \qquad (16)$$

Where $0 \leq t \leq T$ and i = 1, 2, 3, …..m
Where
E_{min} = energy of the signal with lowest amplitude.
One merit of QAM over M-array PSK is that it has a good power efficiency.

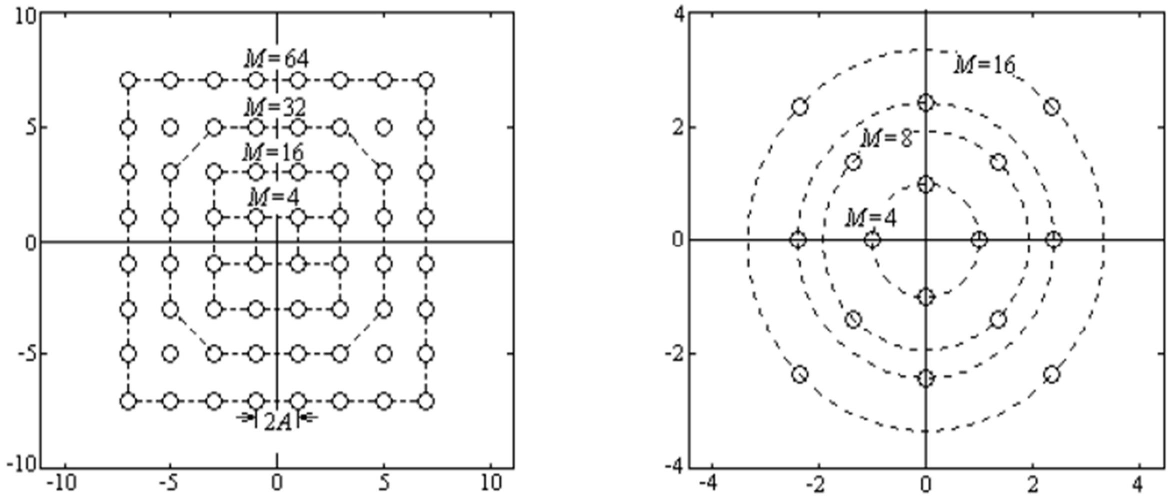

Fig 1. (a) Shows the Rectangular QAM signal constellation diagram and (b) the circular QAM signal constellation diagram with different modulation order.

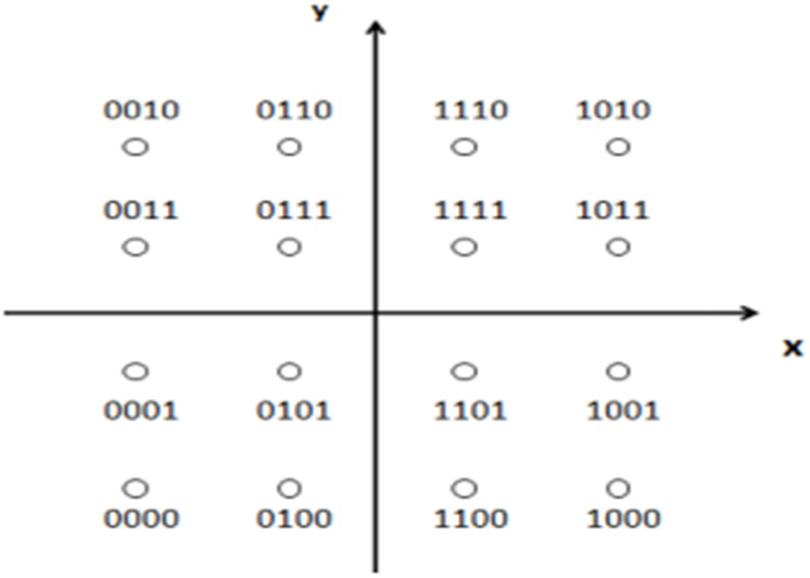

Fig 2. Constellation Diagram of 16 QAM.

3. Simulation

MATLAB is used to model and simulate OFDM in an AWGN channel, Rayleigh fading channel and Rician fading channel looking at the QPSK and QAM (16, 32, 64, 128) with respect to the required modulation order. The number of subcarriers is 128 using cyclic prefix (CP) of 32. The maximum bit error is placed at 100 and above at 1e7 maximum number of bits. The idea is to evaluate each scheme with respect to comparing the BER of each scheme to the SNR. The Simulink model of each scheme is shown in fig. 1-6 in the three different channels (AWGN, Rayleigh and Rician Channel) below. The Graphical representation is shown in Figures 7 to 14.

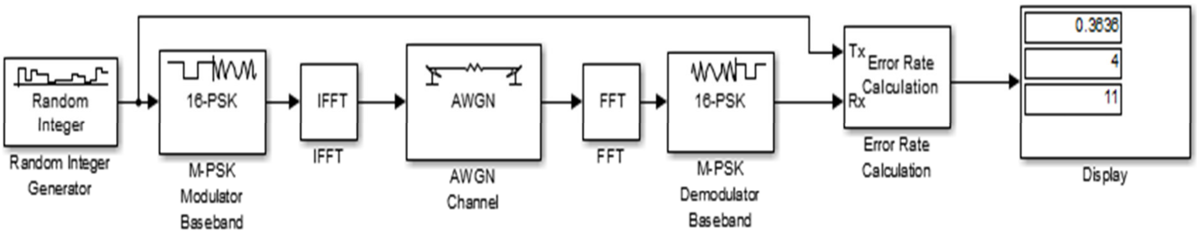

Fig. 3. BER output for OFDM system using 16-PSK Modulation in AWGN Channel.

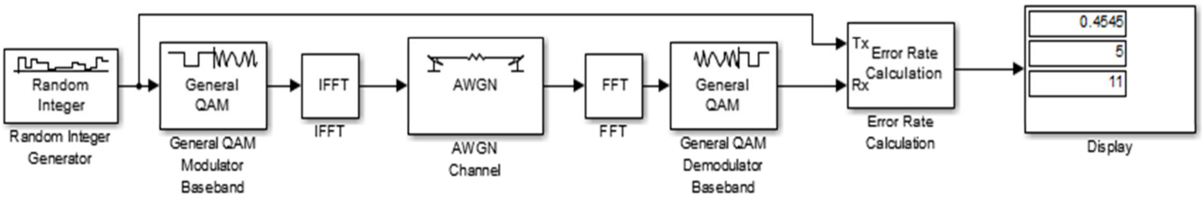

Fig. 4 BER output for OFDM system using QAM Modulation in AWGN Channel.

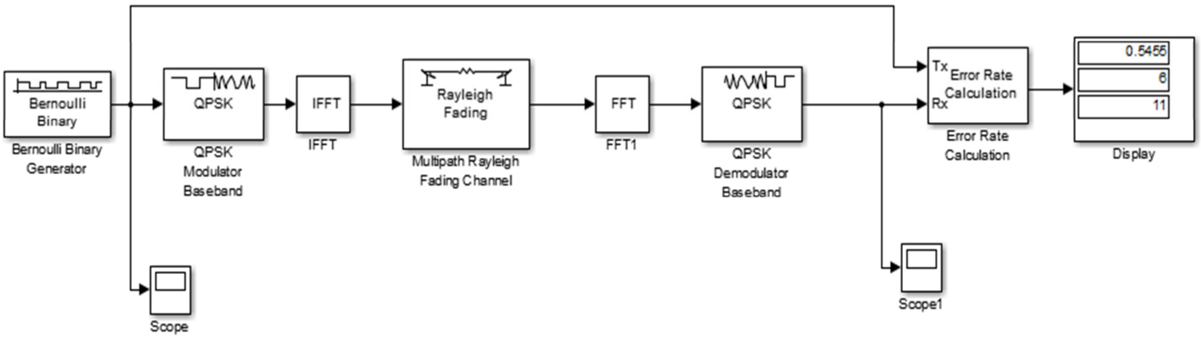

Fig. 5 BER output for OFDM system using QPSK Modulation in Rayleigh Channel.

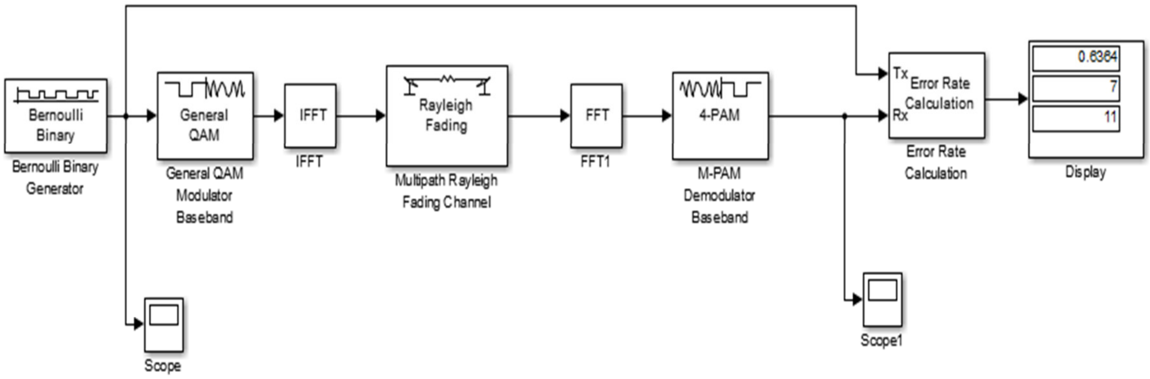

Fig. 6 BER output for OFDM system using QAM Modulation in Rayleigh Channel.

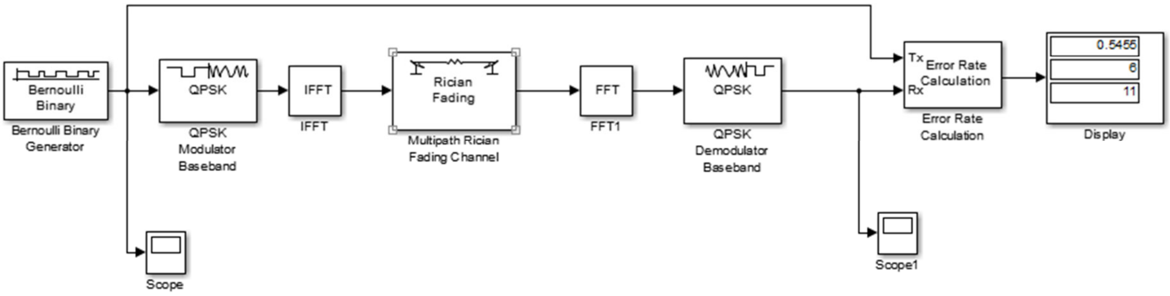

Fig. 7 BER output for OFDM system using QPSK Modulation in Rician Channel.

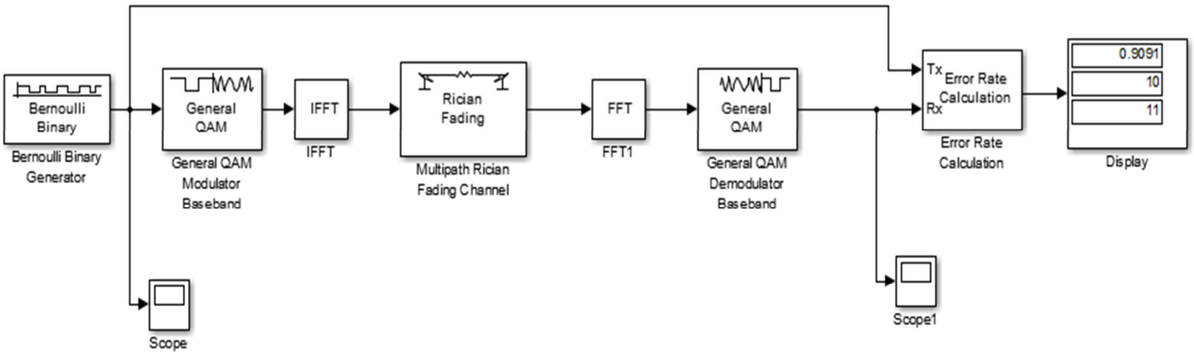

Fig. 8 BER output for OFDM system using QAM Modulation in Rician Channel.

Fig 2-4 shows the simulation of OFDM system of 16-PSK, and QAM Modulation in AWGN channel using Simulink. Fig 5-6 shows the simulation of OFDM system of QPSK and QAM modulation in Rayleigh channel using Simulink. Whereas Fig 7-8 is the simulation of OFDM system of QPSK and QAM modulation in a Rician channel.

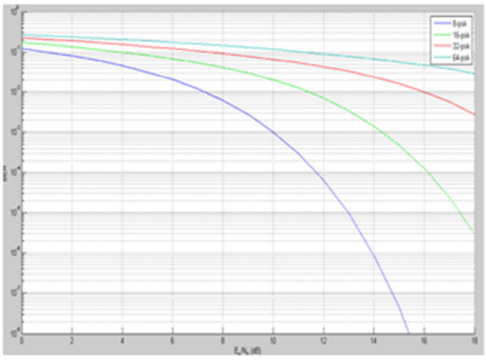

Fig. 9 Shows PSK (8,16,32,64) graph in AWGN channel.

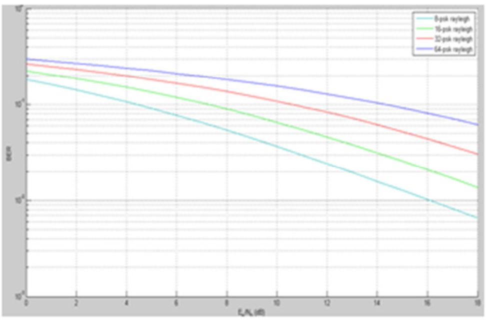

Fig. 10. Shows PSK (8,16,32,64) in Rayleigh channel.

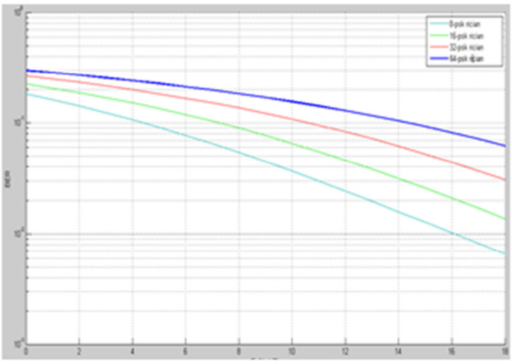

Fig. 11 Shows PSK (8,16,32,64) Rician channel.

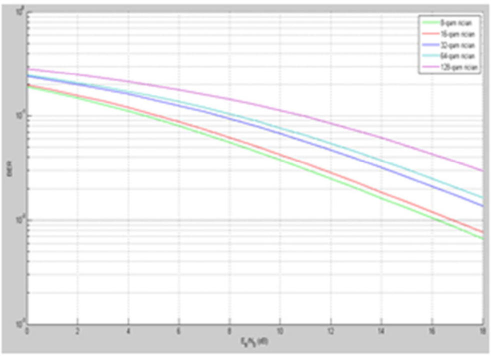

Fig. 12 Shows QAM (8,16,32,64,128) in Rician channel.

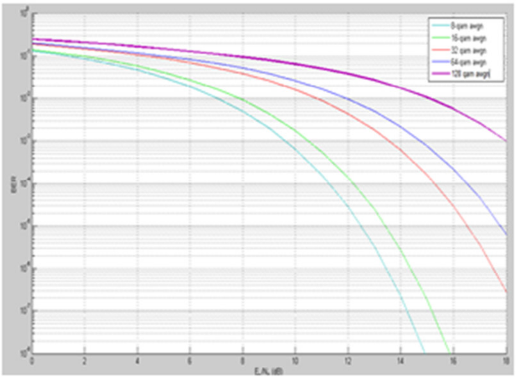

Fig. 13 Shows QAM (8,16,32,64,128) in AWGN channel.

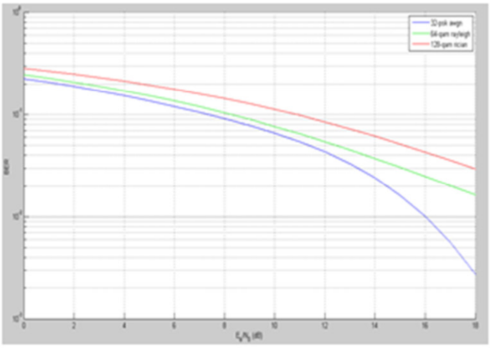

Fig. 14 Shows 32-PSK, 64-QAM and 128-QAM in AWGN, Rayleigh and Rician channels.

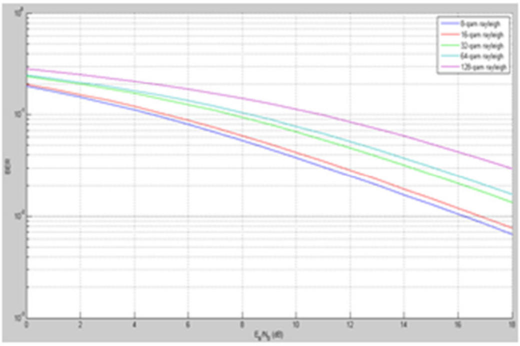

Fig. 15. Shows QAM (8,16,32,64,128) in Rayleigh channel.

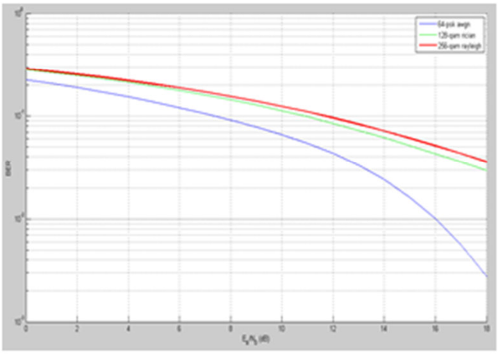

Fig. 16. Shows 64-PSK, 128-QAM and 256-QAM in AWGN, Rayleigh and Rician channel.

4. Conclusion.

From the series, of simulation done first with Simulink shown from Fig 2-8 and secondly with MATLAB from Fig 9-16, it is observed that the AWGN have a lower BER to SNR as compared to the Rayleigh and Rician Fading channel. At the Rice factor is 0, Hence the Rayleigh faded model and Rician fading Model are closely related under such condition as seen in the results. QPSK have a more better response in an OFDM system than the QAM at 128 subcarriers with 32 Cyclic Prefix. The QPSK also has more better performance in OFDM system than the QAM. QPSK has lower BER than the QAM in AWGN, Rayleigh and Rician channel. The performance of QPSK in OFDM is better than the QAM in the OFDM system.

Future Work. Future work will be done in a MIMO OFDM system.

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