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# Comparative Analysis of Digital Modulation Techniques in LTE 4G Systems

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**Abstract** The basic criteria for best modulation scheme depends on Bit Error Rate (BER), Signal to Noise Ratio (SNR), Available Bandwidth, Power efficiency, better Quality of Service, cost effectiveness. The performance of each modulation scheme is measured by estimating its probability of error produced by noise and interference induced in the channel. Modulation methods which are capable of transmitting more bits per symbol are more vulnerable to error caused by noise. The modulation technique used for OFDM-LTE (4G) syatems are M-PSK and QAM, so in this paper the Bit error rate (BER) of M-PSK and QAM digital modulation schemes are compared under AWGN, and Rayleigh fading channels to identify a suitable digital modulation scheme for OFDM application. The research has been performed by using MATLAB SIMULINK for simulation and evaluation of Bit Error Rate (BER) and Signal-to-Noise Ratio (SNR) for OFDM system models.

**Keywords** Digital Modulation, LTE, M-PSK, QAM, BER, SNR, OFDM

## 1. Introduction

Modulation is of utmost importance to all wireless communications. Most wireless transmissions as of today are digital with limited available spectrum; thus the type of modulation employed is crucial. The transition of analogue to digital modulation offered improved data security, enhanced quality communication, additional information-carrying capacity, compatibility with digital data services, swift system availability as well as RF spectrum sharing to accommodate added services [1, 2].

However, factors such as bandwidth availability, permissible power and inherent noise level of the system are major restrictions developers of communication systems face in the industry which affect spectral efficiency; thus slowing down how fast information can be transmitted in an allotted bandwidth [1]. Other factors include the increased data rates, higher mobility, larger carrier frequencies, and system reliability due to increase in services demanded by users [3].

Digital Modulation techniques provide numerous benefits such as greater capacity to transmit large quantity of data with high noise immunity. Another silient advantage is easy detection of its distinct transmission state at the receiver in a noisy medium [4].

When a digitally transmitted signal is initiated as analogue waveform, trade-off is always made due to loss of some information in quantization process required to convert the analogue signal to a digital signal [5]. The choice of digital modulation techniques employed is very important, particularly in uplink-downlink transmission where resources such as bandwidth and time slots are limited.

The performance of a modulation technique is measured in terms of its Bandwidth and power efficiency. Bandwidth efficiency is the ability of a modulation technique to accommodate data within a limited bandwidth while power efficiency is the capability of a modulation technique to preserve the bit error probability of the digital message at low power levels [1, 5].

So we have chosen PSK as digital modulation technique. The performance of different forms of PSK such as BPSK (2-PSK), QPSK (4-PSK), 8-PSK and 16-PSK have been evaluated in order to find which modulation technique will be suitable to get maximum benefit from available network.

In a communication system the quality of the transmission is usually quantified by either the Bit Error Rate (BER) or the Packet Error Rate (PER), where a packet contains a number of bits. The main goal in the design of digital communication system is to achieve least probability of error and effective utilization of channel bandwidth.

Spectral efficiency refers to the amount of information that can be transmitted over a given bandwidth in a specific digital communication system. It is a measure of the number of bits transferred per second for each Hz of bandwidth and thus the spectral efficiency $S_E$ is given by:

$$S_E = \frac{C}{W} = log_2\left(1 + \frac{S}{N}\right) \quad (1)$$

where both the signal and noise are linear scale and the spectral efficiency is measured in b/s/Hz [3].

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The key to achieving this higher level of service delivery is a new air interface. Orthogonal Frequency Division Multiplexing (OFDM) is an alternative wireless modulation technology to CDMA. It is a digital modulation and multiplexing technique suitable for 4G technology.. The driving force behind the need to satisfy this requirement is the explosion in mobile telephone, Internet and multimedia services coupled with a limited radio spectrum.

The spectral efficiency of OFDM signal can be found by multiplying the spectral efficiency of modulation technique by the number of Subcarriers.

The BER performance of an OFDM signal in a fading channel is much better than the performance of QPSK/FDM which is a single carrier wideband signal. Aithough the underlying BER of an OFDM signal is exactly the same as the underlying modulation, that is, if 8PSK is used to modulate the sub-carriers then the BER of the OFDM signal is the same as the BER of 8PSK signal in Gaussian channel. But in channels that are fading, the OFDM offers far better BER than a wideband signal of exactly the same modulation. The advantage is due to the diversity of the multi-carrier such that the fading applies only to a small subset.

Signal to noise ratio (SNR) is the difference between the signal strength a system reproduces compared to the strength or amplitude of its background noise. According to Shannon's Theory of information, the maximum capacity of a channel of bandwidth $W$, with a signal power of $S$, affected by white noise of average power $N$, is given by [3, 6]

$$C = W log_2\left(1+\frac{S}{N}\right) \quad (2)$$

This paper is the comparative study of digital modulation techniques that can be used in OFDM which is core part of WIMAX model. The outcome of this study, and the comparison of the results, will enable us come up with the combination of different encoding-decoding and modulation-demodulation techniques which will best suit the current expectations of end-users.

The necessity for 4G networks is associated with the increased utilization of data websites such as You Tube and Facebook, which require tremendous bandwidth, in order to be used successfully.

4G speeds are much faster compared to 3G. 4G speeds are meant to exceed that of 3G whose maximum current speeds are at about 14Mbps downlink and 5.8Mbps uplink. To be able to qualify as a 4G technology, speeds of up to 100Mbps must be reached for a moving user and 1Gbps for a stationary user. So far, these speeds are only reachable with wired LANs. The fourth generation is faster, it is said to be four times faster than its predecessor. This allows for a connection speed more comparable to DSL and home cable networks. It is great news for those completing work and accomplishing important tasks away from their home and office. When uploading large documents and communicating via the internet, a fast connection is important, whereas 3G does not favour such speed as compared to that of 4G.

The next difference between the third and fourth generation is bandwidth. At first glance, the bandwidth of both 3G and 4G are the same, between 5 and 20 MHz. However, the rate of data is what makes the difference between the two. While the data rate of the third generation only goes up to 2 Mbps, the fourth goes all the way up to between 100 Mbps to 1 Gbps.

3G system is based on wideband CDMA that operates in 5 MHz of bandwidth and can produce download data rates of typically 384 kb/s under normal conditions and up to 2 Mb/s in some instances. 3G phone standards have been expanded and enhanced to further expand data speed and capacity. The WCDMA phones have added high speed packet access (HSPA) that use higher level QAM modulation to get speeds up to 21 or 42 Mb/s downlink (cell site to phone) and up to 7 and/or 14 Mb/s uplink (phone to cell site), whereas 4G, also known as LTE, uses a completely different radio technology. Instead of CDMA, it uses orthogonal frequency division multiplexing (OFDM) and OFDM access. This modulation technique divides a channel usually 5, 10 or 20 MHz wide into smaller subchannels or subcarriers each 15 kHz wide. Each is modulated with part of the data. The fast data is divided into slower streams that modulate the subcarriers with one of several modulation schemes like QPSK or 16QAM. It also defines multiple input multiple output (MIMO) operation that uses several transmitter-receiver-antennas. The data stream is divided between the antennas to boost speed and to make the link more reliable. Using OFDM and MIMO lets LTE deliver data at a rate to 100 Mb/s downstream and 50 Mb/s upstream under the best conditions. In 4G the theoretical upper data rate is 1 Gb/s.

Available bandwidth, permissible power and inherent noise level of the system are the constraints which should be considered while developing the communication systems. Due to error-free capability in digital modulation, it is preferred over the analogue modulation techniques. The Worldwide interoperability for Microwave Access (Wi-max) uses combinations of different modulation schemes which are BPSK, QPSK, 4-QAM AND 16-QAM and it is a promising technology which offers high speed voice, video and data services.

In analog communications an analog signal is taken and it is modulated using an analog carrier, whereas in the digital communications a digital signal or binary data is taken and modulated using an analog carrier.

In OFDM, BER depends upon the modulation technique. As the simulation shows by increasing the PSK order, BER will increase as a trade-off for decreasing runtime. As SNR increases, BER will decrease. And higher order PSK requires a larger SNR to minimize BER. QAM is widely used rather than QPSK because it comprises of amplitude as well as phase, while QPSK only have phase. If the signal in QAM is corrupted it can be corrected either by amplitude or phase. By using QAM error will be reduced or SNR will improve compared to QPSK.

The main objective of our work is to measure Bit Error Rate with different modulation schemes and come to the best configuration to achieve better utilization of bandwidth.

## 2. Bit Error Probability ($P_b$) of M-PSK and QAM Modulation Schemes

### 2.1. Binary Phase Shift Keying (BPSK)

Phase modulation offers PSK which is divided into techniques such as BPSK, QPSK etc. In these techniques data is conveyed by changing the phase of the carrier wave. BPSK digital modulation technique is the simplest form of the phase shift keying modulation. It uses two phases which are separated by a phase shift of 180° which makes it to be referred to as 2-PSK.

The signal shifts the phase of the waveform to one of the two states to represent binary symbol of either 1 or 0 respectively. Coherent BPSK has one dimensional signal space with two message points, in order to generate a BPSK signal, the input binary data in polar form with symbol 1 and 0 are represented with a constant amplitude level of $\sqrt{E_b}$ and $-\sqrt{E_b}$. The signal transmission encoding process is carried out by a Non Return Zero level encoder (NRZ). The output binary wave together with the sinusoidal carrier $\emptyset_1(t)$, whose frequency is given by $f_c = \frac{n_c}{T_b}$ are fed into the product modulator and the desired BPSK wave is attained as the output of the modulator.

To demodulate the original binary sequence of 1 and 0 the incoming BPSK signal is passed into a correlator, which is made up of the multiplier and the integrator. The incoming signal together with the coherent reference signal $\emptyset_1(t)$ is multiplied and the output is fed into the integrator. The output of the correlator $x_1$ is compared with a threshold of 0 and decision is made based on the decision rule. If $x_1 > 0$ the device generates output of 1 but if $x_1 < 0$, the device generates output of 0.

BPSK is employed majorly in satellite communication due to its implementation simplicity and robustness. Other advantages of BPSK include 3dB power improvement and double information carrying capacity when compared to BASK [7-10]. However it is important to note that this modulation technique is bandwidth inefficient due to the fact that it is only able to transmit 1bit/symbol, thus making it inapt for high speed data rate application.

The mathematical representation for BPSK signal can be expressed as

$$S_c(t) = \sqrt{\frac{2E_b}{T_b}} cos(2\pi f_c t) + \pi(1-n) \ldots . n = 0,1 \quad (3)$$

BPSK system under constant transmitted bit energy, noise level and other distortion gives the lowest bit error rate since BPSK system has the largest distance between two signal points.

The probability of bit error of BPSK in Additive White Noise Gaussian Noise (AWGN) can be obtained using

$$P_{e,BPSK} = Q\sqrt{\frac{2E_b}{N_0}} \quad (4)$$

where $E_b$ is energy per bit and $N_0$ is the noise power spectral density. $Q$ is the $Q$ function which is used frequently for calculating the area under the tail of the Gaussian pdf denoted by *Q(x)*.

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-\left(\frac{t^2}{2}\right)} dt \quad (5)$$

$$\int a^x dx = \frac{a^x}{lna} + C$$

### 2.2. Quadrature Phase Shift Keying (QPSK)

Another extension of PSK is the digital modulation technique which is a higher order of PSK that uses a four level phase state to transmit 2bits/symbol simultaneously, by selecting one of the four possible equally spaced carrier phase shift of 0, π/2, π and 3π/2, where each value of the carrier phase corresponds to a distinct pair of message bits of 00,01,10,11. This avails the signal the availability of carrying double information using the same bandwidth. This implies that QPSK is more bandwidth efficient than BPSK [12].

In the demodulator the received signal is multiplied with a reference signal $\emptyset_1(t)$ and $\emptyset_2(t)$ both in the in- phase and quadrature channels. The multiplied output from each channel is integrated with the help of an integrator. The output of each of the integrator $x_1$ and $x_2$ is compared with the threshold value of 0 and a decision is made by the decision maker. The condition for the output of in-phase channel is; if $x_1 > 0$ a decision is made to produce 1 but if $x_1 < 0$ then 0 is produced while the output for the quadrature channel is if $x_2 > 0$ a decision is made to produce 1 but if $x_2 < 0$ then the decision made is to produce 0. Once this is done the binary sequences in both the in-phase and quadrature channel outputs are combined together in the multiplexer to generate the demodulated binary data sequence.

QPSK is used for satellite transmission of applications such as video conferencing, cellular phone systems and other digital communication over RF carrier.

The mathematical representation of QPSK signal is expressed as

$$S_{qpsk}(t) = \left\{\sqrt{E_s} cos\left[(i-1)\frac{\pi}{2}\right]\emptyset_1(t) - \sqrt{E}_s sin\left[(i-1)\frac{\pi}{2}\right]\emptyset_2(t)\right\}$$

$$i = 1,2,3,4 \quad (6)$$

$$\emptyset_1(t) = \sqrt{\frac{2}{T_s}} \cos(2\pi f_c t) \;,$$

$$\emptyset_2(t) = \sqrt{\frac{2}{T_s}} \sin(2\pi f_c t) \qquad 0 \le t \le T_s$$

where $T_s$ is the symbol period, $E_s$ is the energy per symbol

The bit error probability of QPSK is similar to that of BPSK, but QPSK allows double the transmitted information to be sent in the same bandwidth without increasing the transmitted bandwidth. Also, QPSK offers double spectra efficiency with the same energy efficiency. Similar to BPSK, QPSK can be differentially encoded to allow non coherent detection [1]. Therefore, the probability of bit error can be obtained as

$$P_{e,QPSK} = Q\left[\sqrt{\frac{2E_b}{N_o}}\right] \quad (7)$$

QPSK has same probability of bit error as BPSK because of 3dB reduction in error distance of QPSK is offset by 3dB decrease in its bandwidth.

### 2.3. Quadrature Amplitude Modulation

QAM is a digital modulation technique that involves two different signals to be sent simultaneously on the same carrier frequency. In order words the amplitude is allowed to vary with the phase. The combination of ASK and PSK yields higher-order modulation technique such as QAM [9]. It can be divided into different techniques such as 8QAM, 16QAM, 64QAM etc [1, 4].

It is used mainly in digital telecommunication systems and higher data delivery applications such as cable modem systems. When the required data rate is beyond 8PSK, it is advisable to shift to QAM since it is possible to attain a greater distance between the adjacent points in the I and Q plane by even distribution of the points. The only complexity involved is that the demodulator will have to properly detect both the amplitude and the phase because the points are no longer having the same amplitude.

There are different forms of QAM but the common ones are 16QAM, 64QAM, 128QAM and 256QAM. Higher order M-ary QAM gives room for more points within the constellation, therefore the capability of transmitting more bits per symbol is possible, and this inherently enables data to be transmitted in a much smaller bandwidth. However, if the mean energy of the constellation remains constant, the symbols have to be very close together and this makes them more vulnerable to noise and other distortion thereby resulting to higher bit error rate. This signal will have to be transmitted with more power in order for the symbol to spread out more, thus reducing the power efficiency of this technique as compared to other modulation technique. Nevertheless higher order QAM can transmit more data which makes them to produce more spectrally efficient transmission however they are less reliable when compared to lower order QAM [13, 14].

The general form of M-ary QAM signals can be expressed mathematically as

$$S_i(t) = \sqrt{\frac{2E_{min}}{T_s}}a_1\cos(2\pi f_c t) + \sqrt{\frac{2E_{min}}{T_s}}b_1\sin(2\pi f_c t), \quad (8)$$

$$0 \le t \le T, i = 1,2,3, \dots . M$$

where $E_{min}$ is the energy of the signal with the lowest amplitude, $a_1$ and $b_1$ are a pair of independent integers chosen according to the location of the particular signal point.

The average probability of error in an AWGN for M-ary QAM can be represented as [13]

$$P_e \cong 4\left(1-\frac{1}{\sqrt{M}}\right)Q\left(\sqrt{\frac{2E_{min}}{N_o}}\right) \quad (9)$$

Higher order QAM modulation schemes are vulnerable to error. Therefore, error correction coding ensures higher chances of signal survivability in AWGN and multipath Rayleigh Channel and thus enhances the performance of the system.

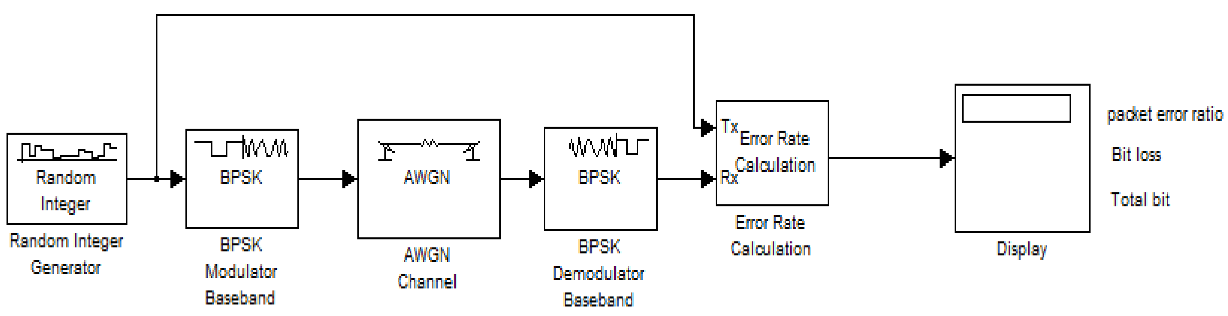
However, there is always a trade off in the applications due to the fact that a particular application may need higher precision in reception of data while for another application the requirement desirable may be available bandwidth or power.

The choice of the technique cannot be underestimated because it greatly influences the characteristics, performance and overall physical attainment of a communication system.

Digital Modulation will continue to be relevant in the world of voice and data communication with high throughput since the major aim of a communication system designer is to transmit information within the shortest possible time within the available bandwidth and at an affordable cost and with smallest amount of probability of error.

## 3. Simulation Results and Evaluations

In this work we have analyzed BER value of different modulation techniques in two different channel bandwidth of 1.25MHz and 6 MHz with different SNR values. At the end of the analysis we have concluded that as we increase channel bandwidth we get better throughput but BER increases. As we go up the order of modulation BER increases for a given SNR value. As we go on increasing SNR value for a given modulation technique BER goes on decreasing.



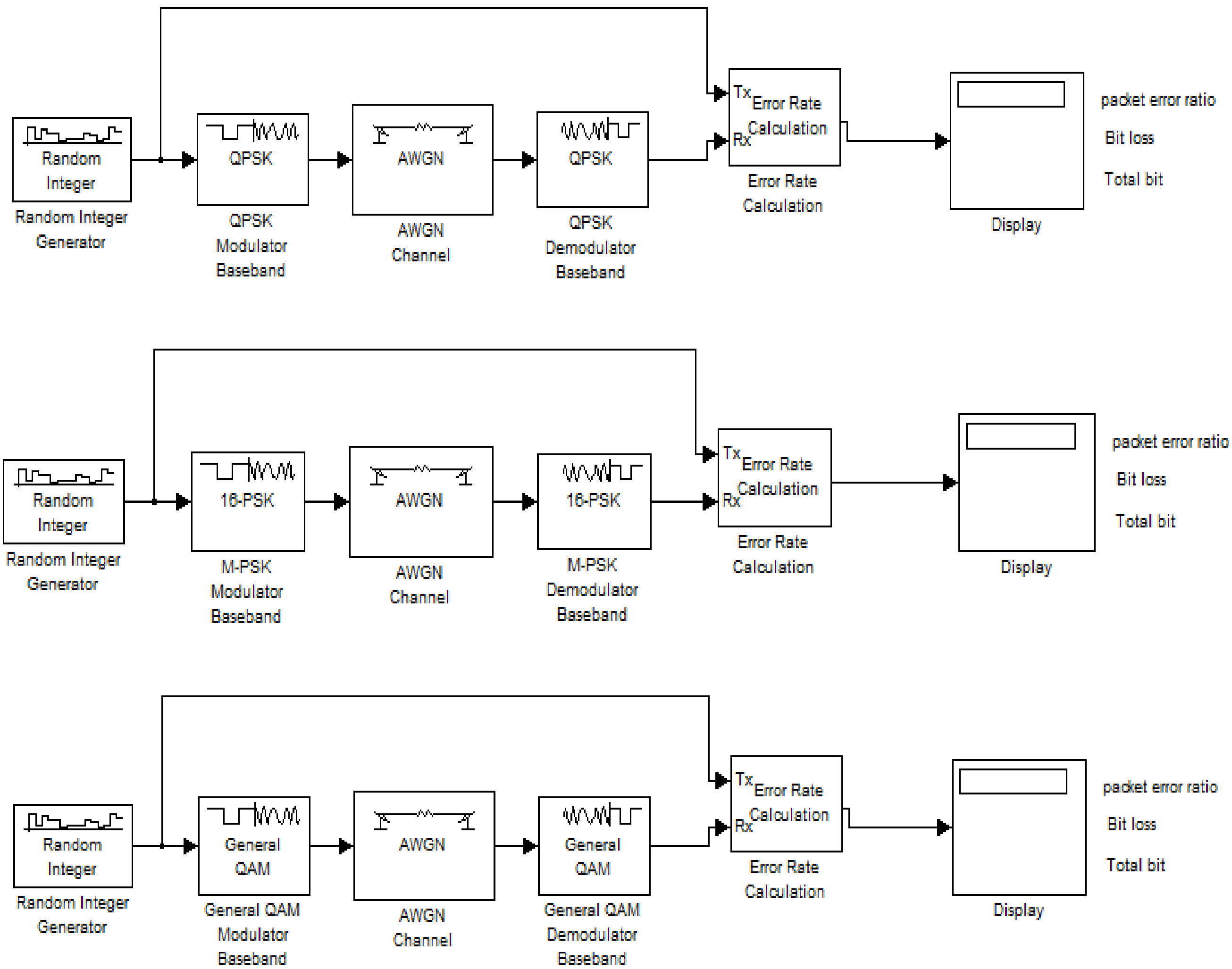



**Figure 1.** Simulation setup for the modulation techniques in AWGN of two channel bandwidth of 1.25MHz and 6 MHz

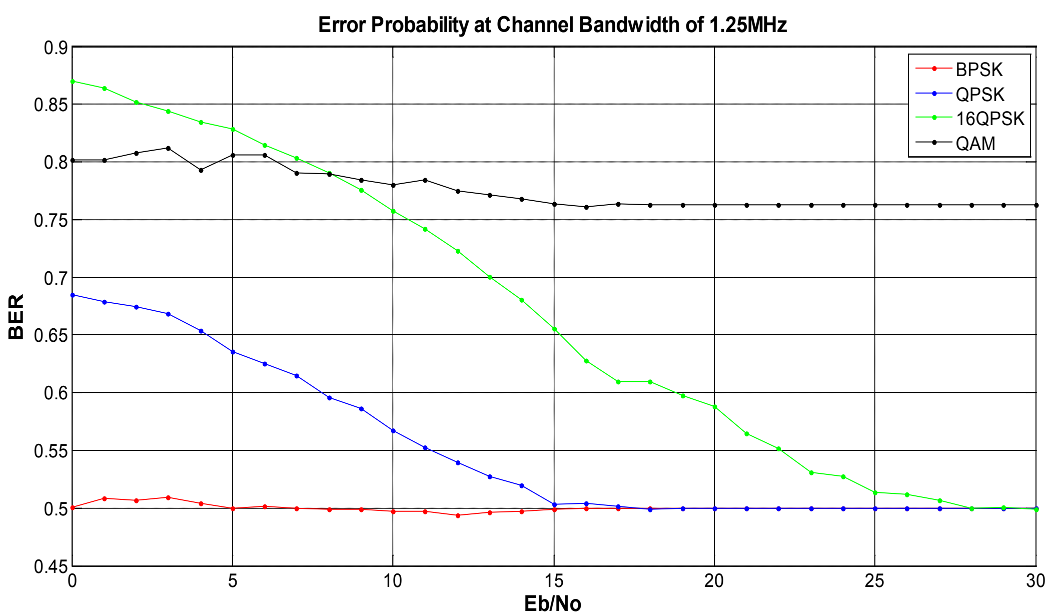



**Figure 2.** BER against SNR for OFDM System in a channel bandwidth of 1.25 MHz

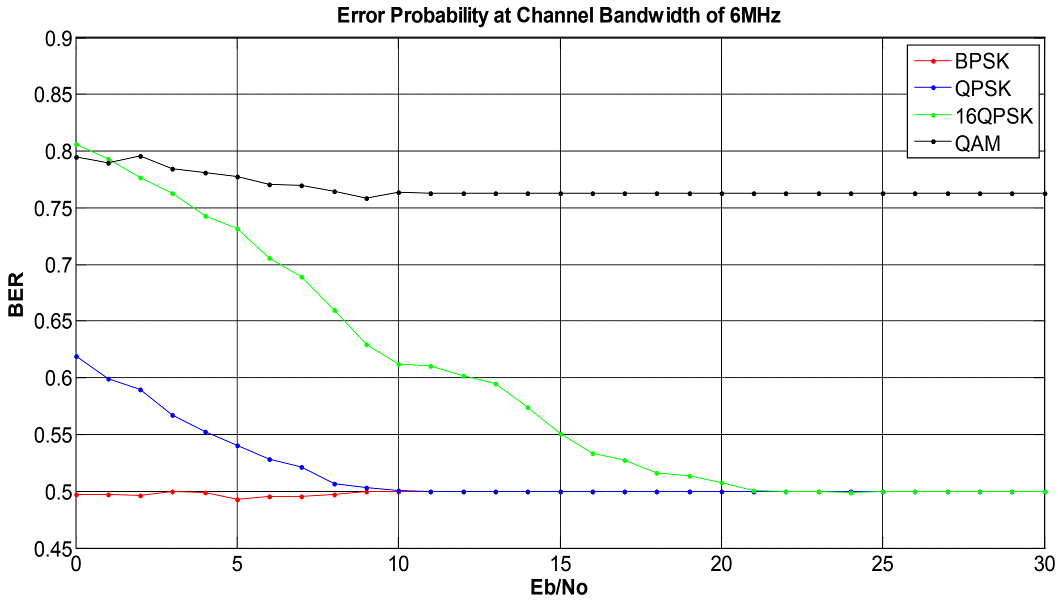



**Figure 3.** BER against SNR for OFDM System in a channel bandwidth of 6MHz

The probabilities of error of different modulation schemes are given in their respective sections. It can be seen that the bit error probability $P_{e,QPSK}$ of QPSK is identical to BPSK, but twice as much data can be sent in the same bandwidth. Thus when compared to BPSK, QPSK provides twice the spectral efficiency with exactly the same energy efficiency. Similar to BPSK, QPSK can also be differentially encoded to allow non coherent detection.

Moreover, errors can be easily produced as the number of users is increased and the mobile terminal is subjected to mobility.

## 4. Conclusions

The ever increasing demand for a faster communication system by users has brought about development of newer digital modulation techniques such as BPSK etc.

The design of a communication system is application-oriented and totally dependent on the type of signal involved. This is due to different level of complexity involved in each technique in the design process involved in modulation and demodulation of the systems.

In this paper, we have discussed various digital modulation techniques such as BPSK (2bits), QPSK (4 bits), QAM, 16 QAM and 64 QAM. We have designed simulation environment in MATLAB with various configurations of OFDM technique. The main objective of our work is to measure Bit Error Rate with different modulation schemes and come to the best configuration to achieve better utilization of bandwidth. We have studied existing configurations with analog and digital modulation techniques and compared the results.

Of all the digital modulation techniques discussed it can be concluded that higher order QAM can transmit more data but are less reliable due to its high error rate when compared to lower order QAM. However it is possible to reduce the error by introducing error-correction techniques, such as convolution coding and turbo coding, which helps to improve the system performance.

Findings show that lower end phase shift keying schemes can be used for purposes that involve low error performance and minimum power but low bandwidth efficiency while the higher schemes suit purposes that require higher bandwidth efficiency but are low power efficient.

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