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Performance Analysis Of Cyclic Prefix OFDM Using Adaptive Modulation Techniques

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ABSTRACT *— A Orthogonal Frequency Division Multiplexing (OFDM) scheme provides high spectral efficiency and better resistance to fading environments. In OFDM the data is modulated using multiple number of sub-carriers that are orthogonal to each other. The Inter Symbol Interference (ISI) and Inter Channel/Carrier Interference (ICI) are reduced to a great extent with use of OFDM. A guard time, in the form of Cyclic Prefix (CP) is inserted between OFDM symbols to eliminate both the lSI and ICI. In this article, OFDM based BPSK, QPSK and QAM modulation systems are demonstrated incorporating AWGN channels using MATLAB Simulink model. The performance of the system is evaluated in terms of BER. The effect of the CP on the BER is also evaluated for BPSK, 4-QAM, 16-QAM, and 64-QAM modulation schemes.*

KEYWORDS — BER; SNR; Cyclic Prefix; OFDM; QAM; QPSK; BPSK; WIMAX

INTRODUCTION

The Cooper's law, an analogue of Moore's law, observes that wireless bandwidth, speed and capacity of the network has been doubling every after 2.5 years. The Orthogonal Frequency Division Multiplexing (OFDM), a next generation communication standard, can provide large data rates with sufficient robustness to multipath fading. WIMAX system based on OFDM provides a greater bandwidth compared to other broadband technologies like Wireless Fidelity (Wi-Fi) and Ultra Wideband (UWB). In this paper, the research is focused on the effects of BER with SNR and analyzed the effect of cyclic prefix in OFDM using different adaptive modulation techniques.

OFDM has recently grown interest in the telecommunication industry due to the demand of higher data rates and enormous bandwidth of multimedia data transmission. The journey of the theoretical view of simultaneous data transmission through linear band limited channel without ISI and ICI started in December 1966 by Robert W. Chang [1]; later he obtained US patent on OFDM system in 1970. The performance analysis and its' drawback rectification is still a research challenge. In 1980, Peled & Ruiz [2] introduced cyclic prefix or cyclic extension of OFDM symbols instead using empty guard band in frequency domain by performing the circular convolution operation [3]. This method provides orthogonality over dispersive channels when cyclic prefix is longer than the channel impulse response. The advancement of digital signal processing (DSP) technology helps to the inclusion of discrete fourier transform (DFT) and fast fourier transform (FFT) with cyclic prefix in OFDM system. The commercial use of OFDM technology also act as a core technology of digital audio broadcasting (DAB) (1987), digita video broadcasting (DVB) (1993), and DVB along with high definition television (HDTV) terrestrial broadcasting standard (1995). Several wireless local area network (WLAN) and HyperLAN standards appointed OFDM in its Physical (PHY) layer model in 20^{th} century. The IEEE802.11a standard also hire OFDM standard in its PHY layer. This technology also plays an important role in future 5^{th} generation (5G) wireless system.

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Orthogonal Frequency Division Multiplexing is a method of encoding digital data on multiple carrier frequencies. The OFDM technique allows a base station to split a chunk of radio spectrum into sub-channels. OFDM is a special form of spectrally efficient Multi-Carrier Modulation (MCM) technique [4] [5], which involves densely spaced orthogonal sub-carriers and overlapping spectrums. Due to orthogonality nature of the sub-carriers, the use of band pass filters is not required in OFDM. Hence, the available bandwidth is used very efficiently without causing the lCI. OFDM have the potential to handle multipath fading and interference problems in wireless communication channel efficiently. Since OFDM is a multi carrier transmission (MCT) technique, its transmitting bandwidth is divided into subcarriers each has a much smaller bandwidth. Only a small percentage of the sub carriers will be affected by the multipath fading and interference than in case of a single carrier system that can be corrected by error detection and correction coding [6] [7]. OFDM is maintaining orthogonality of the carriers which is shown in Fig 1. and Fig 2. If the integral of the product of two signals is zero over a time period, then these two signals are said to be orthogonal to each other. Two sinusoids with frequencies that are integer multiples of a common frequency can satisfy this criterion. Therefore, orthogonality is defined by the equation (1),

$$\int \left(\cos(2\Pi)n f_0 t\right) \cos((2\Pi)m f_0 t)dt = 0 \quad \ldots\ldots (1)$$

where n and m are two unequal integers; f_0 is the fundamental frequency; t is the period over which the integration is taken. For OFDM, t is one symbol period and f_0 set to $1/t$ for optimal effectiveness. The main reason to use a cyclic prefix for the guard interval is to maintain the receiver carrier synchronization and elimination of silent period of guard bands. OFDM has some drawbacks also like High peak to average power ratio [6]. This impacts the RF amplifier efficiency as the amplifiers need to be linear and accommodate the large amplitude variations.

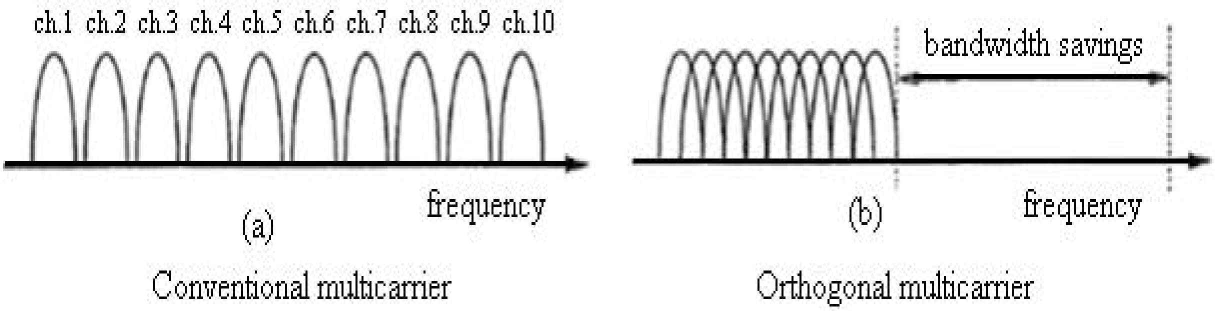

Fig 1: (a) FDM system (b) OFDM system

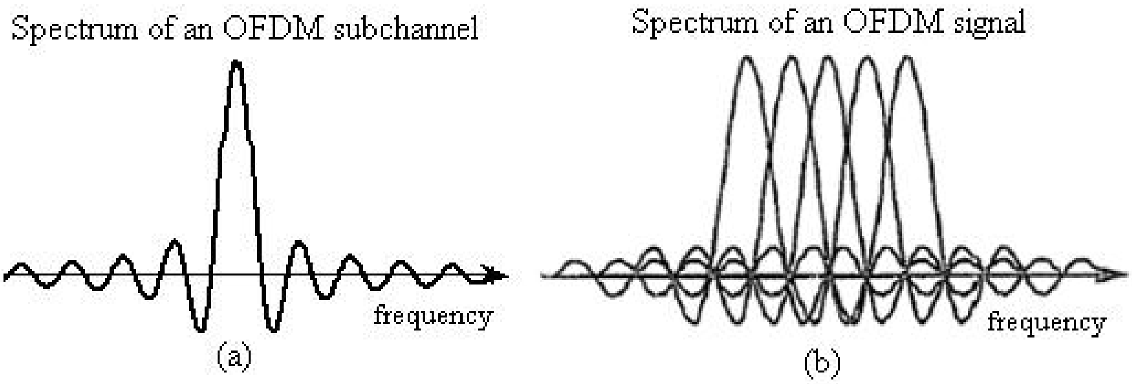

Fig 2: (a) Spectrum of a single channel (b) Spectrum of an OFDM signal

MATHEMATICAL ANALYSIS

Mathematically, if $x(k)$ represents a sequence of N complex modulating symbols, the complex baseband modulated OFDM symbol is represented as in equation (2),

$$1/N \sum x(k)e^{j2}\pi \quad ,0 \le t \le T\, a \qquad k = 0,1, \ldots, (N-1) \quad \ldots\ldots (2)$$

$x(k)$ is the k^{th} symbol modulating the k^{th} sub carrier and f is the inter-sub carrier spacing. Also if the modulated signal in time domain is uniformly sampled with an interval T/N, then n^{th} sample of the OFDM signal is followed by equation (3),

$$X\left\{n\left(T/N\right)\right\} = x(n) = 1/N\ \Sigma x(k) e^{j^2}\, \Pi fn\, T/N$$

$$where\ \ldots\ 0 \le n \langle (N-1) \qquad \ldots\ldots (3)$$

As indicated, the orthogonal sub-carriers occupy the spectral zero crossing positions of other sub-carriers. This ensures that a sub carrier modulated signal with seemingly infinite spectrum does not interfere with the signals modulated by other sub carriers [7]. Further, it also implies that the OFDM modulated signal can be generated by simple Inverse Discrete Fourier Transform (IDFT) which can be implemented efficiently as an N-point Inverse Fast Fourier Transform (IFFT) [8].

Similarly, at the receiving end, an N-point FFT operation does the equivalent job of demodulation of OFDM signal. This makes digital design and implementation of OFDM modulator and demodulator very convenient [9]. However, there are several practical issues which demand proper attention.

Bit error rate (BER) is defined as the number of bit errors in the number of received bits of a data stream over a communication channel that has been altered due to noise, interference, and distortion or bit synchronization errors i.e. it is the rate at which errors occur in a transmission system during a studied time interval [10]. BER is a unit less quantity and expressed by the equation (4) below:

$$P_b = \frac{1}{2}\left(1 - \sqrt{\frac{\left(E_b/N_0\right)}{\left(E_b/N_0\right) + 1}}\right) \quad \ldots\ldots (4)$$

Where Eb/No is energy per bit to noise power spectral density ratio. It is a normalized signal to noise ratio (SNR) measure, also known as the 'SNR per bit'.

A multipath channel can affect the subcarrier orthogonality of an OFDM system. Cyclic Prefix is used to combat lSI and ICI introduced by the multipath channel. CP is a copy of the last part of OFDM symbol which is appended to the front of transmitted OFDM symbol. The length of the CP (Tg) must be longer than the maximum delay spread of the target multipath environment [11]. Fig 3. depicts the benefits arise from CP inclusion, which satisfies the criteria T_{max}< Tx< Tg where T_{max} is the maximum multipath spread [12].

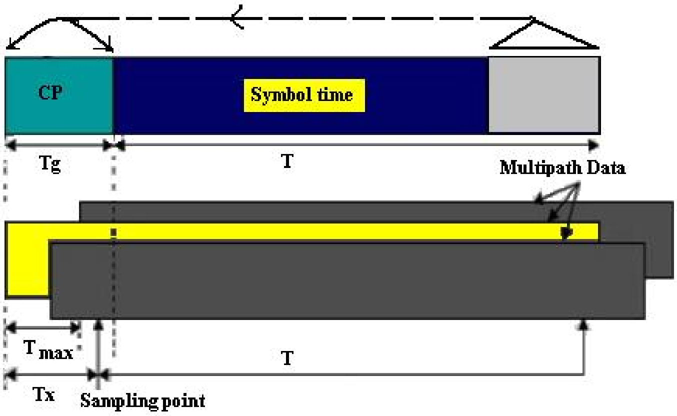

Fig 3: Cyclic prefix inclusion with the OFDM symbol

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SIMULATION PARAMETERS AND RESULT

MATLAB simulation model consists of transmitter, channel and receiver. The AWGN channel is used between transmitter and receiver. At the transmitter end data is generated by random integer generator which generates data with probability 0.5 and sample time of 0.1 second. The bit error rates for different types of digital modulation are calculated through Monte Carlo simulations using MATLAB Simulink model. Table 1. shows the parameters used in Simulink model.

Table 1. Simulink Parameters

Number of bit per symbol	100
Digital Modulation techniques	BPSK,QPSK,QAM
Noise Channel	AWGN Channel
SNR	0-10(db)

A. Proposed Model

The Bit error rate performance of different modulation schemes (QPSK, QAM and BPSK) over additive white Gaussian noise (AWGN) channel using OFDM is projected by the proposed model of Fig 4. In the graph as the value of SNR increases the value of BER decreases abruptly in case of BPSK modulation only.

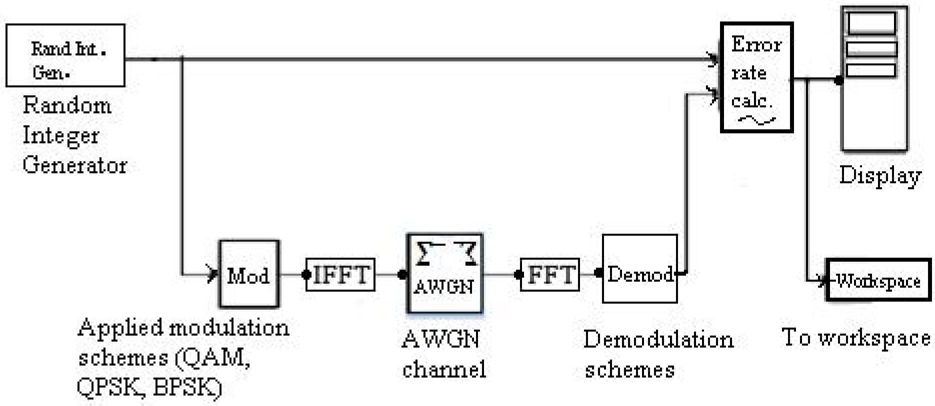

Fig 4: Proposed model of different digital modulation schemes (QPSK, QAM and BPSK) for BER calculation

The Simulink model for the proposed method is based on the following IEEE802.11a specifications of OFDM system as shown in Table 2.

Table 2. IEEE802.11a parameters

Parameters	Values
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, Tcp	0.8us
Data symbol duration, Td	3.2us
Total Symbol duration, Ts	4us

B. Output of various adaptive modulation schemes

Table 3. shows that BER value is the lowest for BPSK modulation scheme over QPSK and QAM scheme. For example at SNR=6 the BER values are 0.202, 0.322 and 0.452 for BPSK, 16-QAM, QPSK respectively.

Also the graph of proposed model for QPSK, QAM & BPSK modulation schemes over AWGN channel is presented respectively in Fig 5. And Fig 6. shows the performance evaluation of various modulation schemes for analyzing BER using MATLAB tool - BPSK has lesser BER compared to all other modulation schemes.

Table 3. Comparison of BER vs. SNR over AWGN Channel using OFDM

SNR(dB)	BPSK(BER)	QPSK(BER)	16-QAM(BER)
1	0.358	0.574	0.646
2	0.320	0.522	0.617
3	0.279	0.496	0.583
4	0.255	0.422	0.520
5	0.223	0.384	0.494
6	0.202	0.322	0.452
7	0.156	0.276	0.385
8	0.123	0.210	0.315
9	0.082	0.121	0.202
10	0.045	0.076	0.118

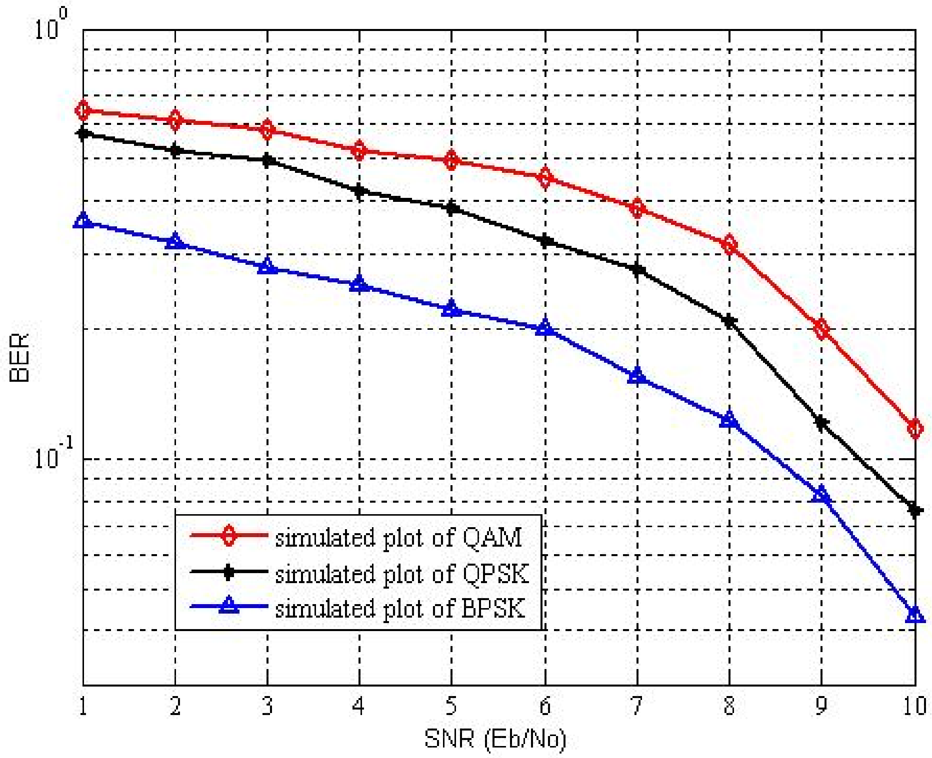

Fig 5. BER vs E_b/N_0 curve over AWGN channel for QPSK, QAM & BPSK modulation

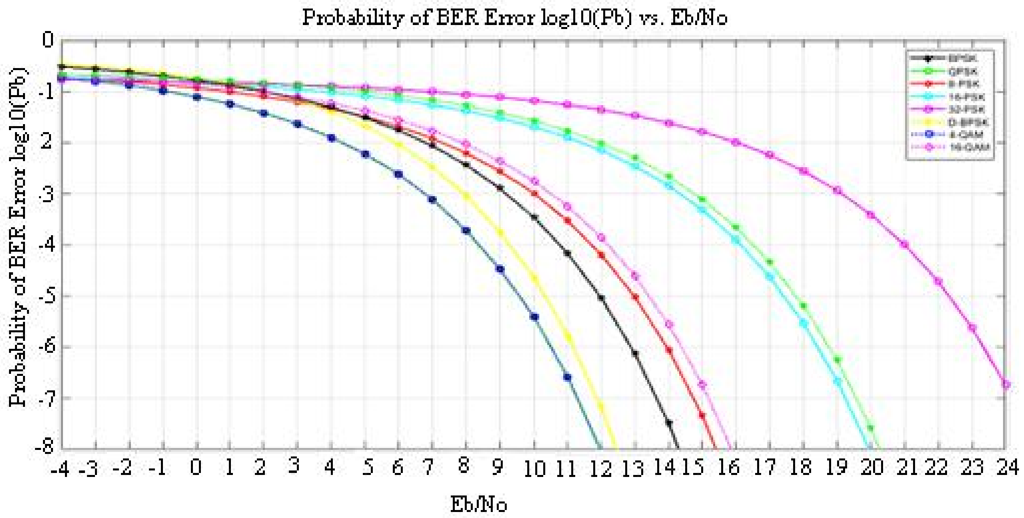

Fig 6. The performance analysis of various modulation schemes for analyzing BER

Table 4. Shows the effect of cyclic prefix on BER over OFDM symbol. The graphical view on the same is shown in Fig 7.

Table 4. Effect of Cyclic Prefix on BER

SNR(Eb/No)	BER (with CP)	BER (without CP)
1	0.4836	0.4996
2	0.4792	0.4956
3	0.4757	0.491
4	0.4696	0.4856
5	0.4648	0.4789
6	0.4584	0.4724
7	0.4532	0.4653
8	0.4451	0.4591
9	0.4349	0.4518
10	0.4223	0.4408

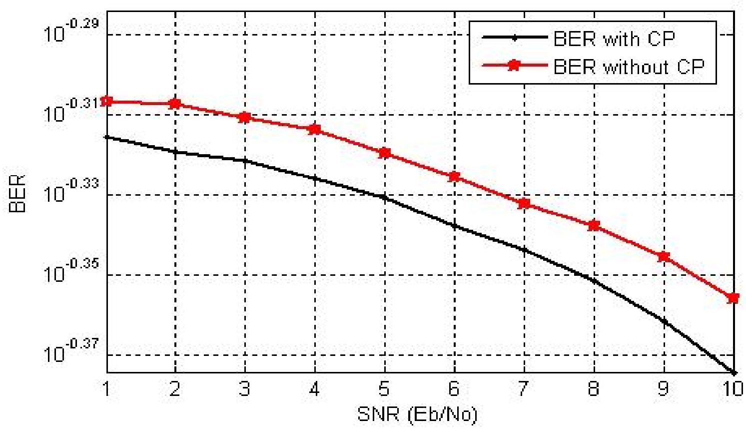

Fig 7. The effect of Cyclic Prefix on BER (With and without CP)

CONCLUSION

In this paper the performance of OFDM system over different modulation scheme viz. QAM. QPSK, BPSK in presence of AWGN channel has been observed. The mathematical analysis and simulation result, both are depicted. The simulation by proposed Simulink model of MATLAB shows that the value of SNR increases as BER decreases. It has been observed that for a particular SNR value, the obtained BER values are in ascending order as considered with the adaptive modulation schemes - BPSK, QPSK and QAM respectively. Thus the analysis of result shows that performance of BPSK is comparatively better than QPSK and QAM modulation.

The theoretical results for BER using CP technique and without CP technique have been revealed. The performance for BER with CP OFDM shows the better performance compared to the result of BER without CP OFDM due to the effectively mitigating the dominant problems of ISI and ICI in the OFDM system.

Furthermore, the simulated results as obtained by the authors agree quite satisfactorily with the available experimental data and with other theoretical works on the different modulation schemes of OFDM System.

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