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Performance Study of OFDM over Multipath Fading Channels for Next Wireless Communications

Kommabatla Mahender
Research Scholar, Department of Electronics and Communication Engineering,
Koneru Lakshmaiah University, Vaddeswaram, Guntur, Andhrapradesh, India

Tipparti Anil Kumar
Professor, Department of Electronics and Communication Engineering,
CMR College of Engineering & Technology, Kandakoya, Secunderabad, Telangana, India.

K.S. Ramesh
Associate Professor
Professor, Department of Electronics and Communication Engineering,
Koneru Lakshmaiah University, Vaddeswaram, Guntur, Andhrapradesh, India.

Abstract

Orthogonal Frequency Division Multiplexing (OFDM) is a very efficient multicarrier technique. OFDM is used more and more in recent wideband digital communications. It has numerous advantages such as the ability to handle severe channel conditions, efficient spectral usage, reduced inter symbol interference (ISI), and high data rate. Therefore, it has been utilized in many future wired and wireless communication systems 4G LTE mobile communications. In this paper, mainly focus on the performance evaluation and study of OFDM system over multipath fading channels such as AWGN, Rician and Rayleigh fading channels. Based on simulation results will make us understand some of these effects and signal-to-noise ratios (SNRs), channels are compared together in order to rank them according to the delivered signal. Quality of the signals, bit-error rates (BERs), and peak signal-to-noise ratios (PSNRs) of the received signals are the aspects in which system performance is evaluated.

Keywords: AWGN, BER, ISI, OFDM and PSNR

INTRODUCTION

The problems of inter symbol interference (ISI) in single carrier communication systems is significantly reduced when the symbol period is made bigger than the time delay [1]. However, having long symbol period results in a very low data rate, which makes the communication system inefficient. Therefore, single carrier communication is not enough to transfer data at a high rate.

Demand for broadband communications is increasing every day. Multicarrier communication is used to meet that increasing need [4]. Frequency division multiplexing (FDM) is a multicarrier technique that subdivides the spectrum of the communication channel to transmit data in parallel through multiple carriers [1]. Inter carrier interference (ICI) is another possible problem, in this case, since carriers are so closely spaced to achieve a high data rate. This issue is resolved by placing guard bands between carriers, which lowers the data rate as a trade off.

Currently, OFDM is the most common technique for many communication systems because of its ability to provide high speed without facing the problem of ICI and ISI [7]. In fact, it is considered to be the dominant communication technique that can handle a digital multimedia application [4].

OFDM is considered to be a special case of FDM [1]. An intuitive understanding of the difference between FDM and OFDM channels is to think of the water flow coming out of a faucet as the FDM channel and the water coming from the shower as the OFDM signal. ISI and multipath fading effects have been minimized by sending data in parallel subcarriers and at a low data rate. OFDM is efficiently utilized in many applications such as the wireless local area network (WLAN), fourth generation communications 4G LTE and digital audio broadcasting (DAB) [2-3] [5].

This paper is mainly concerned with the performance studying of OFDM by analyzing the system performance over multipath fading channels. OFDM performance evaluated with those channels in terms of bit-error rates (BERs), signal-to-noise ratios (SNRs), peak signal-to-noise ratios (PSNRs) over multipath fading channels.

The organization the paper as follows: OFDM communication system explained in Section-II, and BER performance analysis of different digital modulation over multipath fading channels quantitatively explained in Section –III, in Section IV and V describes about simulation results and conclusion of this paper.

OFDM COMMUNICATION SYSTEM

Figure 1 illustrate that the block diagram of OFDM communication system. At the transmitter, the incoming information bit stream (from the data source) is first converted into a stream of *M*-QAM information symbols at the *M*-QAM symbol mapper.

Let $\left\{\hat{X}\left[\hat{k}\right]\right\}$, $\hat{k}=1,2,\ldots N_u$ be the *M*-QAM symbol vector to be transmitted in the *l*-th channel use, where *Nu* is the number of *M*-QAM information symbols to be transmitted in this channel use. Then the pilot tones (i.e. for the channel estimation) and the virtual carriers (i.e. for the guard bands) are inserted into $\left\{\hat{X}\left[\hat{k}\right]\right\}$ symbol vector before it converts into parallel $\left\{X\left[k\right]\right\}^T$ k = 1, 2,..., N symbol vector, where N denotes the IFFT/FFT size $\left(N \geq N_u\right)$. Then the IFFT operation is performed for the $\left\{X\left[k\right]\right\}^T$ symbol vector, and the addition of the CP and the parallel-to-serial conversion are performed to generate the discrete time domain OFDM symbol $\left\{X\left[k\right]\right\}$.

Then the continuous OFDM symbol $x(t)$ ($0 < t \leq T_{sym}$) is generated using the digital-to-analog convertor (DAC), where T_{sym} is the OFDM symbol duration. In practical communication systems, a time domain pulse shaper is used to reduce the out-of-band power in the OFDM symbol before up-converting the OFDM symbol to the pass band (i.e. RF frequency band at which the communication system operates). Finally, this pass band OFDM symbol is transmitted over the channel.

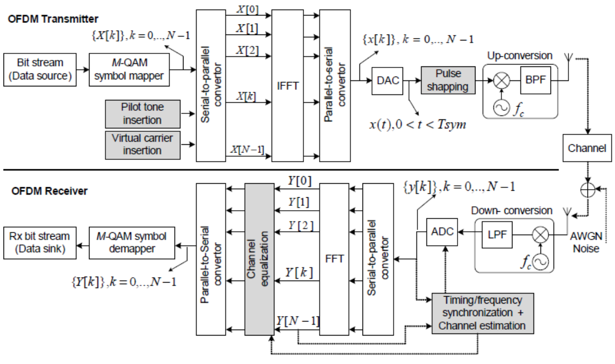

Figure 1: A block diagram of OFDM communication system

BER Performance Analysis of M-Ary Digital Modulation over AWGN, Rayleigh and Rician Fading Channels

In this section, evaluate the effect of fading channels on different digital modulation schemes. The bit error probability (P_b) often known as BER is a better performance measure to evaluate a modulation scheme. The BER performance of any digital modulation scheme in a slow flat fading channel can be evaluated by the following integral

$$P_b = \int_0^{\infty} P_{b,AWGN}(\gamma) P_{df}(\gamma)\, d\gamma \tag{1}$$

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 $\gamma = h^2 \frac{E_b}{N_o}$.

Here, the random variable h is the channel gain, $\frac{E_b}{N_o}$ is the ratio of bit energy to noise power density in a non-fading AWGN channel, the random variable h^2 represents the instantaneous power of the fading channel, $P_{df}(\gamma)$ the probability density function of γ due to the fading channel.

A. *BER of BPSK Modulation in AWGN Channel*

It is known that the BER for M-PSK in AWGN channel is given by [1]

$$BER_{M-PSK} = \frac{2}{\max\left(\log_2 M, 2\right)}$$

$$\sum_{k=1}^{\max(M/4,1)} Q\left(\sqrt{\frac{2E_b \log_2 M}{N_o}} \sin\frac{(2k-1)\pi}{M}\right) \tag{2}$$

For coherent detection of BPSK, Eq. (2) with M = 2 reduces to

$$BER_{BPSK} = Q\left(\sqrt{\frac{2E_b}{N_o}}\right) \tag{3}$$

Where

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} \exp\left(-\frac{y^2}{2}\right) dy$$

Equation (3) can be rewritten as

$$BER_{BPSK,AWGN} = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_o}}\right) \quad (4)$$

where erfc is the complementary error function and $\frac{E_b}{N_o}$ is the bit energy-to-noise ratio. The erfc can be related to the Q function as

$$Q(x) = \frac{1}{2} erfc\left(\frac{x}{\sqrt{2}}\right) \quad (5)$$

For large $\frac{E_b}{N_o}$ and M>4, the BER expression can be simplified as

$$BER_{M-PSK} = \frac{2}{\log_2 M} Q\left(\sqrt{\frac{2E_b \log_2 M}{N_o}} \sin\frac{\pi}{M}\right) \quad (6)$$

B. *BER of BPSK Modulation in Rayleigh Fading Channel*

For Rayleigh fading channels, h is Rayleigh distributed, h^2 has chi-square distribution with two degrees of freedom. Hence

$$P_{df}(\gamma) = \frac{1}{\gamma} \exp\left(-\frac{\gamma}{\bar{\gamma}}\right) \quad (7)$$

Where $\bar{\gamma} = \frac{E_b}{N_o} E\left[h^2\right]$ is the average signal-to-noise ratio. $E\left[h^2\right] = 1$, $\bar{\gamma}$ corresponds to the average $\frac{E_b}{N_o}$ for the fading channel.

By using Equations (1) and (3), the BER for a slowly Rayleigh fading channel with BPSK modulation can be expressed as [9-10]

$$BER_{BPSK,Rayleigh} = \frac{1}{2}\left(1 - \sqrt{\frac{\bar{\gamma}}{1+\bar{\gamma}}}\right) \quad (8)$$

For $E\left[h^2\right] = 1$ Eq. (2.8) can be rewritten as

$$BER_{BPSK,Rayleigh} = \frac{1}{2}\left(1 - \sqrt{\frac{\frac{E_b}{N_o}}{1+\frac{E_b}{N_o}}}\right) \quad (9)$$

C. *BER of BPSK Modulation in Rician Fading Channel*

The error probability estimates for linear BPSK signaling in Rician fading channels are well documented in [11] and is given as

$$P_{b,Rician} = Q_1(a,b) - \frac{1}{2}\left[1 + \sqrt{\frac{d}{d+1}}\right] \exp\left(-\frac{a^2+b^2}{2}\right) I_0(ab) \quad (10)$$

Where

$$a = \left[\sqrt{\frac{K_r^2\left[1+2d-2\sqrt{d(d+1)}\right]}{2(d+1)}}\right]$$

$$, b = \left[\sqrt{\frac{K_r^2\left[1+2d+2\sqrt{d(d+1)}\right]}{2(d+1)}}\right]$$

$$K_r = \frac{\alpha^2}{2\sigma^2},\ d = \sigma^2 \frac{E_b}{N_0}$$

The parameter K_r is the Rician factor. The $Q_1(a,b)$ is the Marcum Q function defined [9] as

$$Q_1(a,b) = \exp\left(-\frac{a^2+b^2}{2}\right) \sum_{i=0}^{\infty} \left(\frac{a}{b}\right)^I I_0(ab)$$

$$b \geq a > 0 \quad (11)$$

$$Q_1(a,b) = Q(b-a) \qquad b \gg 1 \text{ and } b \gg b-a$$

D. *BER Performance of BFSK in AWGN, Rayleigh and Rician Fading Channels*

In BPSK, the receiver provides coherent phase reference to demodulate the received signal, whereas the certain applications use non-coherent formats avoiding a phase reference. This type of non-coherent format is known as binary frequency-shift keying (BFSK).

The BER for non-coherent BFSK in slow flat fading Rician channel is expressed as [10]

$$P_{b,BFSK(Ric)} = \frac{1+K_r}{2+2K_r+\bar{\gamma}} \exp\left(-\frac{K_r\bar{\gamma}}{2+2K_r+\bar{\gamma}}\right) \quad (12)$$

Where K_r is the power ratio between the LOS path and non-LOS paths in the Rician fading channel

Substituting $K_r = \infty$ in Eq. (12), the BER in AWGN channel for non-coherent BFSK can be expressed as

$$P_{b,AWGN} = \frac{1}{2}\exp\left(-\frac{E_b}{2N_0}\right) \quad (13)$$

Whereas substitution of Kr = 0 leads to the following BER expression for slow flat Rayleigh fading channels using non-coherent BFSK modulation

$$P_{b,BFSK(Ray)} = \frac{1}{2+\bar{\gamma}} \quad (14)$$

E. Comparison of BER Performance of BPSK, QPSK, and 16-QAM in AWGN and Rayleigh Fading Channels

The BER of gray-coded M-QAM in AWGN channel can be more accurately computed by [12]

$$BER_{16QAM,AWGN} \approx \frac{4}{\log_2 M}\left(1-\frac{1}{\sqrt{M}}\right) \sum_{i=1}^{\sqrt{M}/2} Q\left(\sqrt{\frac{3\log_2 M E_b}{(M-1)N_0}}\right) \quad (15)$$

In Rayleigh fading, the average BER for M-QAM is given by [6]

$$BER_{M-QAM,AWGN} \approx \frac{2}{\log_2 M}\left(1-\frac{1}{\sqrt{M}}\right) \sum_{i=1}^{\sqrt{M}/2}\left(1-\sqrt{\frac{1.5(2i-1)^2\bar{\gamma}\log_2 M}{M-1+1.5(2i-1)^2\bar{\gamma}\log_2 M}}\right) \quad (16)$$

SIMULATION RESULTS

The major simulation parameters of the OFDM physical layer are listed in below Table 1.

Table 1: Simulation Parameters of the OFDM Communication System

Information rate	6,9,12,18,2436,48 and 54 M bits/sec
Modulation	BPSK- OFDM, QPSK- OFDM, 16-QAM OFDM, 64-QAM OFDM
Error correcting code	K=7 conventional code
Coding rate	1/2, 2/3,3/4
Number of subcarrier	52
OFDM symbol duration	4.0 µs
Guard interval	0.8 µs
Occupied bandwidth	16.6 MHz

In Figure 2 illustrated that the, BER comparison performance of BPSK in AWGN, Rayleigh, and Rician fading channels. We obtain the BER results of 10^{-4}, using BPSK modulation, an AWGN channel requires $\frac{E_b}{N_0}$ of 8.35 dB, Rician channel requires $\frac{E_b}{N_0}$ of 20.5 dB and a Rayleigh channel requires $\frac{E_b}{N_0}$ of 34 dB. It is clearly indicative of the large performance difference between AWGN channel and fading channels.

The relationship between BER and SNR using different M-PSK modulations is shown in Figure 3. It is obvious that BER increases at higher orders of M-PSK. It is also important to notice that BER rates are inversely proportional to the values of SNRs.

In Figure 4 and Table 2 provide similar comparisons in terms of PSNR. Depending on the quality of the received signals BERs and PSNRs, OFDM system shows the best performance over an AWGN channel. Quality of the signal would be excellent in case its power is increased. However, transmission over fading channels in wireless communications showed some distortion in the images.

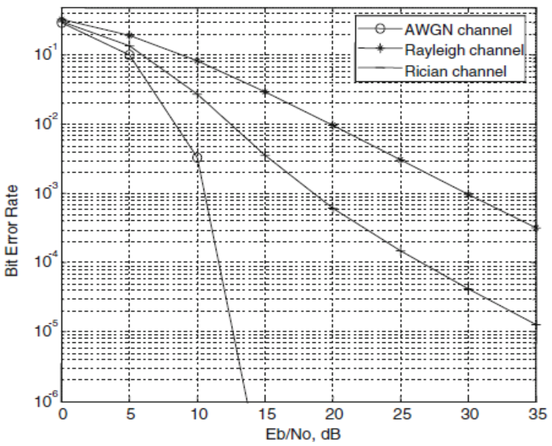

Figure 2: BER performance of BFSK in AWGN, Rayleigh, and Rician fading channels

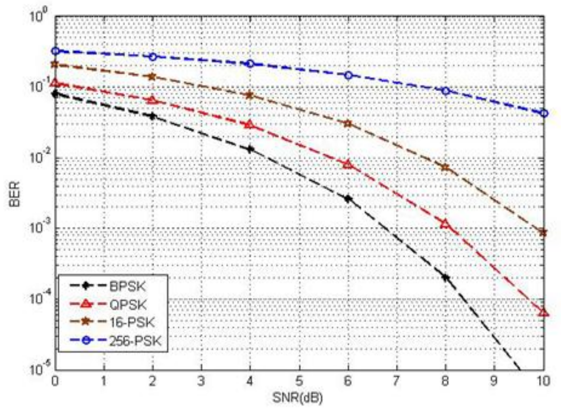

Figure 3: BER versus SNR over the M-PSK Modulation Schemes

It is clear from the results that the quality of the received signal is worsened when the speed of the mobile is increased as well as going from flat fading to frequency selective fading channel.

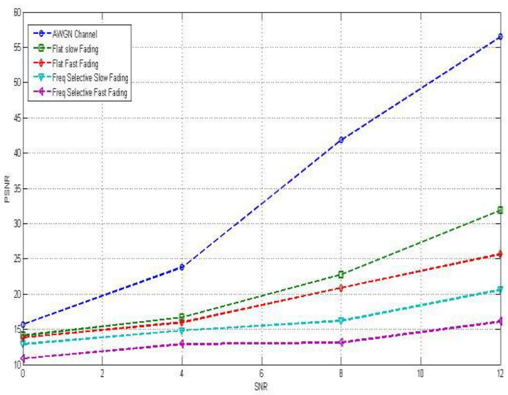

Figure 4: PSNR Comparison of the Different multipath fading Channels

It very important to remember that OFDM has the ability to handle severe channels conditions. Subcarriers have dealt with the fading issues. Hence, the performance over fading channels is quite acceptable.

Table I1: PSNR Measurements vs. SNRs for Different Channels

Channel SNR(dB)	AWGN Fading	Flat Slow Fading	Flat Fast Fading	Frequency Selective Slow Fading	Frequency Selective Fast Fading
0	15.7	14.1	13.826	12.9	10.825
4	23.8	16.7	16	14.8	12.9
8	41.84	22.75	20.9	16.19	13.09
12	56.5	31.9	25.67	20.61	16.08

Tables 2, 3 and Figure 2 show the comprehensive assessment of the innovative capacity performed by the grade method, integral method and in graph form.

CONCLUSION

OFDM systems are very efficient in handling bad conditions and high data rates. Fading channels, however, are very common in wireless communications. They affect the process of signal reception after causing losses in transmitted signal. Fading channels include two types of flat fading and two types of frequency selective fading. Effects that fading channels have on the performance of OFDM systems were investigated.

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