Bit Error Rate Analysis of Digital Modulation Techniques in Wireless Communication System

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Abstract- The main basic components for selecting modulation technique are Bit Error Rate (BER) and Signal to Noise Ratio (SNR). This paper examined the performance of different modulation techniques including 8-QAM, 16-QAM, 32-QAM, 64-QAM and QPSK in Additive White Gaussian Noise (AGWN) and Rayleigh fading channels for wireless communication system using computer simulation bertool of MATLAB software. Simulation and performance evaluation, results indicated that lower order modulation techniques outperform the higher order schemes for transmission of data in both AGWN and Rayleigh fading channels such that for QAM modulation, 8-QAM provided the finest BER with value of (0.000652 and 0.0231), while 16-QAM, 32-QAM, and 64-QAM yielded BER performance of (0.017 and 0.0301), (0.0161 and 0.0665), (0.0265 and 0.0792) with respect to increasing SNR at 10 dB. However, this comes at the cost of the data rate since lower order techniques have lower data rates than their higher order counterpart. Furthermore, it was found that the performance in AGWN channel was better than the performance in Rayleigh fading channel for all considered modulation schemes. On which modulation technique provided the best BER performance, it was observed that QPSK modulation technique outperformed other modulation schemes with BER of 3.8×10^{-6} in AGWN channel and 0.0010 in Rayleigh fading channel at SNR of 10 dB. Generally, the simulation results showed that the BER performance improves as the SNR increases.

Indexed Terms- Bit error rate, Channel, Digital modulation, Wireless Communication.

I. INTRODUCTION

Wireless communication has contributed very much to the technological breakthrough for the provision of effective interactions between mankind all over the world. It is the rapidly growing segment of the communication industry, which has gained the attention and the imagination of the public with possibilities of high-speed and high-quality and offering advantages like portability, flexibility and coverage over wired communication.

Wireless applications include file transfer, paging and short messaging, internet access, web browsing, distance learning, voice, video teleconferencing, entertainment, and others. Systems include cellular telephone systems, ad hoc wireless networks, wireless local area networks (WLAN), wide-area wireless data systems and satellite systems. Coverage regions include in-building, city, regional, and global.

Communicating effectively over a large distance has been a challenge in wireless communication and the transition of modulation systems from analogue to digital has further complicated the situations. Digital modulation schemes provide more information carrying capacity, better quality communication, data security and RF spectrum sharing to accommodate more services. However, the implementation of digital modulation techniques like the Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK) and Phase Shift Keying (PSK) comes with the different compromise. There is a trade-off needed to be made between the available bandwidth and the number of bits/symbols that can be transmitted over the line, which in turn limits the maximum data rate on the link. Thus, the selection of digital modulation techniques is absolutely critical, especially in an environment like the satellite uplink-downlink where resources are very limited and time slots are assigned at very high cost. The primary standards to determine modulation scheme depends on Bit Error Rate (BER), Signal to Noise Ratio (SNR), Available Bandwidth, Power efficiency, better Quality of Service, cost effectiveness. Hence, it is necessary to ascertain which modulation technique that is capable of transmitting more bits per symbol and is more immune to error caused by noise and interference induced in the channel.

In this paper, the study focuses on examining the performance of different modulation methods such as Modulation Phase Shift Keying (M-PSK), Quadrature Phase Shift Keying (QPSK), 16 Quadrature Amplitude Modulation (16 QAM) and 64 Quadrature Amplitude Modulation (64 QAM) in wireless network. The performance investigation is conducted in terms of Bit Error Rate (BER) with respect to Signal to Noise Ratio (SNR) through simulations in MATLAB/Simulink environment.

II. DIGITAL MODULATION TECHNIQUES

If A modulating structure is needed to transmit information over a communication channel. Among the various modulation methods are; amplitude modulation (data encoded by changing the amplitude of the signal), frequency modulation (data encoded by changing the frequency of the signal), and phase modulation (data encoded by changing the phase of the signal). The various digital modulation techniques considered in this paper and channel are presented in this section.

1) Quadrature Phase Shift Keying: The quadrature phase-shift keying (QPSK) modulation scheme is like the binary phase shift keying (BPSK), which is characterized by the fact that the information carried by the transmitted wave is contained in phase. The QPSK system has two successive bits in a bit stream which is combined together to form a message and each message is represented by a distinct value of phase shift of the carrier. In particular, in QPSK, the phase of the carrier takes on one of four equally spaced values, such as π/4, 3π/4,5π/4and 7π/4. The carrier wave is given by [6]:

$$s_i(t) = \sqrt{\frac{2E}{T}}\cos[2\pi os + (2i-1)\pi/4] \qquad (1)$$

where i = 1, 2, 3, 4 and E is the transmitted signal energy per symbol, T is the symbol duration, and f is the carrier frequency. For QPSK modulation scheme there are two normal orthonormal basic functions, $\varphi_1(t),\ \varphi_2(t)$ contained in the expression of $s_i(t)$. In a QPSK system, the transmission rate is two bits per symbol. This means that twice the signal energy per bit is equal to the transmitted signal energy per symbol. So the average probability of error is represented in terms of ratio E_b/N_0 and bit error probability is given by:

$$P_b = \frac{1}{2}\operatorname{erfc}\sqrt{\frac{E_n}{N_0}} \qquad (2)$$

2) Quadrature Amplitude Modulation: Quadrature Amplitude Modulation (QAM) is a method of combining two amplitude-modulated (AM) signals into a single channel, thereby doubling the effective bandwidth. In a QAM signal, there are two carriers, each having the same frequency but differing in phase by 90 degrees (one quarter of a cycle, from which the term quadrature arises). One signal is called the In-phase signal, and the other is called the quardrature signal. Mathematically, one of the signals can be represented by a sine wave, and the other by a cosine wave. The two modulated carriers are combined at the source for transmission. At the destination, the carriers are separated, the data is extracted from each, and then the data is combined into the original modulating information. The QAM signal is mathematically represented as follows:

$$s(t) = m_1(t)\cos(2\pi tt) - m_2(t)\sin(2\pi tt) \qquad (3)$$

where $m_1(t)$ and $m_2(t)$ are the two message signals. One of them is sent in phase i.e. by multiplying it with cos(2πft) and the other one is sent in quadrature by multiplying it with sin(2πft). Finally, the two signals are added to obtain the QAM signal. The symbol error probability of M-ary QAM is given by:

$$p_b \le 4\mathrm{erfc}\left(\sqrt{\frac{3kE_b}{(M-1)N_0}}\right) \quad (\text{for } M = 2^k) \tag{4}$$

where k is the number of bits transmitted by each symbol.

3) Modulation Phase Shift Keying:
Phase-Shift Keying (PSK) is a digital modulation technique that transmits data by changing, or modulating, the phase of a reference signal. The term *M-ary* is derived from the word binary. *M* simply represents a digit that corresponds to the number of conditions, levels, or combinations possible for a given number of binary variables.

The number of bits necessary to produce a given number of conditions is expressed mathematically given by:

$$N = \log_2 M \tag{5}$$

where N is the number of bits necessary, M is the number of conditions, levels, or combinations. For N = 4, M = 2^4 = 8 and this gives 16-PSK, and so on.

4) Channel Model: In wireless communication, radio propagation refers to the behaviour of radio waves when they are propagated from transmitter to receiver. Data are transmitting through the wireless channel with respective bandwidth to achieve higher data rate and maintain quality of service. The transmitting data has to overcome environmental challenge when it is on air with against unexpected noise [7]. In the course of propagation, radio waves are mainly affected by three different modes of physical phenomena: reflection, diffraction, and scattering [8]. In this work, the two wireless channel models considered are Additive White Gaussian Noise (AWGN) and Rayleigh Fading.

- Additive White Gaussian Noise:

This is a channel model in which the only impairment to communication is a linear addition of wideband or white noise with a constant spectral density and a Gaussian distribution of amplitude. The model does not account for fading, frequency selectivity, interference, nonlinearity or dispersion. However, it produces simple mathematical models which are helpful for gaining information of the underlying behaviour of a system before these other phenomena are considered. Additive noise comes from electronic components and amplifiers at the receivers. Channel attenuation is easily integrated into the model. The received signal given by [2]:

$$r(t) = s(t) + n(t) \tag{6}$$

where is $r(t)$ is the received signal, $s(t)$ is the transmitted signal and $n(t)$ is the noise. The probability density function (PDF) AWGN channel is given by [3]:

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \tag{7}$$

where μ is the mean and σ is the standard deviation.

- Multipath Fading Channels

This is a statistical model to provide the effect of fading on the propagation of radio signal in an environment, as used by wireless devices. Rayleigh fading models assume that the magnitude of a signal that has passed through such a transmission medium (also called a communications channel) will vary arbitrarily or fade, according to a Rayleigh distribution the radial component of the sum of two uncorrelated Gaussian random variables. Rayleigh fading is considered as a reasonable model for tropospheric and ionospheric signal propagation as well as the effect of heavily built-up urban environments on radio signals. Rayleigh fading is best applicable when there is no dominant propagation along a line of sight between the transmitter and receiver. If there is a dominant line of sight, Rician fading is of relevance. In this work, Rayleigh fading is used.

Multipath fading channel is usually modeled as Rayleigh and Rician fading channels. The channel characteristics are usually modeled as given by [4]:

$$H = \alpha e^{j\varphi} \tag{8}$$

where α is the Rayleigh distributed magnitude and φ is the phase uniformly distributed in the interval $[-\pi, \pi]$. The received power P_r in a wireless communication channel, with P being the transmit power and H is the channel characteristics, is given by [4]:

$$P_r = P \times |H|^2 \quad (9)$$

Received signal to noise ratio (SNR) is given by:

$$SNR = \frac{P\alpha^2}{\sigma_n^2} \quad (10)$$

where σ_n^2 is the noise power.

The Bit Error Rate (BER) is an average quantity and not an instantaneous quantity given by [4]:

$$BER = \int_0^\infty Q\left(\sqrt{\frac{\alpha^2 P}{\sigma_n^2}}\right) 2\alpha\alpha^{-\alpha^2 /} d\alpha \quad (11)$$

The BER is related to the Signal to Noise Ratio (SNR) by:

$$BER = \frac{1}{2}\left(\sqrt{\frac{SNR}{2+SNR}}\right) \quad (12)$$

At high SNR, the expression in Equation (12) is reduced to:

$$BER \cong \frac{1}{2 \times SNR} \quad (13)$$

Rayleigh distribution model is frequently used for fading signal with infinite or large number of arrival paths at the same time whose gain are statistically independent and no dominant path [4]. The phase component of the channel gain is Gaussian distributed and its probability density function (PDF) is given by [10]:

$$p_z(x) = \begin{pmatrix} \frac{r}{\sigma^2} e^{\left(-\frac{r^2}{2\sigma^2}\right)} & 0 \le r \le \infty \\ 0 & r < 0 \end{pmatrix} \quad (14)$$

where, σ is the RMS value of received signal before detection. And according to [12], the average channel power is given by:

$$E[r] = 2\sigma^2 \quad (15)$$

The received signal power is often weak in a fading channel and bit error occurs [11]. The theoretical average Bit Error Rate of Rayleigh fading channel model is given by [12] as stated in [9]:

$$AvBER = \frac{1}{2}\left(1 - \sqrt{\frac{E_b / N_0}{1 + E_b / N_o}}\right) \quad (16)$$

Generally, the received signal in Rayleigh fading channel can be expressed as [5]; [1]:

$$Y(t) = X(t) \times H(t) + N(t) \quad (17)$$

where Y(t) is the received signal, N(t) is the AWGN with zero mean and unit variance, H(t) is the random channel matrix having Rayleigh distribution, and X(t) is the transmitted signal.

III. RESULT AND DISCUSSION

In this section the results obtained using the bertool of MATLAB to perform computer simulation and numerical analysis of the bit error rate (BER) performance of QAM and QPSK modulation schemes. The simulations were conducted considering AGWN channel and Rayleigh fading channel for QAM (8, 16, 32, and 64), 16-PSK and QPSK. The maximum bit error is placed at 100 and the maximum number of bits taken as 1×10^7. The objective is to evaluate each modulation technique with respect to BER against signal to noise ratio (SNR). Performance analyses of each graphical representation are shown in Tables 1 to 4.

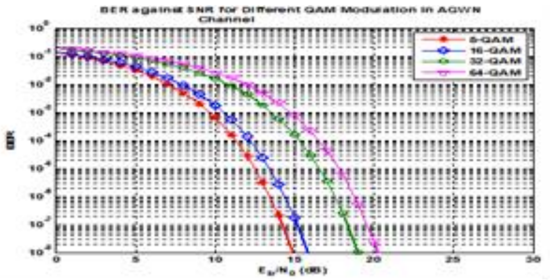

Figure 1 BER against SNR for different QAM modulation scheme in AGWN channel

Table 1 Performance analysis for BER vs SNR for differennt QAM modulation scheme in AGWN channel

SNR(dB)	BER			
	8-QAM	16-QAM	32-QAM	64-QAM
0	0.1326	0.1409	0.1894	0.1998
1	0.1092	0.1189	0.1672	0.1779
2	0.0867	0.0977	0.1461	0.1569
3	0.0657	0.0774	0.1259	0.1371
4	0.0470	0.0586	0.0906	0.1185
5	0.0313	0.0418	0.0880	0.1007
6	0.0191	0.0278	0.0702	0.0838
7	0.0104	0.0169	0.0536	0.0675
8	0.0050	0.0092	0.0387	0.0523
9	0.0020	0.0043	0.0261	0.0384
10	0.000652	0.0017	0.0161	0.0265

It can be deduced from Table 1 that as the BER decreases the SNR (dB) increases with better modulation achieved in terms of BER against SNR as the order of QAM reduces.

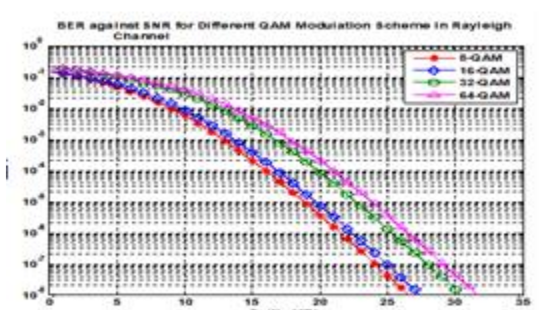

Figure 2 BER against SNR for different QAM modulation scheme in Rayleigh channel

Table 2 Performance analysis for BER vs SNR for differennt QAM modulation scheme in Rayleigh fading channel

SNR(dB)	BER			
	8-QAM	16-QAM	32-QAM	64-QAM
0	0.1471	0.1556	0.2034	0.2129
1	0.1242	0.1334	0.1814	0.1916
2	0.1023	0.1121	0.1601	0.1708
3	0.0819	0.0921	0.1395	0.1507
4	0.0634	0.0734	0.1197	0.1314
5	0.0473	0.0567	0.1008	0.1131
6	0.0338	0.0422	0.0830	0.0956
7	0.0231	0.0301	0.0665	0.0792
8	0.0151	0.0206	0.0517	0.0640
9	0.0094	0.0134	0.0387	0.0501
10	0.0055	0.0083	0.0278	0.0379

It can be seen looking at Table 2 that the BER for both 8-QAM and 16-QAM is very close for SNR less than 9dB. Also, the BER performance of both 32-QAM and 64-QAM seems to be very close for SNR less than 9dB.

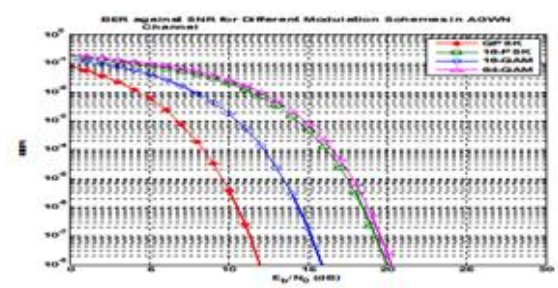

Figure 3 BER against SNR for different modulation schemes in AGWN channel

Table 3 Performance analysis for BER vs SNR for QPSK and QAM modulation schemes in AGWN channel

SNR(dB)	BER				
	16-PSK	16-QAM	32-QAM	64-QAM	QPSK
0	0.1744	0.1409	0.2034	0.2129	0.0786
1	0.1534	0.1189	0.1814	0.1916	0.0562
2	0.1338	0.0977	0.1601	0.1708	0.0375
3	0.1155	0.0774	0.1395	0.1507	0.0228
4	0.0986	0.0586	0.1197	0.1314	0.0125
5	0.0829	0.0418	0.1008	0.1131	0.0059
6	0.0681	0.0278	0.0830	0.0956	0.0023

7	0.0542	0.0169	0.0665	0.0792	0.00077
8	0.0414	0.0092	0.0517	0.0640	0.00019
9	0.0299	0.0043	0.0387	0.0501	0.000033
10	0.0202	0.0017	0.0278	0.0379	0.0000038

From Figure 3 and Table 3, it can be seen that the QPSK modulation has the best BER performance followed by the 16-QAM. Also, both the 16-PSK and the 64-QAM modulations seem to have very closed performance BER as the SNR increases.

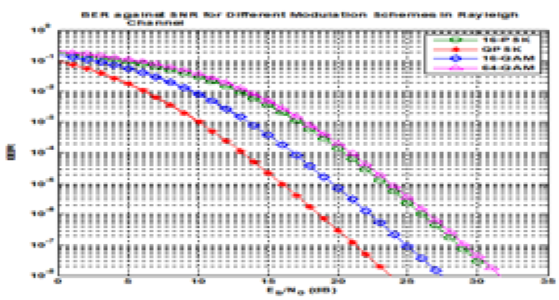

Figure 4 BER against SNR for different modulation schemes in Rayleigh channel

Table 4 Performance analysis for BER vs SNR for QPSK and QAM modulation scheme in Rayleigh fading channel

SNR(dB)	BER				
	16-PSK	16-QAM	16-QAM	64-QAM	QPSK
0	0.1884	0.1556	0.1556	0.2129	0.0975
1	0.1676	0.1334	0.1334	0.1916	0.0756
2	0.1477	0.1121	0.1121	0.1708	0.0564
3	0.1289	0.0921	0.0920	0.1507	0.0404
4	0.1112	0.0734	0.0734	0.1314	0.0276
5	0.0946	0.0567	0.0567	0.1131	0.0180
6	0.0792	0.0422	0.0422	0.0956	0.0112
7	0.0649	0.0301	0.0301	0.0792	0.0066
8	0.0518	0.0206	0.0206	0.0640	0.0037
9	0.0401	0.0134	0.0134	0.0501	0.0020
10	0.0300	0.0083	0.0083	0.0379	0.0010

Figure 4 shows the graphical representation of the performance analysis of different modulation schemes in Rayleigh fading channel. It can be seen that with QPSK modulation having best performance in terms of BER, the 16-PSK and the 64-QAM modulation have very close BER as the SNR (dB) increases. Table 4 shows the performance analysis.

The BER performance of the different orders of QAM modulation scheme shown in Tables 1 and 2 for both AGWN channel and Rayleigh channel showed that 8-QAM provided the best results in terms of BER. However, the performances of the 8-QAM and 16-QAM seem very closed in the Rayleigh fading channel, and the same holds for 32-QAM and 64-QAM.

For the comparison of the BER performances of QPSK, 16-PSK, 16-QAM and 64-QAM in AGWN channel and Rayleigh channel with respect to SNR (dB) as shown in Figures 4 and 5, it can be seen that the QPSK modulation outperformed all the other modulation schemes followed by 16-QAM. Also the performance of the 16-PSK and 64-QAM seems to be very close in both channels.

The performance of the various modulation schemes in terms of BER with respect to SNR at constant maximum number of bit showed that QPSK modulation scheme offered the best minimum BER of 3.8×10^{-8} in AGWN channel and 0.0010 in Rayleigh fading channel at SNR of 10 dB respectively.

Also, the results obtained show that in both AGWN and Rayleigh fading channels, lower order modulation schemes provided better BER performance than higher order schemes with respect to SNR (dB) as can be seen in Tables 1 through 4. Furthermore, from the tables, it can be seen that all the modulation schemes perform better in AGWN channel than Rayleigh fading channel.

Generally, it can be said that over both AGWN and Rayleigh channels, lower modulation techniques performed better than the higher order schemes but this comes at the cost of the data rate, since lower order techniques have lower data rates than their higher order counterpart. Furthermore, performance of all the modulation techniques was better in AWGN channel than Rayleigh fading channel. Hence, through all the numerical values of the simulations, it is evaluated that the QPSK modulation scheme provided the least (most improved) BER, which means it is the most effective method for data transmission in comparison to other methods of modulations considered in terms of BER.

CONCLUSION

This paper has examined the performance of wireless system in different modulation techniques. The scope was limited to two-input two-output wireless system with modulation carried out over two channels. The performance of the system was demonstrated MATLAB/Simulink over two channels namely, AWGN and Rayleigh fading channels, using various modulation techniques such as, 8-QAM, 16-QAM, 32-QAM, 64-QAM, and QPSK was evaluated. The performance of the system was compared for all the modulation techniques employed over both channels

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