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A COMPARATIVE BER PERFORMANCE ANALYSIS OF OFDM SYSTEM USING BPSK MODULATION TECHNIQUE OVER AWGN AND RAYLEIGH FADING CHANNEL

[1]TUSHAR KANTI ROY* and [2]MONIR MORSHED

[1]Department of Electronics and Telecommunication Engineering, Rajshahi University of Engineering & Technology, Rajshahi-6204, [2]Department of Information and Communication Technology, Mawlana Bhashani Science and Technology University, Tangail-1902

Abstract

Orthogonal Frequency Division Multiplexing (OFDM) is becoming the chosen modulation technique for wireless communications. OFDM can provide large data rates with sufficient robustness to radio channel impairments. Digital modulation techniques contribute to the evolution of our mobile wireless communications by increasing the capacity, speed as well as the quality of the wireless network. In this paper, we concentrate on the BPSK digital modulation technique for OFDM system over AWGN and Rayleigh fading channels. BPSK digital simulation is modelled and simulated under different channel conditions. Subsequently, a comparison study is carried out to obtain the BER performance of BPSK-based modulation scheme under AWGN and Rayleigh channel conditions respectively, and to identify which combination gives better performance. From comparison study we can observe that the OFDM- BPSK modulation has no advantage over a normal BPSK scheme in AWGN but OFDM-BPSK modulation in AWGN has great advantage over OFDM-BPSK modulation in Rayleigh fading.

Keywords: AWGN, BER, BPSK, OFDM, Rayleigh fading

Introduction

The growth in use of the information networks lead to the need for new communication technique with higher data rate. There is several modulation techniques are available but among the variety of modulation technique, OFDM modulation technique is the best. In an OFDM scheme, a large number of orthogonal, overlapping, narrow band sub-channels or subcarriers, transmitted in parallel, divide the available transmission bandwidth. OFDM is the modulation technique used in many new broadband communication schemes including digital television, digital audio broadcasting, ADSL and wireless LANs. It also allows digital data to be efficiently and reliably transmitted over a radio channel, even in multipath environments (Chuang and Sollenberger, 2000; Saltzberg, 1967; Armada, 2001). In OFDM, subcarriers overlap but it does not create any problem. Since they are orthogonal that is the peak of one subcarrier occurs when other subcarriers are at zero. This is achieved by realizing all the subcarriers together using inverse fast Fourier transform (IFFT). The analysis of bit error rate (BER) performance suggests that OFDM is better than CDMA which is mostly incorporated in the existing 3G systems (Jain and Roja, 2005; Sklar, 2000). A major problem in most wireless systems is the presence of a multipath channel. In a multipath environment, the transmitted signal

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* Author for Correspondence (roy_kanti@yahoo.com ; monirmorshed.mbstu@gmail.com)

reflects off of several objectives. As a result, multiple delayed versions of the transmitted signal arrive at the receiver. The multiple versions of the signal cause the received signal to be distorted. Many wired systems also have a similar problem where reflections occur due to impedance mismatches in the transmission line. A multipath channel will cause two problems for an OFDM system. The first problem is inter-symbol interference (ISI). This problem occurs when the received OFDM symbol is distorted by the previously transmitted OFDM symbol. The effect is similar to the inter-symbol interference that occurs in a single-carrier system. However, in such systems, the interference is typically due to several other symbols instead of just the previous symbol; the symbol period in single carrier systems is typically much shorter than the time span of the channel , whereas the typical OFDM symbol period is much longer than the time span of the channel. The second problem is unique to multicarrier systems and is called intra-symbol interference. It is the result of interference amongst a given OFDM symbol's own subcarriers. An Adaptive modulation and coding technique to overcome inter-symbol interference (ISI) and analyse the performance of BER is proposed in (Salih and Suliman, 2011). Comparative BER performance of digital modulation techniques under multipath fading is addressed in (Jain and Roja, 2005), in which the performance of the OFDM is tested for M-PSK and M-QAM using MATLAB.

The performance of different modulation schemes for OFDM based WLAN standard IEEE 802.11a is proposed in (Kumar and Sharma).The concept of OFDM is quite simple but the practicality of implementing it has many complexities. A single stream of data is split into parallel streams each of which is coded and modulated on to a subcarrier, a term commonly used in OFDM systems. Thus the high bit rates seen before on a single carrier is reduced to lower bit rates on the subcarrier. It is easy to see that ISI will therefore be reduced dramatically.

Throughout this paper we present the BER performance comparison results over AWGN and Rayleigh fading channel using the digital modulation technique BPSK for OFDM in IEEE802.11a standard so as to obtain the most efficient modulation combination that will give us better performance. Therefore, the purpose of this paper is to implement and find the efficient modulation combination among the normal BPSK and OFDM-BPSK in AWGN and OFDM-BPSK in Rayleigh fading that performs better in the wireless channels and that are mostly multipath.

The rest of this paper is organized as follows. Section II briefly introduces the OFDM system model, in which we describe OFDM transmit signal and received signal mathematical equations. In this section we also describe the relationship between E_s/N_0 and E_b/N_0 for OFDM system as well as cyclic prefix of OFDM. In Section III we describe the Rayleigh fading channel along with cyclic prefix for OFDM system. Section IV describes the detail of BPSK modulation technique. Section V discusses simulation results. Finally, the paper is concluded in Section VI.

System Modelling

OFDM Transceiver

In this section we describe the OFDM transceiver system. Before transmitting information bit in AWGN or Rayleigh multipath fading channel through OFDM transmitter, we use BPSK modulation scheme which is shown in Fig.1. That is, the transmitter section converts digital data to be transmitted, into a mapping of subcarrier amplitude and phase by using modulation techniques. Its then transforms the spectral representation of the data into the time domain using an inverse fast Fourier transform as it is much more computationally efficient and so is used in all practical systems (Hanzo *et al*, 2000; Weinstein and Ebert, 1971). The addition of a cyclic prefix to each symbol solves both ISI and ICI (Cai and Giannakis, 2002; Chen and Zhu, 2004). Digital data is then transmitted over the channel. After the time-domain signal passes through the channel it is broken back into the parallel symbols and the prefix is simply discarded. The receiver performs the reverse operation of the transmitter. The amplitude and phase of the subcarriers is then picked out and converted back to digital data.

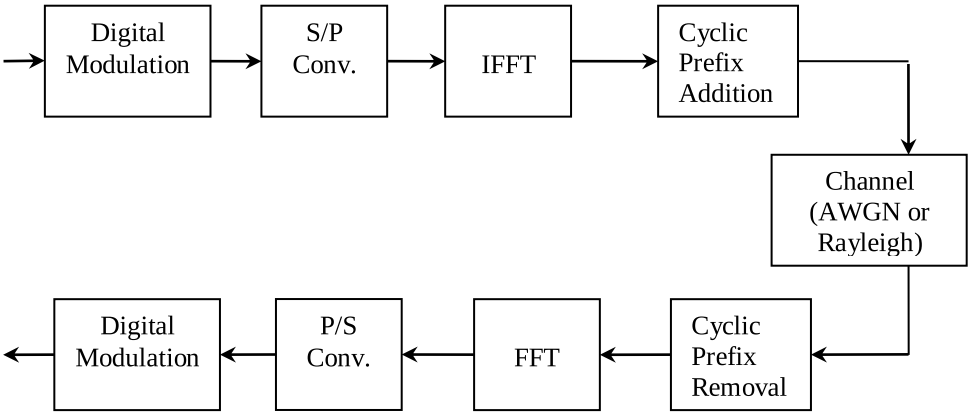

Fig.1. Block diagram of a basic OFDM transceiver

In orthogonal frequency division multiplexing (OFDM), multiple sinusoidal with frequency separation *1/T* is used where *T* is the active symbol period. The information g_k to be sent on each subcarrier *k* is multiplied by the corresponding carrier $g_k(t) = e^{\frac{j2\pi kt}{T}}$ and the sum of such modulated sinusoidal form the transmit signal. Therefore, the sinusoidal used in OFDM can be defined as follows (Islam *et al*, 2011):

$$g_k(t) = \frac{1}{\sqrt{T}} e^{\frac{j2\pi kt}{T}} w(t) \tag{1}$$

Where k *=0, 1, ... N-1* correspond to the frequency of the sinusoidal and *w(t) =u(t)-u(t-T)* is a regular window over *[0, T].* Since OFDM uses multiple sinusoidal having frequency separation 1/T, therefore each sinusoidal is modulated by independent information. Mathematically we can write the transmit signal through the channel is,

$$\begin{aligned} S(t) &= \delta_0 g_0(t) + \delta_1 g_1(t) + \ldots + \delta_{N-1} g_{N-1}(t) \\ &= \sum_{0}^{N-1} \delta_k g_k(t) \\ &= \frac{1}{T} \sum_{0}^{N-1} \delta_k e^{\frac{j2\pi kt}{T}} w(t) \end{aligned} \tag{2}$$

where, δ_k is the k^{th} symbol in the message symbol sequence for *k* in *[0, N-1], N* is the number of carriers.

In an OFDM receiver, we will multiply the received signal with a bank of corelator and integrate over the period *T*. Therefore, the information send on subscriber *k* is

$$\frac{1}{T}\int_T s(t)e^{-\frac{j2\pi mt}{T}} = \begin{cases} g_k, & m = k \\ 0, & m \neq k \end{cases} \tag{3}$$

where, *m* takes values from *0* to *k-1.*

If we consider the AWGN channel then we can remove the frequency domain equalizer from the OFDM receiver (note: frequency domain equalizer will be helpful only if the channel introduces multipath fading). Since we consider the AWGN channel, the frequency domain equalizer block is removed from the above block diagram of the OFDM transceiver system.

Relationship between E_s/N_0 and E_b/N_0 for OFDM System

This section presents the relationship between the relationship between E_s/N_0 and E_b/N_0 for OFDM system. In order to do a Monte Carlo simulation of an OFDM system, required amount of channel noise has to be generated that is representative of required E_b/N_0. In MATLAB it is easier to generate a Gaussian noise with zero mean and unit variance. The generated zero-mean-unit-variance noise has to be scaled accordingly to represent the required E_b/N_0 or E_s/N_0. Normally for a simple BPSK system, bit energy and symbol energy are same. So E_b/N_0 and E_s/N_0 are same for a BPSK system. But for an OFDM-BPSK system they are not the same. Because each OFDM symbol contains additional overhead both time domain and frequency domain. In time domain, the cyclic prefix is an additional overhead added to each OFDM symbol that is being transmitted. In the frequency domain, not all the subcarriers are utilized for transmitted the actual data bits, rather a few subcarriers are unused and are reserved as guard bands. The relationship between symbol energy and the bit energy is as follows [3]:

$$\frac{E_s}{N_0} = \frac{E_b}{N_0}\left(\frac{n.DSC}{n.FFT}\right)\left(\frac{T_d}{T_d + T_{cp}}\right) \tag{4}$$

If we express the above equation in dB then we can write

$$\frac{E_s}{N_0}dB = \frac{E_b}{N_0}dB + 10\log_{10}\left(\frac{n.DSC}{n.FFT}\right) + 10\log_{10}\left(\frac{T_d}{T_d + T_{cp}}\right) \tag{5}$$

where T_d is the data symbol duration, T_{cp} is the cyclic prefix duration and *n.DSC* is the number of used subscriber in the OFDM system.

Cyclic Prefix of OFDM

Since orthogonality is important property for an OFDM system, so synchronization in frequency and time must be extremely good. Once it is lost we experience inter-carrier interference (ICI). This will introduce interference from one subcarrier to another. There is another reason for ICI in OFDM system. If we add the guard time with no transmission then it creates problems for IFFT and FFT, which results in ICI. A delayed version of one subcarrier can interfere with another subcarrier in the next symbol period. This can be avoided by extending the symbol into the guard period that precedes it, which is known as a cyclic prefix. It ensures that delayed symbols will have integer number of cycles within the FFT integration interval. This removes ICI so long as the delay spread is less than the guard period. It should be noted that FFT integration period excludes the guard period. In an OFDM transmission, we know that the transmission of cyclic prefix does not carry ‘extra’ information in additive white Gaussian noise (AWGN) channel. The signal energy is spread over time T_d+T_{cp} whereas the bit energy is spread over the time T_d , i.e.,

$$E_s(T_d+T_{cp})=E_bT_d \tag{6}$$

After simplifying we get the following equation,

$$E_s=\frac{T_d}{(T_d+T_{cp})}E_b \tag{7}$$

Rayleigh Multipath Channel Model

When there are large numbers of paths, applying Central Limit Theorem, each path can be modelled as circularly symmetric complex Gaussian random variable with time as the variable. This model is called Rayleigh fading channel model. A circularly symmetric complex Gaussian random variable is of the form,

$$Z=X+jY \tag{8}$$

where real X and imaginary Y parts are zero mean independent and identically distributed Gaussian random variables. For a circularly symmetric complex random variable Z,

$$E[Z]=E[e^{j\theta}Z]=e^{j\theta}E[Z] \tag{9}$$

The statistics of a circularly symmetric complex Gaussian random variable is completely specified by the variance,

$$\sigma^2=E[Z^2] \tag{10}$$

The magnitude |Z| which has a probability density,

$$p(z)=\frac{z}{\sigma^2}e^{\frac{-z^2}{2\sigma^2}},\quad z\geq 0 \tag{11}$$

It is called a Rayleigh random variable. This model, called Rayleigh fading channel model, is reasonable for an environment where there are large numbers of reflectors. The channel is modelled as n-tap channels with each the real and imaginary part of each tap being an independent Gaussian random variable. The impulse response is,

$$h(t)=\frac{1}{\sqrt{n}}\left[h_1(t-t_1)+h_2(t-t_2)+\cdots+h_n(t-t_n)\right] \tag{12}$$

Where

$h_1(t-t_1)$ is the channel coefficient of the 1st tap,
$h_2(t-t_2)$ is the channel coefficient of the 2nd tap and so on.

The real and imaginary part of each tap is an independent Gaussian random variable with mean 0 and variance 1/2. The term $\frac{1}{\sqrt{n}}$ is for normalizing the average channel power over multiple channel realizations to 1.

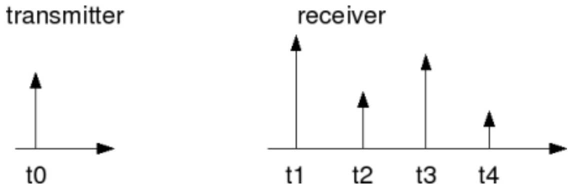

Fig. 2. Impulse response of a multipath channel

Cyclic Prefix in Rayleigh Fading Channel

In this section we discuss the need for cyclic prefix for Rayleigh channel in OFDM transmission and how it plays the role of a buffer region where delayed information from the previous symbols can get stored. Further, since addition of sinusoidal with a delayed version of the sinusoidal does not change the frequency of the sinusoidal (affects only the amplitude and phase), the orthogonally across subcarriers is not lost even in presence of multipath. Since the defined cyclic prefix duration is 0.8us duration (16 samples at 20MHz), the Rayleigh channel is chosen to be of duration 0.5us (10 taps).

BPSK Modulation

BPSK is the simplest form of PSK. It uses two phases which are separated by 180° and so can also be termed 2-PSK. For BPSK modulation the channel can be modelled as

$$y = ax + n \tag{13}$$

where y is the received signal at the input of the BPSK receiver, x is the modulated signal transmitted through the channel , a is a channel amplitude scaling factor for the transmitted signal usually 1 and n is the AWGN random variable with zero mean and variance σ^2. For AWGN the noise variance in terms of noise power spectral density (N_0) is given by,

$$\sigma^2 = \frac{N_0}{2} \tag{14}$$

The theoretical BER for BPSK modulation scheme over an AWGN channel is given by

$$P_b = \frac{1}{2}\, erfc\,(\sqrt{\frac{E_b}{N_0}}) \tag{15}$$

For BPSK modulation schemes the symbol energy is given by

$$E_s = R_c E_b \tag{16}$$

where E_s =Symbol energy per modulated bit (x), R_c is the code rate of the system if a coding scheme is used. In our case since no coding scheme is used $R_c = 1$. E_b is the Energy per information bit. Assuming Es=1 for BPSK (Symbol energy normalized to 1) E_b/N_0 can be represented as (using above equations),

$$\frac{E_b}{N_0} = \frac{E_s}{R_c N_0} \tag{17}$$

From the above equation the noise variance for the given E_b/N_0 can be calculated as

$$\sigma^2 = (2R_c \frac{E_b}{N_0})^{-1} \tag{18}$$

For the channel model random function in MATLAB is used to generate the noise term. This function generates noise with unit variance and zero mean. In order to generate a noise with sigma σ for the given Eb/N0 ratio, use the above equation, find σ, multiply the 'random' generated noise with this sigma, add this final noise term with the transmitted signal to get the received signal. Now, the BER for BPSK in a Rayleigh fading channel is defined as

$$P_b = \frac{1}{2}(1 - \sqrt{\frac{E_b/N_0}{E_b/N_0 + 1}}) \tag{19}$$

Since there is only one bit per symbol that is why the BER for BPSK both in AWGN and Rayleigh fading channel is also defined only intern of the symbol error rate.

Simulation results

In this section we represent the BER performance of BPSK digital modulation with OFDM technique over AWGN and Rayleigh fading channels, respectively. The performance of BER of BPSK modulation has been investigated by means of a computer simulation using MATLAB. Both AWGN and Rayleigh fading based OFDM systems are implemented using MATLAB programming and the graphical results found show the bit error rate probabilities for both of the systems. The results presented show the BER performance as a function of the energy per bit to noise ratio. The OFDM technique MATLAB simulations are based on 802.11a specifications that shown in table 1.

Table 1. Simulation parameters

Parameter	Value
FFT size. nFFT	64
Number of used subcarriers. nDSC	52
FFT Sampling frequency	20MHz
Subcarrier spacing	312.5kHz
Used subcarrier index	{-26 to -1, +1 to +26}
Cyclic prefix duration, T_{cp}	0.8us
Data symbol duration, T_d	3.2us

The BER performance of an OFDM system with BPSK modulation over AWGN channel and N = 64 is shown in Fig.3. From this figure we can observe that the theoretical and simulated results of BPSK modulation over AWGN channel are the same. Hence this result is correct.

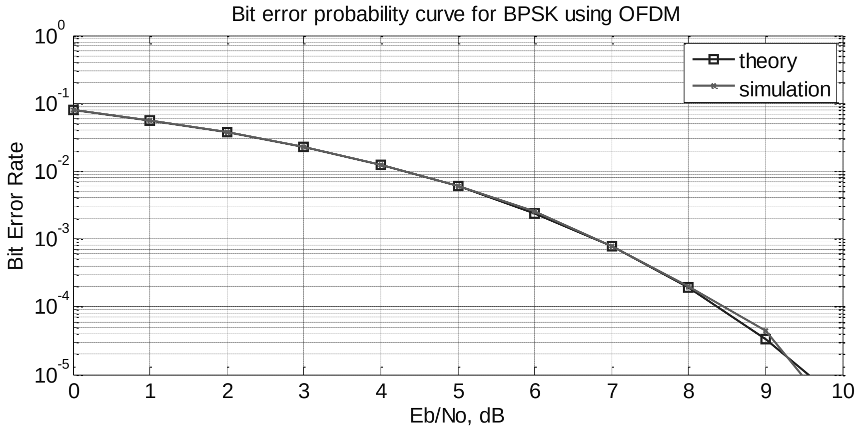

Fig. 3. BER Vs E_b/N_0 for OFDM with BPSK modulation over AWGN channel

Fig.4 shows the BER performance of normal BPSK modulation over AWGN channel. It can be seen that the BER performance of normal BPSK modulation is almost same with the BPSK using OFDM over AWGN channel. From comparison study we can observe that the OFDM-BPSK modulation has no specific advantage over a normal BPSK scheme in AWGN.

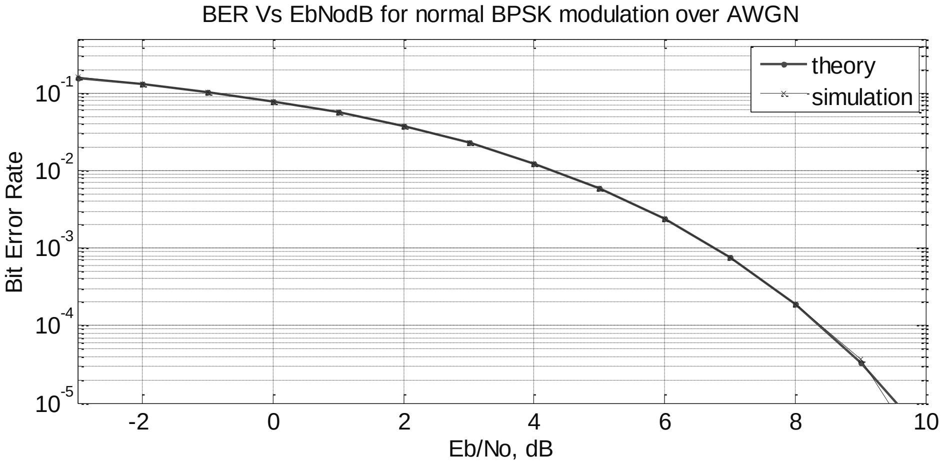

Fig. 4. BER Vs E_b/N_0 for normal BPSK modulation over AWGN channel

Fig. 5 shows the BER performance of an OFDM system having N=64□ and BPSK modulation scheme over frequency flat Rayleigh multipath fading and AWGN channels, where the number of taps are used 10□in calculating the theoretical BER value. As can be seen, the numbers of taps do not introduce much deviation to the real performance given by simulation results. Comparing the theoretical BER for Rayleigh equation, it is identical with the simulation result.

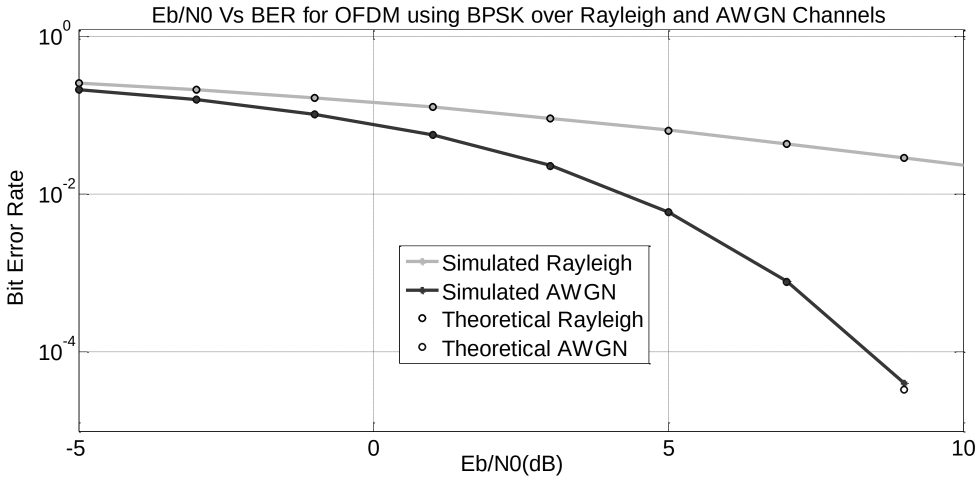

Fig. 5. BER Vs E_b/N_0 for OFDM using BPSK modulation over Rayleigh and AWGN channels

As seen in Fig. 3, 4 and 5, it is found that as the energy per bit to noise ratio increases in any system, a decrement in bit error rate is encountered. Also, AWGN based system performs better in terms of bit error rate probability as compared to Rayleigh fading based system for any value of E_b/N_0 in all two channel scenarios.

Conclusion

This paper compares the performance of Fourier transform based OFDM system in terms of bit error rate probability for different channels scenarios. From the performed simulations in the Additive White Gaussian Noise (AWGN) channel, it is found that OFDM- BPSK modulation has no advantage over a normal BPSK scheme. But is found that both OFDM-BPSK and normal BPSK having small bit error rate probability than that of the Rayleigh fading based BPSK system. The purpose of this paper is to implement and find the efficient modulation combination that performs better in the wireless channels that are mostly multipath. The paper compares the performance of the systems using binary phase shift keying whereas the future work may include the implementation of other modulation schemes and different channel scenarios for performance evaluation of any OFDM based system.

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