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Simple Analysis of BER Performance for BPSK and MQAM Over Fading Channel

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Abstract: In communication systems during convey messages through wireless channels many factors may effect quality of the messages. Multipath fading, interference and signals phase shift playing crucial roles in deterioration conveying signals. Bit Error Rate (BER) is one of the key metrics which employing to assess quality of such traveling signals. So, this paper is conducted to analyze influence of different factors on the BER with considering effect of multipath fading. Multipath is the propagation phenomenon that results in radio signals' reaching the receiving antenna by two or more paths. The effects of multipath include constructive and destructive interference, and phase shifting of the signal. This distortion of signals caused by multipath is known as fading. Fading causes fluctuations in the attenuation of the signals as traveling along the medium. There are many fading models for the distribution of the attenuation, in this paper Rayleigh fading channel is considered. BER performance for BPSK and MQAM signals over AWGN and Rayleigh fading channels are investigated and analyzed with Matlab. The achieved results show that as the modulation order increases bit error rate also increases, and the BER for BPSK and MQAM over an AWGN channel is less than that obtained with conveying the signals over Rayleigh channel for certain values of signal to noise ratio.

Keywords: BER, Fading channel, Bit error probability, PSK, QAM**.**

1. Introduction

Physical channels with time-varying transmission characteristics may be characterized as time-varying linear filters [1]. Such linear filters are described by a time-varying impulse response h(t). In mobile cellular radio transmission, the signals transmitted from the base station to the mobile receiver, is called downlink signals, are usually reflected by surrounding objects, such as buildings, hills, and other obstructions. The signals arrive to the receiver via different propagation paths will be collected with different delays. These signal components are known as multipath components [2].

The multipath channel is its time-varying nature. This time variation arises because either the transmitter or the receiver is moving, and therefore the location of the reflectors in the transmission path, which give rise to multipath, is changing over time. Thus, if we repeatedly transmit pulses from a moving transmitter, it will observe changes in the amplitudes, delays, and the number of multipath components corresponding to each pulse. However, these changes occur over a much larger time scale than the fading due to constructive and destructive addition of multipath components associated with a fixed set of scatters. The signal multipath components generally have different carrier-phase offsets and hence, they may be added destructively at times, resulting in signal fading [1]. Due to presence of fading and noise, the received signal can be combination of first modification of the transmitted signal (characterized by the channel impulse response) and second addition of noise. Mathematically it may be expressed as:

$$y(t) = h(t) * s(t) + w(t) \qquad (1)$$

Here, y(t) is the received signal, h(t) is the channel impulse response, s(t) is the transmitted signal and w(t) is the additive noise [2]. There is a variation in the received signal power over distance due to path loss and shadowing. The path loss is caused by dissipation of the power radiated by the transmitter as well as the effects of the propagation channel. Shadowing is caused by obstacles between the transmitter and the receiver that absorb power. When the obstacle absorbs all the power, the signal is blocked. Variation due to path loss occurs over very large distances (100-1000 meters), whereas

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variation due to shadowing occurs over distances proportional to the length of the obstructing object (10-100 meters in outdoor environments and less in indoor environments) [3]. The effect of shadow fading differs from multipath fading in an important way. The duration of a shadow fade lasts for multiple seconds or minutes, and hence occurs at a much slower time-scale compared to multipath fading.

On the left side of Fig. 1, at first the signal appears very random. Upon closer look we can break it down into three main components: propagation path Loss, shadowing or large scale fading and multipath fading or small scale fading. The performance of the communication system, measured in terms of the probability of error (BER), depends on the received SNR (E_b/N_0) where E_b is the transmitted energy/bit and $N_0/2$ is the power spectral density of the additive noise. BER is inversely related to SNR, that is high BER causes low SNR. High BER causes increases packet loss, increase in delay and decreases throughput.

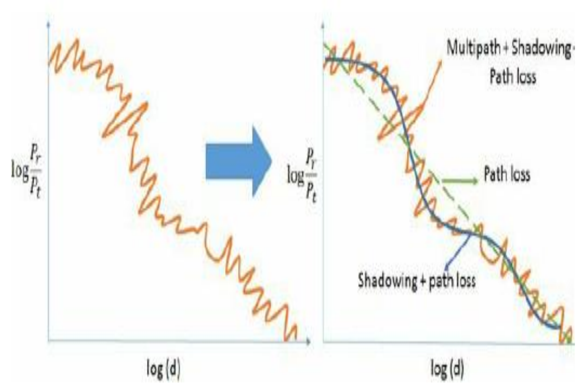

Figure. 1 Path Loss, Shadowing and Multipath versus Distance [2].

Hence, the additive noise ultimately limits the performance of the communication system [1]. The bit error ratio is the number of error bits divided by the total number of transferring bits during a studied time interval. BER is a unit less performance measure, often expressed as a percentage. In simple form is given by [4]:

$$BER = \frac{number\ of\ bit\ in\ error}{total\ number\ of\ bit\ sent} \qquad (2)$$

The bit error probability, PE, is the expectation value of the bit error ratio. When data is transmitted over a data link, there is a possibility of errors being introduced into the system [5]. In practice, for a fixed E_b/N_0, acceptable BER is possible with channel coding. This can be achieved by adding additional digits to the transmitted information stream [6]. These additional digits do not have any new information, but they make it possible for the receiver to detect and correct errors, thereby reducing the overall probability of error [7]. This paper is organized as follows. Multi-path fading will be introduced in Section 2, factors influencing fading in Section 3 and type of fading in Section 4. The simulation result of Matlab demonstrates in Section 5, which provide a brief discussion of the obtained results. Finally, conclusions are drawn in Section 6.

2. FADING

The world of wireless communications is nowadays facing a serious problem of growing the interference level [8], multi-path is the propagation phenomena that results in radio signals reaching the receiving antenna by two or more paths [2]. When the waves of multi-path signals are out of phase, reduction of the signal strength at the receiver can occur. This can result in deep nulls in the received signal power due to destructive interference. The Causes of multi-path include atmospheric scattering, ionosphere reflection, reflection from water bodies and terrestrial objects such as mountains and buildings. Delayed signals are the result of reflections from terrain features like trees, hills, mountains, or buildings. These delayed waves interfere with the direct wave and cause inter-symbol interference (ISI) which causes degradation of network performance. Multipath radio signal propagation occurs on all terrestrial radio links [9]. The transmitted signal does not leave the transmitting antenna in only the direction of the receiver (line of sight path), but over a range of angles even when a directive antenna is used [10]. Consequently, multiple propagation paths exist between transmitter and receiver, hence arriving the signal with multiple replica as depicted in Fig.2.

In digital radio communications (such as GSM) multipath can cause errors and affect the quality of communications. The errors are due to Inter-symbol interference (ISI). Equalizers are often used to correct the ISI.

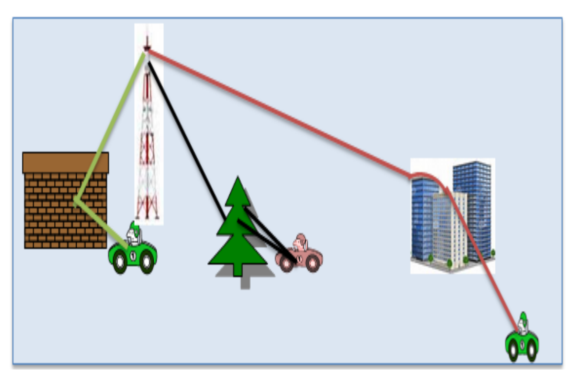

Figure. 2 Multipath Propagation

Thus, copies of the signal following different paths can undergo different attenuation, distortions, delays and phase shifts. Constructive and destructive interference occur at the receiver. When destructive interference occurs, the signal power may be significantly diminished. This phenomenon is called fading [7].

Strong destructive interference is frequently referred to as a deep fade and may result in temporary failure of communication due to a severe drop in the channel signal-to-noise ratio. Deep fades have a tendency to occur approximately every half a wavelength of motion [11]. When a received signal experiences fading during transmission, both its envelope and phase fluctuate over time. For example, the transmitted signal from the BTS (base transceiver station) may suffer multiple reflections from the buildings nearby, before reaching the mobile station. Fading causes fluctuations in the attenuation of the signal as it travels along the medium [2]. Fading channel models are often used to model the effects of electromagnetic transmission of information over the air in cellular networks and broadcast communication. Fading channel models are also used in underwater acoustic communications to model the distortion caused by the water [12]. Mathematically, fading is usually modeled as a time-varying random change in the amplitude and phase of the transmitted signal. Examples of fading models for the distribution of the attenuation are:

- Nakagami fading model.
- Weibull fading model.
- Rayleigh fading model.
- Rician fading model.
- Log-Normal Shadowing model.

In our paper we will considering only Rayleigh fading channel. The Rayleigh fading is primarily caused by multipath reception. Rayleigh distribution is statistically used to model a faded signal, when there is no dominant LOS path. The envelope of the received signal with Rayleigh distribution has the probability density function (pdf) given by as

$$P(\alpha)=\frac{\alpha}{\sigma^2}\exp\left(-\frac{\alpha^2}{2\sigma^2}\right), \quad \alpha \geq 0 \qquad (3)$$

Where α is the channel fading amplitude. Fading of the signal can be mitigated by different diversity techniques, where the signal is transmitted through multiple independent fading paths in terms of the time, frequency or space and combined constructively at the receiver.

3. FACTORS INFUENCING FADING

- *Multipath propagation*: Multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. The effects of multipath include constructive and destructive interference, and phase shifting of the signal.
- *Mobility*: The relative motion between the base station and the mobile results in random frequency modulation due to different Doppler shifts of each of the multipath components.
- *Transmission Bandwidth of the signal*: If the transmitted radio signal bandwidth is greater than the bandwidth of the multipath channel (quantified by *coherence bandwidth*), the received signal will be distorted.

4. TYPE OF FADING

The fading phenomena can be classified into two main groups known as large scale fading and small scale fading [10]. The large scale fading is used to describe the signal level at the receiver after traveling over a large area (hundreds of wavelengths). Small scale fading is used to describe the signal level at the receiver after encountering obstacles near (several wavelengths to fractions of wavelengths) the receiver [3]. Large-scale fading represents the average signal power attenuation or path loss due to motion over large areas. This phenomenon is affected by prominent terrain contours (hills, forests, billboards, clumps of buildings, etc.) between the transmitter and receiver. The receiver is often represented as being shadowed by such prominences, log normal shadowing is the result of the signal being blocked by large objects in the propagation path, (path D) in Fig. 2. The type small-scale of fading experienced by the signal through a mobile channel depends on the relation between the signal parameters (bandwidth, symbol period) and the channel parameters (delay spread and Doppler) [7,9]. In free-space, the attenuation of a signal due to distance refers to relative path loss, in this case line of sight (LOS) signal (path B) in Fig. 2. In the case of non-line-of-sight (NLOS) signals (path A), the additional loss of power in propagation channels occurs when part of the reflected signal is lost. Typically, the fading method is characterized by a Rayleigh distribution for a non-line-of-sight path and a Rician distribution for a line-of-sight path [10]. This paper concerns with small scale fading, which depend on the relation between bandwidth and symbol period of signal and time delay spread and Doppler spread of the channel [13].

4.1 Fading Effects due to Multipath Time Delay Spread

Types of small scale fading due to time delay spread are:

A- Flat Fading

In flat (non- selective) fading, the symbol period of the signal is more than the delay spread of the channel, Equivalently, in narrowband systems in which the transmitted signal bandwidth is much smaller than the channel's coherence bandwidth [9]. Then, the flat fading occurs when

$$B_s << B_c \qquad (4)$$

where B_S is the signal bandwidth and B_c is the coherence bandwidth. Also

$$T_s >> T_c \qquad (5)$$

where T_s is the symbol period and T_c is the rms delay spread. Flat fading may cause a dramatic increase in either the average bit-error-rate or the signal outage probability [3].

B- Frequency Selective Fading

Frequency selective fading occurs when the signal bandwidth is greater than the coherence bandwidth of the mobile radio channel or equivalently the symbol duration of the signal is less than the rms delay spread.

$$B_s >> B_c \qquad (6)$$

and

$$T_s << T_c \qquad (7)$$

At the receiver, it obtains multiple copies of the transmitted signal, all attenuated and delayed in time. The channel introduces inter symbol interference.

4.2 Fading Effects due to Doppler Spread

Types of small scale fading due to movement of the communication device in multipath propagation environment, the information carrying radio signal experience a shift in frequency domain, are:

A- Fast Fading

In a fast fading channel, the channel impulse response changes rapidly within the symbol duration of the signal. Due to Doppler spreading, signal undergoes frequency dispersion leading to distortion. Therefore, a signal undergoes fast fading if

$$T_s >> T_c \qquad (8)$$

where T_c is the coherence time and

$$B_s << B_D \qquad (9)$$

Where B_D is the Doppler spread. In a fast fading channel, Doppler causes spectral broadening, which leads to adjacent channel interference (typically small at reasonable user velocities), Also, causes to an irreducible error floor in signals with differential phase encoding (e.g. DPSK) [3].

B- Slow Fading

The fading is said to be slow if the symbol time duration T_s is smaller than the channel's coherence time T_c [3]. Hence

$$T_s << T_c \qquad (10)$$

and

$$B_s >> B_D \qquad (11)$$

It is observable that the velocity of the user plays an important role in deciding whether the signal experiences fast or slow fading. Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building obscures the main signal path between the transmitter and the receiver.

The methods that can help reduce the problem of fading in wireless communication; they are Diversity for fast and slow fading, Equalization for flat and frequency selection fading, Rake receiver for multipath fading and Channel Coding for deep fading. Diversity is a method used to develop information from several signals transmitted over independent fading paths. It is a very simple concept where if one path undergoes a deep fade, another independent path may have a strong signal. The signal level due to multipath fading is a function of position, frequency, and (if the paths are time-varying) time. So diversity techniques differ in the ways of obtaining independently-fading signal sources. The paths can come from different: locations (space diversity), frequencies (frequency diversity), times (time diversity) and antenna polarizations (polarization diversity). Rake receiver, can combine multipath components, which are time-delayed versions of the original signal transmission. This combining is done in order to improve the signal to noise ratio (SNR) at the receiver [14]. Equalization compensates for Inter Symbol Interference (ISI) and deep fading created by multipath within time dispersive channels. An equalizer is a filter at the mobile receiver, whose impulse response is inverse of the channel impulse response. If the channel is frequency selective, the equalizer enhances the frequency components with small amplitudes and attenuates those with large amplitudes. In channel coding, redundant data bits are added in the transmitted message so that if an instantaneous fade occurs in the channel, the data may still be recovered at the receiver without the request of retransmission [15].

5. RESULTS AND DISCUSION

It is necessary to explore what happens to the signal as it travels from the transmitter to the receiver. Then it is very easy to understand the concepts in wireless communications. One of the important aspects of the path between the transmitter and receiver is the occurrence of fading [16]. The concept of fading is demonstrated by the approach available in MATLAB. In this section, the results obtained from the MATLAB simulations are discussed.

The digital modulation schemes can be categorized basically either on the basis of their detection characteristics or in terms of their bandwidth compaction characteristics [17]. The Worldwide interoperability for Microwave Access (Wi-max) uses combinations of different modulation schemes which are BPSK, QPSK, 4-QAM and 16-QAM and it is a promising technology which offers high speed voice, video and data services [13]. The basic criteria for the best modulation scheme depends on Bit Error Rate (BER), Signal to Noise Ratio (SNR), Bandwidth, Power efficiency, better Quality of Service and cost effectiveness [18]. The bit error probability P_b often referred to as BER is a better performance measure to evaluate the modulation scheme [19]. After passing through the fading channel, the signal is perturbed at the receiver by additive white Gaussian noise (AWGN), which is typically assumed to be statistically independent of the fading, and which is characterized by a one-sided power spectral density N_0 (W/Hz) [10]. Additive white Gaussian noise provide fairly good performance corresponding to an open country environment, while Rayleigh channel, which best describes the urban environment fading, provides relatively worse performance. The BER performance of any digital modulation scheme in a slow flat fading channel can be evaluated by the following integral [7]:

$$P_b = \int_0^\infty P_{b,AWGN}\ (\gamma) P_{df}\ (\gamma) d\gamma \qquad (12)$$

Where $P_{b,AWGN}(\gamma)$ is the probability of error of a particular modulation scheme in AWGN channel at a specific signal-to-noise ratio $\gamma = h^2 \frac{E_b}{N_0}$. Here, the random variable h is the channel gain, $\frac{E_b}{N_0}$ is the ratio of bit energy to noise power density in non-fading AWGN channel, the random variable h^2 represents the instantaneous power of the fading channel, and $P_{df}(\gamma)$ is the probability density function of γ due to the fading channel.

A- BER of BPSK Modulation in AWGN Channel

In Phase shift keying (PSK), the phase of the carrier is modulated to represent the binary values. The carrier phase change between 0 and π by the bipolar digital signal. Binary states "1" and "0" are represented by the positive and negative polarity of the digital signal. The assumption of AWGN essentially means that we are assuming that the primary source of the noise is at the receiver or is radiation impinging on the receiver that is independent of the paths over which the signal is being received. A key property is that the projections of a white Gaussian random vector on to any orthonormal vectors are independent and identically distributed (i.i.d.) Gaussian random variables. The simplest form of PSK is BPSK. It is known that the BER for M-PSK in AWGN channel is given by [7]:

$$BER_{M\text{-}PSK} = \frac{2}{\max(\log_2 M, 2)} \sum_{k=1}^{\max(\frac{M}{4},1)} Q\left(\sqrt{\frac{2E_b \log_2 M}{N_0}} \sin\frac{(2k-1)\pi}{M}\right) \qquad (13)$$

B-BER of BPSK Modulation in Rayleigh Fading Channel

The Rayleigh flat fading channel is commonly used to describe multipath fading channels when there is no Line-Of-Sight (LOS) component between the transmitter and receiver (see path c) in Fig.2. It represents the worst case scenario for the transmission channel. For Rayleigh fading channels, h is Rayleigh distributed, h^2 has a chi-square distribution with two degrees of freedom. Hence,

$$P_{df}(\gamma) = \frac{1}{\bar{\gamma}} e^{\frac{\gamma}{\bar{\gamma}}} \qquad (14)$$

where $\bar{\gamma} = \frac{Eb}{No} E[h^2]$ is the average signal to noise ratio. For $E[h^2] = 1$, $\bar{\gamma}$ Corresponds to average E_b/N_o for the fading channel. From Fig.3 it can be seen that, to obtain a BER of 10^{-2}, using BPSK, an AWGN channel requires $\frac{E_b}{N_0}$ = 6.8 dB and a Rayleigh channel requires $\frac{E_b}{N_0}$ = 14 dB. It is clearly that BER performance of BPSK over AWGN shows better performance than over Rayleigh fading channel. The BER decreases with the increasing in signal to noise ratio in both AWGN channel & Rayleigh fading channel, for example, If, the $\frac{E_b}{N_0}$ in AWGN channel increases to 9dB so the obtained BER goes to 10^{-3}. The same effect can be seen when signals pass through the Rayleigh fading channel. The obtained BER ≈ 10^{-1} for the same amount of SNR (i.e. 9 dB) but the error rate in Rayleigh fading channel is much higher than the error rate in the AWGN channel for the same value of signal to noise ratio.

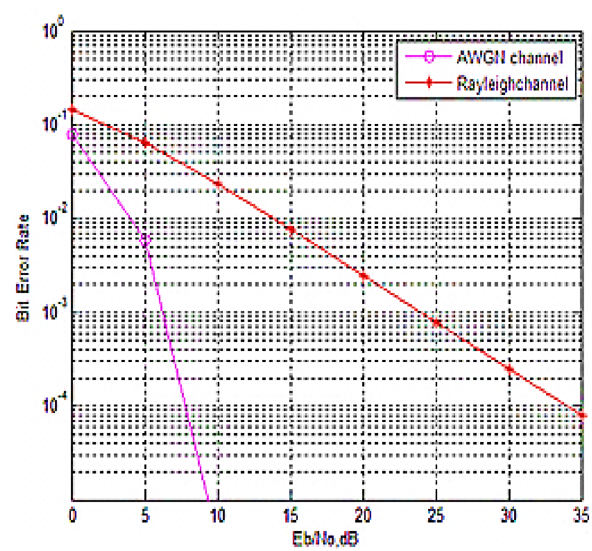

Figure. 3 BER performance of BPSK in AWGN and Rayleigh fading channel.

C- BER of M-QAM Modulation in AWGN Channel.

Quadrature Amplitude Modulation (QAM) has been adopted by many wireless communication standards such as WiMAX and LTE. It provides higher bit rates and consequently higher spectral efficiencies. Due to the high spectral efficiency M-QAM is an attractive modulation technique for wireless communication. It is usually used in conjunction with Orthogonal Frequency Division Multiplexing (OFDM) which provides a simple technique to overcome the time varying frequency selective channel [18]. QAM is the encoding of the information into a carrier wave by variation of the amplitude of both the carrier wave and a 'quadrature' carrier that is 90^0 out of phase with the main carrier in accordance with two input signals [20]. That is, the amplitude and the phase of the carrier wave are simultaneously changed according to the information we want to transmit. Additive White Gaussian Noise (AWGN) channel model is the simplest radio environment in a wireless communications system. Where the channel adds white Gaussian noise to the signal that passes through it. It is the basic communication channel model and used as a standard channel model. The transmitted signal gets disturbed by a simple additive white Gaussian noise process. Additive white Gaussian Noise comes from many natural sources such as vibration of atoms in conductor, shot noise, radiation from earth and other warm object and from celestial sources such as the Sun.

The BER of gray code M-QAM in AWGN channel given by [7]

$$\mathrm{BER}_{\mathrm{MQAM}} = \frac{4}{\log_2 M}\left(1-\frac{1}{\sqrt{M}}\right)\sum_{i=1}^{\frac{\sqrt{M}}{2}} Q\left(\sqrt{\frac{3\log_2 M E_b}{(M-1)N_0}}\right) \qquad (15)$$

In this case fading does not exist but the only distortion that exists is introduced by the AWGN.

D- BER of M-QAM Modulation in Rayleigh Fading Channel

In Rayleigh fading, the average BER for M-QAM is given by [7]

$$\mathrm{BER}_{\mathrm{MQAM}} = \frac{2}{\log_2 M}\left(1-\frac{1}{M}\right)\sum_{i=1}^{\frac{\sqrt{M}}{2}}\left(1-\sqrt{\frac{1.5(2i-1)^2\gamma\cdot \log_2 M}{M-1+1.5(2i-1)^2\,\gamma\cdot \log_2 M}}\right) \qquad (16)$$

The theoretic BER performance of 4-QAM, 8-QAM, and 16-QAM modulations in AWGN and Rayleigh fading channels shown in Fig. 4.

As shown from Fig. 4, as number of bits in a symbol increases, i.e., from 4, 8 to 16 the error rate also increases. Each additional bit per symbol required about 2dB extra in signal to noise ratio to achieve the same bit error rate. The comparison between 16 QAM over AWGN channels without fading effect and 16 QAM over Rayleigh fading channel, reveals that to achieve a certain value of BER, for example, $=10^{-2}$ the required E_b/N_0 is 14dB and 4dB for 16 QAM over an AWGN channel and Rayleigh fading channel, respectively. It can be seen from this result that as the signal pass through a Rayleigh fading channel it required more signal power to overcome the fading effect [21].

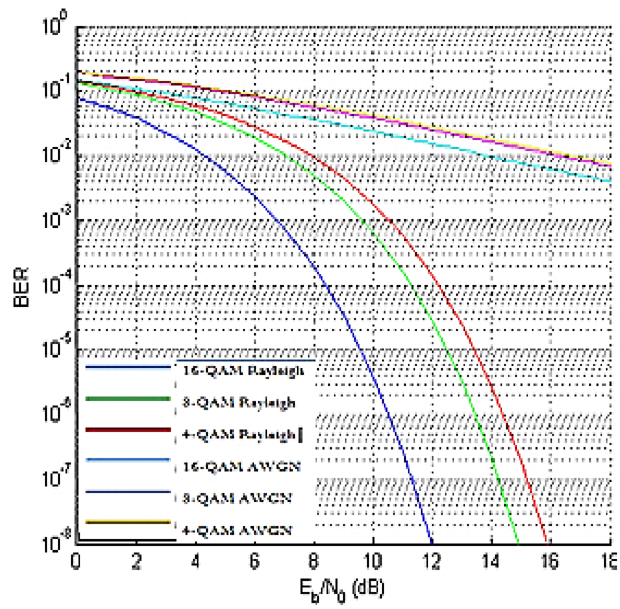

Figure. 4 BER performances of 4-QAM, 8-QAM, and 16-QAM in AWGN and Rayleigh fading channel

6. CONCLUSIONS

In this paper, bit error rate (BER) performances for BPSK and MQAM signals over AWGN and Rayleigh fading channels are investigated. A multipath propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths are presented. The effects of multipath include constructive and destructive interference, and phase shifting of the signal. When destructive interference occurs, the signal power may be significantly diminished causing fading. Factors influencing fading and types of fading, large scale fading and small scale fading are discussed. This paper concerns with small scale fading, which depend on the relation between bandwidth and symbol period of signal and time delay spread and Doppler spread of the channel. Simulation results showed that for MQAM modulation, as number of bits in a symbol increases, i.e., from 4, 8 to 16 the error rate also increases. Also bit error rate for digital modulation (BPSK, MQAM) over an AWGN channel is less than that obtained over Rayleigh channel for the same value of signal to noise ratio. In general Additive white Gaussian noise provide fairly good performance corresponding to an open country environment, while Rayleigh channel, which best describes the urban environment fading, provides relatively worse performance.

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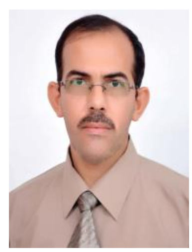

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