Effect of Noise on BER of BPSK, QPSK, DPSK, and QAM Modulation Techniques

J. A. Desai\textsuperscript{1}, S. N. Kulkarni\textsuperscript{2}

Department of E & TC Engineering, NBN Sinhgad School of Engineering, Ambegaon (Bk.). Pune, India

Abstract—This paper presents the theoretical background of digital modulation and evaluates the performance of BPSK, QPSK, and QAM modulation techniques with respect to Bit Error Rate in presence of Gaussian, Rayleigh, and Rician noise. The primary objective of any communication system is to receive the data with minimum errors as the errors degrades the system performance. Bit Error Rate (BER) is an important factor that decides the performance of different modulation techniques. This paper focusses on the effect of different types of noise for the above mentioned modulation schemes under AWGN channel. The complete system is implemented in MATLAB Simulink Environment.

Keywords— BER, AWGN, Gaussian, Rayleigh, Rician, MATLAB Simulink.

I. INTRODUCTION

In digital modulation, digital symbols are converted into waveforms that are compatible with the characteristics of the channel. Bandpass modulation is a process by which the information signal is converted to sinusoidal waveform for digital modulation. Coherent and non-coherent modulation/demodulation is the basic types of bandpass modulation. Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), and Quadrature Amplitude Modulation (QAM) are specialized formats of these techniques [3]. In an ideal channel the transmitted signal from the transmitter will pass through channel upto the receiver, where it is demodulated to get a perfect representation of the original signal. However in reality the received signal consists of mixture of attenuated and reflected version of the transmitted signal [2]. In addition to these, the channel adds various types of noise to the signal. This affects the Bit Error rate of the system.

II. BIT ERROR RATE

The quality of transmission is decided by parameter, Signal to Noise ratio (SNR) in analog and by Bit Error Rate (BER) in digital. In digital communication, the ratio Eb/No, a normalized version of SNR as a figure of merit is used. Eb is bit energy and can be described as signal power S times the bit time Tb. No is noise power spectral density and can be described as noise power (N) divide by bandwidth (W). Since bit time and bit rate Rb are reciprocal, we can replace Tb with 1/Rb. [2]

\[
\frac{E_b}{N_0} = \frac{S}{W} = \frac{S}{R_b}
\]

In Digital communication the number of bit errors is the number of received bits of a data stream over a communication channel that has been altered due to noise, interference, distortion or bit synchronization errors. The bit error rate or bit error ratio (BER) is the number of bits in error divided by the total number of transferred bits during a studied time interval. BER is a unit less performance measure; often expressed as a percentage. The performance of each modulation technique is measured by calculating the BER in presence of different types of noise.

III. DIGITAL MODULATION SCHEMES

A digital signal can modulate amplitude, frequency, or phase of sinusoidal carrier wave. If the modulating waveform consists of NRZ rectangular pulses, then the modulated parameter will be switched or keyed from one discrete value to another. This results into three basic types of digital modulation schemes namely Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), and Phase Shift Keying (PSK) [4].

This paper deals with the types of PSK viz. BPSK, DPSK, QPSK and QAM. This section will describe these methods in detail.

1. \textit{BPSK:} In BPSK, the carrier gets 0 or 180° phase shift corresponding to two different voltage levels of binary modulating signal. If the sinusoid is of amplitude A, it has a power \( P_s = \frac{1}{2} A^2 \). So that \( A = \sqrt{2P_s} \). The transmitted signal is given by

\[
v_{BPSK}(t) = b(t)\sqrt{2P_s}\cos \omega_0 t
\]

Where \( b(t) \) is a stream of binary digits with voltage levels [6][7].

2. \textit{DPSK:} DPSK is a modification of BPSK which eliminates the ambiguity about whether the demodulated data is or is not inverted. It is a type of non-coherent detection. The term differential
encoding refers to the procedure of encoding the data differentially i.e. the presence of binary 1 or 0 is manifested by the symbol’s similarity or difference when compared with the preceding symbol.

\[ P_e = \frac{1}{2} \exp \left(-\frac{E_b}{N_0}\right) \]

3. **QPSK**: When a data is transmitted using BPSK technique the channel bandwidth required is 2f_0. The QPSK technique reduces that bandwidth to f_0. It is a multilevel phase modulation. In this two successive bits in a bit stream are combined together to form a message and each message is represented by distinct value of phase shift of a carrier. The QPSK signal is represented as. Since there are 4 phases it is called as 4-PSK or Quadrature PSK systems [6][7].

\[ v_{QPSK}(t) = \sqrt{2P_e} \cos \left( \omega_0 t + (2m + 1) \frac{\pi}{4} \right) \quad \ldots \ldots m = 0, 1, 2, 3 \]

\[ P_e = \text{erf}c \sqrt{\frac{E_b}{N_0}} \]

4. **QAM**: QAM improves the noise immunity of the system by allowing the signal vectors to differ, not only in their phase but also in amplitudes. It utilizes carrier phase shifting and synchronous detection to permit two DSB signals to occupy the same frequency band. The two DSB signals are orthogonal to each other.

\[ P_e = 2(1 - \frac{1}{\sqrt{M}})^2 \text{erf}c \sqrt{\frac{E_b}{N_0}} \]

IV. NOISE AND CHANNELS IN COMMUNICATION SYSTEMS

A. Noise in Communication Systems

The term noise refers to unwanted electrical signals that are always present in electrical systems. The presence of noise superimposed on a signal tends to obscure or mask the signal; limits the receiver’s ability to mask correct symbol decisions, and thereby limits the rate of information transmission [2].

Contaminating noise in signal transmission usually has an additive effect in the sense that noise often adds to the information-bearing signal at various points between the source and the destination. For the purpose of analysis, all the noise will be lumped into one source added to the signal in the AWGN channel. So, in this paper, effect of various noise on BER of different modulation schemes have been studied. The various sources of noise used for this system are mentioned below:

1. **Gaussian Noise**: Various types of noise sources are gaussian and have a flat spectral density over a wide frequency range. Such a spectrum has all frequency components in equal proportion and is therefore called white gaussian noise otherwise it is non-white gaussian noise. The gaussian noise generator block used, generates discrete time white gaussian noise.

2. **Rayleigh Noise**: In digital communication, we are interested in the two dimensional noise distributed around each state in the phase plane. The noise can be characterized in two ways. A three dimensional picture is given by the product of two orthogonal gaussian distributions with the same standard deviation. Alternately, with the polar coordinates centered on the undeviated position of the state, the radial distribution of the noise is described by the Rayleigh distribution. The Rayleigh noise generator block used, generates Rayleigh distributed noise.

3. **Rician Noise**: Unlike additive Gaussian noise, Rician noise is signal-dependent and consequently separating signal from noise is a difficult task. Rician noise is problematic for low signal-to-noise ratio.

B. AWGN channel

In communication theory it is often assumed that the transmitted signals are distorted by some noise. The most common noise to assume is additive Gaussian noise, i.e. the so called Additive White Gaussian Noise channel, AWGN. The detection process of a channel with AWGN is that the noise affects each transmitted symbol independently. Such a channel is called memory-less channel. The term additive means that the noise is simply superimposed or added to signal that there are no multiplicative mechanisms at work. This channel is linear and time-invariant and its frequency response is flat for all the frequencies.

V. MATLAB SIMULINK MODELS

This section describes the simulation models of various digital modulation techniques. A Bernoulli Binary Generator feeds into digital modulation techniques (BPSK, QPSK, DBPSK, and QAM) used for transmission. To analyze the effect of noise, the modulated signal along with the Rayleigh, Gaussian and Rician noise is transmitted on the AWGN channel. The received signal is demodulated using various demodulation techniques and is used to calculate the bit error rate for transmission process. The BER is calculated by using the Monte Carlo simulations in MATLAB Simulink Tool.

![Fig. 1. Effect of Rayleigh noise on BPSK](image-url)
Fig. 2: Effect of Gaussian noise on BPSK

Fig. 3: Effect of Rician noise on BPSK

Fig. 4: Effect of Rayleigh noise on QPSK

Fig. 5: Effect of Gaussian noise on QPSK

Fig. 6: Effect of Gaussian noise on QPSK

Fig. 7: Effect of Rayleigh noise on DPSK

Fig. 8: Effect of Gaussian noise on DPSK

Fig. 9: Effect of Rician noise on DPSK

Fig. 10: Effect of Rayleigh noise on QAM

Fig. 11: Effect of Gaussian noise on QAM
The above Simulink models are built to analyze the effect of different types of noise (Rayleigh, Gaussian, and Rician) on BER of different modulation schemes (BPSK, QPSK, DBSK, and QAM). The results obtained for $E_b/N_0 = 1$ and samples per frame=1000, are tabulated as follows:

<table>
<thead>
<tr>
<th>Type of Modulation</th>
<th>BER without noise</th>
<th>BER with Rayleigh Noise</th>
<th>BER with Gaussian Noise</th>
<th>BER with Rician Noise</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPSK</td>
<td>0.048</td>
<td>0.479</td>
<td>0.496</td>
<td>0.465</td>
</tr>
<tr>
<td>QPSK</td>
<td>0.245</td>
<td>0.723</td>
<td>0.745</td>
<td>0.726</td>
</tr>
<tr>
<td>DBPSK</td>
<td>0.115</td>
<td>0.489</td>
<td>0.499</td>
<td>0.486</td>
</tr>
<tr>
<td>QAM</td>
<td>0.538</td>
<td>0.852</td>
<td>0.867</td>
<td>0.847</td>
</tr>
</tbody>
</table>

The analysis shows that QAM is least affected by noise for the given Simulink models.

VI. CONCLUSION

In this paper effect of different types of noise on BER of various modulation schemes have been analyzed. Simulation study shows that the systems are least affected by Rician Noise as the Rician PDF (Probability Distribution Function) provides a better overall fit to the data than gaussian PDF. The table shows that BER value of QPSK technique is more in presence of additional noise.

REFERENCES