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BER Performance Evaluation of Different Digital Modulation Schemes for Biomedical Signal Transceivers under AWGN and Fading Channel Conditions

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Abstract— The RF transceivers play an important role in the wireless medical monitoring system. Compared to the conventional RF transceiver, the transceiver in medical sensor nodes has more stringent constraints in terms of power consumption, size limitation and the quality of transmission. Digital modulation schemes used in the wireless transceivers plays an important role in the performance of the transceiver. In this paper the Bit error rate (BER) of different digital modulation schemes are compared under AWGN, Rayleigh and Rician fading channels to identify a suitable digital modulation scheme for biomedical application.

Index Terms— probability of error, BER, transceiver, AWGN, Rayleigh, Rician

I. INTRODUCTION

Biomedical signal transceivers are essential for future mobile health monitoring devices. A wireless transceiver provides a cost effective way to transmit biomedical signals to the various personal electronic devices, such as mobile phones, computers and other mobile devices. By utilizing wireless transmission, the user gains the freedom to connect with fewer constraints to their personal devices to view and monitor their health conditions. Bluetooth and ZigBee are some of the promising technologies used in Wireless Personal Area Networks (WPAN). Transceivers based on these technologies can be used for biomedical application typically in Body Area Networks (BAN). In order to select a particular wireless transceiver for biomedical application, the performance of these systems should be properly analyzed. In a communication system the quality of the transmission is usually quantified by either the Bit Error Rate (BER) or the Packet Error Rate (PER), where a packet contains a number of bits. The main goal in the design of digital communication system is to achieve least probability of error and effective utilization of channel bandwidth. In case of digital modulation systems, there are two performance criteria of interest [1]. They are the probability of error relative to the symbol or bit errors and the outage probability defined as the probability that the instant signal to noise ratio falls below a given threshold.

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In this paper the theoretical bit error rate performance of different digital modulation schemes are compared for the selection of suitable modulation scheme for biomedical wireless transceiver. Simulations were performed to study the bit error rate (BER) versus signal to noise ratio (SNR) of the designed models. The results show the effects of various modulation schemes on the BER operating in AWGN channel without any interference. The performance of the different modulation in Rayleigh and Rician fading channels are also analyzed. The BER performance of different modulation schemes is theoretically analyzed to identify the one with best performance for biomedical signal transceivers.

II. OVERVIEW OF THE DIFFERENT FADING CHANNEL MODELS

Fading refers to the distortion that a carrier-modulated telecommunication signal experiences over certain propagation media. In wireless systems, fading is due to multipath propagation and is sometimes referred to as multipath induced fading. There are many models that describe the phenomenon of small scale fading. Out of these models, Rayleigh fading, Rician fading and Nakagami fading models are most widely used. In communications theory, Nakagami distributions, Rician distributions, and Rayleigh distributions are used to model scattered signals that reach a receiver by multiple paths. Depending on the density of the scatter, the signal will display different fading characteristics. Rayleigh and Nakagami distributions are used to model dense scatters, while Rician distributions model fading with a stronger line-of-sight. Nakagami distributions can be reduced to Rayleigh distributions, but give more control over the extent of the fading.

a) ***Rayleigh fading model***: The Rayleigh fading [1,2] is primarily caused by multipath reception. Rayleigh fading is a statistical model for the effect of a propagation environment on a radio signal. It is a reasonable model for troposphere and ionospheres signal propagation as well as the effect of heavily built-up urban environments on radio signals. Rayleigh fading is most applicable when there is no line of sight between the transmitter and receiver. It is frequently used to model the statistics of signals transmitted through radio channels such as cellular radio.

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Let

$$y=x_1^2+x_2^2 \tag{1}$$

Where x_1 and x_2 are zero mean statistically independent Gaussian random variables each having a variance of σ^2. Y is a chi-square distributed variable with two degrees of freedom. The pdf of y is

$$Py(y) = \frac{1}{2\sigma^2} e^{-y/_{2\sigma^2}} \tag{2}$$

From [1] a new random variable is defined

$$R=\sqrt{{x_1}^2+{x_2}^2}=\sqrt{y} \tag{3}$$

The pdf of R is

$$P_R(r) = \frac{r}{\sigma^2} e^{-r^2/_{2\sigma^2}} \tag{4}$$

This is the pdf of a Rayleigh distributed random variable[1].

b) ***Rician fading model*****:** The Ricean fading model [1, 2] is similar to the Rayleigh fading model, except that in Ricean fading, a strong dominant component is present. This dominant component is a stationary (non fading) signal and is commonly known as the LOS (Line of Sight Component). Rice distribution is related to noncentral chi-square distribution. Y has a noncentral chi-square distribution with noncentrality parameter

$$s^2=m_1^2+m_2^2 \tag{5}$$

The pdf of Y is

$$P_Y(y)= \frac{r}{2\sigma^2}\, e^{-(s^2+y)/_{2\sigma^2}} I_0\left(\sqrt{y}\ \frac{s}{\sigma^2}\right) \quad \text{where } y\geq 0 \tag{6}$$

Now a new random variable is defined [1]

$$R=\sqrt{y} \tag{7}$$

The pdf of R is

$$P_R(r) = \frac{r}{\sigma^2} e^{-(r^2+s^2)/_{2\sigma^2}}\ \mathrm{I}_0\left(\frac{rs}{\sigma^2}\right) \text{ where } r\geq 0 \tag{8}$$

This is the pdf of the Ricean distributed random variable. I_0 is the zero-order modified Bessel function of the first kind. If r has a Rician distribution with parameters s and σ, then $(r/\sigma)^2$ has a noncentral chi-square distribution with two degrees of freedom and noncentrality parameter $(s/\sigma)^2$. This pdf characterizes the statistics of the envelope of a signal corrupted by additive narrowband Gaussian noiseI It is also used to model the signal statistics of signals transmitted through some radio channels.

c) ***Additive White Gaussian Noise Model:*** The simplest radio environment in which a wireless communications system will have to operate is the Additive-White Gaussian Noise (AWGN) [1] environment. Additive white Gaussian noise (AWGN) is the commonly used to transmit signal while signals travel from the channel and simulate background noise of channel.

In AWGN channel the modulated signal $s(t) = Re\{u(t)e^{j2\pi fct}\}$ has noise n(t) added to it prior to reception. The mathematical expression in received signal that passed through the AWGN channel is

$$r(t) = s(t) + n(t) \tag{9}$$

Where s(t) is transmitted signal and n(t) is background noise. In the channel model the transmitted waveform is assumed to get corrupted by noise 'n', typically referred to as Additive White Gaussian Noise (AWGN)[1]. The values of the noise 'n' follow the Gaussian probability distribution function,

$$p(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(x-\mu)^2} \text{ With } u = 0 \text{ and } \sigma^2 = \frac{N_0}{2}. \tag{10}$$

III. BIT ERROR PROBABILITY PB OF DIGITAL MODULATION SCHEMES

A. System model for BPSK modulation

The system model for BPSK modulation [1] is as shown in the Figure below.

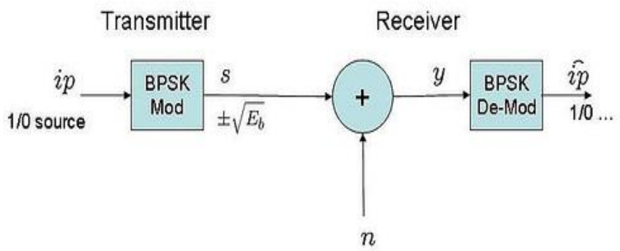

Figure1. Block diagram of BPSK Transceiver

Total probability of bit error for BPSK [1,6] Modulation is

$$P_b=Q\sqrt{\frac{2E_b}{N_0}} \tag{11}$$

E_b is the energy per bit and N_0 is the Noise power spectral density. Q is the Q function which is used frequently for calculating the area under the tail of the Gaussian pdf denoted by Q(x).

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-\left(t^2/_2\right)}\, dt \tag{12}$$

B. Bit error probability P_b of digital modulation schemes

The probabilities of error of different modulation schemes are given in [1,4,5 and 6]. The bit error probability Pb of QPSK is identical to BPSK, but twice as much data can be sent in the same bandwidth. Thus when compared to BPSK, QPSK provides twice the spectral efficiency with exactly the same energy efficiency. Similar to BPSK, QPSK can also be differentially encoded to allow non coherent detection. Phase modulation with Quadrature offset is referred to as OQPSK. OQPSK has the same spectral properties as QPSK for linear amplification, but it has higher spectral efficiency under nonlinear amplification [1].

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The maximum phase transition of the signal is 90°, corresponding to the maximum phase transition in either the in phase or Quadrature branch but not both simultaneously. This Quadrature offset makes the signals less sensitive to distortion during symbol transitions.

Comparing the equation of QPSK and OQPSK, the offset QPSK has exactly same probability of symbol error in an AWGN channel as QPSK except the delay in the basis function. The equivalence in noise performance between these phase shift keying schemes assumes the use of coherent detection. The reason for the equivalence is that statistical independence of the Inphase and Quadrature components applies to both QPSK and OQPSK. The error probability Pb in the Inphase and Quadrature components applies to both QPSK and offset QPSK. Therefore the Pb of OQPSK [1] is

$$P_b = Q\sqrt{\frac{2E_b}{N_0}}$$

E_b is the energy in one bit and N_0 is the noise power spectral density.

The P_b of DPSK [4,8] for size of modulation constellation M=2 is

$$P_b = \frac{1}{2}e^{-\frac{E_b}{N_0}} \quad (13)$$

The P_b of FSK [1,4] for M=2 is

$$P_b = Q\sqrt{\frac{E_b(1 - Re[\rho])}{N_0}} \quad (14)$$

ρ is the complex correlation coefficient

$$\rho = \frac{1}{2E_b}\int_0^{T_b} S_1(t){S_2}^*(t)\,dt \quad (15)$$

S1 and S2 are the complex low pass signals

From [1,4] P_b of FSK for M=2 in eq.[14] becomes

$$P_b = Q\sqrt{\frac{E_b(1 - \sin(2\pi\Delta f T_b)/(2\pi\Delta f T_b))}{N_0}} \quad (16)$$

where Δf is f_1-f_2

IV. Simulation Results

In the first part of the simulation, the channel is assumed to be AWGN. The various digital modulation schemes considered are Binary Phase Shift Keying (BPSK), Minimum Shift Keying (MSK), Frequency Shift Keying (FSK), Offset Quadrature Phase Shift Keying (OQPSK), Differential Phase Shift Keying (DPSK) and Pulse Amplitude Modulation (PAM). In the second part of the simulation, Rayleigh and Rician fading channels are considered with a diversity order of 1 for transmission of the modulated signals. The following figures (figures 2,3 & 4)give the result of the theoretical BER performance evaluation of different digital modulation schemes with varying signal to noise ratios (Eb/N0). The simulations are done using Matlab software.

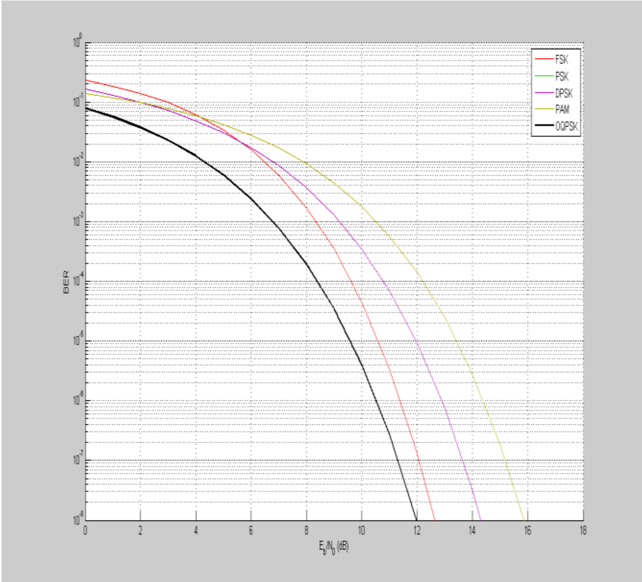

Figure 2. BER of the different digital modulation schemes in AWGN channel

From the simulated results, it is observed that the OQPSK and BPSK modulation gives best performance than any other digital modulation schemes. Similarly the BER performance of various modulation schemes (BPSK, FSK, OQPSK, DPSK, PAM) in Rayleigh Channel [4] gives the following results as shown in Figure 3.

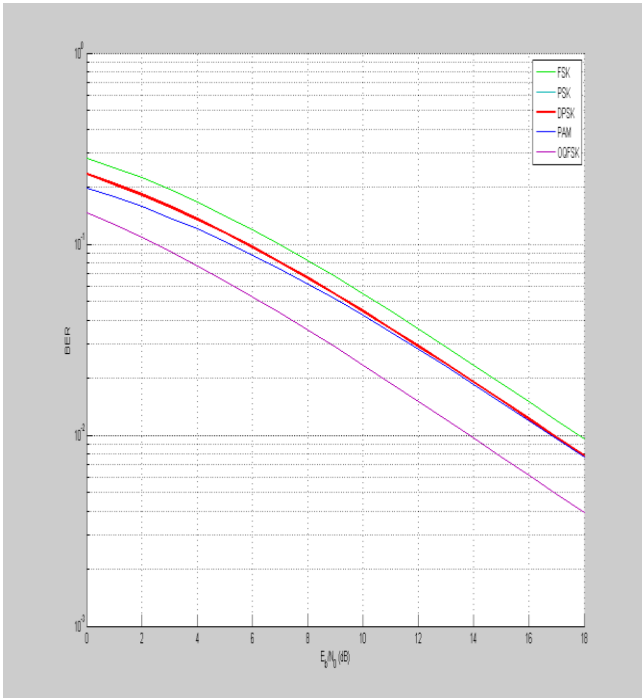

Figure 3 BER of the different digital modulation schemes in Rayleigh channel.

The performance of different modulation schemes in Rician channel [4] is also simulated. The BER performance is similar to that in Rayleigh channel. In Rayleigh fading channel also OQPSK modulation gives best performance.

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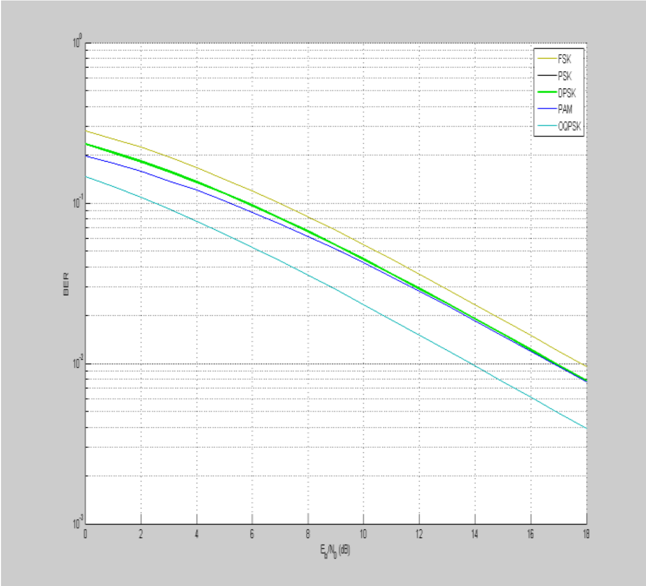

Figure 4 BER of the different digital modulation schemes in Rician channel

V. CONCLUSION

The choice of digital modulation scheme will significantly affect the characteristics, performance and resulting physical realisation of a communication system. There is no universal best choice of scheme, but depending on the physical characteristics of the channel, required levels of performance and target hardware trade-offs, some will prove a better fit than others. In this paper different digital modulation scheme for application in wireless transceivers are theoretically evaluated under AWGN and fading (Rayleigh and Ricean) channel conditions. It is observed that the BER is minimum for AWGN and maximum for Rayleigh and Ricean channels. In AWGN channel, Rayleigh fading channel and Rician channels OQPSK and BPSK gives best performance than all other digital modulation schemes. The Zigbee/IEEE 802.15.4 protocol is considered as a newly introduced WPAN standard for medical application [7,9] is based on OQPSK and BPSK modulation. Wireless transceivers using Zigbee standard can be considered as a suitable candidate for biomedical application when low bit error rate is desired.

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