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Comparison of Modulation Techniques Used In WCDMA

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Abstract

Wideband Code Division Multiple Access (WCDMA) was introduced to provide higher data rates in mobile communication. This technology provides the users with many multimedia rich applications such as video streams and high resolution pictures. Thus in order to enhance the performance of this technology it is necessary to determine a suitable modulation technique. Also suitable error correcting mechanisms need to be implemented to enhance these services. Analysis of these techniques is crucial to improve the performance of a system. We have considered two modulation techniques of Quadrature Amplitude Modulation (QAM) and Quadrature Phase Shift Keying (QPSK) used in WCDMA systems. We have studied the performance of these two modulation techniques and compared them using the parameters of eye pattern. This analysis will help us determine a suitable modulation technique for WCDMA. We have used MATLAB for the simulation of WCDMA transmitter section.

Keywords— WCDMA, UMTS, TDMA, FDMA, CDMA, BER, SNR, Orthogonality, LOS, DSSS.

I. INTRODUCTION

Today, cellular communication system is the most widely used wireless telecommunication system. The evolution of the different generations of cellular communications systems, i.e., 1G, 2G, 2.5G, 2.75G to 3G is to incorporate high data rate transmission of different data like voice and multimedia stream data with minimum errors and noise in multipath fading channels. In 3G technology, Wideband Code Division Multiple Access is the most widely deployed cellular network being used by the Universal Mobile Telecommunication System. It uses the same core network as the GSM networks, which is a 2G system, but it transmits data via Code Division Multiplexing air interface instead of Time Division Multiplexing which is used in GSM systems. WCDMA uses spread spectrum technology, in which the transmissions are spread over a wide bandwidth of 5MHz. It boasts of a peak data rate for uplink and downlink transmission of 384kbps unlike GSM, which has a peak data rate of 14.4kbps and downlink speed of WCDMA is 2Mbps to GSM with a downlink speed of 384kbps. Because of higher data rate, WCDMA can cover more area with fewer towers. Hence, WCDMA is a better technology than GSM. However, with higher data rate of transmission and increase in the number of users in the network, there is a higher probability of errors due to noise and interference of data in the channels. To combat these shortcomings, the system needs better modulators, demodulators, filters and a transmission path to incorporate an optimum modulation technique.

II. BER ANALYSIS

BER is a performance measurement that specifies the number of bits corrupted or destroyed as they are transmitted from a source to its destination. Several factors that affect system performance include BER, SNR, transmission speed and transmission medium.

The definition of Bit error rate can be translated into a simple formula [3][10]:

BER = No. of errors/Total no. of bits sent

III. SNR ANALYSIS

Signal to noise power ratio is the measure of the amount of desired signal divided by the amount of noise being received. In general, a high signal to noise power ratio is good because it means we are getting more signal and less noise. It is usually the logarithm of the ratio received. Generally high noise i.e. low SNR can lead to high BER, which in turn leads to observable problems in the received signal [3][10].

IV. MULTIPATH FADING/ NOISE AND INTERFERENCE

In today's communication systems and networks, we want to achieve high data rate. Certain modulation techniques are used which also provide good bandwidth efficiency and would transfer more information to many users efficiently. However these schemes/ techniques while delivering the required performance are also affected by errors which are caused by noise and interference (AWGN and MULTIPATH RAYLEIGH FADING). Some information bits are lost while signal may also face fading. This error increases as number of users increases and also when an MS is moved from one BS to another. So we need to design the transmitter and receiver sections taking into account these aspects.

V. AWGN (ADDITIVE WHITE GAUSSIAN NOISE)

This term is made up of additive, white, Gaussian, noise. This noise is called additive because received signal is the addition of transmit signal and the noise. The term additive means the noise is superimposed or added to the signal that tends to obscure or mask the signal where it will limit the receiver ability to make correct symbol decisions and limit the rate of information transmission. When noise power has a constant and uniform spectral density, it is referred as white noise. The adjective "white" refers to its similarity with white light, which contains equal amounts of all frequencies within the visible band of electromagnetic (EM) radiation.

Its pdf (probability density function) can be accurately modelled to signal which behaves like a Gaussian distribution. It is noise because it distorts the received signal. AWGN is the thermal noise which refers to the unwanted electrical signals which are always present in systems (due to thermal agitation between electrons in wires, resistors, etc.) and add up to the signal which limits the ability to get correct symbol decision and limits the rate of information.

Mathematically, thermal noise is described by a zero-mean Gaussian random process where the random signal is a sum of Gaussian noise random variable and a dc signal

that is, $z = a + n$

where, pdf for Gaussian noise can be represented as follows:

$$\text{Pdf}: p(z) = \frac{1}{\sigma(2\pi)^{1/2}} \exp[-(1*\{z-a/\sigma\}^2)/2]$$

where, (sigma)^2 is the variance of n.

A simple model for thermal noise assumes that its power spectral density Gn(f) is flat for all frequencies and is denoted as,

$$Gn(f) = N_0/2$$

where, the factor 2 indicates that Gn(f) is a two-sided power spectral density.

Thus if the variance of the noise is higher, the deviation of the received symbols with respect to the constellation set will be more. Therefore, the probability to demodulate a wrong symbol and make errors is higher [3].

VI. RADIO PROPAGATION AND FADING

A transmitted radio signal goes through several changes while travelling via air interface to the receiver. There are reflections, diffractions, phase shifts and attenuation that are observed. Due to length divergence of the signal paths, multipath components of the signal arrive at different times to the receiver and can be combined either destructively or constructively which depends on the phases of the multipath components. When the multipath components are in phase they combine constructively and when they are out of phase they combine destructively. Fading is the deviation of attenuation affecting a signal over certain propagation media. In wireless system, a signal can travel over multiple reflective paths, which is referred to as multipath propagation. It causes to multipath fading or scintillation. Scintillation described the multipath fading caused by physical changes in the propagation medium.

Multipath fading is caused due to multipath propagation of signal. Large-scale fading represents the average signal power attenuation or path loss due to motion over large areas. Small-scale fading refers to the dramatic changes in signal amplitude and phase that can be experienced as a result of small changes (as small as a half-wavelength) in the spatial separation between a receiver and transmitter.

VII. RAYLEIGH FADING

Signal generally travels close to the ground by multipath propagation, which may cause degradation in the signal quality. This may result in fluctuations in amplitude, phase and angle of arrival of the received signal. Thus what we observe multipath fading. Small-scale fading is also known as Rayleigh fading since the fluctuation of the signal envelope is

Rayleigh distributed when there is no predominant line of sight between the transmitter and receiver and its probability density function (pdf) is given by

$$\text{Rayleigh Pdf} = \frac{x}{\sigma^2} e^{-x^2/2\sigma^2}$$

where sigma is the root mean squared value of the received signal before detection and sigma^2 is the average power of the received fading signal.

When no LOS path exists between transmitter and receiver, but only have indirect path then the resultant signal received at the receiver will be the sum of all the reflected and scattered waves. Rayleigh fading models assume that the magnitude of a signal that has passed through such a transmission medium (also called communications channel) will vary randomly, or fade, according to a Rayleigh distribution. Rayleigh channel assumes that all the paths arrive with random amplitude [3].

VIII. RICIAN FADING

Rician fading occurs when there is a LOS as well as non LOS path in between transmitter and receiver i.e. received signal comprises of both direct and scattered multipath waves. Rician fading occurs when one of the paths, typically a line of sight signal, is much stronger than the others. In Rician fading, the amplitude gain is characterized by a Rician distribution. Rician channel assumes that there is LOS component that has much larger amplitude [3][12].

Its probability density function (pdf) is given by,

$$\text{Rician Pdf} = \frac{x}{\sigma^2} \exp\left(\frac{-(x^2+\nu^2)}{2\sigma^2}\right) I_0\left(\frac{x\nu}{\sigma^2}\right)$$

IX. MODULATION TECHNIQUES

Modulation is the process by which a carrier wave is able to carry the message or digital signal (series of ones and zeroes). There are three basic methods to this: amplitude, frequency and phase shift keying. Higher orders of modulation allow us to encode more bits per symbol. The techniques used by us are QPSK (Quadrature Phase Shift Keying) and QAM (Quadrature Amplitude Modulation).

A. Quadrature Phase Shift Keying (QPSK)

QPSK adds two more phases: 90 and 270 degrees. Hence two symbols per bit can be transmitted. Each symbol's phase is compared relative to the previous symbol; so, if there is no phase shift (0 degrees), the bits 00 are represented. If there is a phase shift of 180 degrees, the bits 11 are represented.

B. Quadrature Amplitude Modulation (QAM)

ASK and PSK can be combined to create QAM where both the phase and amplitude are changed. The receiver then receives this modulated signal, detects the shifts and demodulates the signal back into the original data stream. The use of adaptive modulation allows a wireless system to choose the highest order modulation depending on the channel conditions.

C. Spread Spectrum Modulation

Spread spectrum is a means of transmission in which the data sequence occupies a bandwidth in excess of the minimum bandwidth necessary to send it. The spectrum sending is accomplished before transmission through the use of a code that is independent of the data sequence. The same code is used in the receiver. Spread spectrum is a method of 'camouflaging' information bearing signal [5].

Spread spectrum and the principle of direct sequence CDMA

There are several spread spectrum system designs:

In Direct sequence spread spectrum we spread or code the message we want to send by directly multiplying it with a large bandwidth user specific code called the spreading sequence.

Frequency hopping spread spectrum utilises the large system bandwidth by periodically changing the carrier frequency of the narrow band message according to a user specific sequence.

Time hopping spread spectrum uses a user specific sequence to key the transmitter on and off at equal duration time segments. Unlike GSM, there is no user specific time slot.

The direct sequence (DS) spread spectrum method is used in both the 2^{nd} generation CDMA systems (i.e., IS-95) and in the new 3rd generation Wideband CDMA (WCDMA).

Let us visualise the spreading process. We have the information bits with some power per bits. The spreading signal is like a monster truck driving over the bits. The bits get "squashed" and spread over the ground. The power that previously defined the height of the bits is also flattened. The power is spread over the spectrum that is to say that the power per unit bandwidth is small. This is our goal. For someone not knowing how the information was actually squashed, it is very difficult to detect the presence of a spread spectrum user. All one would hear is an increased amount of noise. In a spread spectrum system all the users are in the same frequency band. The frequency band is not divided in time to the users as in GSM. All users may send at the same time. The user's information is spread over the whole frequency band with a user specific pseudo-noise (PN) signal, the spreading code. The transmitted signal occupies a much wider bandwidth than would be necessary to send the information [8].

We call the bits in the code, chips. The chip rate of our code is four times the bit rate of our message. We call this factor the spreading factor. So in this instance, the spreading factor (SF) is 4. If the bit rate of our data would be for example 512 Kbps, the resulting chip rate after spreading would be 2,048 chips per second (cps).

In a multiple access environment, we will have at the receiver our spread spectrum signal summed with the other user signals. Our receiver will decode the original message fine as long as the noise caused by the other signals present is not too high. This is why we can say that each user is sharing a pool of power in the system [9].

In WCDMA, Direct Sequence Spread Spectrum is utilized. In Direct Sequence Spread Spectrum, the data signal b(t) and the pseudo noise signal c(t) is given to a modulator or multiplier where the output is the convolution of both data and PN sequence. Data signal is narrowband and PN sequence is wideband then the output m(t) will have a spectrum nearly equal to and will have almost the same wideband as the PN sequence. Therefore, the PN sequence performs the role of spreading code.

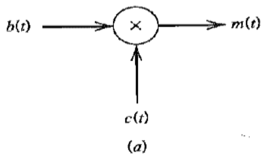

Figure 1. Transmitter

After convolution the convoluted signal is transmitted through the channel. But during transmission, the signal mixes with unwanted interference.

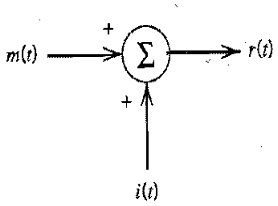

Figure 2. Channel

Hence at the receiver, the signal received r(t) is the transmitted data signal with addition of noise. When the received signal is passed through the receiver, it is first convoluted, a large part of the noise signal is filtered out, thus reducing the effect of interference power at receiver.

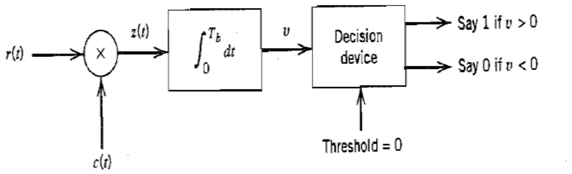

Figure 3. Receiver

The output of the demodulator is given by:

$z(t) = c(t)\,r(t)$

$\therefore z(t) = c^2(t)b(t) + c(t)i(t)$

But $c(t) = \pm 1$

$z(t) = b(t) + c(t)i(t)$

Hence at the receiver we have the original data signal b(t) which is narrowband as well as c(t)i(t) which is wideband. When the received signal is passed through the receiver a large part of c(t)i(t) is filtered out, thus reducing the effect of interference power at receiver [6].

This system will give optimum output under the condition that the transmitter and receiver work in synchronization with each other.

X. MULTIPLE ACCESS

Multiple Access is the simultaneous use of a communication system by more than one user. Each user's signal must be kept uniquely distinguishable from other users' signal to allow private communications on demand. Users can be separated in many ways physically on separate wires by arbitrarily defined channels established if frequency, time, or any other variable imaginable.

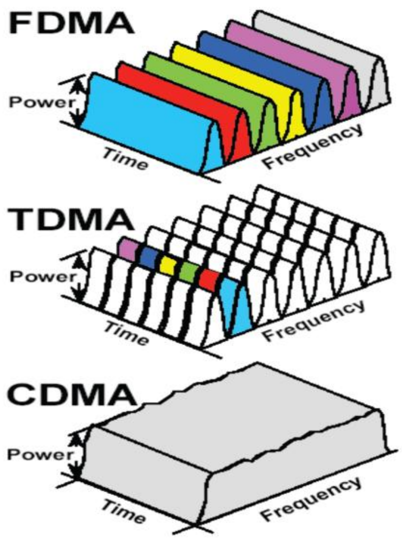

Figure 4. FDMA, TDMA, CDMA

A. Frequency Division Multiple Access (FDMA)

In December 1900, Reginald Fessenden accomplished the first human voice transmission via radio. This first link was over a mile long. Six years later the same person transmitted the first radio broadcast. Soon afterwards FDMA technology was used. Different broadcasts in the same geographical region could be heard by using different radio frequencies. That is the idea behind Frequency Division Multiple Access, the frequency range is broken down into unique bandwidths and distributed to the users. FDMA is used in cellular communications. One frequency to speak on and one to listen on; thus we have duplex communications. That way multiple users can operate in a particular frequency spectrum [8].

B. Time Division Multiple Access (TDMA)

To provide greater network capacity was to not only to divide frequencies into different cells but to divide this frequency into different slices of time. Originally, the frequency could only carry one conversation, but with TDMA technology, multiple users could carry on conversations using the same frequency in the same cell or space. That is the idea behind TDMA; dividing the frequency into multiple time slices so multiple users can access the same frequency at the same time [8].

C. Code Division Multiple Access(CDMA)

Each user's signal is a continuous unique code pattern buried within a shared signal, mingled with other users' code patterns. If a user's code pattern is known, the presence or absence of their signal can be detected, thus conveying information [8].

Code Division Multiple Access (CDMA), using digital format, identifies each conversation uniquely by a code rather than a frequency or slice of time.

XI. UMTS

The Universal Mobile Telecommunications System (UMTS) is a third generation mobile cellular system for networks based on the GSM standard. Developed and maintained by the 3GPP (3rd Generation Partnership Project), UMTS is a component of the International Telecommunications Union IMT-2000 standard set and compares with the CDMA-2000 standard set for networks based on the competing CDMAOne technology. UMTS uses wideband code division multiple access (W-CDMA) radio access technology to offer greater spectral efficiency and bandwidth to mobile network operators. UMTS specifies a complete network system, which includes the radio access network (UMTS Terrestrial Radio Access Network, or UTRAN), the core network (Mobile Application Part, or MAP) and the authentication of users via SIM (subscriber identity module) cards [2].

The technology described in UMTS is sometimes also referred to as Freedom of Mobile Multimedia Access (FOMA) [1] or 3GSM. Unlike EDGE (IMT Single-Carrier, based on GSM) and CDMA2000 (IMT Multi-Carrier), UMTS requires new base stations and new frequency allocations. W-CDMA - the radio technology of UMTS - is a part of the ITU IMT-2000 family of 3G Standards [2].

XII. WCDMA

In telecommunication field the major challenge is to convey the information as efficiently as possible through limited bandwidth, though some of information bits are lost in most of the cases and signal which is sent originally will face fading. To reduce the bit error rate the loss of information and signal fading should be minimized. CDMA has a bandwidth of 1.25 MHz whereas WCDMA has a bandwidth of 5 MHz. Thus it is called Wideband CDMA. Wideband Code Division Multiple Access (WCDMA) is a CDMA channel that is four times wider than the current channels that are typically used in 2G networks in North America. It is an air interface standard found in 3G mobile networks.

Wideband Code Division multiple Access (WCDMA) is being used by Universal Mobile Telecommunication System (UMTS) as platform of the 3rd generation cellular communication system. WCDMA requires a minimum bandwidth allocation of 5MHz, which is an important distinction from the other generation standards. Packet data rates up to 2Mb/s per user in indoor or small-cell outdoor environments and at rates of up to 384 Kbit/s in wide-area coverage is supported by WCDMA.

Third generation systems are designed for multimedia communication which can be enhanced with high quality video. Both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) variants are supported [1]. W-CDMA is a spread-spectrum modulation technique; one which uses channels whose bandwidth is much greater than that of the data to be transferred [7].

Instead of each connection being granted a dedicated frequency band just wide enough to accommodate its envisaged maximum data rate, W-CDMA channels share a much larger band [1]. The modulation technique encodes each channel in such a way that a decoder, knowing the code, can pick out the wanted signal from other signals using the same band, which simply appear as so much noise [11]. WCDMA technology is the most widely used third generation system which is spreading over a wide bandwidth by multiplying the user information with spreading sequence in WCDMA [4].

W-CDMA uses noise-like broadband frequency spectrum it provides high resistance to multipath fading, this was not present in 2nd generation (2G) communication system. In 2G communication network, Gaussian Minimum Shift Keying (GMSK) modulation scheme is widely used in GSM (Global System for Mobile) Communication. This modulation can only transmit data rate of 1 bit per symbol. So this kind of modulation scheme is not suitable for providing higher data rate in the next generation communication system. So there is a need for the performance analysis of suitable new modulation, error correction coding and technology to be used in WCDMA system to improve the system performance in a multipath fading channel.

UMTS uses a core network derived from that of GSM, ensuring backward compatibility of services and allowing seamless handover between GSM access technology and WCDMA [2].

XIII. PROBLEM STATEMENT

WCDMA is a competitive communication technique which can be used in the field of 3G mobile technology. Its high resistance to ISI and ability to provide reliable reception of the data signal even in a multipath fading environment is what makes it superior in comparison to the already existing and developed multiple access techniques. The modelled system transceiver that is being developed is based on 3GPP and UMTS standards.

It operates with a channel bandwidth of 5MHz and supports a theoretical data transmission rate of 384 Kbps with wide area coverage, 2 Mbps with local coverage. With the help of MATLAB/SIMULINK we intend designing our WCDMA transceiver and analyse this system in detail. There are two basic modulation techniques that we intend to evaluate with our developed system, namely QPSK and16-QAM. Additionally, the study of parameters in every block of the WCDMA transceiver will be done in depth. With each model we will be attempting to develop different methods to minimize the BER using different coding techniques. These could include the checking of Convolutional codes. Implementation of WCDMA using these modulation techniques and thus verification of the BER and SNR is to be performed. In addition we also will be comparing the four mentioned modulation techniques with the help of MATLAB/SIMULINK and with the Bit Error rate v/s the Signal to Noise Ratio, we will be choosing the most appropriate and efficient technique for the WCDMA model that would yield the most beneficial results. Furthermore, the study of the Doppler Effect on the modelled system may also be done to reduce its harmful effects on the system, thereby enhancing the efficiency of the simulated system further. The performance of the modelled system with different channels will also be studied [4].

XIV. IMPLEMENTATION USING SIMULINK

This paper is based on study and simulation using scientific computer simulation software, MATLAB. The simulation will be done using m files of MATLAB. It will be simulated in multi-user environment based on Direct Sequence Spread Spectrum (DSSS), Wideband-Code Division Multiple Access (W-CDMA).

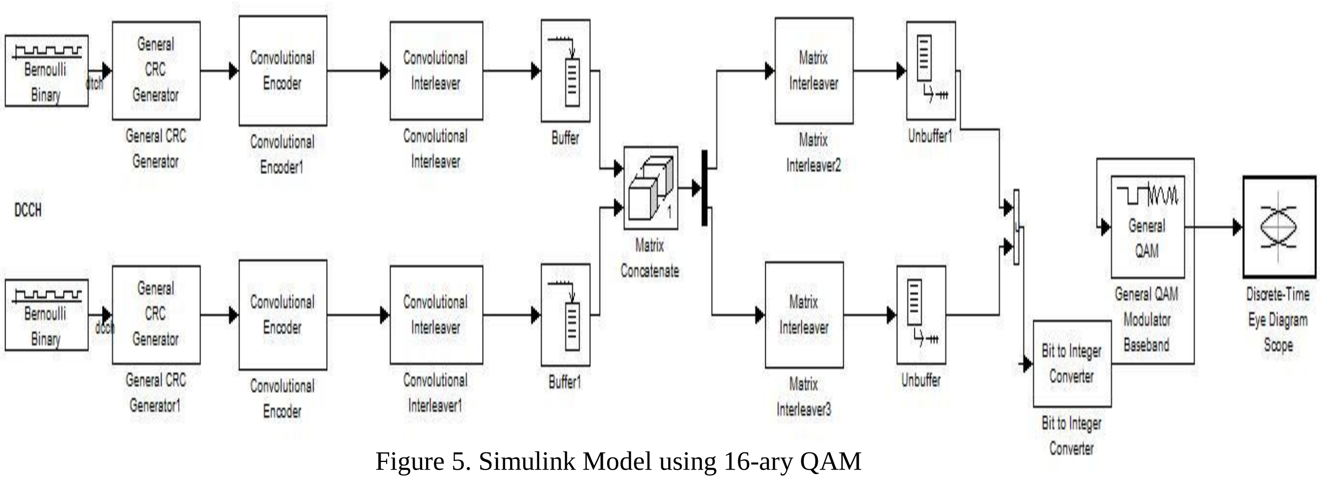

Figure 5. Simulink Model using 16-ary QAM

XV. SIMULATION RESULTS

Simulation results have been found for QPSK and 16-ary QAM using SIMULINK. We have obtained the eye patterns which are as follows:

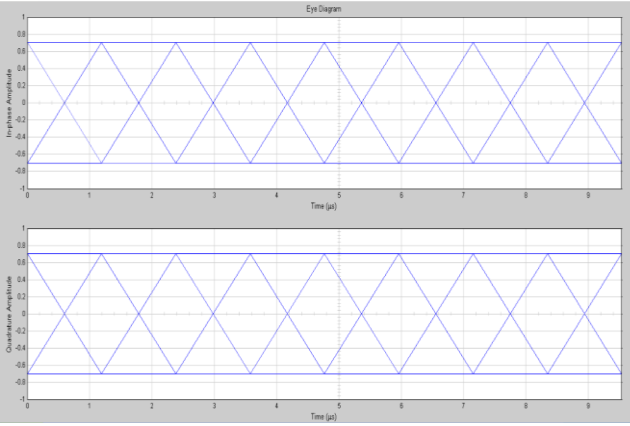

Figure 6. Eye Diagram of QPSK

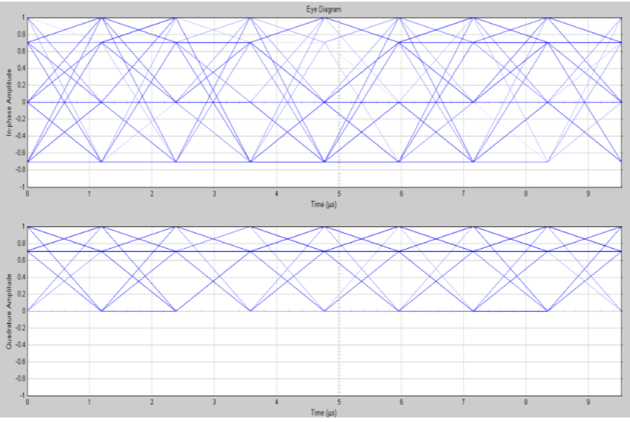

Figure 7. Eye Diagram of QAM

A. *16-ary QAM Modulation*

Width of the eye
= time at which the signal can be sampled
= 1.05us
Margin over noise = 0.7 dB
Sensitivity to timing error is very high.
Distortion at sampling time = 0.3 dB
Distortion at zero crossing = 0.05 us

B. *QPSK Modulation*

Width of the eye
= time at which the signal can be sampled
= 1.2us
Margin over noise = 0.7 dB
Sensitivity to time error is very high.

XVI. CONCLUSION

With the fast growing technological world and the tremendous advancement in field of communication the major challenge is to convey the information as efficiently as possible through limited bandwidth. Although some of information bits are lost in most of the cases and signal which is sent originally will face fading as already discussed in this paper on account of multipath propagation.

To reduce the bit error rate the loss of information and signal fading should be minimized. In our paper we analyze two modulation techniques, QPSK and 16-QAM to reduce the error performance of the signal and compare which technique is better.

We have simulated this using MATLAB/SIMULINK and the eye diagrams for the same have been found which suggest that QPSK performs better than QAM. As the distortion at sampling time and distortion at zero crossing is present in 16-ary QAM modulation, which is absent in QPSK, 16-ary QAM is lossier.

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