Department of Electronics and Communications Engineering

COMPARATIVE ANALYSIS OF VARIOUS QAM MODULATION TECHNIQUES FOR LTE

Prepared By

Md. Majharul Islam
ID: 2011-2-55-027

Supervised By

Md. Asif Hossain
Assistant Professor, Dept. of ECE

April 2017

Letter of Transmittal

To
Md. Asif Hossain
Assistant Professor
Department of Electronics and Communication Engineering
East West University

Subject: Submission of Project Report as (ETE-498)

Dear Sir,

We are pleased to let you know that we have completed our project on **"Comparative Analysis of Various QAM Modulation Techniques for LTE"**. The attachment contain of the project that has been prepared for your evaluation and consideration. Working on this project has given us some new concepts. By applying those concepts we have tried to make something innovative by using our theoretical knowledge which we have acquired since last four years from you and the other honorable faculty members of EWU. This project would be a great help for us in future.

We are very grateful to you for your guidance, which helped us a lot to complete my project and acquire practical knowledge.

Thanking You.

Yours Sincerely

Md. Majharul Islam
ID: 2011-2-55-027
Department of ECE
East West University

Declaration

This is certified that the project is done by us under the course Project (ETE-498) **"Comparative Analysis of Various QAM Modulation Techniques for LTE"** has not been submitted elsewhere for the requirement of any degree or any other purpose except for publication.

Md. Majharul Islam
ID: 2011-2-55-027

Acceptance

*This Project paper is submitted to the **Department of Electronics and Communication Engineering, East West University** is submitted in partial* *fulfillment of the requirements for the degree of* ***Bachelor of Science*** *in* ***Electronics & Telecommunications Engineering (ETE)*** *under complete supervision of the undersigned.*

____

Md. Asif Hossain

Assistant Professor
Dept. of ECE
East West University

Abstract

Wireless communication is the heart of all the modern communications techniques. The future communication is mostly all about related to wireless communications. In wireless communication, different modulation methods are playing the vital roles. In this project,

theoretical BER (bit error rate) analysis with E_b /No (Energy per Bit to Noise Power) has been done for various digital modulations techniques such as 8-QAM, 16-QAM, 64-QAM and 256-QAM. The paper has also included convolution encoder in the analysis. For all the analysis, AWGN (Additive White Gaussian Noise) and Rayleigh channel have been considered.

Table of Content

CHAPTER 1

INTRODUCTION

In telecommunications, modulation is the method of varying one or more properties of a waveform which is called 'carrier signal' along with a modulating signal which contains information to transmit. A carrier signal is a periodic signal with constant height (amplitude) and frequency (Hz), where information can be added to the carrier by varying its amplitude, frequency or phase. There are mainly two types of modulation techniques: analog modulation and digital modulation. If the modulating signal is analog then we use analog modulation and when the modulating signal is digital then we use digital modulation. In digital modulation, PSK, QAM, ASK, FSK modulation are popularly used [1].

While transmitting the signal through the wireless channel there might be some bit errors. To combat this bit error, various channel coding methods have been used such as convolutional coding, block coding, cyclic coding and so on [2]. In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that has been altered due to noise, interference, distortion or bit synchronization errors. It is the number of bit errors per unit time. It is a unit less performance measure, often expressed as a percentage. It is a great tool to analyze the performance of the various modulation techniques [3].

E_b/N_o (the energy per bit to noise power spectral density ratio) is a very important parameter in digital communication. It is a normalized signal-to- noise ratio (SNR) measure, also known as SNR per bit. It is especially useful when comparing the bit error rate (BER) performance of different digital modulation schemes without taking bandwidth into account [4].

AWGN (Additive White Gaussian Noise) Channel is a basic channel model used in analysis. It is the commonly used to transmit signal while signals travel from the channel and simulate background noise of the channel. Mathematical expression in received signal passed through the

AWGN channel is: $r(t) = s(t) + n(t)$ where $s(t)$ is transmitted signal and $n(t)$ is background noise [5]. It is flat and not “frequency-selective” as in the case of other fading channel.

There are several researches have been done on the performance comparisons of the various modulation techniques and channel coding schemes with the lie of E_b/N_o vs BER.

In [6], the authors have investigated the effect of multipath channels on bandpass modulation by simulating a selective frequency fading channel with 6 rays in MATLAB Environment. The authors in [7] have analyzed QPSK Modulation with Convolution Coding under AWGN and Rician channel. Similar works have been found in [8-12].

The project has been organized as: chapter1 will introduce the project, chapter 2 will describe the modulation schemes while chapter 3 will describe the channel coding. The results have analyzed in chapter 4 and chapter 5 conclude the project.

CHAPTER 2
Long-Term Evolution (LTE)

Long-Term Evolution (LTE) is a standard for high-speed wireless communication for cell phones and data terminals which based on the GSM/EDGE and UMTS/HSPA technologies in telecommunication. It increases the speed and capacity using a different radio interface together instead of core network improvements. LTE is the upgrade path for carriers with both GSM networks and CDMA2000 networks. The different LTE frequencies and bands used in different countries. It means that only multi-band phones are able to use LTE in all countries where it is supported.

3GPP engineers named the technology "Long Term Evolution", it represents the next step (4G) in a progression from GSM, a 2G standard, to UMTS, the 3G technologies based upon GSM.

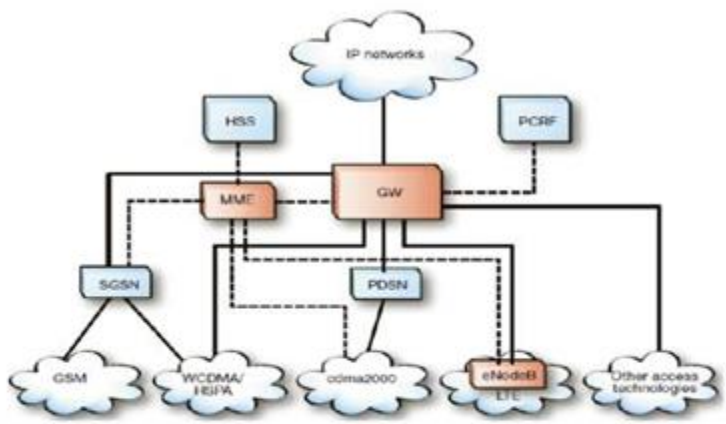


Fig. 1 LTE's Architecture

Using of LTE

LTE uses OFDM (Orthogonal Frequency Division Multiplexing).The upper layers of LTE are based upon TCP/IP, which will likely result in an all-IP network similar to the current state of wired communications

LTE will support mixed data, voice, video and messaging traffic. The higher signal to noise ratio (SNR) at the receiver enabled by MIMO, along with OFDM, It provides improved coverage especially in dense urban areas.

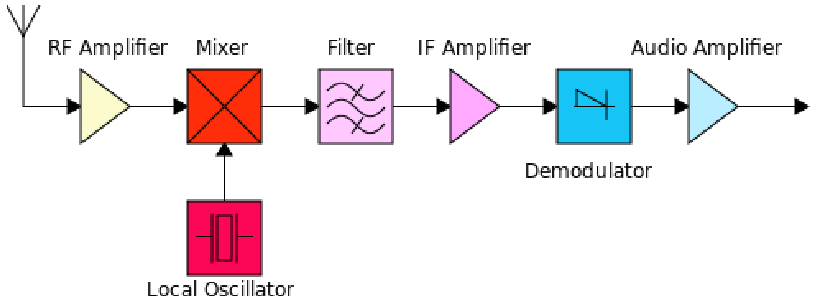
These networks will compete with WiMAX for both enterprise and consumer broadband wireless customers. Outside of the US telecommunications market, GSM is the dominant mobile standard, with more than 80% of the world's mobile phone users.

LTE is commonly marketed as **4G LTE**, but it does not meet the technical criteria of a 4G wireless service. The most significant advancements are that WiMAX, Evolved High Speed Packet Access and LTE bring to the original 3G technologies. To differentiate LTE Advanced and WiMAX-Advanced from current 4G technologies, ITU has defined them as "True 4G".

CHAPTER 3

MODULATION

Electronic devices produce messages like analog baseband signals in the form of audio, video or



even messages can be in the form of digital bits from computer. To send these messages we must have some communication channel like wires, co-axial cable, even wireless radio waves, microwaves or infrared. We can easily transmit messages through wires or cables. Voice, Video, bit streams from computer are having lower frequency band and can travel few distance with wires but cannot be sent through wireless media. Voice signal has lower Bandwidth therefore it will not propagate through space and will be attenuated.

Fig. 2a Basic Modulation Block Diagram

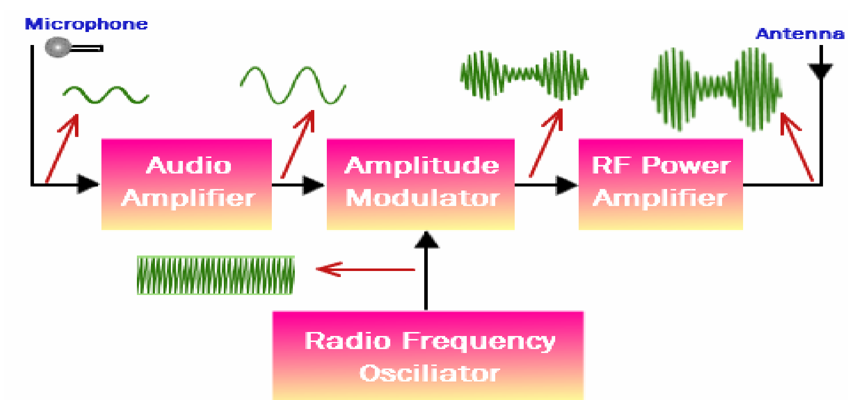


Fig. 2b Basic Modulation Block Diagram

To transmit voice signal a large size antenna is required as antenna length is proportional to half of wavelength. The size of the antenna will be more than the distance between transmitter and receiver. Again when more than one transmitter is involved all station will overlap in one frequency band. For those above reasons we choose a carrier, which is a highfrequency radio wave, can travel long distance without attenuation and as the frequency is high smaller antenna is required. Selecting different carrier frequency for different transmitting stations can eliminate overlapping of frequency band.

Types of Modulation

There are two types such as,

- Analog Modulation
- Digital Modulation

Analog Modulation

The aim of analog modulation is to transfer an analog baseband (or lowpass) signal, for example an audio signal or TV signal, over an analog bandpass channel at a different frequency, for example over a limited radio frequency band or a cable TV network channel. Analog modulation facilitate frequency division multiplexing (FDM), where several low pass information signals are transferred simultaneously over the same shared physical medium, using separate passband channels (several different carrier frequencies).

This can be three types,

- Amplitude Modulation (AM)
- Frequency Modulation (FM)
- Phase Modulation (PM)

Digital modulation

The aim of digital modulation is to transfer a digital bit stream over an analog bandpass channel, for example over the public switched telephone network (where a bandpass filter limits the frequency range to 300–3400 Hz) or over a limited radio frequency band. Digital modulation facilitate frequency division multiplexing (FDM), where several low pass information signals are transferred simultaneously over the same shared physical medium, using separate pass band channels (several different carrier frequencies).

The aim of digital baseband modulation methods, also known as line coding, is to transfer a digital bit stream over a baseband channel, typically a non-filtered copper wire such as a serial bus or a wired local area network.

These can three types,

1. Amplitude shift keying (ASK)

2. Frequency shift keying (FSK)

3. Phase shift keying (PSK)

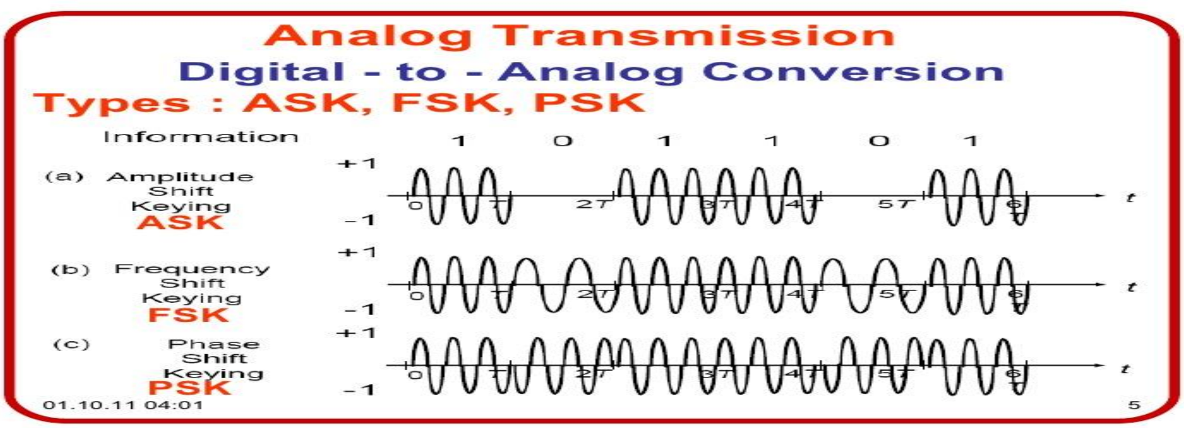
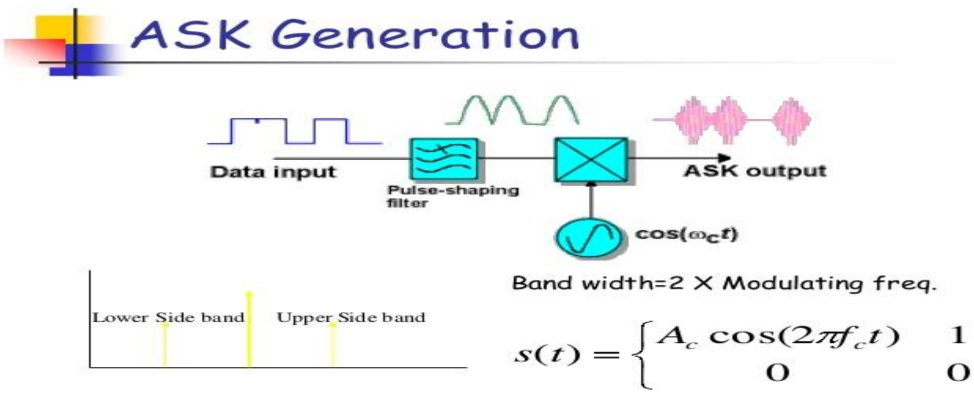


Fig. 3: ASK, PSK AND FSK

Amplitude shift keying (ASK)

Amplitude-shift keying (ASK) is a form of amplitude modulation that represents digital data as variations in the amplitude of a carrier wave. In an ASK system, the binary symbol 1 is represented by transmitting a fixed-amplitude carrier wave and fixed frequency for a bit duration of T seconds. When the carrier amplitude is varied in proportion to message signal m(t). We have the modulated carrier $m(t)\cos w_c t$ where $\cos w_c t$ is the carrier signal. As the information is an on-off signal the output is also an on-off signal where the carrier is present when information is 1 and carrier is absent when information is 0. Thus this modulation scheme is known as on-off keying (OOK) or amplitude shift key.



$$s(t) = \begin{cases} A_c \cos(2\pi f_c t) & 1 \\ 0 & 0 \end{cases}$$

Fig. 4 ASK Modulation signal diagram

Application

- Used in our infrared remote controls
- Used in fiber optical transmitter and receiver.
- **Frequency shift keying (FSK)**

Frequency-shift keying (FSK) is a frequency modulation scheme in which digital information is transmitted through discrete frequency changes of a carrier signal. The technology is used for communication systems such as amateur radio, caller ID and emergency broadcasts. The simplest FSK is binary FSK(BFSK).

When Data are transmitted by varying frequency of the carrier, we have the case of frequency shift key. In this modulation carrier has two predefined frequency w_{c1} and w_{c2}. When information bit is 1 carrier with w_{c1} is transmitted i.e. $\cos w_{c1}$ and When information bit is 0 carrier with w_{c0} is transmitted i.e. $\cos w_{c0}$

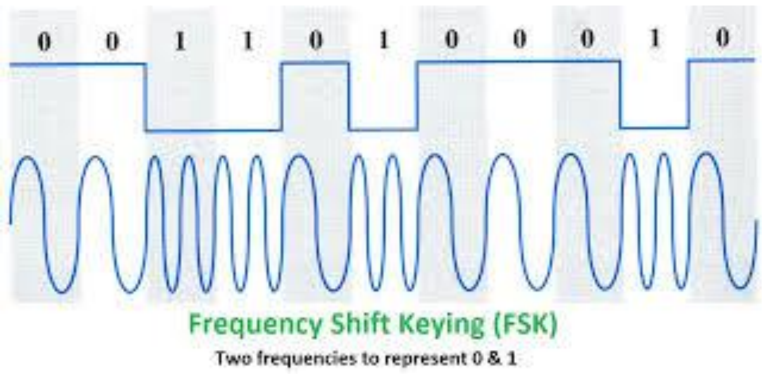


Fig. 5 FSK Modulation signal diagram

Application

- Many modems used FSK systems.

Phase shift keying (PSK)

Phase-shift keying (PSK) is a digital modulation scheme that conveys data by changing (modulating) the phase of a reference signal (the carrier wave). The modulation is impressed by varying the sine and cosine inputs at a precise time. It is widely used for wireless LANs, RFID and Bluetooth communication.

The phase of the carrier is shifted for this modulation. If the base band signal m(t) =1 carrier in phase is transmitted. If m(t)=0 carrier with out of phase is transmitted i.e. $\cos(w_c t+\Pi)$. If phase shift is done in 4 different quadrants then 2bit of information can be sent at a time. This scheme is a special case of PSK modulation known as QPSK or Quadrature Phase Shift Key.

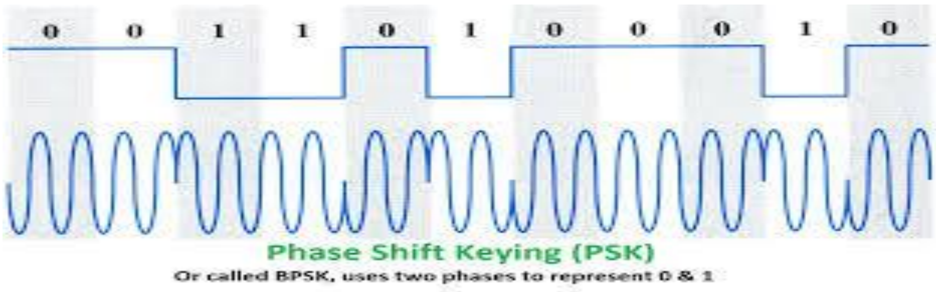


Fig. 6 PSK Modulation signal diagram

Application

- Used in our ADSL broadband modem
- Used in satellite communication
- Used in our mobile phones

QAM (Quadrature Amplitude Modulation)

QAM (Quadrature Amplitude Modulation) is a method of combining two amplitude-modulated (AM) signals into a single channel, thereby doubling the effective bandwidth. Especially in wireless applications QAM is used with pulse amplitude modulation (PAM) in digital systems.

Types Of QAM

1. 8-QAM
2. 16-QAM
3. 32-QAM
4. 64-QAM
5. 128-QAM
6. 256-QAM

Comparison of 8-QAM, 16-QAM, 32-QAM, 64-QAM 128-QAM, 256-QAM

QAM is mostly used in many digital data radio communications and data communication applications. A variety of forms of QAM are available and some of the more common forms include 8-QAM, 16-QAM, 32-QAM, 64-QAM, 128-QAM, 256-QAM, 512-QAM,1024-QAM, 2048-QAM, 4096-QAM.

The various flavors of QAM may be used when data-rates beyond those offered by 8-PSK are required by a radio communications system. This is because QAM achieves a greater distance between adjacent points in the I-Q plane by distributing the points more evenly. In this way the points on the constellation are more distinct and data errors are reduced.

While it is possible to transmit more bits per symbol, if the energy of the constellation is to remain the same, the points on the constellation must be closer together and the transmission becomes more susceptible to noise. This results in a higher bit error rate than for the lower order QAM variants. In this way there is a balance between obtaining the higher data rates and maintaining an acceptable bit error rate for any radio communications system.

QAM applications:

QAM is in many radio communications and data delivery applications. However some specific variants of QAM are used in some specific applications and standards.For domestic broadcast applications for example, 64 QAM and 256 QAM are often used in digital cable television and cable modem applications. In the UK, 16 QAM and 64 QAM are currently used for digital terrestrial television using DVB - Digital Video Broadcasting. In the US, 64 QAM and 256 QAM are the mandated modulation schemes for digital cable as standardized by the SCTE in the standard ANSI/SCTE 07 2000. In addition to this, variants of QAM are also used for many wireless and cellular technology applications.

Constellation diagrams for QAM

The constellation diagrams show the different positions for the states within different forms of QAM (quadrature amplitude modulation). As the order of the modulation increases, so does the number of points on the QAM constellation Diagram.

The diagrams below show constellation diagrams for a variety of formats of modulation:

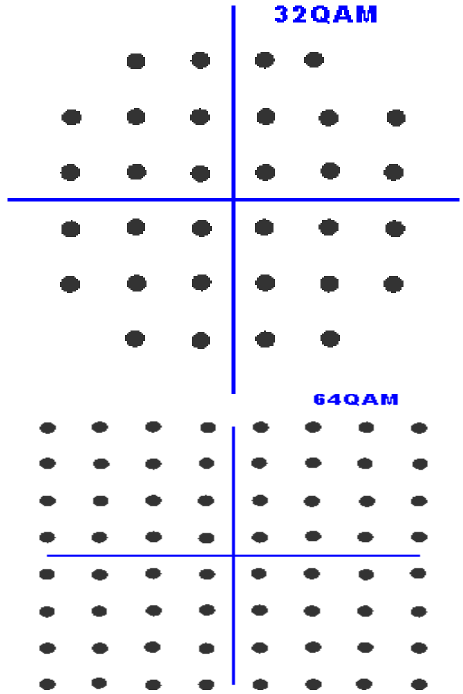


Fig.7 Constellation Diagrams of various QAM

QAM bits per symbol

The advantage of using QAM is that it is a higher order form of modulation and as a result it is able to carry more bits of information per symbol. By selecting a higher order format of QAM, the data rate of a link can be increased.

The table below gives a summary of the bit rates of different forms of QAM and PSK.

Table 1: Bit rates of different forms of QAM .

Modulation	Bit per symbol (BPS)	Symbol rate
16-QAM	4	1/4 bit rate
32-QAM	5	1/5 bit rate
64-QAM	6	1/6 bit rate
128-QAM	7	1/7 bit rate
256-QAM	8	1/8 bit rate

CHAPTER 4

SNR, E_b/N_o, BER,AWGN& Rayleigh Channel

SNR (Signal-to-noise ratio)

Signal-to-noise ratio (abbreviated SNR or S/N) is a measure used in science and engineering that compares the level of a desired signal to the level of background noise. It is defined as the ratio of signal power to the noise power, often expressed in decibels.

BER (Bit error rate)

The bit error rate *(*BER) is the number of b*it* errors per unit time. The bit error ratio (also BER) is the number of bit errors divided by the total number of transferred bits during a studied time interval. BER is a unit less performance measure, often expressed as a percentage.

Difference between SNR & BER

SNR is signal to noise ratio. Generally, it is the ratio of signal magnitude to thermal noise for the signal bandwidth which you are examining. Bit error rate is a measure of the errors one gets over time for a given digital signal. The two are strongly coupled. They are not 1:1 coupled in that interference other than thermally generated noise can increase bit error rate.

Normally, one can measure what is known as a waterfall diagram for a givenchannel. The channel characteristics such as bandwidth, frequency, modulation, etc can give one a "best case" waterfall diagrams. This is usually based on thermal noise alone.

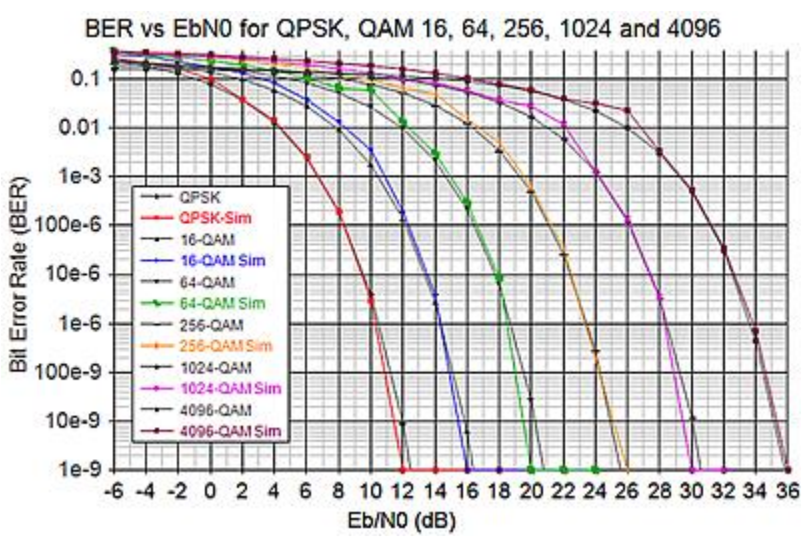


Fig. 8 waterfall diagram of BER vs SNR

As one can see from the waterfall diagram, BPSK/QPSK modulation is more "robust" than 16PSK modulation in that at 10dB bit to thermal noise (a measure of signal to noise), a QPSK signal experiences slightly more that 1 error per million bits while 16PSK experiences 1 error per 50 bits. If you were sending a ZIP file, the QPSK channel has a decent chance of getting through while the 16PSK channel would fail badly.

E_b/N_o

E_b/N_o (the energy per bit to noise power spectral density ratio) is an important parameter in digital communication or data transmission. It is a normalized signal-to-noise ratio (SNR) measure, also known as the "SNR per bit". It is especially useful when comparing the bit error rate (BER) performance of different digital modulation schemes without taking bandwidth into account.

As the description implies, E_b is the signal energy associated with each user data bit; it is equal to the signal power divided by the user bit rate (not the channel symbol rate). If signal power is in watts and bit rate is in bits per second, Eb is in units of joules (watt-seconds). N_0 is the noise spectral density, the noise power in a 1 Hz bandwidth, measured in watts per hertz or joules. These are the same units as E_b so the ratio E_b/N_0 is dimensionless; it is frequently expressed in decibels. E_b/N_0 directly indicates the power efficiency of the system without regard to modulation type, error correction coding or signal bandwidth (including any use of spread spectrum). This also avoids any confusion as to which of several definitions of "bandwidth" to apply to the signal.

Channel

In telecommunications and computer networking, a communication channel or channel, refers either to a physical medium such as a wire, or to a logical connection over a multiplexed medium such as a radio channel. A channel is used to convey an information signal, for example a digital bit stream, from one or several senders (or transmitters) to one or several receivers. A channel has a certain capacity for transmitting information, often measured by its bandwidth in Hz or its data rate in bits per second.

Noise

Noise is any type of disruption that interferes with the transmission or interpretation of information from the sender to the receiver.

Gaussian noise

Gaussian noise is statistical noise having a probability density function (PDF) equal to that of the normal distribution, which is also known as the Gaussian distribution. In other words, the values that the noise can take on are Gaussian-distributed.

AWGN (Additive white Gaussian noise)

Additive white Gaussian noise (AWGN) is a basic noise model used in Information theory to mimic the effect of many random processes that occur in nature. The modifiers denote specific characteristics: Additive because it is added to any noise that might be intrinsic to the information system.

Rayleigh Channel

The delays associated with different signal paths in a multipath fading channel change in an unpredictable manner and can only be characterized statistically. When there are a large number of paths, the central limit theorem can be applied to model the time-variant impulse response of the channel as a complex-valued Gaussian random process. When the impulse response is modeled as a zeromean complex-valued Gaussian process, the channel is said to be a Rayleigh fading channel.

The model behind Rician fading is similar to that for Rayleigh fading, except that in Rician fading a strong dominant component is present. This dominant component can for instance be the line-of-sight wave.

Bit rate

The number of bits per second that can be transmitted along a digital network. In telecommunications and computing, bitrate (sometimes written bit rate or as a variable R) is the number of bits that are conveyed or processed per unit of time.

Sample rate

Sample rate is the number of samples of audio carried per second, measured in Hz or kHz (one kHz being 1 000 Hz). For example, 44 100 samples per second can be expressed as either 44 100an audio stream.

Baud rate

In telecommunication and electronics, baud is the unit for symbol rate or modulation rate in symbols per second or pulses per second. It is the number of distinct symbol changes (signaling events) made to the transmission medium per second in a digitally modulated signal or a line code.

CHAPTER 5

SIMULATIONS & RESULTS ANALYSIS

In this project, we have used Matlab 2016 Simulink to generate the results. We have also used 'bertool' to generate the graphs which will be discussed in this chapter 4.

This section will discuss and analysis the results obtained from MATLAB 2016a. In various figures we have presented the performances of various modulation techniques with and without channel coding.

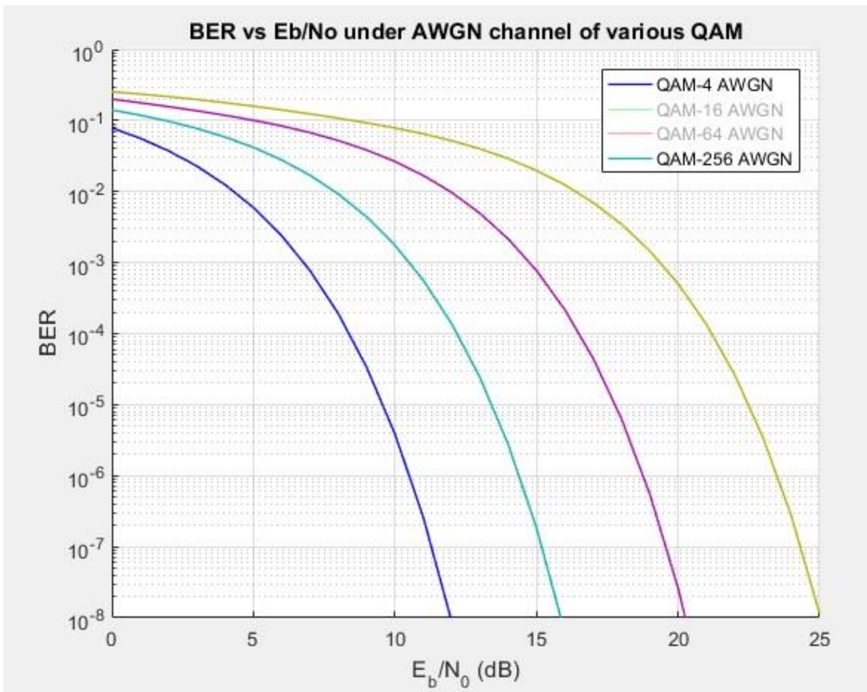


Fig. 9 Various QAM under AWGN channel without channel coding

In Fig. 9, the performances between various QAM modulations have been shown. Here the channel has been considered is AWGN channel and without any channel coding. From the figure it has been found that the performance of 4-QAM is the best while 256-QAM as the worst. Say for 10 dB E_b/N_o, 4-QAM's BER lies between 10^{-6} to 10^{-5}while for 16-QAM it is between 10^{-3} to $10^{-2.5}$, for 64-QAM it is between 10^{-2} to $10^{-1.5}$ and for 256-QAM it is near to 10^{-1}.

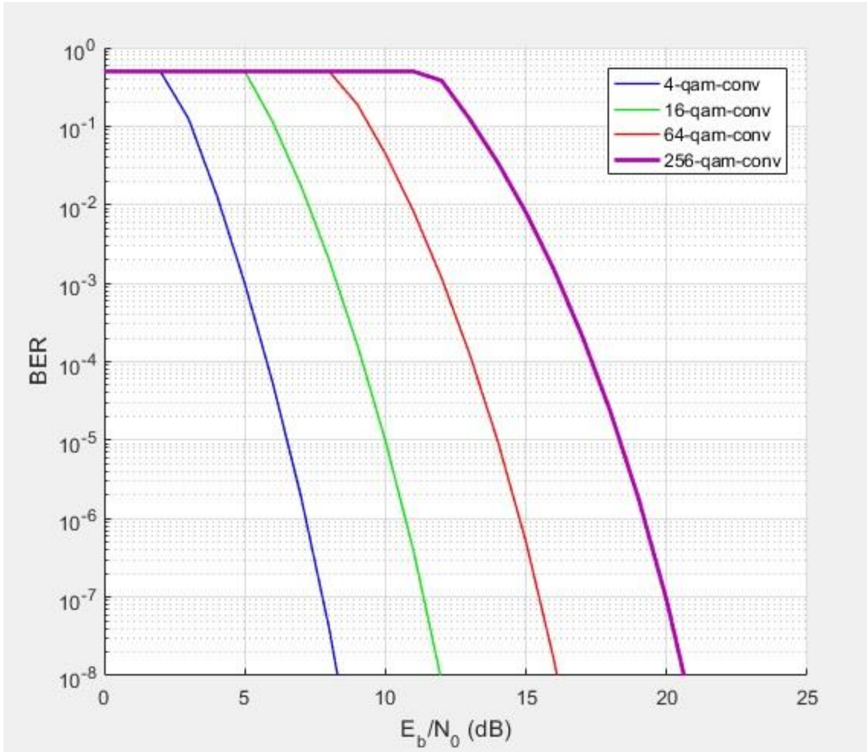


Fig. 10 Various QAM under AWGN channel with convolutional coding

In Fig. 10, the performances between various QAM modulations have been shown under AWGN channel with considering the convolutional coding. From the figure it has been found that the performance of 4-QAM is the best while 256-QAM as the worst.But overall performances of all the modulations schemes are better than the previous results as coding has been incorporated. In the figure for 5 dB E_b/N_o, 4-QAM's BER is less than 10^{-3}while for other QAM it is around 1.

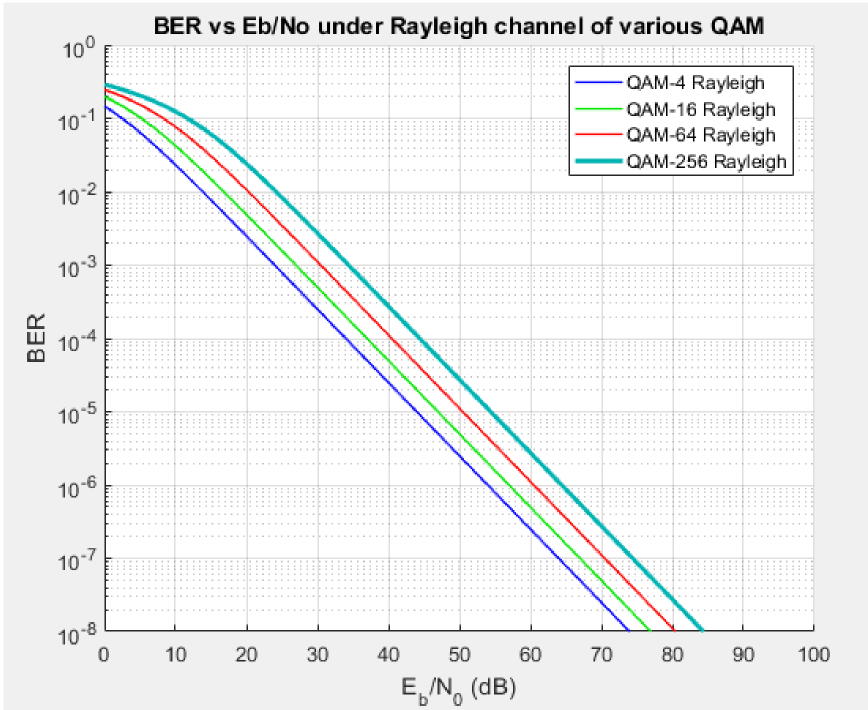


Fig. 11 Various QAM under Rayleigh channel

In Fig. 11, the performances between various QAM modulations have been shown. Here the channel has been considered as rayleigh channel and without any channel coding. From the figure it has been found that the performance of 4-QAM is the best while 256-QAM as the worst. Though the difference between the performances are not too much.

From the Fig. 9 and 11, it has been observed that to obtain the same BER value we need higher SNR value in case of Rayleigh channel than the AWGN channel.

CHAPTER 6

Conclusion

In this project, the bit error rate has been theoretically analyzed for different QAM wireless modulation techniques used in LTE. In the analysis, it has been found that the performance of 4-QAM with convolutional coding is the best and the 256-QAM without any channel coding is the worst. It has been found that the convolution encoder reduces significant amount of bit error. The performance of the modulation techniques under AWGN channel is better than under the Rayleigh channel. To obtain the same BER value, we need higher SNR value in case of Rayleigh channel than the AWGN channel. In future, similar analysis will be done for practical cases with considering some parameters like filters, channel equalizers, other channels and so on.

References:

[1] Harpreet Kaur Channi, “A Comparative Study of Various Digital Modulation Techniques”,International Journal in IT and Engineering, Vol.04 Issue-03, pp 39-49, 2016.

[2] Clark Jr, George C., and J. Bibb Cain. Error-correction coding for digital communications. Springer Science & Business Media, 2013.

[3] Kaur, Hardeep, and M. L. Singh. “Bit error rate evaluation of IEEE 802.16 (WiMAX) in OFDM System”, International Journal of Computer Applications40, no. 12 (2012): 10-13.

[4] Hamdi, Khairi Ashour, “Exact SINR analysis of wireless OFDM in the presence of carrier frequency offset”, IEEE Transactions on Wireless Communications 9, no. 3 (2010): 975-979.

[5] Babu, A. Sudhir, and Dr KV Sambasiva Rao, “Evaluation of BER for AWGN, Rayleigh and Rician fading channels under various modulation schemes”, International Journal of Computer Applications, 26, no. 9 (2011).

[6] S.A.Oyetunji, A.A.Akinninranye, Performance Evaluation of Digital Modulation Techniques in AWGN Communication Channel, IJERT, ISSN: 2278-0181, Vol. 2, Issue 5, May 2013.

[7] Koshti. R. et. al, “Performance Comparison of WRAN over AWGN and RICIAN Channel Using BPSK and QPSK Modulation with Convolution Coding” , Communication Systems and Network Technologies (CSNT), 2013 International Conference , 6-8 April 2013.

[8] D. Dutt Bohra and A. Bora, "Bit Error Rate Analysis in Simulation of Digital communication Systems with different Modulation Schemes", *International Journal of Innovative Science*, vol. 1, no. 3, 2014.

[9] E. Taissir, "Effet of AWGN and Fading (Rayleigh and Rician) Channels on BER Performance of Free Space Optics (FSO) Communication Systems", *International Journal of Research in Wireless Systems (IJRWS)*, vol. 2, no. 2, 2013

[10] B. L. Ahlem, M. Béchir Dadi and C. Belgacem Rhaimi, "Evaluation of BER of digital modulation schemes for AWGN and wireless fading channels," *Information Technology and Computer Applications Congress (WCITCA), 2015 World Congress on*, Hammamet, 2015, pp. 1-5.

[11] N. V. Panicker and A. K. Sukesh, "BER Performance Evaluation of Different Digital Modulation Schemes for Biomedical Signal Transceivers under AWGN and Fading Channel Conditions",*International Journal of Engineering and Advanced Technology (IJEAT)*, vol. 3, no. 5, 2014.

[12] H. Kaur, B. Jain and A. Verma, *Comparative Performance Analysis of Mary PSK Modulation Schemes using Simulink*, 2011.