Image Transmission in Hierarchically Modulated Signals over Fading and Shadowing Channels

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ABSTRACT

In order to have a higher throughput, it is essential to apply a higher order M-ary QAM modulation to yield more data on each carrier. This can be considered as the basis for adaptive transmission rate control where more parameters and signal information are available.

In this thesis, M-ary modulation techniques are simulated over AWGN channel, Rayleigh fading channel and Log-Normal shadowing channel. To achieve the purpose of achieving higher throughput, it is necessary to recognize the performance indicators and investigate the criteria which are used for good performance.

The five scenarios presented in this thesis are as follows: 1) Comparing the effect of Log-Normal Shadowing on different Hierarchical Modulations such as (64-QAM, 16-QAM, 4-QAM and 2-QAM). 2) The evaluation of BER of QAM system over AWGN and Rayleigh fading channels and considering the effect of shadowing. 3) Determine the important factors on the lognormal shadowing phenomena and how the factors affect this process. 4) Studying the relationship between the BER and variance in shadowing and fading channel. 5) The random input has been replaced by an image to investigate the effect of shadowing on quality of image.

It is found that depth of shadowing influences the received signal quality and causes to have poor performance and throughput. Depth of shadowing is varied by the mean and variance of shadowing distribution function. Therefore, the Bit Error Rate (BER) of the system has been analyzed from low to high *Eb/No* through MATLAB/R2012a Simulink application in order to find out the effective factors on depth of fading phenomenon. It is observed that the system desirably works at high *Eb/No*. One of the significant parts of this research consists of the effects of Log-Normal Shadowing phenomenon on systems BER performance. Based on the results of the simulation, it is obvious that shadowing has a negative effect on the systems BER performance. In this study, 2-QAM system has received more attention because of having less sensitivity to shadowing phenomenon in comparison with 4, 16 and 64-QAM. Then the effective factors of shadowing have been studied and the results show that variance of Log-Normal distribution can be controlled as the only factor to control shadowing. This effect can be easily seen in the images, obtained.

Keywords: Hierarchical Modulation, QAM Modulation, Multipath Fading Channel, AWGN Channel, Rayleigh Fading, Depth of Shadowing, Log-normal Shadowing ,Small Scale Fading and Large Scale Fading.

ÖZ

Alınan sinyal kalitesinin bağımsız kanal bozuklukları tarafından etkilendiği oldukça açıktır. Bu nedenle, kanalın farklı zaman örneklerinde alınan sinyal kalitesi üzerinde farklı bir rol oynayan yük belirleyeni bulmak için çeşitli faktörler vardır. Kanal bozuklukları daha az etkilenen faktörlere bağlı olarak, sistemdeki kaynak için bir artan fazlalık tanıtılacaktır. Bu teknik, alınan sinyal kalitesini artırmak amacıyla alıcılar için bir fırsat yaratmaktadır.

Daha yüksek bir verim elde etmek için, yüksek mertebeli bir M-ary QAM modülasyonu uygulamak gereklidir. Bu nedenle, her bir alt taşıyıcı üzerinde, çok sayıda veri bulunacaktır. Bu konuyu adaptif iletim hızı kontrolü için bir temel olarak düşünebiliriz ki daha fazla parametre ve sinyal bilgisi değiştirmek için mevcut olacaktır.

Bu tezde, çok yollu sönümleme, AWGN kanalı, Rayleigh kanalı ve Log-Normal dağılımı üzerinde benzetimleme edilir. Bu çalışmada, daha yüksek verime ulaşmak için, performans faktörleri tanımak ve performansın ne kadar iyi olduğu karar vermek için kullanılan kriterleri araştırmak gereklidir.

Bu tezde sunulan Beş senaryo şunlardır: 1) farklı hiyerarşik Modülasyonlar (64-QAM, 16-QAM, 4-QAM ve 2-QAM) üzerinde Log on-Normal Gölgelemenin etkisini karşılaştırılması. 2) gölgeleme etkisi dikkate alınarak AWGN ve Rayleigh sönümlü kanallar üzerinden QAM sisteminin değerlendirilmesi. 3) Lognormal gölgeleme olayları üzerinde önemli fakförler ve nasıl bu süreci etkilemekleri

belirlemek. 4) Faktörler sistemde nasıl kontrol edilebilir.5) Çıktıyı yapmak için, Rastgele giriş bir görüntü ile değiştirilmiştir.

Bu alınan sinyal kalitesi ve zayıf performans ve kötü verim elde edilme nedenleri üzerinde solmaya etkiler derinliği olduğu bulunmuştur. Solma derinliği dağılım fonksiyonu sinyalin ortalama ve varyans ile değişir. Yani, sistemin Bit Hata Oranı (BER) solma fenomeni derinliği üzerine etkili olan faktörler bulmak için düşük MATLAB/R2012a Simülasyon uygulaması ile yüksek Eb / No analiz edilmiştir. Eb / No değeri artırarak, sistemin iyice çalıştığı görülmektedir. Bu araştırmanın önemli bölümlerinden biri, log-normal gölgeleme fenomen etkisidir. Simülasyon sonuçlarına göre, gölgeleme sistemlerinin system üzerinde olumsuz bir etkiye sahip olduğu açıkça ortadadır. Bu çalışmada, 2-QAM sistemi için diğerleri ile karşılaştırıldığında, fenomen gölgeleme içinde daha az hassasiyet olduğundan dolayı daha fazla ilgi çekiyor.

Bu tezin ileri bölümlerinde, gölgeleme etkili faktörleri incelenip ve elde edilen sonuçlar, Log-Normal dağılım variyansının, gölgeleme kontrolu için tek bir faktör olarak sayıldığını gösteriyor.

Anahtar Kelimeler: Hiyerarşik Modülasyon, QAM Modülasyon, Çoklu Fading Channel, AWGN Kanal, Rayleigh Fading, Fading, Log-normal Gölgeleme Derinliği, Küçük Ölçekli Fading ve Büyük Ölçekli Fading

Dedicated to my parents for their immense love and support

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B_c	Coherence Bandwidth
B_d	Doppler Spread
B_s	Bandwidth of Signal
C	Speed of Light
d	Distance between Transmitter and Receiver in Meter
F	Carrier Frequency of Transmitter
G_t	Transmitter antenna gain
G_r	Receiver antenna gain
L	System loss factor
$P_r\,(d)$	Received power
P_t	Transmitted power
R_X	Receiver
T_c	Coherence Time
T_m	Delay Spread
T_s	Symbol Time
T_u	Symbol duration
T_x	Transmitter
V	Velocity of Observer
α	Constellation Ratio of OFDM
f_d	Doppler Frequency
Θ	The Angle between Signal and Motion Direction
λ	Wavelength in meter

σ	Standard Deviation
ϕ	Power Ratio Transmit Receiver
ASK	Amplitude Shift Keying
AWGN	Additive White Gaussian Noise
A-HQAM	Adaptive Hierarchical Quadrature Amplitude Modulation
BER	Bit Error Rate
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
DVB	Digital Video Broadcasting
DVB-C	Digital Video Broadcasting Cable
DVB-H	Digital video broadcasting Handheld
DVB-S	Digital Video Broadcasting Satellite
DVB-T	Digital Video Broadcasting Terrestrial
Eb/No	Energy per bit to noise power spectral density ratio
ERF	Error Function
GI	Guard Interval
HDTV	High-definition television
HP	High Priority
HQAM	Hierarchical Quadrature Amplitude Modulation
LOS	Line of Sight
LP	Low Priority
MIMO	Multiple Input Multiple Output
MP	Medium Priority
MPEG-2	Moving Picture Experts Group
MPEG-TS	MPEG transport stream

NLOS	N0N-Line of Sight
OFDM	Orthogonal Frequency Division Multiplexing
PDF	Probability Density Function
PDP	Power Delay Profile
QAM	Quadrature Amplitude Modulation
QASK	Quadrature Amplitude Shift Keying
QPSK	Quadrature Phase Shift Keying
SNR	Signal to Noise Ratio
TDM	Time-division multiplexing
UEP	Unequal Error Protection
WIFI	Wireless Fidelity
WIMAX	Worldwide Interoperability for Microwave Access
WSSUS	Wide Sense Stationary with Uncorrelated Scattering
2-QAM	2-ary Quadrature Amplitude Modulation
3G	Third Generations
4-PSK	Quadrature Phase Shift Keying
4-QAM	4-ary Quadrature Amplitude Modulation
16-QAM	16-ary Quadrature Amplitude Modulation
64-QAM	64-ary Quadrature Amplitude Modulation

Chapter 1

INTRODUCTION

1.1 Introduction

One of the common phenomena in the communication using wireless is known as Multipath fading. During the signal transmission using radio channel, reflection, refraction and diffraction are very vital issue. Especially at the local and suburb zone that phone mobiles have been frequently used, the communication places modified rapidly and mentioned more difficulties and doubt to the reaction of the channels.

The phenomenon happens because of receiving of radio waves from different magnitude and time delays using mobile receiver. Movement of a mobile device from one position to another cause changes in income wave amplitude and phase. So the fading means the substantial amplitude plus phase fluctuations. This is known as fading [1]. Multipath fading is recognizable by many signals through the frequency spectrum from the high frequency bands right up to microwaves and beyond. Below are shown some explanation about this issue by Christoph Hausl [2].

It is tried with short wave radio communications and many other shapes of radio communication systems where signals fade in period of time.

Multipath fading takes place in any environment where there is multipath broadcasting and also some movement of elements exists within the radio communications system. It may contain the receiver position or radio transmitter, or in the elements that increase the reflections. That is way the multipath fading can often be relatively deep. Distortion to the radio signal can be caused by multipath fading as well. As the different paths that can be taken by the signals which are different in length, so in that case the signal that are transmitted at a specific case, will be received at the receiver over a range of times. During the data transmissions, it can cause some problems such as phase distortion and inter-symbol interference. As a consequence, it may be essential to incorporate features within the radio communications system that helps to minimize the effects of these problems. The aim of this research is, to minimize the effect of multipath fading to the radio signals using hierarchical modulation which is going to be proposed in this text. This method was originally suggested to transmit image data for mobile communication by M.M. Ghandi and M. Ghanbari as follow [3]. This is the hearth of graceful degradation method.

1.2 Background

Basically, the channels of the mobile radio communication are changing with the time and multi-path fading channels. In this kind of systems, very ways exist to signal traveling from the transmitter to the receiver. But still there can be a direct path for signals travelling between transmitter and receiver without obstruction of signals. Occasionally, the signal parts can be reversed by some materials which are lay down between the transmitter and the receiver. For instance: buildings, vehicles and hills and even the various overhead padding. These elements move in various ways and they join at receiver. It is obviously clear that each path can have a different physical length from others. That is way; the signals in every different ways effected from various transmission delays because of the limited propagation speed.

The adaption of these kinds of signals causes in ruinous of structural interposition depends on the related delays which participated. Changing in environment by passing cause to having signal variation. Also, the signals are affected by the movement of an ultimate. Little distance motion would make an obvious change in the propagation ways, it can change the signal's strength which received by terminal. So the problem unique to wireless networks is the very argumentative and random nature of the channels that present distortion and noticeably degrades the quality of the transmitted signal, being text, audio or video.

Generally, signal fading reasons for the large fluctuations in the amplitude of the received signal, and therefore in signals which are the received, it is very hard to distinguish the different multiple levels amplitude. This is a reason that, ASK and QASK are commonly avoided to be used in fading channels for digital communication.

Lately a lot of relay plans based on hierarchical or superposition modulation have been checked to meliorate the reliability of information transmission for users placed in shadow zone or at cell boundaries [4].

Here it can be better to apply a robust video coding algorithm to the error-prone signals over the communication channels. In some researches, applying unequal error protection by hierarchical coding to both scalable and data partitioned bit-streams is analyzed [3]. To achieve unequal error protection in practice, hierarchical signal constellations are employed, specifically hierarchical quadrature amplitude modulation (QAM)[5].To evaluate the performance of hierarchical QAM, most research focuses on the computation of the bit error rate (BER) of certain hierarchical signal constellations by Simon G¨ortzen et al [5]. In their study, they have presented a constructive approach to obtain arbitrary hierarchical QAM constellations [5]. An adaptive HQAM (A-HQAM) scheme is proposed in [6] where the ratios between the constellation distances are regularly adjusted based on the channel condition with the objective of maximizing the transmission efficiency.

A. Annamalai et al. in [7] explain that the usefulness of hierarchical modulations can be extra controlled at the data link layer to raise the network throughput without dynamically altering the signal constellation size at the transmitter, or losing the energy efficiency or transmission bandwidth.

Suggestion of this research is an asymmetric modulation method which is called Hierarchical Quadrature Amplitude Modulation (HQAM) used for the transmission of data over a wireless multipath channel. It is an adjustment of QAM which prepares unequal error protection (UEP). HQAM is an efficient method that non-uniform signal-constellation which is used in bits transmission for having different degrees of protection on them. The main advantage of this approach is that without an increase in bandwidth, different degrees of protection are achieved opposed to channel coding that raises the data rate by adding redundancy to the transmitted signal.

1.3 Thesis Objectives

This research mostly concentrates on application of hierarchical modulation and possible improvements which can be made for mobile multipath fading channel during transmission over a shadowing channel. These aspects can be count as goal of this research:

- Present an overview of Hierarchical modulation and Fading of mobile radio signals
- The evaluation BER of QAM systems over Rayleigh channel
- Comparing the effect of Log-Normal Shadowing on QAM systems such as(2-QAM,4-QAM,16-QAM and 64-QAM)
- Determine the important factors in shadowing phenomena.
- Investigating the effect of shadowing over quality of image.

1.4 Thesis Contribution

In this thesis we propose to use hierarchal modulation (QAM) for transmitting the image and investigating the effect of shadowing in this process. It involves two main steps. The first one is, evaluating BER on QAM systems which consist of designing and implementation of log-normal shadowing module in SIMULINK/MATLAB for simulating the shadowing effect on the communication system performance.

The second steps is, transmitting an image over a fading and shadowing channel in various conditions and observe the resulting effect on the quality of the transmitted image. In all cases color image are turned to gray-scale image for being normalized between (0-256) colors. Then, they are converted to the binary-form for being sent into the communication channels.

1.5 Thesis Structure

This thesis is composed of five chapters. Chapter 2 is a brief introduction of hierarchical modulation involved, time multiplexing, superposition and hierarchical QAM scheme of basic and incremental signals, hierarchical constellation and hierarchical modulation characteristics, QAM transmission in mobile multipath fading channel is investigated. Chapter 3 is a literature review of short term fading and long term fading of mobile radio signals. In Chapter 4 presents the simulation of long term fading of mobile radio signals and generation of lognormal variables of skating the signal power and shows the results of this simulation. Chapter 5 contains results and conclusions and proposes some work which still remains to be done in the future.

Chapter 2

HIERARCHICAL MODULATION

2.1 Introduction

There is a technique for modulating and multiplexing in signal processing which is named as hierarchical modulation and also there is a huge possibility to use it on the broadcasting systems. In fact, two different service levels with different coverage are available which can be noted as: basic reception quality and higher reception quality. Note that basic reception quality must be existed for all system users approximately nevertheless higher reception quality can only be existed for some system users.

In some OFDM digital systems such as DVB-T, hierarchical modulation has been used to overcome the effects and it also is applied as an alternative and replaced by conventional modulation methods such as quadrature amplitude modulation(QAM) and quadrature phase-shift keying (QPSK).

2.2 The Types of Receiver

The receiver that is placed within a cell is categorized in two main groups. The first one consisting of receiver which is sited in near vicinity ($\mathrm{r} < \mathrm{R}_{\mathrm{x}_1}$) of T_x and it is including of a direct non-zero component. Note that the mentioned class named by a Rician fading channel with highly SNR [8].Second main group is located at the greater distance ($R_{x_1} < r < R_{x_2}$) from T_x which does not have direct component. Note that the mentioned class named by a Rayleigh fading channel with moderate SNR [8]. All explanation is indicated in Figure 2.1 as follow:

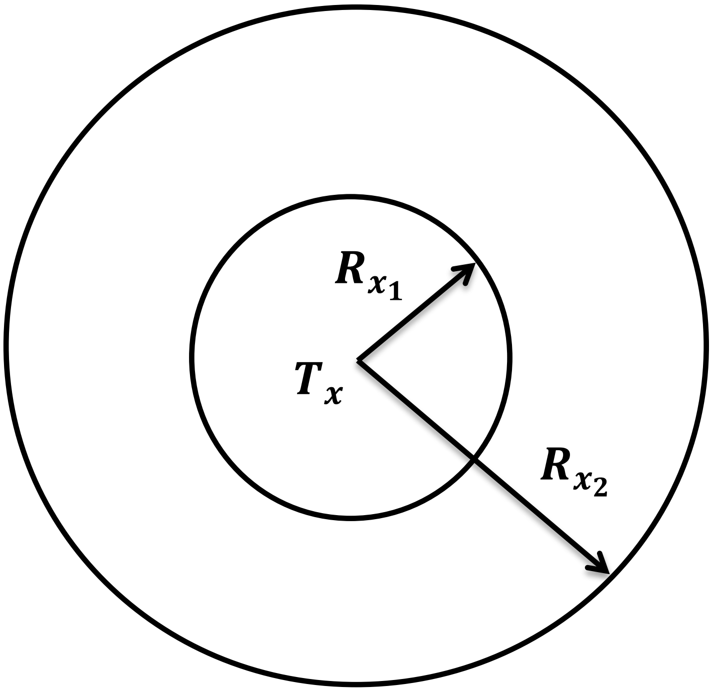


Figure 2.1: Explanations of Cell Model Receiver **[9]**

2.3 High and Low Priority Signals

In order to minimize the effects of transmission errors on reconstructed video quality, error resilient video coding techniques [10] have been proposed. Among the error resilient video coding techniques, unequal error protection (UEP), which is based on the idea that the binary bits in a compressed video bit-stream are not equally important, has gained attention in recent years. The reconstructed video quality will be severely degraded if transmission errors fall on these important bits and thus, these important bits should be allocated with a higher protection order compared to the rest of the video bit-stream.

Hierarchical source encoder/decoder is the first requirement in the hierarchical transmission scheme that splits the digital TV data into two parts of basic signal and incremental signal, which the first on called high priority signal (HP) and the second one known as low priority signal (LP).

The High and Low Priority Signals are different in responsibility to noise. The high priority signal, is greatly secured from interference and noise, however cannot acquire a high data rate, but the low priority signal able to support a higher data rate. Therefore, the area which they can coverage is different in size. In contrast to non-hierarchical modulation, high priority signal can cover great size of area. However the area covered by the low priority signal is a little smaller. In practice, using of the high priority signal is for mobile reception and portable indoor, but the low priority signal can be used to transmit a HDTV program to a non-movable receiver like TV set used at home.

2.3.1 Hierarchical 16-QAM

Figure 2.2 depicts the constellation diagram of hierarchical 16- QAM modulation, where d1 and d2 are the minimum distance between quarters and the minimum distance between points inside each quarter. To achieve UEP for HP data and LP data, d1 and d2 are adjusted such that d1 > d2. By referring to Figure 2.2, let alpha value, α, be given by

$$\mathrm{d}_1 > \mathrm{d}_2 \text{ and } \alpha = \frac{\mathrm{d}_1}{\mathrm{d}_2} \tag{2.1}$$

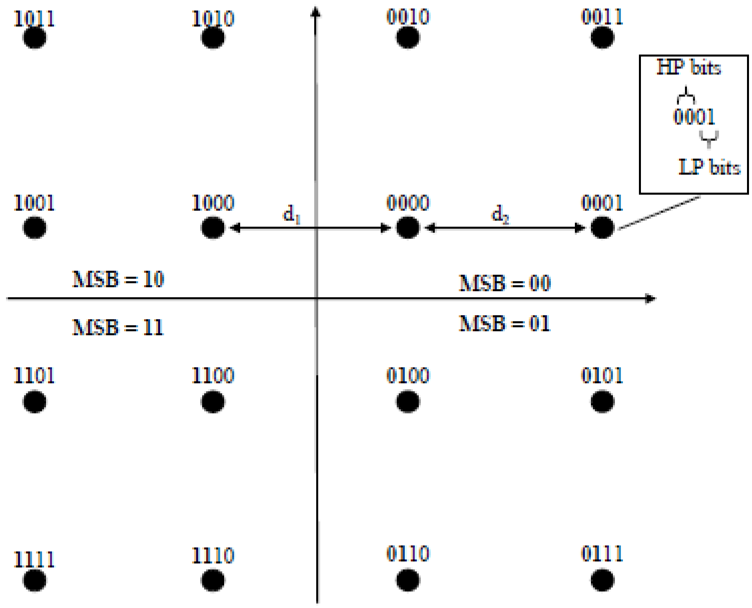


Figure 2.2: Configuration of Hierarchical 16-QAM **[10]**

For UEP using hierarchical 16-QAM, the compressed video bit-stream is classified into two priorities, namely HP and LP data bits, as shown in Figure 2.3

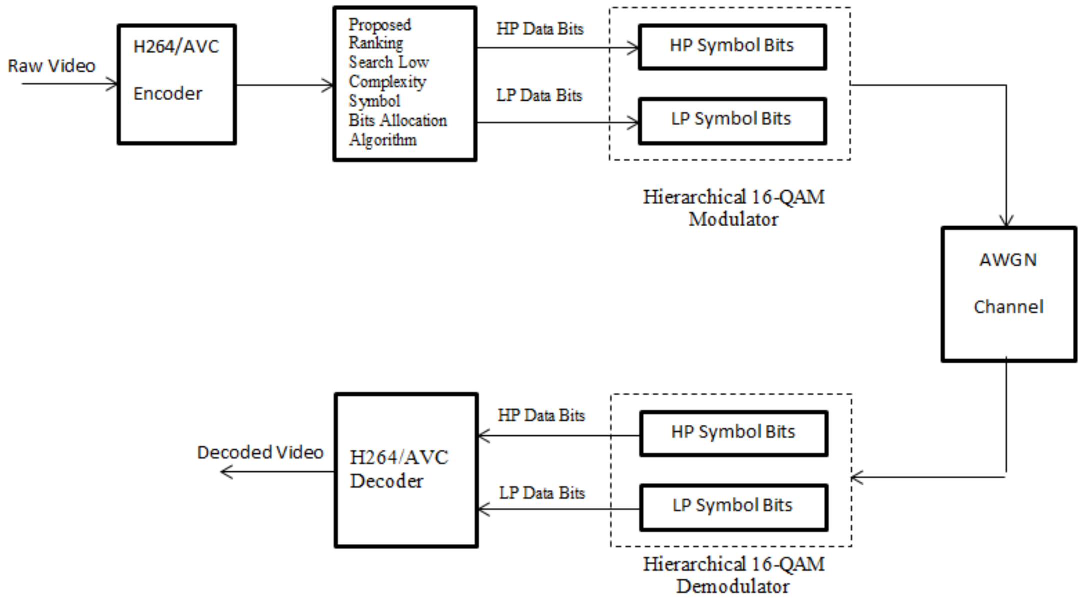


Figure 2.3: General Configuration of UEP with Hierarchical 16-QAM **[10]**

2.3.2 Hierarchical 64-QAM

By referring to Figure 2.4 let beta value, β, be given by

$$\alpha = \frac{d_1}{d_2} \text{ and } \beta = \frac{d_3}{d_2} \tag{2.2}$$

As it mentioned in above paragraph, a conventional 64-QAM has been obtained by using α and β equal to 1 and also a hierarchical 64-QAM has been gained if α and β are greater than 1.

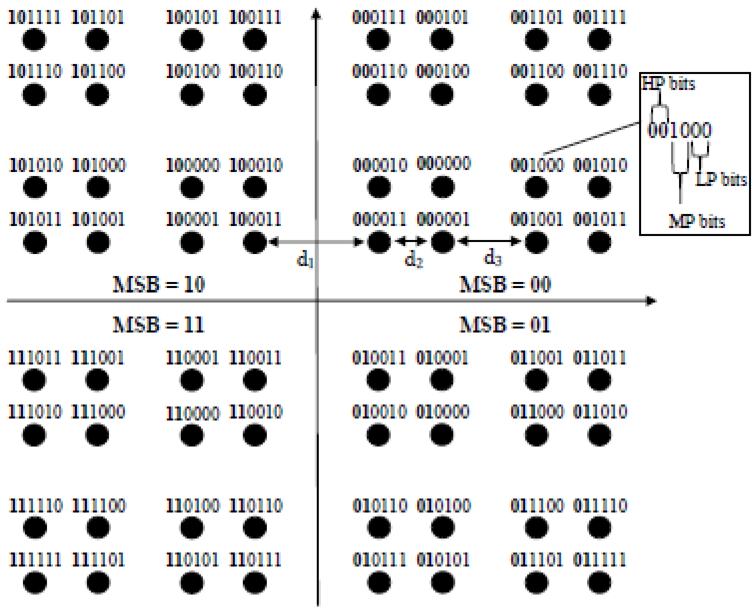


Figure 2.4: Configuration of Hierarchical 64-QAM **[10]**

The compressed video data is classified into HP, MP and LP data by taking into consideration the non-uniformly distributed importance frames in a group of pictures (GOP) and macro blocks in a video frame.

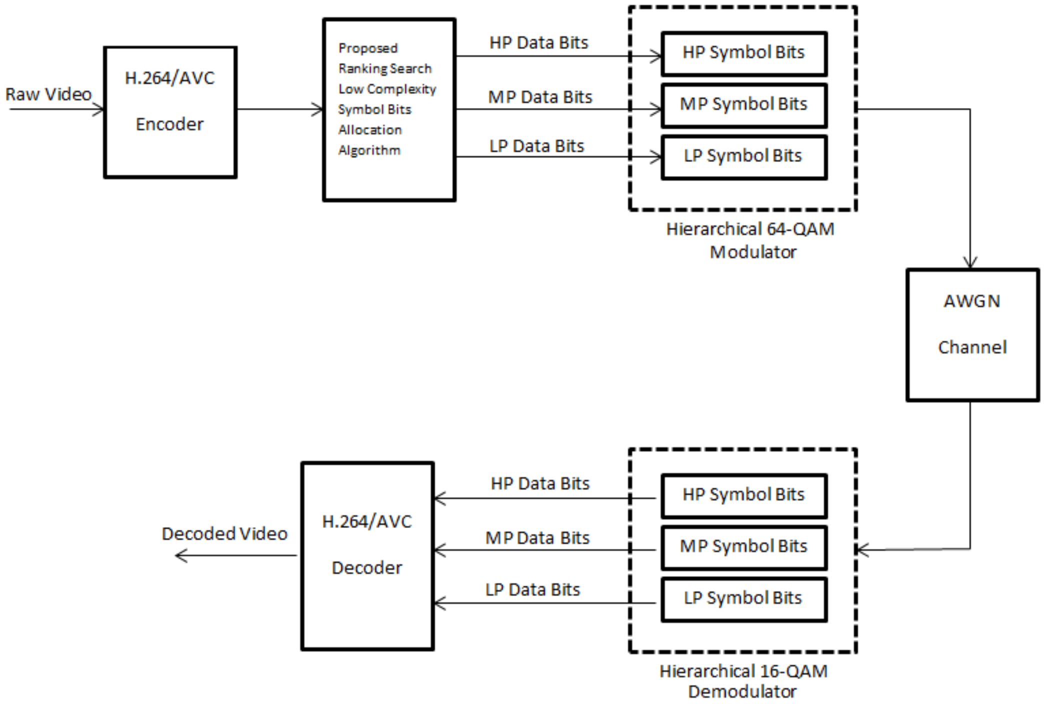


Figure 2.5: General Configuration of UEP with Hierarchical 64-QAM **[10]**

2.4 Basics of Hierarchical Modulation

Hierarchical modulation, which has been used in the digital video broadcast (DVB) standard, offers another degree of freedom in protecting the transmitted messages according to their relative importance [11]. Hierarchical Modulation is defined to be used on quadrature amplitude modulations (QAM) and generally contains of two distinct bit streams, high and low priorities that are modulated onto a single bit stream. High Priority (HP), is modulated with basic quadrature modulation order (4-QAM) and Low Priority (LP), is embedded on HP stream to define high order QAM modulation than 4-QAM. For instance, the basics of hierarchical modulation will be described in this research using 64-QAM. The constellation diagram of 64-QAM is illustrated in Figure 2.6. In the complex plane that contains of phase and amplitude, dots in black color illuminate each permissible state. Therefore, it can transmit 64 possible values which come from 6 bits. Figure 2.6 illustrates the duty of the binary data values to the permissible digital states.

Hierarchical 64 QAM has two embedded sub-constellations, and thus is denoted by 4/16/64 QAM. The hierarchical 64-QAM runs as 16 or 64-QAM when channel quality is better and it works as quarter phase shift keying (QPSK) when channel conditions are poor. The Bit error rate of hierarchical 22*K* QAM, *PMn*, is given by a recursive expression by Seok-Ho Chang [12].

There are 4 x 4 different states and 4 transmitted bits in the case of 16-QAM , on the other hand, there are only 2 x 2 states and with just 2 transmitted bits in the case of 4-PSK.

The probable cases in hierarchical and non-hierarchical modulation are totally interpreted differently. The situation of a case in the quadrant of it, considered as significant and particular information in hierarchal modulation

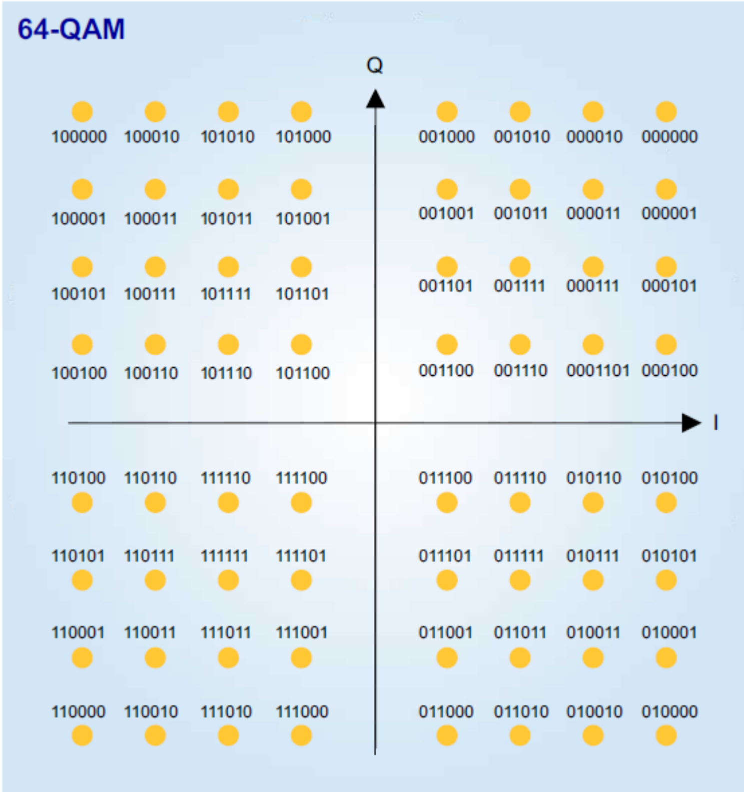


Figure 2.6: Constellation Chart for 64-QAM Modulation
(with α = 2 for modulation) **[13]**

Also, other important information to be specified in hierarchal modulation (HM) is the number of quadrant like 1, 2, 3 or 4 where the case is situated in. Therefore, for transmission, two different data streams can be generated. Through hierarchical interpretation 64-QAM is the mixture of 4-PSK and 16-QAM modulation. This combination can be referred to as “4-PSK in 64-QAM”. A 64-QAM stream is constituted of two partial streams’ bit-rates together. In Figure 2.7 DVB-H physical layer’s block diagram with HM is represented. In this Figure, it is illustrated that how the inputs include two distinct MPEG-2 transport streams in hierarchical modulation case (the hierarchical modulation has been shown by add dotted-line). Any multimedia data can be considered as the input of the system. Through using HM, the information that comes from two channels can be either different or the same as multiplexed at the level of interior interleaver.

The composite stream will be sent to the transmitting antenna through its way actually after combining at the level of interior interleaver. So, it can be clearly seen that hierarchical modulation generates two separate data streams with distinct transmission performances in a common single frequency of TV channel [14].

It is appropriate here to compare hierarchical modulation (4-PSK in 64-QAM) and non-hierarchical modulation (64-QAM). If in a block its states are interpreted as probable states like a 16-step modulation scheme the separation of the states in non-hierarchical modulation (64-QAM) will not change as it is obvious in Figure 2.6. Therefore, there is insignificant and slight greater noise sensitivity in the case of 4-PSK in 64-QAM compared to non-hierarchical by considering the slight lower encoding gain in the terms of error protection. In addition, the noise sensitivity for the data stream of 4-PSK in the hierarchal modulation realization is significantly lower than the noise sensitivity of the 64-QAM non-hierarchical and even hierarchical modulation data stream. The reason of this fact is the dependence of two-bit information with a quadrant would be distributed with less probability.

So, the quadrant information would not be wrong if the constellation state be distributed such as confusing by other arbitrary states in the same quadrants. Besides with gaining two independent data streams on 4-PSK in 64-QAM, the data stream which has lower rate for transferring is less susceptible to noise than other which is in a non-hierarchal modulation scheme.

Exactly at the same time, the hierarchical modulation data stream with higher rate of transferring data is not significantly less robust than equal data stream in a non-hierarchical modulation realization. The accumulation of rate of transferring data of two hierarchical modulations is identical compared to the data rate of a non-hierarchical modulation scheme. The yield data rate will in any condition be lower because of incurred overhead in MPEG-TS in the case of HM by considering two complexes.

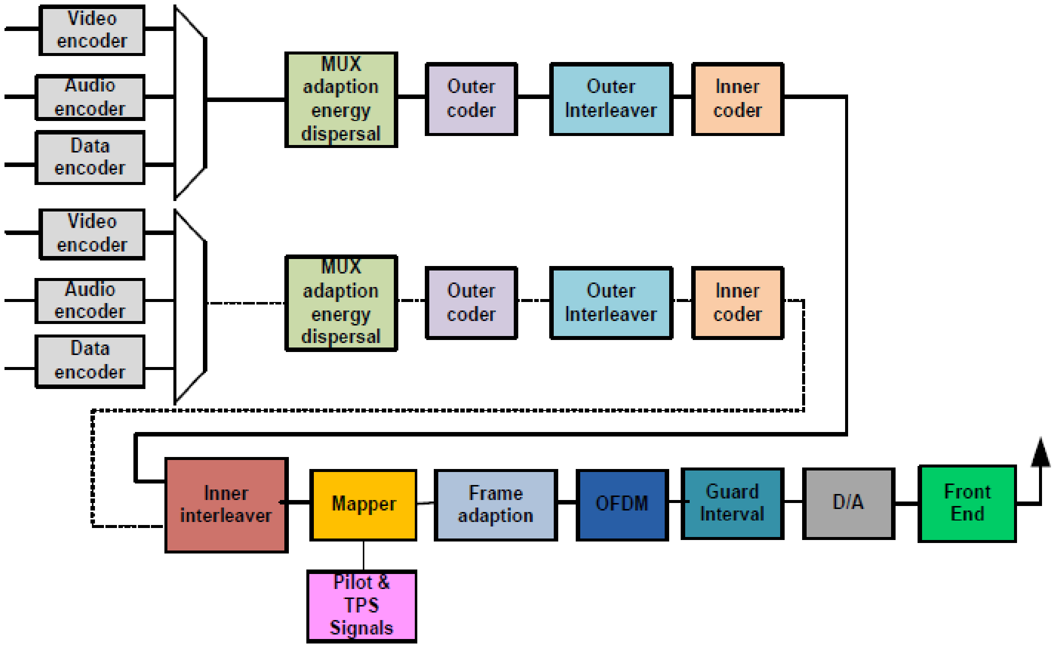


Figure 2.7: Block Diagram of a DVB-T System with Hierarchical Modulation **[15]**

2.5 Benefits of Hierarchical Modulation

HM has a significant throughput tradeoff and coverage for wireless communications. Between two traditional and hierarchical modulation methods, the HM method has received little attention, so that HM compared to traditional methods is more flexible. For example, if you consider two-layer transmission scheme, the same video signal may be transmitted with either poorer or better quality in signal in the equivalent data stream, when both enhancement-layer symbols and base-layer symbols are synchronously accumulated and superimposed together before the transmission take place.

Furthermore, it is feasible to expand the area of covering basic signal through changing the modulation parameter, but the robustness of the incremental signal will be lost and this leads the reduction in the coverage of the incremental signal. Hierarchical mode compared to non-hierarchical one provides more rugged main services. The coverage for basic signal service area is relatively greater though there are a lot of small losses of the coverage for the incremental signal service area. To have an equivalent coverage, because the performance loses with a multipath, more bit-rate is required for hierarchical mode compared to non-hierarchical one. Whereas, it is considerable point that the gained advantages from hierarchical mode is significantly is more than its drawbacks.

As hierarchical modulation is reversely compatible in practical constructions, so it is worthy to expand receivers in the networks which are equipped with hierarchical broadcast. According to a non-hierarchical scheme, the former or original receivers have their own ability and can receive basic signal. Meantime, a new receiver which is designed to receive incremental signal has also the potential to receive the basic signal exactly at the same time [4].

Chapter 3

FADING of MOBILE RADIO SIGNAL

3.1 Introduction

The wireless medium has some problems like quite unreliability and a low bandwidth, and is of broadcast nature. But it can support uniquely the mobility of users. All wireless transmissions share the air as the same medium. With the wireless medium, the system capacity is limited by allocation of a limited frequency spectrum for operation in a certain area for a specific application until some special techniques are deployed.

The three most important radio propagation characteristics used in the design, analysis, and installation of mobile communication systems are the achievable signal coverage, the maximum data rate that can be supported by the wireless channel, and the rate of signal fluctuations in the wireless channel. For efficient data communications on wireless channels, the maximum data rate that can be supported becomes a critical design parameter. The multipath structure of the wireless channel and the fading characteristics of the multipath component of the signals being transmitted strongly influence the data-rate capabilities. This also results in the need of a proper signaling scheme and receiver design. Depending on the nature of the operating environment, and the data rates that need to be supported by an application, some characteristics are much more important than others. For example, signal coverage and slow fading are more important for low data rate narrowband systems such as cellular voice and low speed data applications. The multipath delay spread becomes important for high data rate wide band systems such as systems designed using spread-spectrum modulation schemes as CDMA and 3G cellular services.

3.2 Channel

The term channel refers to the medium between the transmitting antenna and the receiving antenna as shown in Figure 3.1.

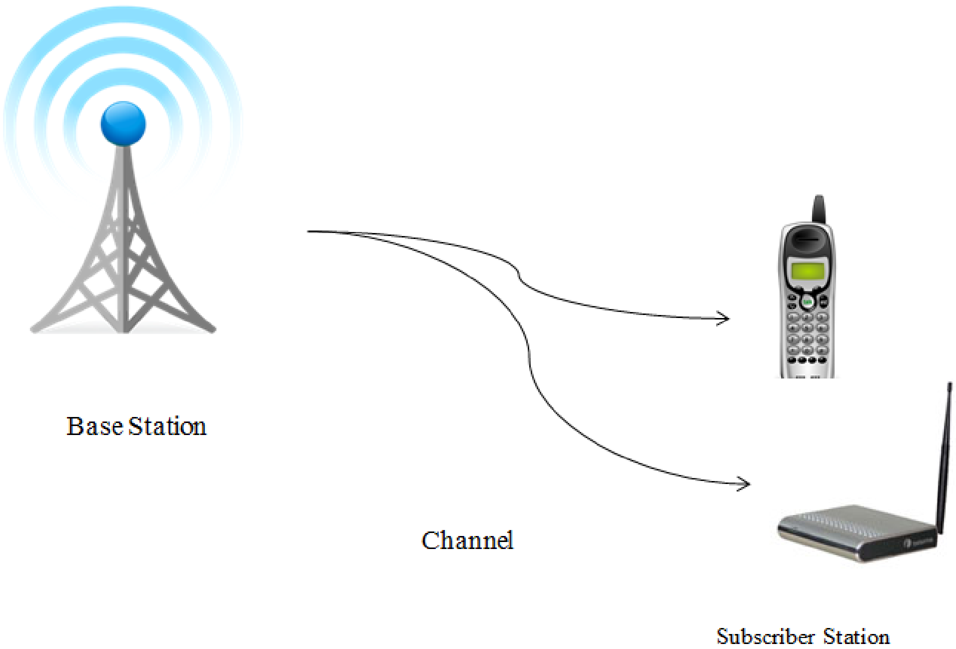


Figure 3.1: Modeled Channel

In fact any devices which connect transmitter to receiver, is a kind of channel.

In Communication there are two types of channel, one of them is physically like wire and another one is not physically and it can be name as wireless channel. When the signals transmit from transmitter, channel carries the signal to receiver. The capacity of channel can be determined by bandwidth with Hz or data rate in bit per second. There are two types of channel in wireless communication: when there is only direct path between transmitter and receiver, Line of Sight (LOS), Rician channel use and when there are both direct and reflected path between transmitter and receiver, NON-line of Sight (NLOS) Rayleigh channel exist. There is another model of channel in simulation, the AWGN Channel which adds white Gaussian noise to a real or complex input signal.

3.2.1 AWGN Channel

Additive White Gaussian Noise (AWGN) is one of the important channel models in communicant system. This model does not accept the fading or interference non linearity or dispersion. The AWGN channel has wideband or white noise with constant spectral density. This model generates the simple mathematical noise models before other phenomena are considered. White noise in AWGN comes from different natural sources; one of them is vibrations of atom in conductors. The AWGN channel is not useful for terrestrial system because of multipath and interference, but it will be used to simulate background noise of the channel under study.

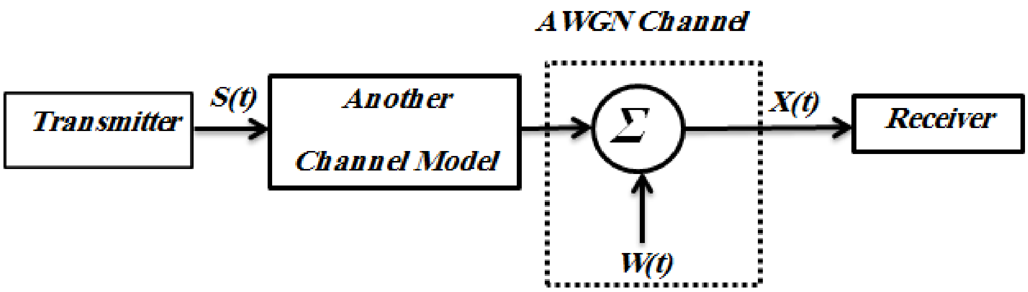


Figure 3.2: Communication System Model with AWGN

3.2.1.1 Theoretical Error Probability for QAM Signaling in AWGN Channel

In general, according to the Table of 2-4.14 in [16], the theoretical error probability for QAM signaling in AWGN channel (for even K) is noted in equation (3.1):

$$P_{be} = \frac{4}{K}\left(1 - \frac{1}{\sqrt{M}}\right) Q\left(\sqrt{\frac{3K}{M-1}\gamma_b}\right) \qquad \text{for} \quad K=2,4,6,8,\ldots \tag{3.1}$$

Where K= $\log_2 M$, $\gamma_b = E/KN$ and $P_{be} \approx \ P_e/K$

K is the number of bits per symbol and M is size of modulation constellation and Q is Q-function.

The probability error per bit for 2-QAM (BPSK) which k is equal to 1 and it is odd given by:

$$P_{be} = Q\left(\sqrt{\frac{2E_b}{No}}\right) = Q\left(\sqrt{2\gamma_b}\right) \tag{3.2}$$

Where $E_b = E/K$

As an example the probability error per bit for 4-QAM (QPSK) which k is equal to 2 with respect to the equation (3.1) is given by:

$$P_{be} = Q\left(\sqrt{\frac{2E_b}{No}}\right) = Q\left(\sqrt{2\gamma_b}\right) \tag{3.3}$$

With respect to the equation (3.2) and (3.3), P_{be} for BPSK and QPSK is the same but, BER value is different regarding to (3.4)

$$P_{be} \approx P_e/K \qquad (3.4)$$

Note that, equation (3.1) can be used for the rest of QAM levels (K=even).

3.2.2 Rayleigh Fading Channel

In wireless communication signals bear when there is not LOS between transmitter and receiver. The receiver receives some reflected signal which contains different amplitude and phase distortion. The Rayleigh fading channel is useful when there is not any Line of Sight between receiver and transmitter. In the big city generally the high buildings prevent to receive direct signal from transmitter to receiver so the Rayleigh fading channel could be suitable model for this. The Rayleigh channel has worst performance compare to AWGN channel and Rician fading channel because there is not any LOS in Rayleigh fading channel.

3.2.2.1 Theoretical Error Probability for QAM Systems in Rayleigh Channel

In a multipath Rayleigh fading channel, the equation (3.5) has been used for the probability of symbol error is given by [41].

$$P_s = 4\frac{\sqrt{M}-1}{\sqrt{M}} Q\left(\sqrt{\frac{3}{M-1}\frac{KE_b}{N_o}}\right) - 4\left(\frac{\sqrt{M}-1}{\sqrt{M}}\right)^2 Q^2\left(\sqrt{\frac{3}{M-1}\frac{KE_b}{N_o}}\right) \qquad (3.5)$$

$$P_b = \frac{2}{\sqrt{M}\log_2\sqrt{M}} \times \tag{3.6}$$

$$\sum_{k=1}^{\log_2\sqrt{M}} \sum_{i=0}^{(1-2^{-k})\sqrt{M}-1} \left\{ (-1)^{\left\lfloor \frac{i2^{k-1}}{\sqrt{M}} \right\rfloor} \left(2^{k-1} - \left\lfloor \frac{i2^{k-1}}{\sqrt{M}} + \frac{1}{2} \right\rfloor \right) Q\left((2i+1)\sqrt{\frac{6\log_2 M}{2(M-1)}\frac{E_b}{N_o}} \right) \right\}$$

probability of bit error is given by (3.6) [41].

The relationship between Symbol Error Rate (SER) and Bit Error Rate (BER) is:

$$\frac{E_s}{N_O} = k\frac{E_b}{N_o} \tag{3.7}$$

Where K is the number of bits per symbol. For QPSK, there are two bits per symbol. Therefore equation (3.7) becomes:

$$\frac{E_s}{N_O} = 2\frac{E_b}{N_o} \tag{3.8}$$

Then the BER is:

$$\frac{E_b}{N_O} = \frac{1}{2} \times \frac{E_s}{N_o} \tag{3.9}$$

For detailed development of equation (3.5), refer to [9].

3.3 Definition

In this part some basic concept will be explained which has been employed in the thesis simulation such as path loss, standard deviation, shadowing, multipath and Doppler Effect.

3.3.1 Path Loss

Path loss or path attenuation is decreasing in the power of density of electromagnetic waves as it distributes through space. The path loss is one of the most important parts for designing the link budget in telecommunication system.

Path loss generally is used in signal propagation and wireless communication. So Many effects like refraction, diffraction, reflection, absorption and free space loss can generate the path loss. In addition the terrain contours, surroundings (urban, rural), or the distance between receiver and transmitter can effect on path loss.

3.3.2 Standard Deviation

The standard deviation indicates how much variation exists from mean. When the data point is close to mean the standard deviation has low value and when the standard deviation is high it shows that the data points are spread out over large range of value. Determining the standard deviation value depends on the geographical area like buildings, hills and trees. The standard deviation can be between 5dB and 12dB depending on geographical condition. So the standard deviation (σ) is proper device to define the condition of geographical area.

3.3.3 Shadowing

Due to the changes along transmission, the signal will be diffracted and the average power of signal is different. Shadowing refers to slow changing in the local mean of the received signal strength. If something such as building or terrain blocks the signal, the shadowing will be happened. It causes to change the mean power of received signal which contributes the gradual in the mean power of the received signal. Shadowing is generally modeled by log-normal distribution.

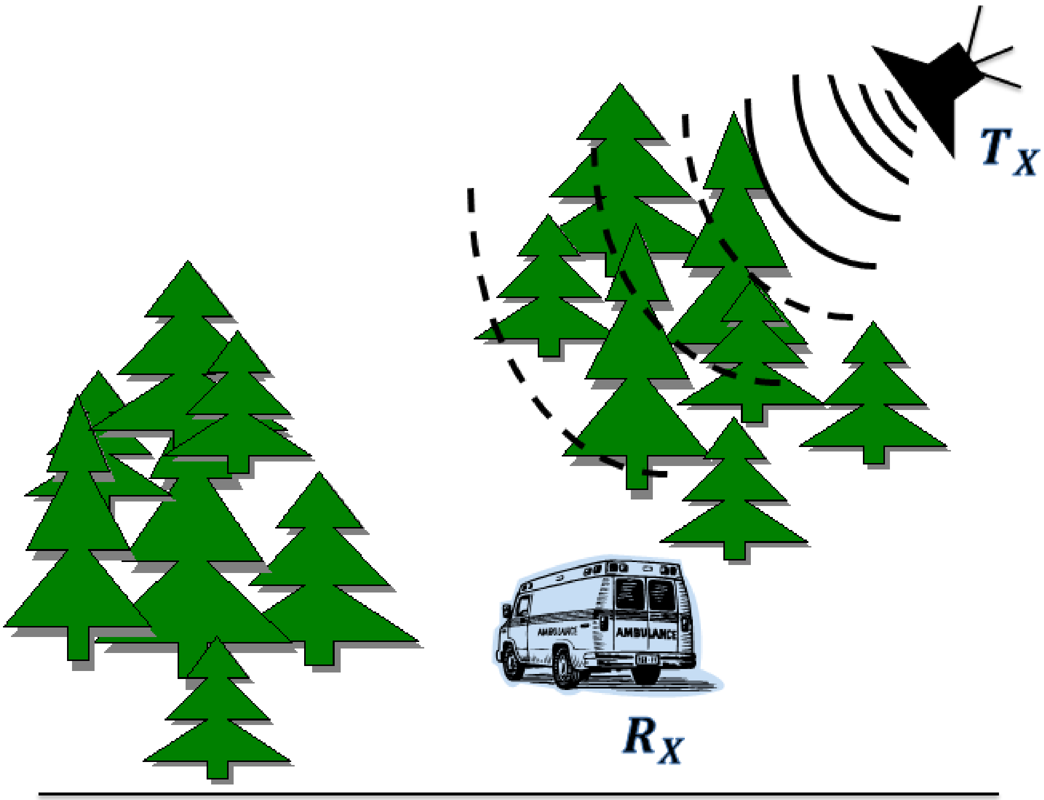


Figure 3.3: Illustration of Shadowing Effect in Wireless Communication

3.3.4 Log Normal Shadowing

The slow variation of the signal level, effects on the link quality in terrestrial and satellite land-mobile due to the shadowing from trees, buildings and terrains. The quality of communication system will appertain only on shadowing if the radio receiver is capable to take half value the fast multi path fading. The logarithm of random variable has a normal distribution in log-normal distribution. The pdf and cumulative distribution function (cdf) will be presented in equations 3.11 and 3.12 respectively.

$$P(r) = \frac{1}{r\sigma\sqrt{2\pi}} e^{\frac{-(\ln r - m)^2}{2\sigma^2}} \quad (3.10)$$

$$D(r) = \Pr(x \langle r) = \frac{1}{2}[1 + erf(\frac{\ln r - m}{\sigma\sqrt{2}})] \quad (3.11)$$

σ and m are standard deviation and mean respectively, erf(x) is well known error function and the *Pr* is the probability function.

The power ratio of transmit to receive *is* $\Psi = \frac{P_t}{P_r}$ and it considered to be random with log- normal distribution.

$$p(\psi) = \frac{10}{\sqrt{2\pi}\sigma_{\psi_{dB}} \psi \times \ln 10} \exp(-\frac{(\psi_{dB} - m_{\psi_{dB}})^2}{2\sigma^2_{\psi_{dB}}}) \quad \psi \rangle 0 \quad (3.12)$$

Where $\psi_{dB} = 10\log_{10}\psi$, in the equation ψ is between 0 and 1. In case of large scale fading the fluctuation will happen for mean. In the summer the tree with foliage causes shadowing almost 3dB higher loss due to shadowing than the similar tree in the winter.

3.3.5 Multipath

The objects placed between receiver and transmitter can reflect on the signal. Some of these reflected signals take different amplitude and phase. Base on the phase, the received power at the receiver can be increased or decreased. Even the small move in position contributes to important difference in phase of signal and so the whole received power.

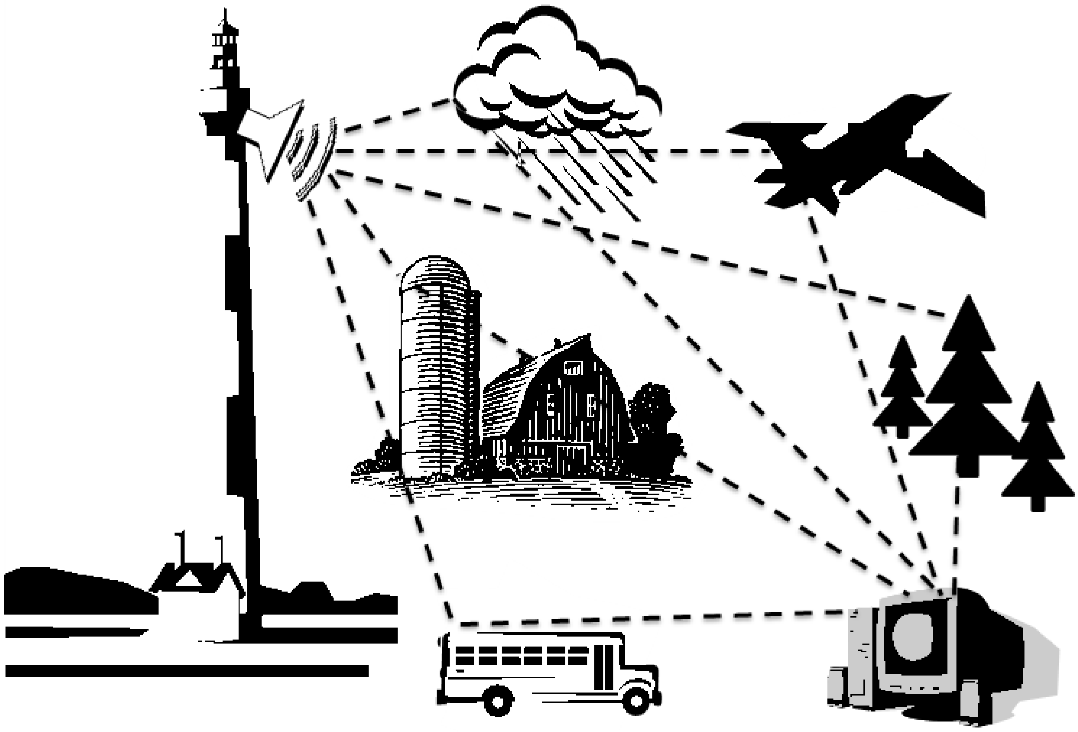


Figure 3.4: Multipath Propagation Model of Microwave Signals

Depending upon the phase, these multiple signals may result in increased or decreased received power at the receiver. Even a slight change in position may result in a significant difference in phases of the signals and so in the total received power. The three components of the channel response are shown clearly in Figure 3.5. The thick dashed line represents the path loss. The lognormal shadowing changes the total loss to that shown by the thin dashed line. The multipath finally results in variations shown by the solid thick line. Note that signal strength variations due to multipath, change at distances in the range of the signal wavelength.

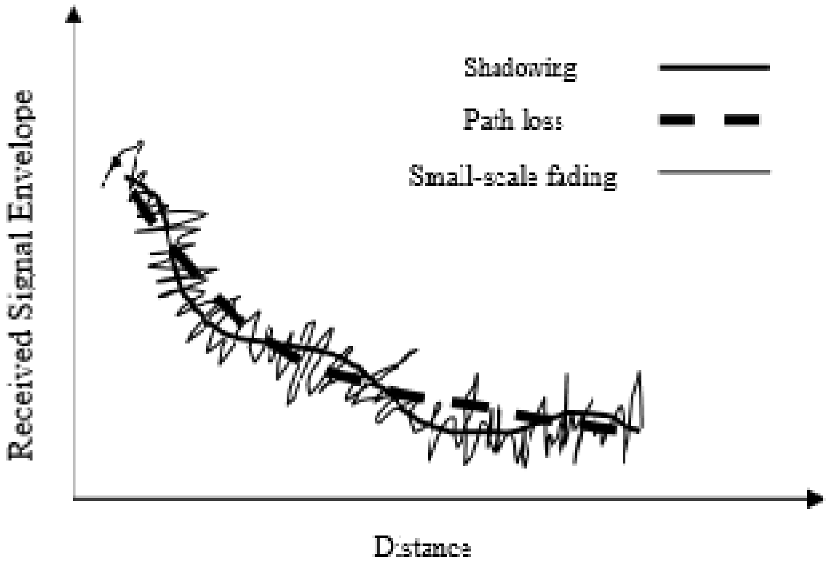


Figure 3.5: Effects of Pass Loss, Shadowing and Small-Scale Fading on the Received Signal Envelope [17]

3.3.6 Channel Characterizations

Channel characterization counts as an important issue because of the time changing root channel of the wireless. Surveying of the channel of mobiles are necessary based on to use its features. In the mobile communications which are wireless theory, the channel features alerts according to the time because of the related movement between receivers and transmitters, the variation of time in the mediocre structures, etc. It would make it random in character. Its nature correspondingly gets boring. The received signal's stability directly depends on the channel features and separation of the receiver and transmitter. The mobile wireless channel characteristic can be the channel changing stability on frequency and time. In the wide sense, channels would be modeled into two various manners, large scale and small scale propagation models. The propagation model which anticipates the average of strength of the signal for receiver and transmitter separately gets beneficial in computing the transmitter covering place. It is totally named as a large scale propagation model. The propagation model which features fast signal's oscillations which is received into some lengths of the wave (very little distance) is named as a small scale propagation model. Figure 3.6 indicates the slow large-scale changing and much more frequently alerting the variation of the small scale for a radio communications system which is indoor [24]. These models are going to be analyzed in the next sections in deeply details.

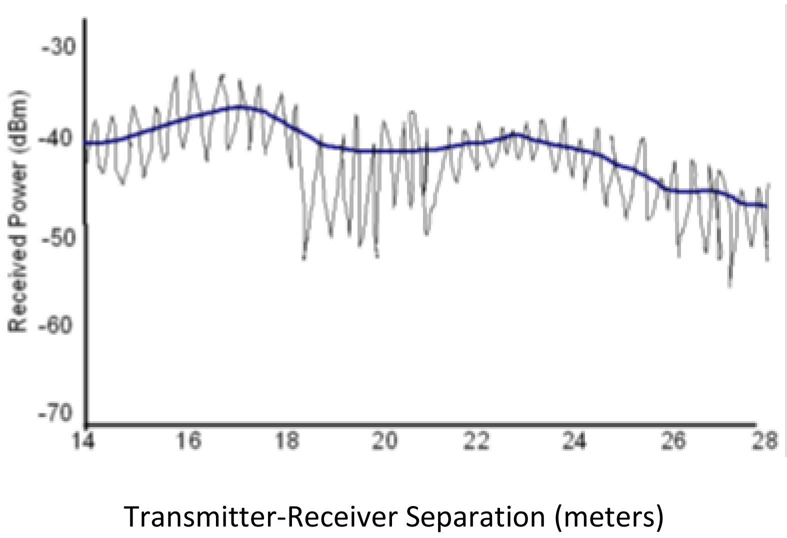


Figure 3.6: Small-Scale and large-Scale Fading Manifestation **[9]**

3.4 Radio Propagation

There are many kinds of radio propagation model. One of them is large-scales which can be used in characterization of signal strength over large transmitter-receiver distance (could be greater than thousands meters). On the other hand the small-scale can be used in a short time and short distance.

3.4.1 Small Scale Fading

To explain the fast fluctuation of multipath delays, phase and amplitude the simply fading or small fading is employed. Two or more signals which arrive at the receiver through various paths make fading. The small scale fading effects is created by multipath in radio channel. The different between bandwidth, symbol period and channel specification and various transmitted signals causes various kinds of fading.

3.4.1.1 Small Scale Propagation Models

Multiple forms of the transmitted signal that reached by the receiver are the result of small scale fading which is a property of radio propagation that is produced by the presence of reflectors and scatters. These signals are varied in amplitude, phase and angle of arrival [18].

3.4.2 The Types of Small-Scale Fading

Small-scales fading can be classified base on the multipath time delay and Doppler spread. The below Figure illustrates the different kinds of fading which will be derived from small scale fading.

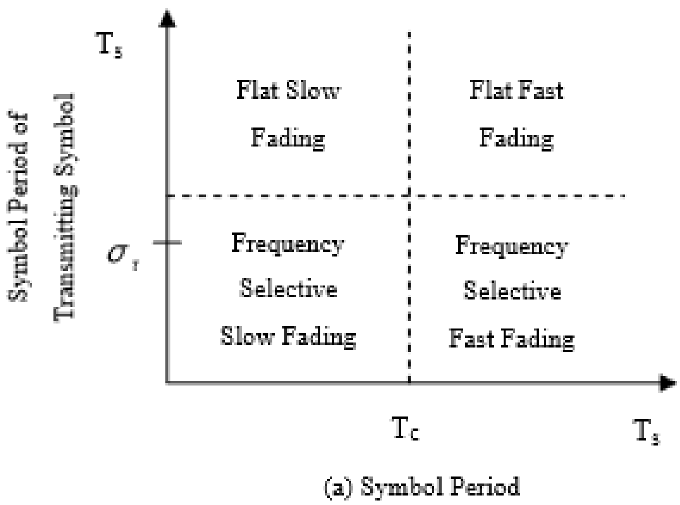


Figure 3.7: Small Scale Fading Based on Symbol Period [19]

This category depends on the multipath time delay . Another category is based on the Doppler spread and consists of Fast fading and Slow fading as the below Figure indicates.

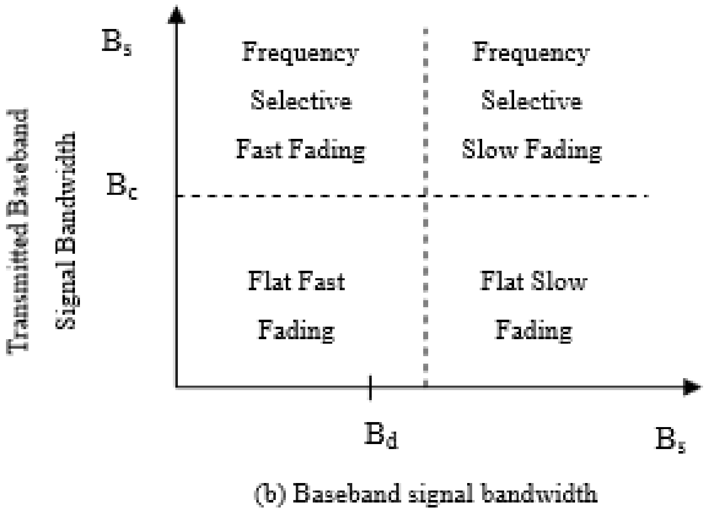


Figure 3.8: Small Scale Fading Based on Coherence Bandwidth [19]

3.4.2.1 Flat Fading Channel

When the transmitted signal in bandwidth is smaller than coherent bandwidth of channel, the channel can be named as Flat fading channel. in flat fading channel the symbol duration is longer than delay spread. in addition the inter-symbol interference will not happen in flat fading channel. Another name of flat fading is amplitude varying channels or narrowband channels.

The flat fading channel behaves just like a pass filter within coherence bandwidth. The frequency could not effect on time varying channel gain, so the following formula represents this

$$H\,(f;\,t) = g(t) \tag{3.13}$$

In the above formula the *g(t)* is complex Gaussian process.

3.4.2.2 Frequency Selective Fading

If the transmitted signal has greater bandwidth compare to the channel, the channel makes frequency selective fading on the received signal which means that, the transmitted signal`s bandwidth is bigger than the coherence bandwidth.

$$B_s > B_c \tag{3.14}$$

Another characterization of frequency selective fading is the delay spread is more greater than the symbol period and this is not desirable for communication system. One of the reason of this is high data rate.

$$T_s < \sigma_\tau \tag{3.15}$$

Under this condition the received signal include multipath copy of transmitted signal, so the signal will go to the distortion. The characterization of the frequency selective fading is shown in the below Figure.

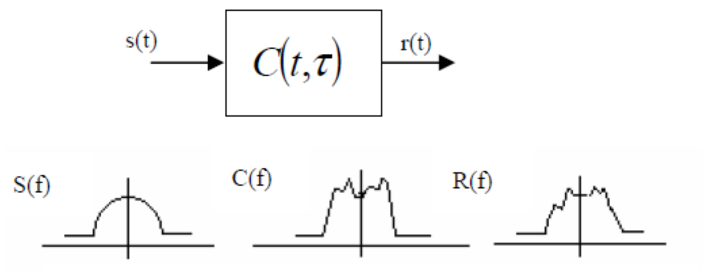


Figure 3.9: Frequency Selective Fading [20]

The normal model for frequency selective fading is WSSUS. This system is wide sense stationary with uncorrelated scattering.

3.4.2.3 Fast Fading

In fast fading, symbol time period of transferred signal might be larger rather than the channel coherence time. Another name of fast fading is time selective fading and it causes the signal distortion. With increasing the Doppler spread the fast fading will be increased relative to the bandwidth of transmitted signal. In another characteristic of fast fading, Doppler spread of the channel is greater than bandwidth of signal.

$$T_s > T_c \qquad \text{Or} \qquad B_s < B_d \tag{3.16}$$

3.4.2.4 Slow Fading

In slow fading the coherence time of the channel is much greater than the symbol time of the signal.

$$T_c >> T_s \tag{3.17}$$

In addition, the signal's band-width is much larger rather than Doppler spread as equation (3.19) shows.

$$B_s >> B_d \tag{3.18}$$

It should be mention that the velocity of the object in the channel and the baseband signal define weather a signal goes to fast fading or slow fading.

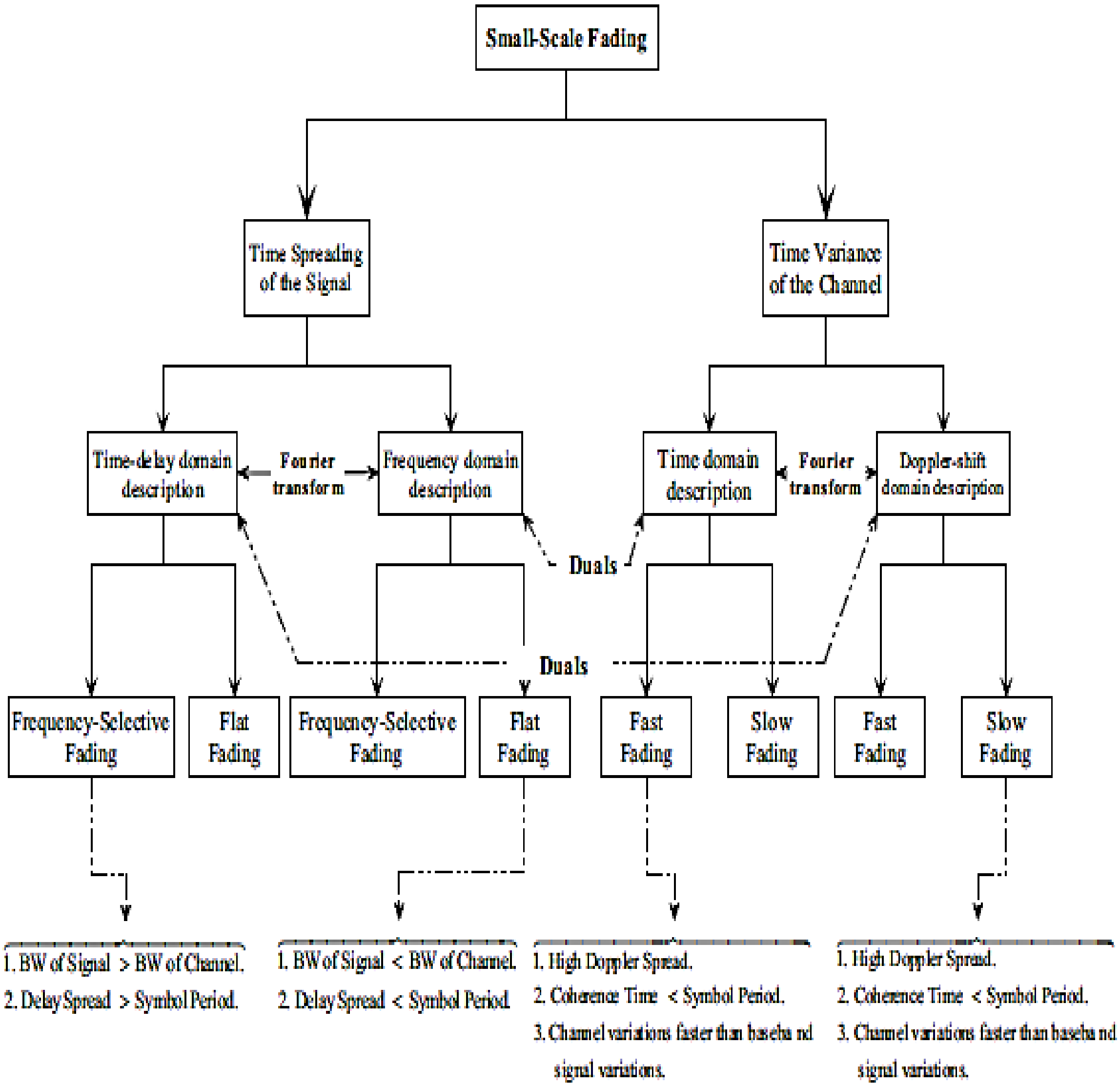


Figure 3.10: Types of Small-Scale Fading [21]

3.5 Mobile Multipath Channels Parameters

The parameters of mobile multipath channel are excess delay, Doppler shift, coherence bandwidth and delay spread .These parameters are changed respect to fix time delay.

3.5.1 Fading

As mobile terminal moves from one location to another, the phase relationship between the various incoming waves also change, thus there are substantial amplitude and phase fluctuations. This is known as fading.

Some parameters can change the fading, such as radio frequency and environment. Generally the random process can model the fading.

3.5.2 Doppler Shift

If receiver or transmitter moves to each other the Doppler Effect will be happened. The high frequency sound is obtained when transmitter or receiver moves toward each other. And the low frequency sound is gained when transmitter or receiver moves far from each other. The Doppler Effect is in light waves, electromagnetic waves and sound wave. In addition the Doppler Effect is useful in medicine (speed and direct of blood). Equation bellows Presents Doppler Effect

$$f_d = v \times (\frac{f}{c}) \times cos\theta \quad (3.19)$$

f_d is Doppler frequency , v= velocity of observer, f is carrier frequency of transmitter, C is speed of light and θ is the angle between signal and motion direction. As can be seen f_d has direct relation with v, f and $cos\theta$.

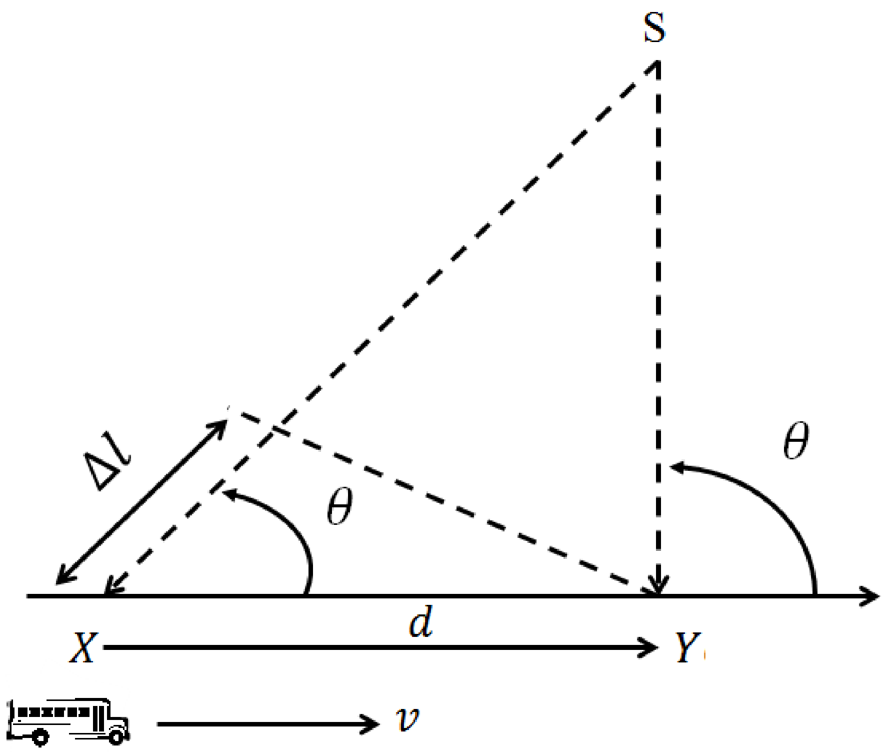


Figure 3.11: Illustration of Doppler Effect on Channel [21]

3.5.3 Power Delay Profile Φc(τ)

Another name of Power Delay Profile is multipath intensity profile, can be defined as autocorrelation with $\Delta t = 0$: $A_c(t)$= $A_c(t, 0)$. The Power Delay Profile indicates the average power. It is not difficult to determine empirically. The Power Delay Profile can describe the average and delay spread [16] .

$$\mu_{T_m} = \frac{\int_0^\infty \tau A_c(\tau) d\tau}{\int_0^\infty A_c(\tau) d\tau} \tag{3.20}$$

$$\sigma_{T_m} = \sqrt{\frac{\int_0^\infty (\tau - \mu_{T_m})^{2A_c(\tau)d\tau}}{\int_0^\infty A_c(\tau)d\tau}} \qquad (3.21)$$

The μ_{T_m} is mean and σ_{Tm} is rms delay profile.

3.5.4 Coherence Bandwidth

The coherence bandwidth describes a significant explanation about the distortion of signal which transmitted. A measure of range of frequencies over which the channel may be considered flat is termed as coherence bandwidth. It is a frequency band in all the spectral components of the transmitted signal with equal gain and linear phase through a channel. Over this bandwidth the channel remains invariant. If the transmitted signal`s bandwidth is bigger than the coherence bandwidth, some sinusoidal part will go under channel fades variously from others. So the channel distorts signal severely. It is too difficult to recover the original signal.

3.5.5 Delay Spread (T_m)

If the delay is located between original signals and reflected signal the delay spread will be happened. The long delay spread could contribute to inter-symbol interference (ISI). Various frequencies generate various in multipath, for instance the ISI can effect on the wave length. If the longer symbols are used in communication system before ISI the long delay will occur. In addition if the reciprocal of bandwidth is longer than delay spread it approximately does not effect on system.

3.6 Large Scale Propagation Models

There are a lot of kinds of large-scale propagation model which are employed for calculation the path loss between ideal transmitter and receiver under different conditions. Before explaining the model, the few path loss should be explained.

Depending the result and equation the path loss can be negative or positive. The negative path loss will be added to whole transmitter power to specify the received power level. A positive path loss is subtracted from the transmitter power to specify the received power level. Path loss and radio frequency power commonly is represented in units of decibels. Generally Wi-Fi and Wi MAX have the receiver sensitivities about -85dBm for the strongest modulation techniques. The sensitivities in the satellite is -120dBm and in case of 3G (third generation) cellular handset occasionally receive signal is-80dBm.

The most famous propagation model is Friis Free Space equation and the equation (3.22) represents it

$$FS(dB)=10log_{10}((\frac{\lambda}{4\pi d})^{2}) \tag{3.22}$$

λ= wave length (m)

d= the transmitter to receiver separation distance (m)

The equation product a positive path loss quantity and discuss for the separation distance between transmitter and receiver and the wave length of transmitted signal. Another famous model of large scale is 2-ray ground reflection and log-normal shadowing.

3.6.1 Deterministic Approach

3.6.1.1 Free Space Propagation Model

The free space propagation model is employed to anticipate the received signal power when there is not any obstacle between transmitter and receiver. It means that there is Line Of Sight.

Satellite communication system generally undergoes free space propagation. The equation (3.23) indicates the free space propagation model.

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \tag{3.23}$$

The G is related to both A_e and λ . A_e is related to the physical size of antenna and the λ has relation to carrier frequency.

$$\lambda = \frac{c}{f} = \frac{2\pi c}{w_c} \tag{3.24}$$

The c is the speed of light and the f represents the carrier frequency in Hertz. When the L is 1 it means that there is not loss in the system hardware. According to the equation 3.23 if d is going to increase $P_r\,(d)$ would decrease and reverse. In addition, with increasing f, $P_r\,(d)$ tends to decrease.

3.6.1.2 Long-Distance Path Loss Model

The propagation model depicts, that mean of received power decreased dramatically and logarithmically with respect to the receiver distances according to the outdoor and indoor radio channel which is noted by:

$$\overline{PL}(d) = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_0 \tag{3.25}$$

X_0 is a Gaussian random variable with zero mean and variance in dB.

Chapter 4

SIMULATIONS AND RESULTS

4.1 Introduction

This chapter is devoted to analysis of the BER versus *Eb/No* performance of Hierarchical Modulation (QAM) system on AWGN and Rayleigh fading channel in various situations. At the first, Implementation has been done basic system with AWGN channel. By adding the Rayleigh fading channel, the system will be closed to real and finally, in order to achieve a perfect system, the conditions of shadowing were applied in log-normal shadowing block. In all aforementioned three steps, the BER has been calculated and its diagrams have been drawn by MATLAB simulation. By this step, the obtained system will be ready for evaluating BER versus *Eb/No*.

4.2 Simulation System Design and Bit Error Analysis

The main purpose of this part is to compare different rates of QAM (such as: 64-QAM, 16-QAM, 4-QAM and 2-QAM) in shadowing and without shadowing condition.

The system which has been used for simulation is a hierarchical modulation (QAM system) with AWGN and Rayleigh channels. This system consists of Bernoulli Binary Generator, Rectangular Pulse Filter, Complex Phase Difference, Align Signals, Down Sample, AWGN Channel, QAM Modulator, QAM Demodulator, Rayleigh Fading Channel and lognormal shadowing block. The range of the phase difference is generally from - π to π and the correlation window length to align signals is 400 samples. The applied Down Sampling Rate is 8.

The *Eb/No* in AWGN channel is from 0 to 40 dB, and 32 samples per symbol, the input signal power is normalized to 1 and 1/10000 seconds is the symbol period. The most important part of this simulation is design and implementation of Log-Normal shadowing which has several blocks such as Free Space Path Loss, Gaussian noise generator and Gain.

At the end, two different channels have been used: the first one is AWGN which has the best performance during this simulation and the second one is Rayleigh with maximum Doppler shift of 100 Hz, zero second delay and zero dB gain. In the next section, it is necessary to study and compare the performance of different QAM in AWGN and Rayleigh fading channels with considering the effect of shadowing.

4.3 Basic QAM System over AWGN Channel

The main purpose of this simulation is to recognize how the system works without existence of shadowing phenomena, detecting the important factors which have effect on Depth of Fading, or even analyzing different methods when only the AWGN channel is employed. The system consists different blocks such as M-ary QAM modulator and Demodulator, AWGN channel, Complex phase shift and Align Signal. In this part the basic system with AWGN channel will be evaluated.

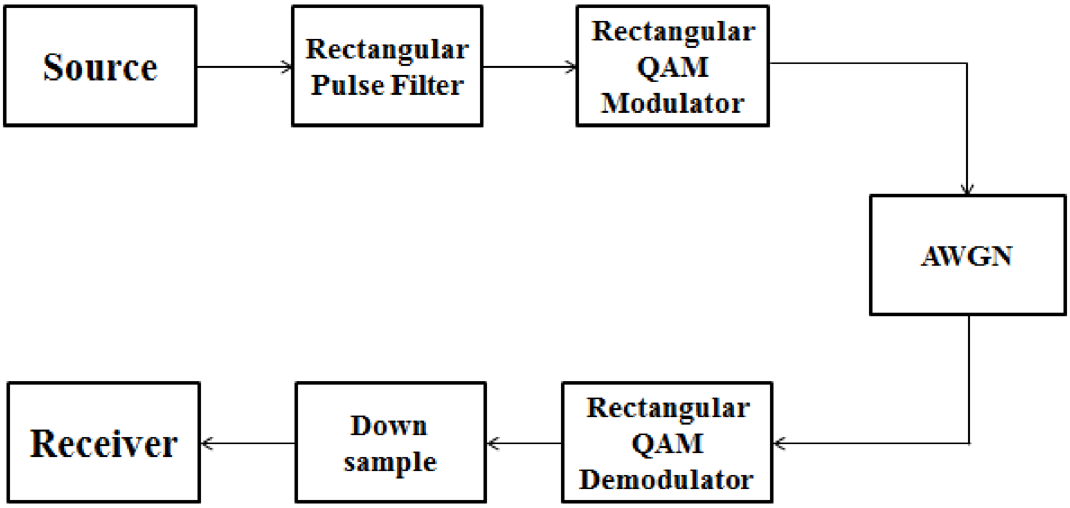


Figure 4.1: Block Diagram of QAM Systems over AWGN Channel

4.3.1 2-QAM System over AWGN Channel

In Figure 4.2 the simple line is related to the theoretical situation and the stars line shows the simulation result.

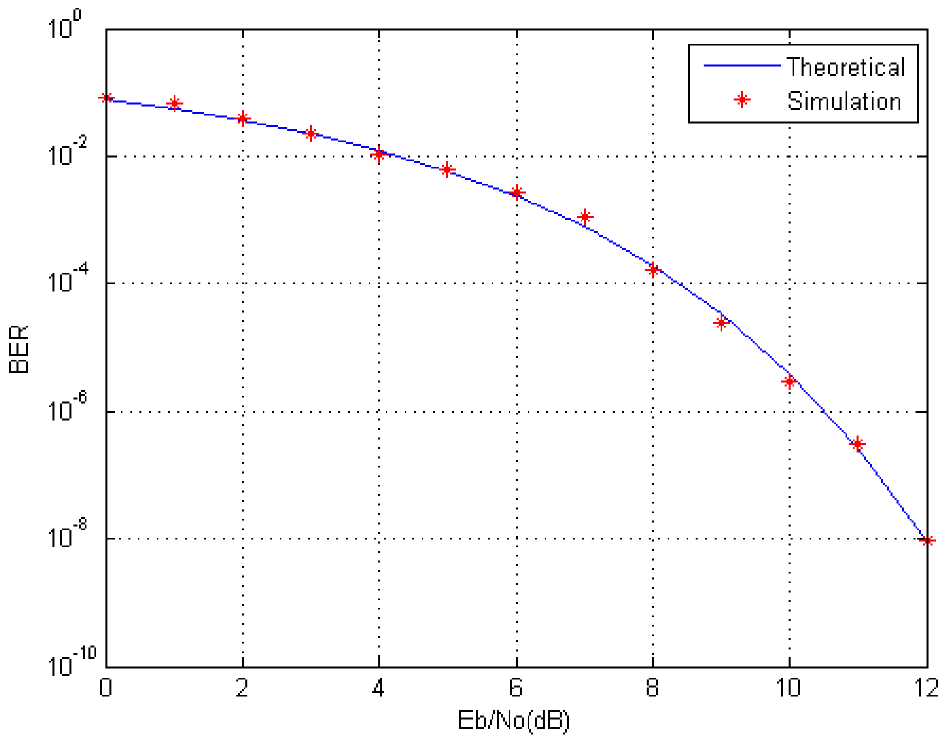


Figure 4.2: The Basic System Model of 2-QAM over AWGN Channel

4.3.2 4-QAM System over AWGN Channel

In this part, a 4-QAM over AWGN is used instead of 2-QAM system which simulation and theoretical values are still close to each other similarly which illustrates that BER value is same for both systems. The corresponding data are shown in Figure 4.3. It can be mentioned that, by applying 16-QAM and 64-QAM systems as BER value will have great amount, consequently the simulation would not be applicable.

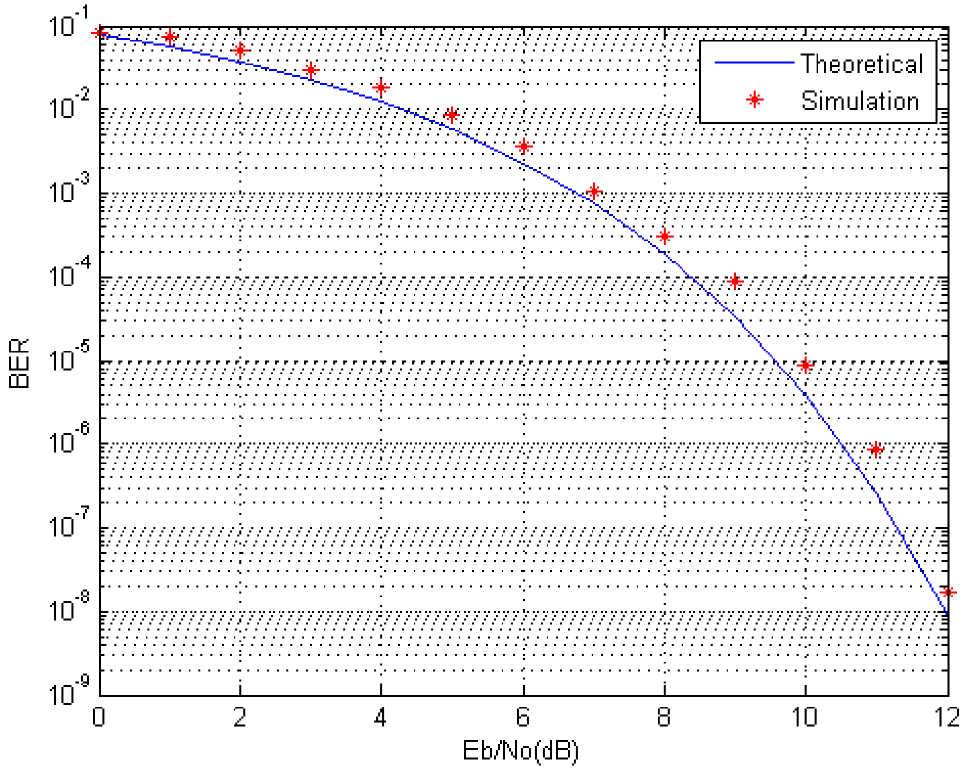


Figure 4.3: The Basic System Model of 4-QAM over AWGN Channel

4.4 QAM Systems over Rayleigh Channel without Shadowing Effect

The main idea of this section is to understand how systems act by adding Rayleigh channel. The system consists of different blocks such as: complex phase, difference gain, 2-QAM, AWGN channel and Multipath Rayleigh Fading channel with Doppler

Effect 100Hz which is in flat mode channel. Like previous case theoretical result is compared with simulation result.

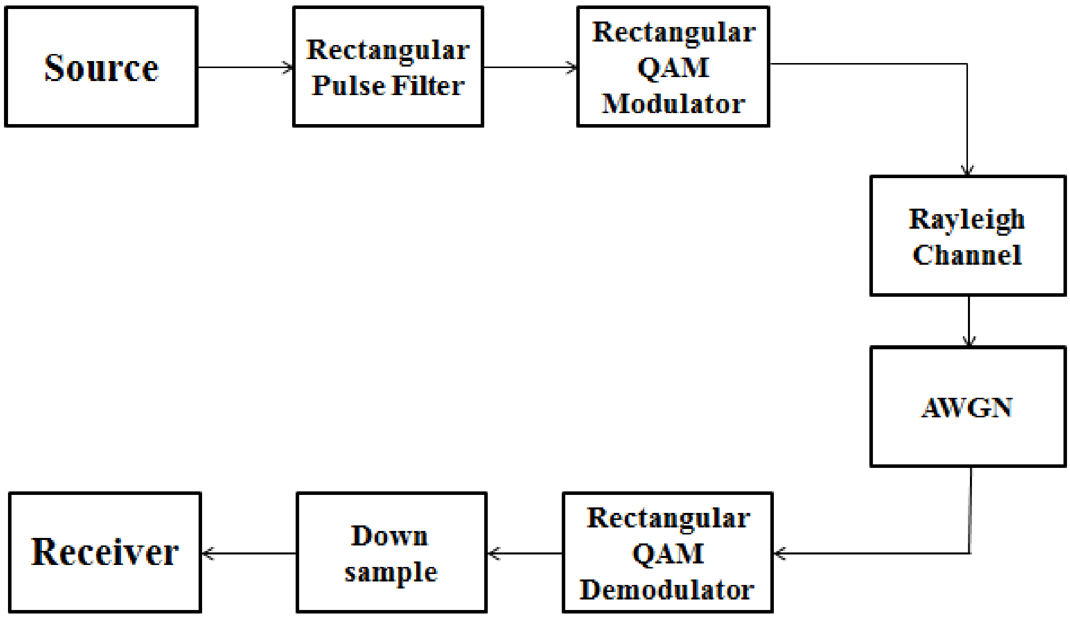


Figure 4.4: Block Diagram of QAM Systems over Rayleigh Channel

4.4.1 2-QAM System over Rayleigh Channel without Shadowing Effect

The Figure 4.5 indicated that at the beginning point, both graphs have similar BER. This condition is going to be continuing until *Eb/No* = 30dB.by looking on the Figure 4.2 it can be mentioned that after *Eb/No*= 30dB the 2-QAM system with Rayleigh channel has a phenomena that is name Irreducible and it causes by increasing the number of bit after *Eb/No*= 28dB. For instance in Eb/No=16dB the BER in 2-QAM system without shadowing according to the Figure 4.2 is 0.0053. As a result, it is obvious that the 2-QAM system which has Rayleigh channel without considering shadowing effect include the acceptable performance.

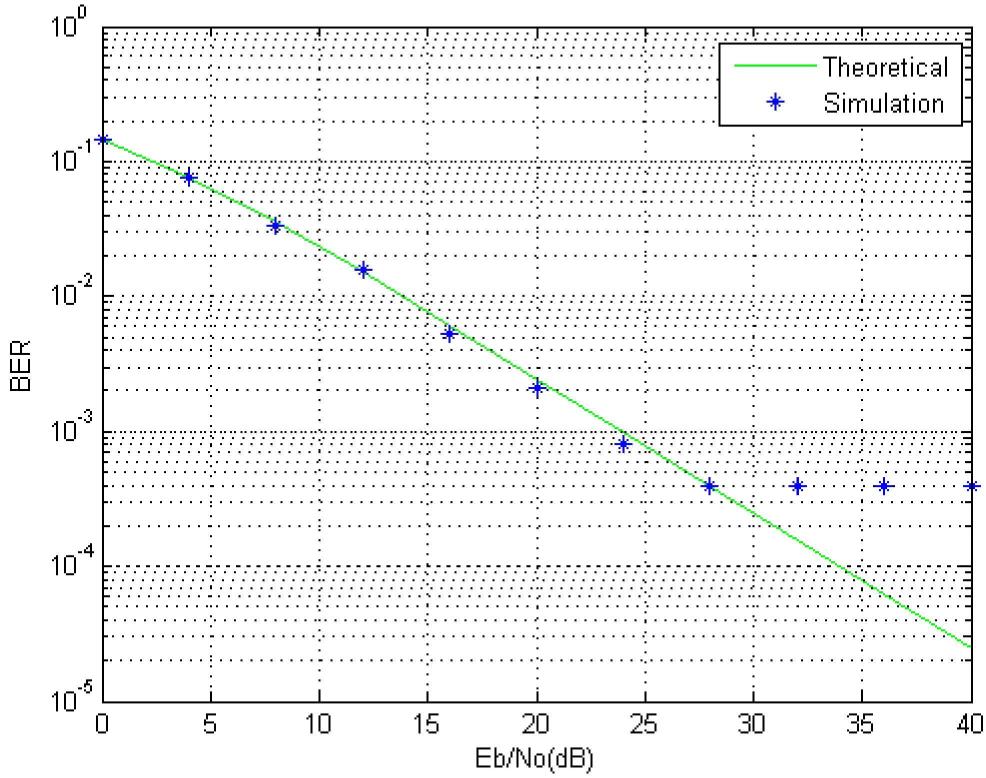


Figure 4.5: The Basic System Model of 2-QAM over Rayleigh Channel without Shadowing Effect (f_d =100Hz)

4.4.2 4-QAM System with Rayleigh Channel without Shadowing Effect

As it can be seen in Figure 4.6, both theoretical and simulation data have the same BER value at first. The BER value is approximately the same for these two graphs until Eb/No=28dB which at this point BER difference between them start to increase, it should be mentioned that the amount of this value for simulation is nearly 0.0007. By comparing Figure 4.3 which is related to 4-QAM with only AWGN channel with Figure 4.6 which has AWGN and Rayleigh channels, it is obvious that BER value has more greater amount when two channels are mixed together. By comparing Figures 4.5 and 4.6 it is obvious that BER in 4-QAM is a little more than 2-QAM. For instance For instance in Eb/No=16dB the BER is equal to 0.01.

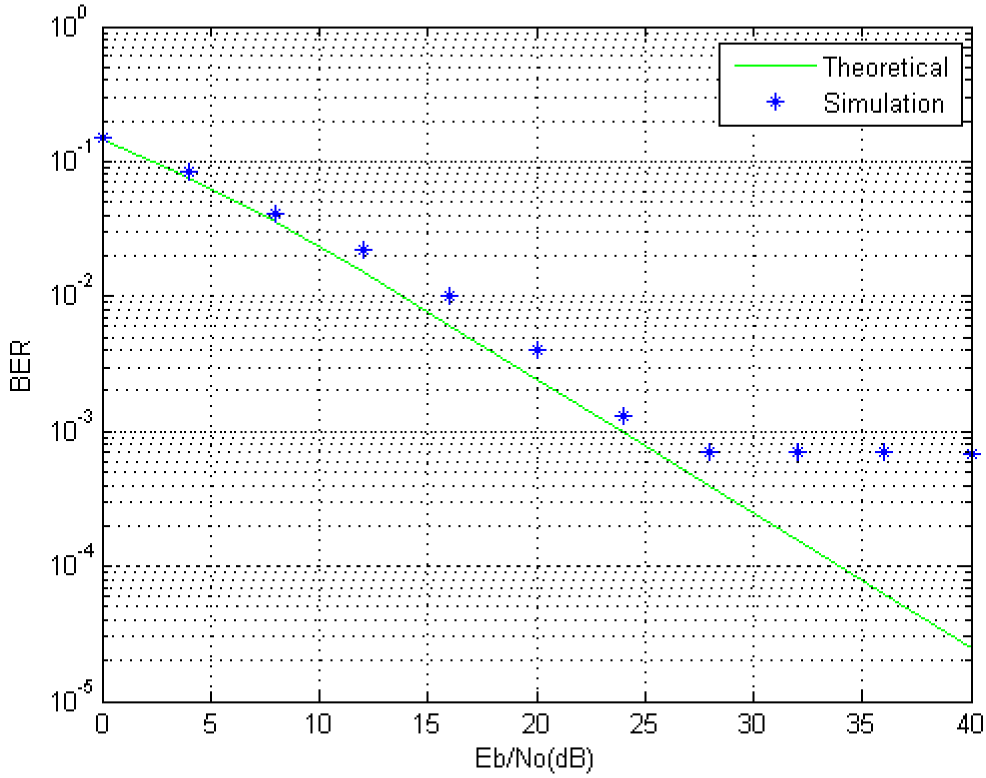


Figure 4.6: The Basic System Model of 4-QAM over Rayleigh Channel without Shadowing Effect (f_d =100Hz)

4.4.3 16-QAM System with Rayleigh Channel without Shadowing Effect

Figure 4.7 shows the basic system model of 16-QAM over Rayleigh channel. By comparing this Figure 4.7 with Figure 4.6, it can be mentioned that in the Figure 4.6 BER difference starts increasing for simulation and theoretical at point *Eb/No*=24 while in the Figure 4.7 this variation starts at *Eb/No*=16. For instance, BER value at point *Eb/No*=24 is 0.0108 for 16-QAM system, while this amount was 0.0013 for 4-QAM system and it means BER value for 16-QAM system is greater than 4-QAM system.

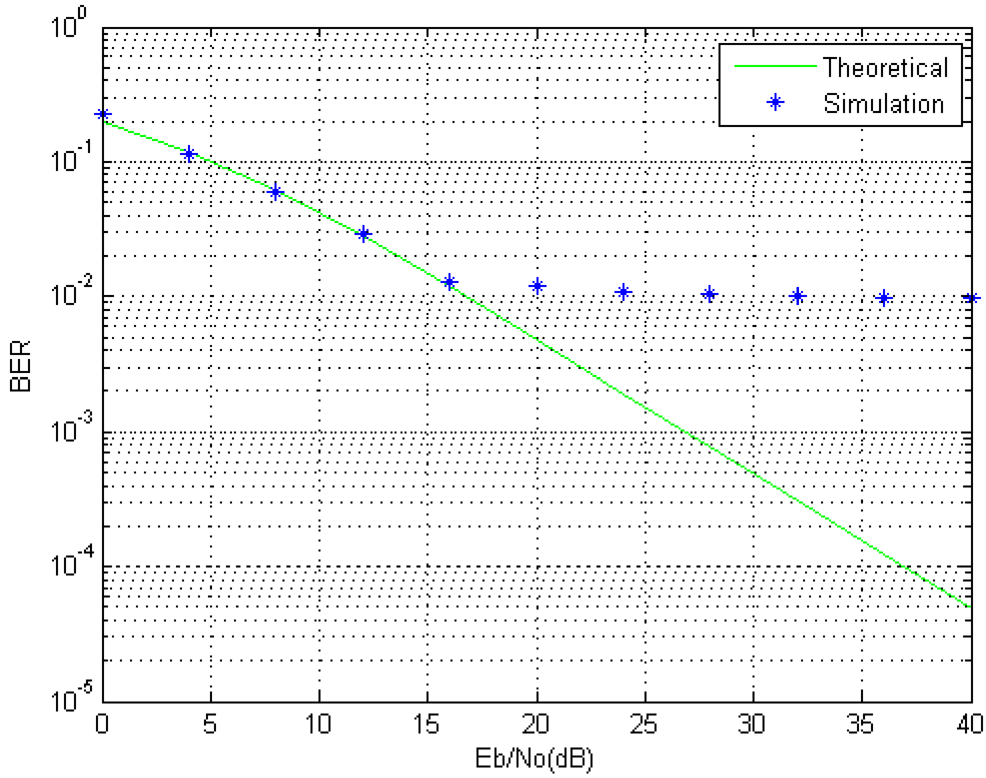


Figure 4.7: The Basic System Model of 16-QAM over Rayleigh Channel without Shadowing Effect (f_d =100Hz)

4.4.4 64-QAM System over Rayleigh Channel without Shadowing Effect

A 64-QAM system is shown in Figure 4.8. It can be seen the simulation and theoretical values have greater difference compare to 16-QAM and 4-QAM systems. This would be as the result of vast number of data which are transmitting. Figure 4.8 can illustrate that the BER value for high modulation systems are much higher than low modulation systems. As an example, the BER value at point *Eb/No*=24 for 64-QAM system is nearly 0.0643 which is high error compare to 4-QAM system.

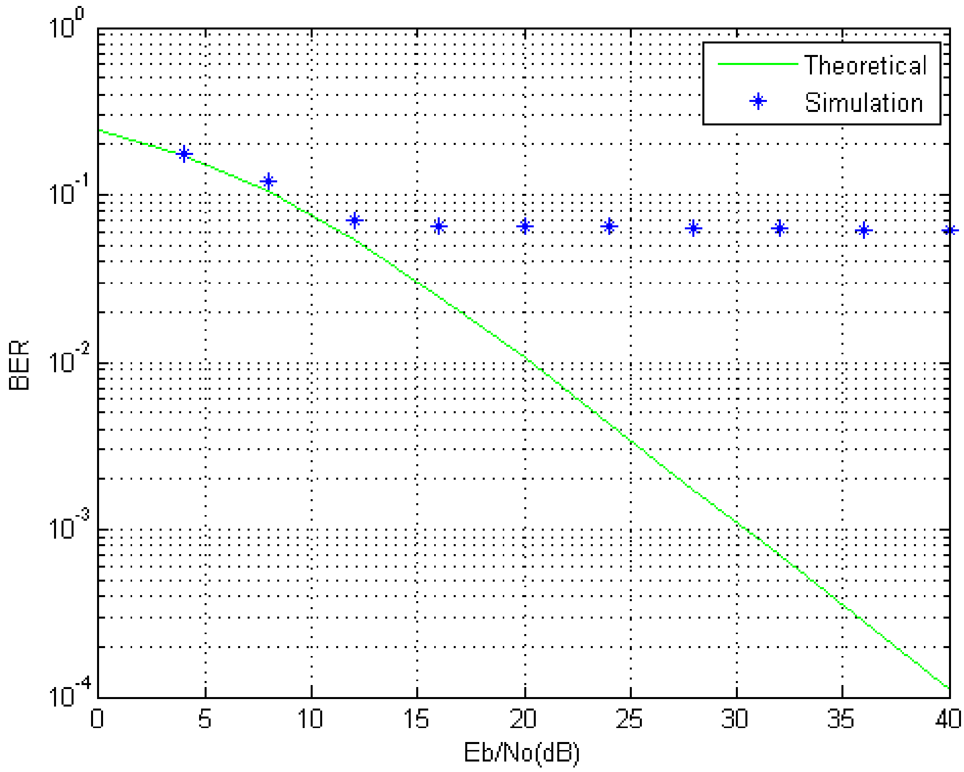


Figure 4.8: The Basic System Model of 64-QAM over Rayleigh Channel without Shadowing Effect (f_d =100Hz)

4.4.5 Different Levels of QAM System over Rayleigh Channel without Effect of Shadowing:

In Figure 4.9 all the corresponding graphs for 2,4,16 and 64-QAM systems are shown in one Figure in order to better compare their differences. It can be Figured out that the BER value for 2-QAM system is less than the other systems. Table 4.1shows the exact BER value for *Eb/No*=8, 24 and 36db.

Table 4.1: Different Levels Modulation over Rayleigh Channel

	2-QAM	**4-QAM**	**16-QAM**	**64-QAM**
Eb/No=8	0.0337	0.0414	0.0590	0.1201
Eb/No=24	7.99 e-4	12.99 e-4	0.0108	0.0643
Eb/No=36	3.96 e-4	6.94 e-4	0.0099	0.0618

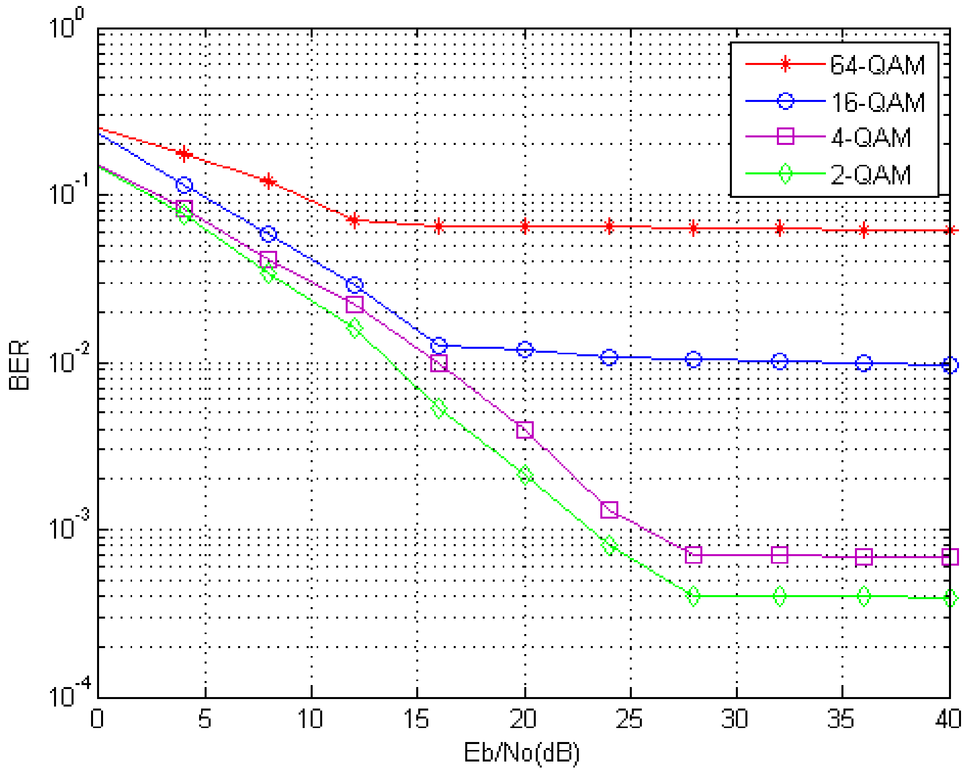


Figure 4.9: BER Simulation in QAM System over Rayleigh Channel in Different Levels of Modulations (f_d =100Hz)

In the next part of this chapter the effect of Depth Fading and shadowing will be analyzed.

4.5 QAM with Rayleigh Channel with the Effect of Shadowing

The target of this section is to determine the BER of Rayleigh channel with considering the effect of shadowing. The system has various blocks such as: M-ary QAM modulator/demodulator, AWGN channel and Rayleigh channel with 100Hz Doppler Effect and extra block that simulate the shadowing effect. This block (log normal shadowing) has sub models such as Free Space Path Loss, Gaussian Noise Generator, Gain, Math Function and multiplier which is implemented based on equation (3.25).

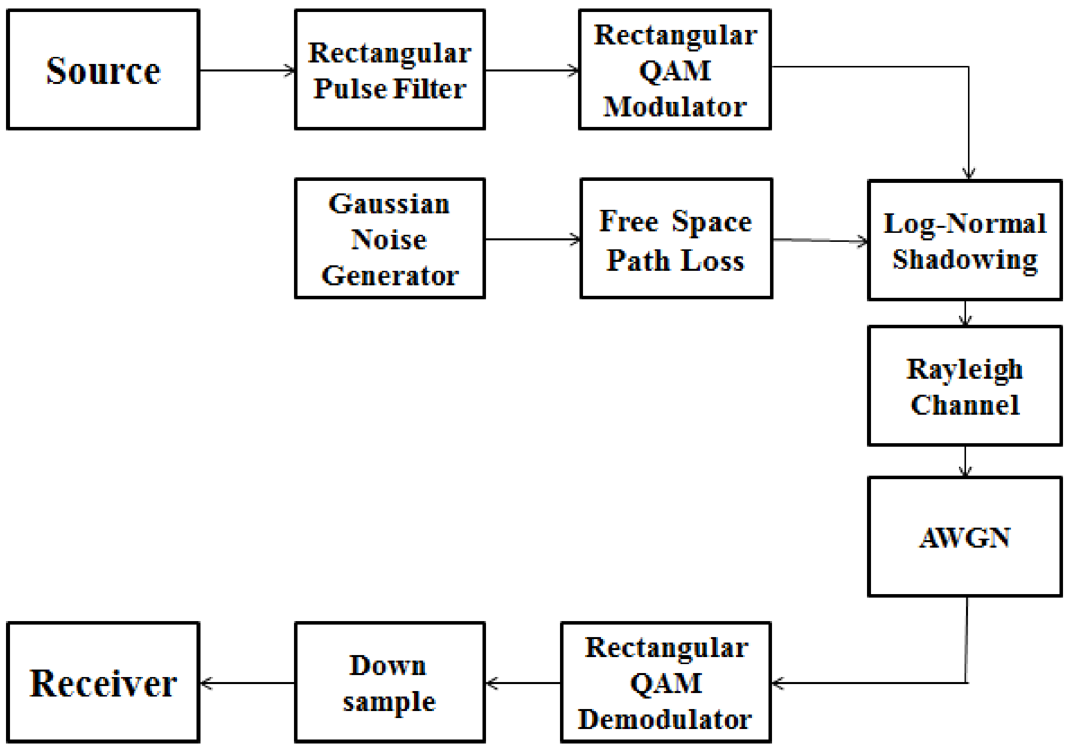


Figure 4.10: Block Diagram of QAM Systems over Rayleigh Channel with Shadowing Effect

4.5.1 2-QAM System over Rayleigh Channel with the Effect of Shadowing

The Figure 4.11 illustrates the BER in 2-QAM system over a Rayleigh channel with considering the effect of shadowing. It is expected that the system with Rayleigh channel without shadowing indicates better performance. The system which works with considering shadowing effect shows the worse BER. As an example, the BER value at point *Eb/No*=16dB for Figure 4.11 is nearly 0.0071 which is more compare to Figure 4.5 that is 0.0053.It means that 2-QAM system loss 0.0018 information due to the transmit for exist shadowing effect.

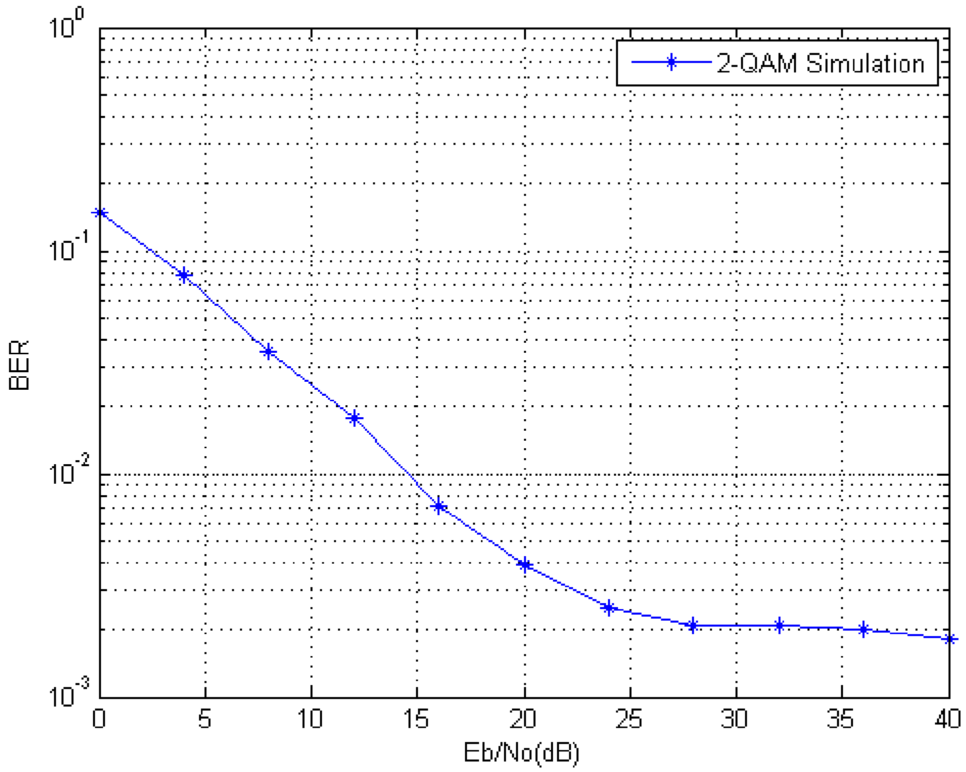


Figure 4.11: The Basic System Model of 2-QAM over Rayleigh Channel with Shadowing Effect (f_d =100Hz, σ=10 dB)

4.5.2 4-QAM System over Rayleigh Channel with the Effect of Shadowing

In Figure 4.12 it can be seen that the while the size of modulation increasing, BER increase also. For instance the value of BER at *Eb/No*=16dB in Figure 4.11 is 0.0071 but this value on Figure 4.12 is equal to 0.0245. As the result, it can be mentioned that the shadowing effect on 4-QAM system is more obvious than 2-QAM system which is also based on expectation. On the other hand the result of comparing the Figure 4.12 with 4.6 said that 4-QAM in transmitting data loss about 0.01 information.

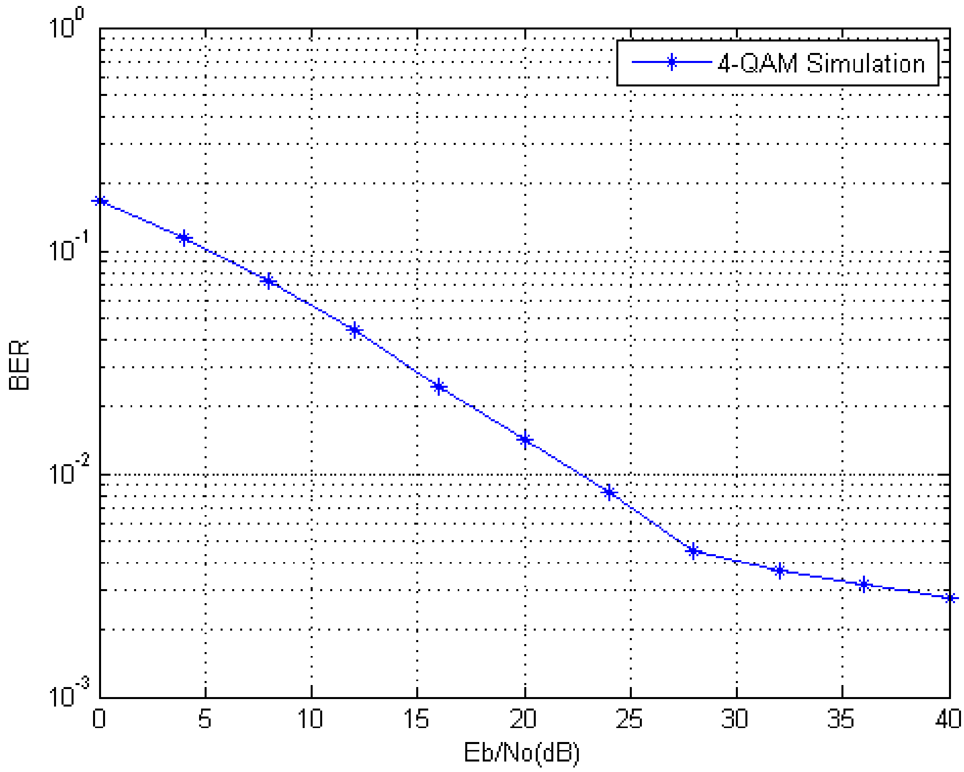


Figure 4.12: The Basic System Model of 4-QAM over Rayleigh Channel with Shadowing Effect (f_d =100Hz, σ=10 dB)

4.5.3 16-QAM System over Rayleigh Channel with the Effect of Shadowing

The main target of this section is BER analysis in the 16-QAM system with shadowing vs. the 16-QAM system without shadowing. As can be seen the Figure 4.13 shows the system with shadowing has worse performance than the system without shadowing. For instance in Eb/No=16dB the BER in system with shadowing is 0.3114 and this parameter in system without shadowing is 0.0127. As a result the 16-QAM system loss about 0.30 information due to the transmit for exist shadowing effect on the channel.

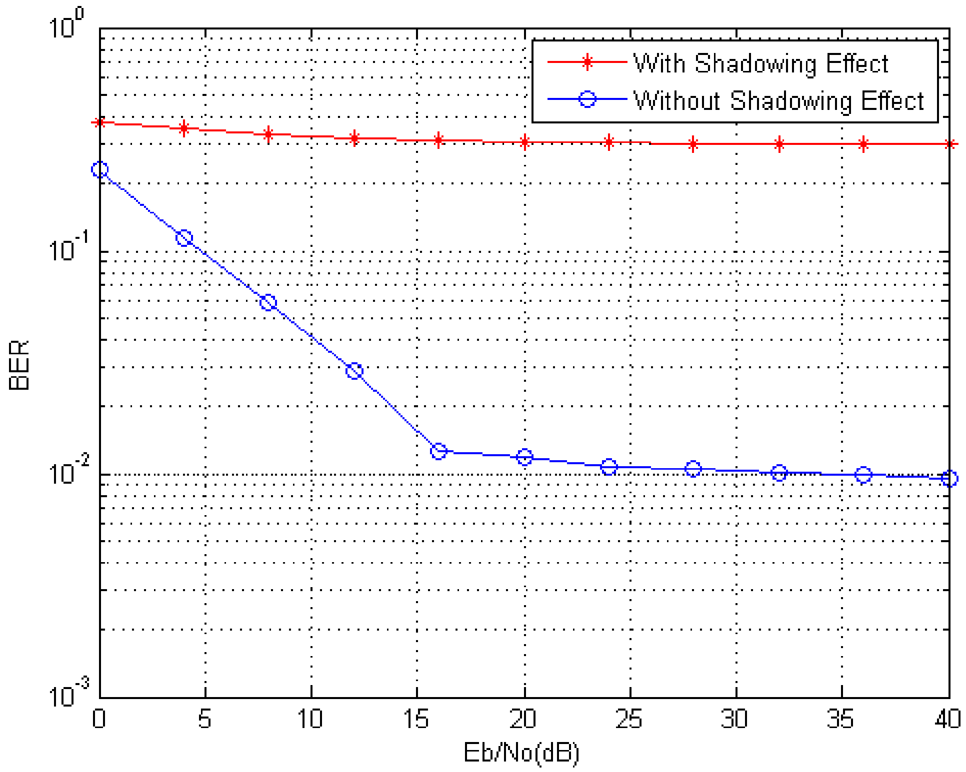


Figure 4.13: The Basic System Model of 16-QAM over Rayleigh Channel with Shadowing Effect (f_d =100Hz, σ=10 dB)

4.5.4 64-QAM System over Rayleigh Channel with the Effect of Shadowing

The main goal of this section is BER analysis in the 64-QAM system with shadowing vs. the 64QAM system without shadowing. As the Figure 4.14 illustrates the system with shadowing has worse performance than the system without shadowing. For instance in Eb/No=16dB the BER in system with shadowing is 0.4344 and this parameter in system without shadowing is 0.0651. As result the result the 64-QAM system loss about 0.42 information due to the transmit for exist shadowing effect on the channel.

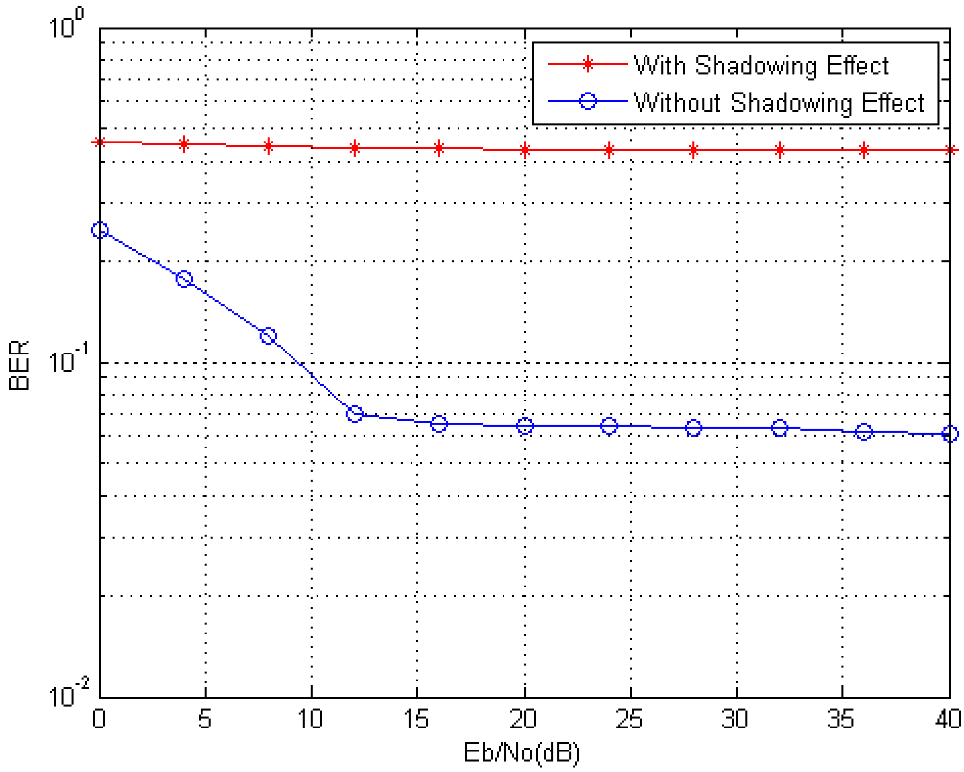


Figure 4.14: The Basic System Model of 64-QAM over Rayleigh Channel with Shadowing Effect (f_d =100Hz, σ=10 dB)

4.5.5 Different Levels of QAM System with Rayleigh Channel with Shadowing Effect

In Figure 4.15 all the corresponding graphs for 2, 4, 16 and 64-QAM systems have been shown. It can be mentioned that, the effect of shadowing on 64-QAM system is greater than the others while it has the least effect on 2-QAM system. Furthermore, the exact BER values for the points Eb/No= 8, 24 and 36 are described in Table 4.2.

Table 4.2: Different Levels Modulation over Rayleigh Channel

	2-QAM	**4-QAM**	**16-QAM**	**64-QAM**
Eb/No=8	0.0355	0.0733	0.3310	0.4488
Eb/No=24	0.0025	0.0083	0.3038	0.4316
Eb/No=36	0.0020	0.0032	0.3006	0.4304

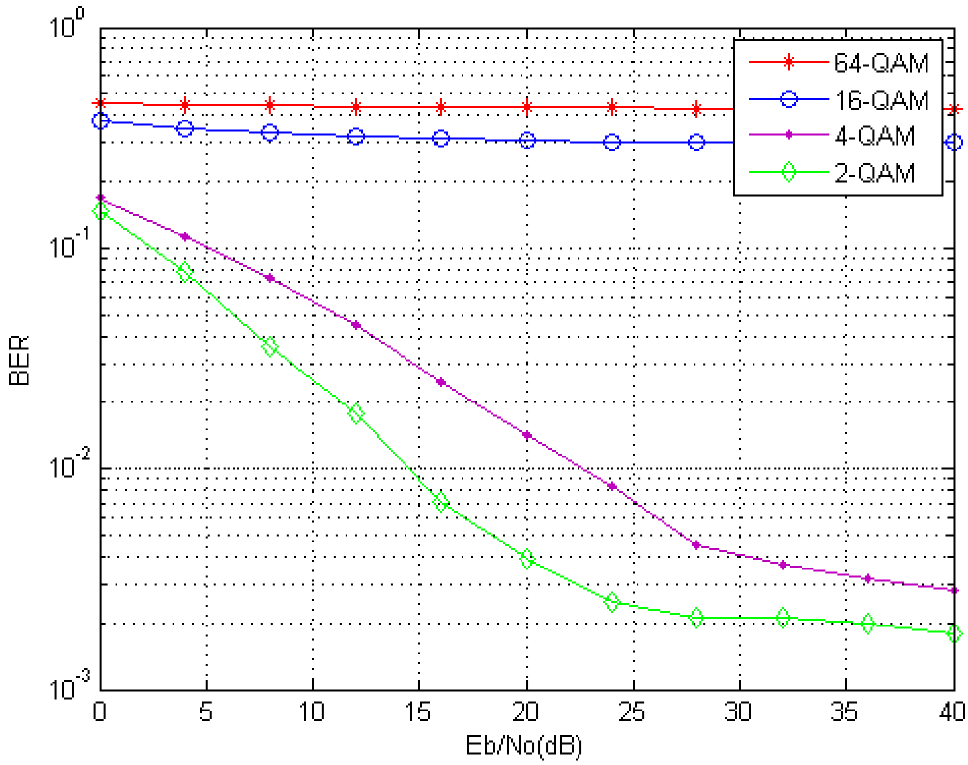


Figure 4.15: BER Simulation in QAM System over Rayleigh Channel with Shadowing Effect in Different Levels of Modulations (f_d =100Hz, σ=10 dB)

4.6 Comparing Shadowing Effect versus without Shadowing Effect

The main aim of this research is to find out different factors which have effects on the situation with shadowing and to find out a way for controlling these effects for the goal of reaching better performance and being more close to the theoretical situation.

The main target of this section is comparing the effect of shadowing with theoretical. The system has different blocks such as: 2-QAM, AWGN channel and Rayleigh channel with 100Hz Doppler Effect and flat fading channel which extra block that simulate the shadowing effect. This block has subsystems such as Free Space Path Loss, Gaussian Noise Generator, Gain, Math Function and Multiplier.

By looking on the Figure 4.16, it can be observed that both lines show the same BER before 20 *Eb/No*, but after these certain *Eb/No* each line shows different pattern. It can be observed that the squares line which is the situation with shadowing effect shows more BER after 20 *Eb/No* but the starts line which illustrates the situation without shadowing effect recorded less BER after 20 *Eb/No* and it should be mentioned that the same results were be predicted before this certain analyzes.

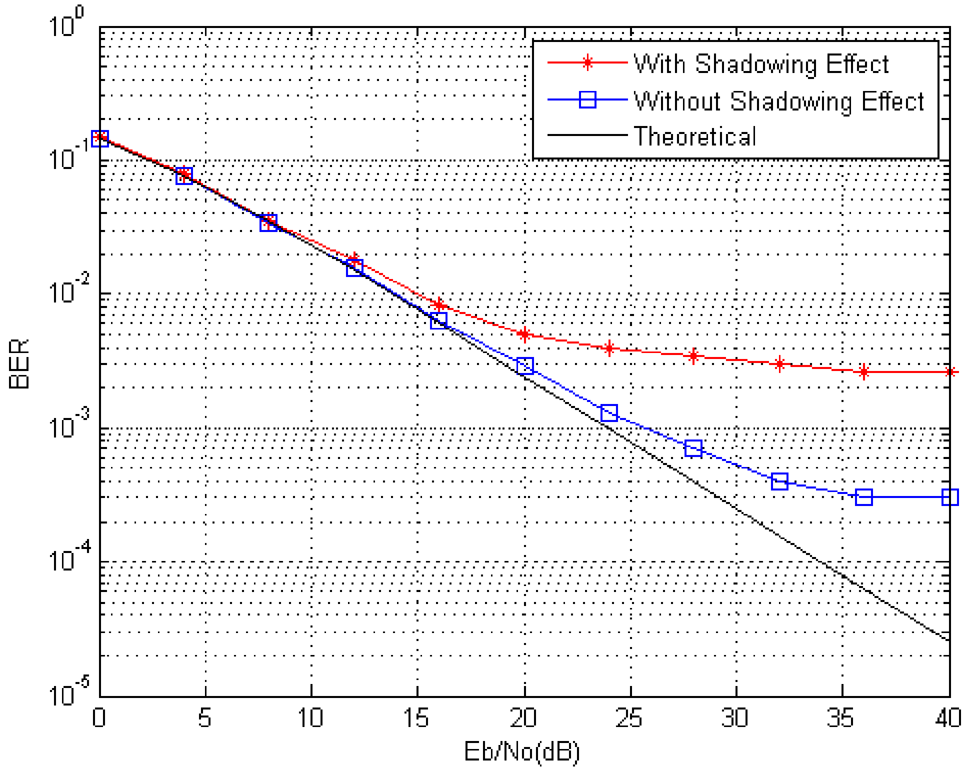


Figure 4.16: Comparing the BER Versus *Eb/No* for BPSK in Rayleigh Fading Channel With and Without Shadowing Effect With the Theoretical Results (f_d =100 Hz , σ =10 dB)

By looking more precisely on the Figure 4.16, it can be observed that the starts line which illustrates the condition without shadowing is more close to the theoretical situation but it should be mentioned that the difference between these two lines is not significant before 20 *Eb/No* but after this certain *Eb/No* this difference will be more significant.

4.7 Important factors in Deep Fading

The main purpose of this part is comparing different factors which have effect on shadowing. In the first step these factors should be identified, in the next step various effects of them should be analyzed and finally different methods for controlling these effects must be presented. There are various parameters which can be presented in this part such as: stop time simulation, initial seed and variance of the lognormal distribution. In this part of chapter 4 different effects of these statistics should be analyzed separately based on the model which presented in the previous section. In this study, it can be found that we can't predict the simulation performance based on the difference in stop time and initial seed and we can't also control the result. It should be indicated that the only important factor in lognormal shadowing effect is variance which it can be predicted.

4.7.1 Variance

One of the parameters which has effect on Depth Fading is variance. Like the other cases for finding the relation between these variable and BER, several value of this parameter were checked. By looking on the Figure 4.17 it can be fined that by increasing the value of variance, BER will increase.

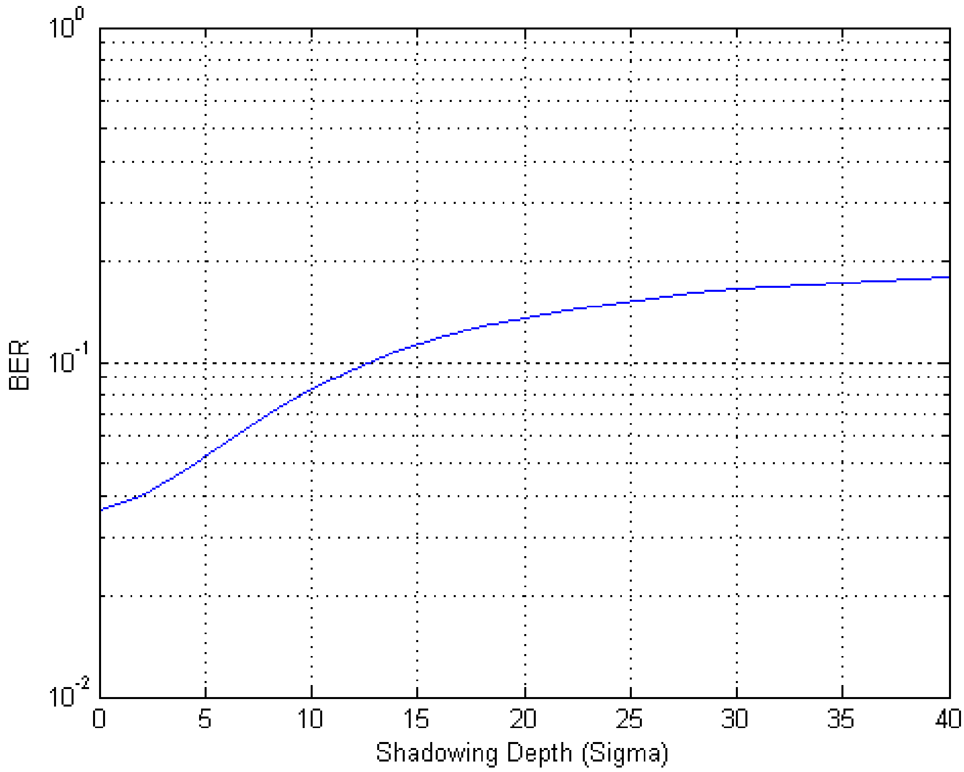


Figure 4.17: BER vs Shadowing Depth (Sigma) for BPSK Modulated Signal over a Rayleigh Fading Channel. (*Eb/No*=8dB in AWGN, f_d =100Hz)

By looking on the Figure 4.17 it can be understand that by increasing sigma, BER will increase. That means there is a positive relation between these two variables. As a result by controlling sigma, BER will be controlled. In the next Figure the effects of different sigma will be discussed.

4.8 Compare of Different Levels of Sigma

By looking more precisely on the Figure 4.18, it can be mentioned that there is a direct relation between sigma and BER. Like the previous diagram, it can be observed that by increasing the value of sigma, BER will increase.

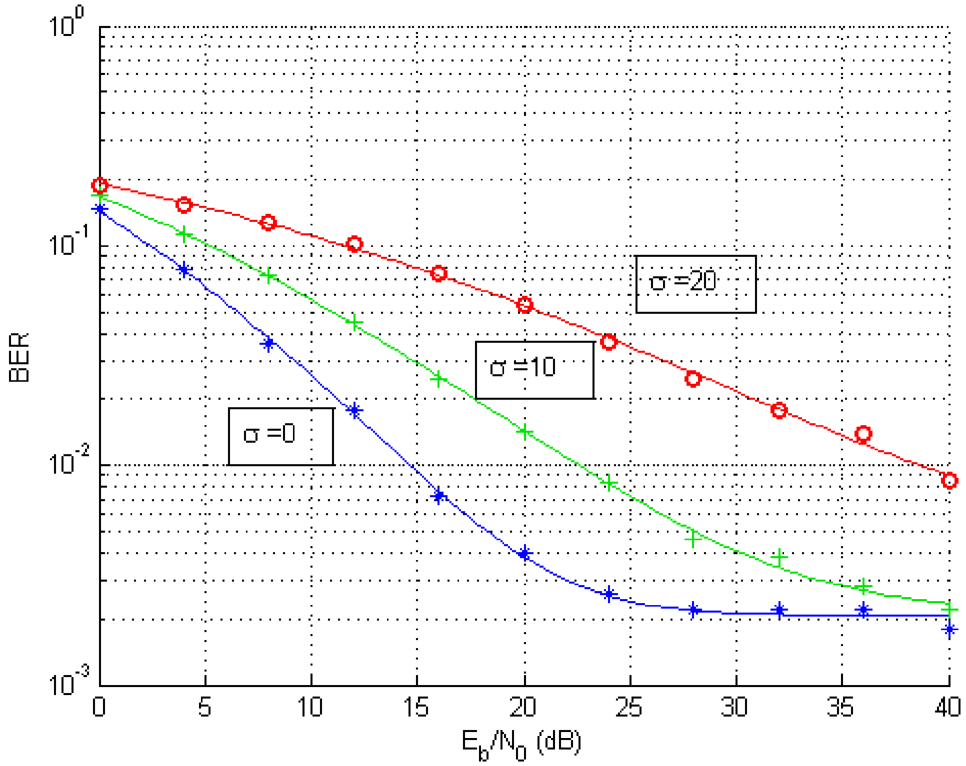


Figure 4.18: Comparison of BER Versus *Eb/No* for BPSK over a Rayleigh Fading Channel for Different Levels of Fade Depth (sigma) in dB (f_d =100Hz , σ = 0, 10, 20 dB)

In the Figure 4.18, the stars line is related to the case which sigma is equal to 0, the pluses line is for the situation which sigma is equal to 10 and finally the circles line is related to the case which the value of sigma is 20. It can be observed that by increasing sigma BER will increase, that means BER for $\sigma = 0$ is less than BER for $\sigma = 10$ and in the other hand BER for $\sigma = 10$ is less than BER for $\sigma = 20$dB.

4.9 Image Transmission

In this part, it is tried to compare and investigate the obtained results in another visually way. As we know, the input which has been applied to the system is randomly obtained by the Bernoulli binary generator. But the results and effects of channels was not completely clear. So, by considering an image as a fixed input we can compare and investigate the results in more detail.

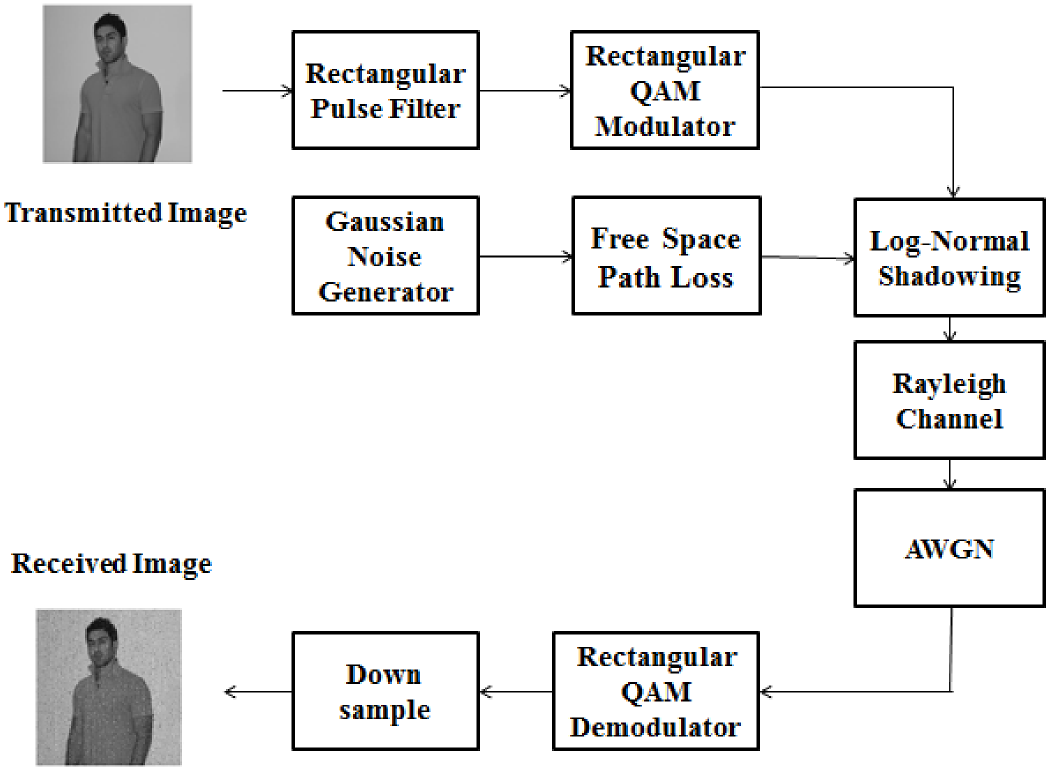


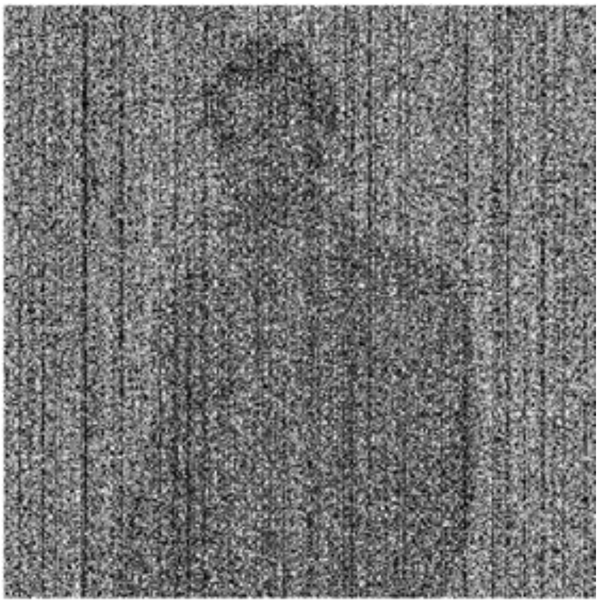
Figure 4.199: Block Diagram of Image Transmitting over QAM System

The transmitted image is indicated In Figure 4.20:

Figure 4.20: Transmitted Image

4.9.1 Transmitted Image Analysis in Different Rates of QAM with Shadowing

In Figure 4.20 the results of the different rates of QAM are shown as follows. Figure 4.20 (a) indicates the output of 2-QAM system and Figure 4.20 (b) shows the output of 4-QAM and part (c) and (d) of Figure 4.20 depict the results which obtained by 16-QAM and 64-QAM respectively.



(a) 64-QAM (f_d =0.001 Hz, *Eb/No*=18 dB, σ =4 dB)

(b) 16-QAM (f_d =0.001 Hz, *Eb/No*=18 dB, σ=4 dB)

(c) 4-QAM (f_d = 0.001 Hz, *Eb/No*=18 dB, σ=4 dB)

(d) 2-QAM (f_d = 0.001 Hz, *Eb/No*=18 dB, σ=4 dB)

Figure 4.21: Comparison of Received Image for Different Levels of QAM systems

By looking at the above Figure 4.20, it is clearly obvious that the shadowing effect was negligible on 2-QAM system and 64-QAM has been affected by shadowing more than the other systems and the result shows that, more than 38% of image information is missed. Following Table 4.4 indicates the computed BER values.

Table 4.3: Computed BER Values from Different levels of QAM

M-ary QAM	2-QAM	4-QAM	16-QAM	64-QAM
BER	0.005	0.007	0.148	0.381

4.9.2 Analysis on 2-QAM System with Different Depth of Fading

With respect to the Table 4.4 and shadowing effect on 2-QAM which was the minimum effect among the other systems, we will only focus on 2-QAM system. Following Figure 4.21 shows 2-QAM system results with applying different σ values (Depth of Fading).

(a) 2-QAM (f_d = 0.001 Hz , *Eb/No*=18 dB, σ=12 dB)

(b) 4-QAM (f_d = 0.001 Hz , *Eb/No*=18 dB, σ=10 dB)

(c) 2-QAM (f_d = 0.001 Hz , *Eb/No*=18 dB, σ=7 dB)

(d) 2-QAM (f_d = 0.001 Hz , *Eb/No*=18 dB, σ=4 dB)

Figure 4.22: Comparison of Fade Depth (σ) for BPSK over a Rayleigh Fading

Transmitted image has been applied to 2-QAM system with different fade depth (σ) and as it is expected (see Figure 4.17 and Figure 4.18) by increasing σ, the quality of received image has been reduced.

Chapter 5

CONCLUSION

5.1 Conclusion

The main aim of this thesis is to investigate the performance of hierarchically modulated (QAM) signals over multipath fading and Log-Normal Shadowing channel. At the first step the different systems with 64-QAM, 16-QAM, 4-QAM and 2-QAM are simulated for analyzing the performance of hierarchical modulation. The following results are obtained: The effect of shadowing on 64-QAM is more severe than 16-QAM, 4-QAM and 2-QAM. For example, as shadowing increases, the BER also increases and becomes useless at around 0.45 for 64-QAM with *Eb/No*=24dB. These BER is observed to drop only to 0.3038 for 16-QAM but the BER drops drastically to useful levels of 0.0083 and 0.0025 respectively for 4-QAM and 2-QAM. As a result 2-QAM is shown to perform much better than higher levels of modulation under shadowing.

In the second step, 2-QAM is focused and simulated over AWGN channel and Rayleigh channel under the effect of shadowing. The target of this section is to detect which parameters are important in shadowing effect.

In the third scenario, the 2-QAM system under different levels of shadowing is simulated and the following results are obtained: The shadowing depth and systems

BER performance are closely related such that when shadowing depth increases, the BER performance is reduced.

Finally in the last scenario, the random input is replaced by an image in order to observe the effect of shadowing on the image quality. The quality of the received images is shown an obvious degradation under worsening shadowing conditions and increasing levels of hierarchical modulation. As it is expected, when 64-QAM modulation is used, the image output had the poorest quality in comparison with the others and 2-QAM generates the best quality. When the shadowing condition is worsened, the variance of shadowing increases and the quality of output image is decreased.

5.2 Future Work

In this research the influence of different shadowing conditions on different QAM-systems is studied. As a future work, advanced performance improvement techniques such as diversity, equalization, source coding and channel coding could be employed and the performance improvement could be estimated by computer simulations under various shadowing conditions and different levels of hierarchical modulation in order to yield higher throughput.

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