Performance Analysis of OFDM with Different Cyclic Prefix Length

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Abstract— **Due to the spectacular growth of the wireless services and demands in recent years, Orthogonal Frequency Division Multiplexing (OFDM) is a latest and suitable modulation scheme for commercial high-speed broadband wireless communication systems. OFDM is one of the main techniques proposed to be employed in 4th Generation Wireless Systems. One of the OFDM key parameters is a cyclic Prefix (CP). Cyclic prefix is a guard time length padded with every OFDM symbol to completely alleviate Inter-symbol Interference (ISI) and to preserve orthogonality among OFDM subcarriers as long as the guard time length is sufficiently greater than channel delay spread. This paper analyzes OFDM system and the effect of cyclic prefix and length of cyclic prefix on OFDM system. Besides, compare the performance of the system with and without cyclic prefix. The simulations were carried out over AWGN and Rayleigh fading channels, and the results have been compared with the theoretical ones.**

Keywords- OFDM; BER, BPSK; Cyclic prefi;, ISI

I. INTRODUCTION

In Orthogonal Frequency-Division Multiplexing (OFDM) scheme a large number of narrow band sub channels are used to transmit high data rate. These sub channels are orthogonal to each other. They are closely spaced and narrow band. OFDM is being used because of its capability to handle with multipath interference at the receiver. The main principle of OFDM is to split a high rate data stream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers. The relative amount of dispersion in time caused by multipath delay spread is decreased because the symbol duration increases for lower rate parallel subcarriers. As modulation scheme can be used basically any form of digital modulation, the most common being BPSK, QPSK and QAM. The outputs of all the modulators added and the result is the signal to be transmitted. The OFDM system using channel coding and BPSK modulation produce minimum value of BER as compared to other modulation technique. So BPSK based OFDM system using FFT and cyclic code produces minimum value of BER [1].

The basic idea of OFDM is to divide the available spectrum into several orthogonal sub channels so that each narrowband sub channels experiences almost flat fading. The major advantages of OFDM are its ability to convert a frequency selective fading channel into several nearly flat fading channels and high spectral efficiency. The orthogonality of the carriers means that each carrier has an integer number of cycles over a symbol period. This implying the spectrum of each carrier has a null at the center frequency of another carriers in the system. This results in no interference between the carriers, allowing then to be spaced as close as theoretically possible. This overcomes the problem of overhead carrier spacing required in FDMA. Each carrier in an OFDM signal has a very narrow bandwidth (i.e.1kHz), thus the resulting symbol rate is low. This results in the signal having a high tolerance to multipath delay spread, as the delay spread must be very long to cause significant inter-symbol interference (e.g. > 500 μsec) [2].

The level of robustness can in fact be increased even more by the addition of a guard period between transmitted symbols .The guard period allows time for multipath signals from the previous symbol to impair before the information from the current symbol is gathered. The most effective guard period to use is a cyclic extension of the symbol [3]

II. OFDM TRANSCEIVER

The basic model of OFDM system is shown in Fig. 1. That is, the transmitter section modulate a digital data to be transmitted using BPSK modulation technique then the data is converted to several parallel stream. The modulated signals are processed by IFFT block to transform the spectral representation of the data into the time domain as it is much more computationally efficient, and so is used in all practical systems [4, 5]. Then the cyclic prefix is added to the signals. The cyclic prefix, which is transmitted during the guard interval, consists of the end of the OFDM symbol copied into the guard interval, and the guard interval is transmitted followed by the OFDM symbol. The reason that the guard interval consists of a copy of the end of the OFDM symbol is so that the receiver will integrate over an integer number of sinusoid cycles for each of the multi-paths when it performs OFDM demodulation with the FFT. OFDM has excellent robustness in multi-path environments. Cyclic prefix preserves orthogonality between sub carriers. Cyclic prefix allows the receiver to capture multipath energy more efficiently. Then the signals are converted to serial form and transmitted through transmitter. Digital data is then transmitted over the channel.

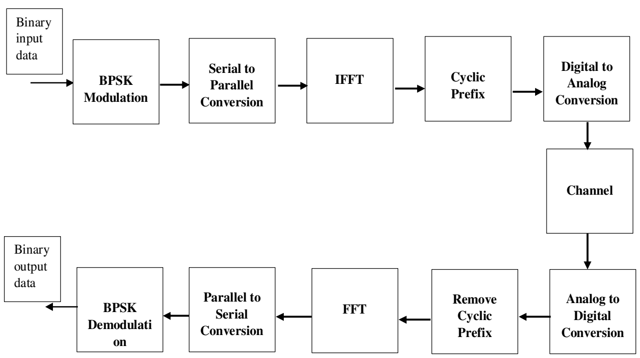

Figure 1. Basic OFDM Transceiver

At the receiver the reverse process is performed. The serial data is received which is converted to parallel form. Then cyclic prefix is removed. After removal of cyclic prefix, Fast Fourier Transform is performed. Then the signals are demodulated to get the original data.

III. OFDM SYMBOLS WITH CYCLIC PREFIX

Cyclic prefix is a guard interval in time domain which inserts between OFDM symbols to mitigate the inter-symbol interference (ISI). Cyclic Prefix is to extend the OFDM symbol by copying the last segment of the OFDM symbol into its head side. Let T_G and T_{sym} denote the length of CP in terms of samples and symbol duration. Therefore the extended OFDM symbols now have the duration of $T_{sym(G)} = T_{sym} + T_G$. Fig. 2 shows two consecutive OFDM symbols, each of which has the CP of length T_G. Fig. 3 illustrates them jointly in the time and frequency domains. Fig. 4 shows the ISI effects of a multipath channel on some subcarriers of the OFDM symbol. It can be seen from this figure that if the length of the guard interval (CP) is set longer than or equal to the maximum delay of a multipath channel, the ISI effect of an OFDM symbol (plotted in a dotted line) on the next symbol is conned within the guard interval so that it may not affect the FFT of the next OFDM symbol, taken for the duration of $T_{sym(G)}$. Guard interval should be longer than maximum delay of the multipath channel for maintaining the orthogonality among the subcarriers [6]. As the continuity of each delayed subcarrier has been warranted by the CP, its orthogonality with all of the subcarriers is maintained over T_{sub} [7].

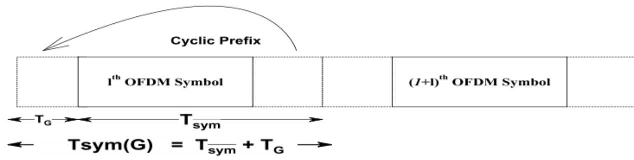

Figure 2. OFDM Symbol with Cyclic prefix

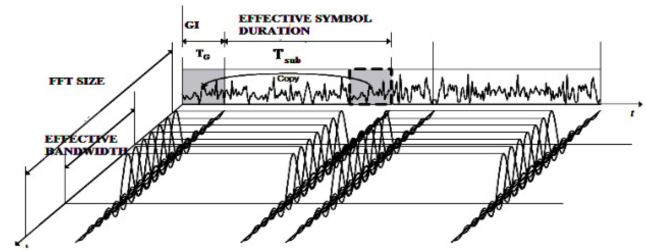

Figure 3. Time/Frequency domain OFDM Symbol with CP

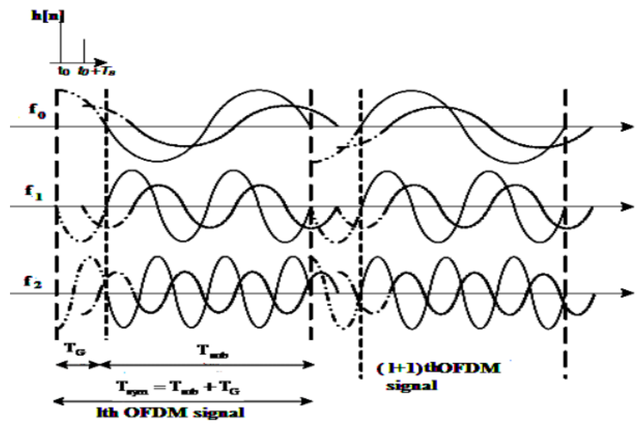

Figure 4. ISI effect on OFDM Symbol

IV. RAYLEIGH MULTIPATH CHANNEL MODEL

Rayleigh fading channel model, is a statistical model which 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,

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

Where, n is the number of taps, $h_1(t-t_1)$ is the channel coefficient of the first tap, and $h_2(t-t_2)$ is the channel coefficient of the second tap and so on.

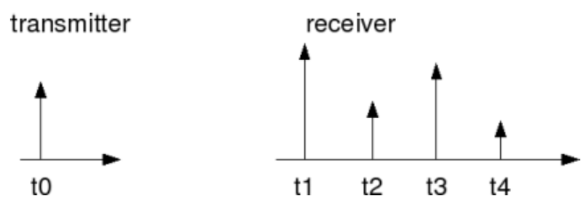

Figure 5. Impulse response of a multipath channel

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.

V. BER OF OFDM SCHEME

BPSK is the simplest form of PSK. It uses two phases which are separated by 180° and so can also be termed 2-PSK. The theoretical BER expressions for BPSK signaling in AWGN and Rayleigh channels are respectively given as [8].

$$p_b = \frac{1}{2} erfc\left(\frac{E_b}{N_0}\right) \tag{2}$$

$$p_b = \frac{1}{2}\left(1 - \sqrt{\frac{\frac{E_b}{N_0}}{\frac{E_b}{N_0}+1}}\right) \tag{3}$$

Where E_b/N_0 is the energy per bit to noise power spectral density ratio.

VI. SIMULATION RESULTS

The performance analysis of OFDM has been carried out in term of BER as a function of (energy per bit to noise ratio). The BER performances of the proposed OFDM scheme are examined by using MATLAB simulation. The simulated system uses 52 subcarriers with 64-point FFT for 10000 transmitted OFDM symbols and 10 number of taps for multipath Rayleigh channel, since each OFDM symbol convolves with a 10-tap Rayleigh fading channel. In the given OFDM system, BPSK is the digital modulation technique and the channels are AWGN and Rayleigh fading. The different CP lengths in term of samples is applied in [3, 9]. These references used CP length (2, 4, 8, 16... etc.) samples, where the cyclic prefix consists of the last few samples of the OFDM symbol that are copied in front of the data block. Therefore the BER performance is presented with different CP length of samples (2, 4, 8and 16) for both considered channels. The theoretical and simulated results are shown in Fig.6 and Fig.7. These figures are indicated the effect of varying CP is negligible in AWGN channel because there is no multipath signal and it is significantly varies in Rayleigh fading channel. Hence, the BER performance improves as much as CP length increases. In Fig. 7 at CP=16 samples, this value equal to a quarter of the length for the Fast Fourier Transform (N=64). The performances of the system for the Rayleigh fading and for the guard interval with a length equal to a quarter of the length for the Fast Fourier Transform are in accordance with the theoretical ones [10] for a maximum channel delay spread of delay intervals due to 10-taps. Therefore, the BER gives better performance than the other CP values and approaching the theoretical curve. The signal to noise ratio (E_b/N_0) difference between OFDM/CP AWGN system and OFDM/CP Rayleigh system shown in Fig. 8 is approximately 9.8 dB, for a BER=10^{-2}, and it increases for the lower values of BER. In this figure, the simulated result considered CP=16.

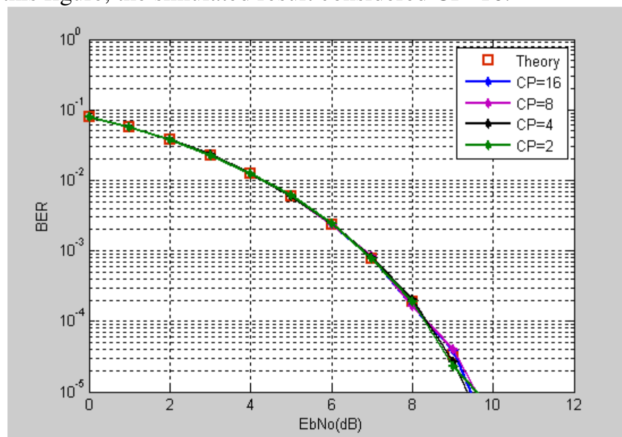

Figure 6. BER Vs. Eb/No for OFDM over AWGN channel with different CP

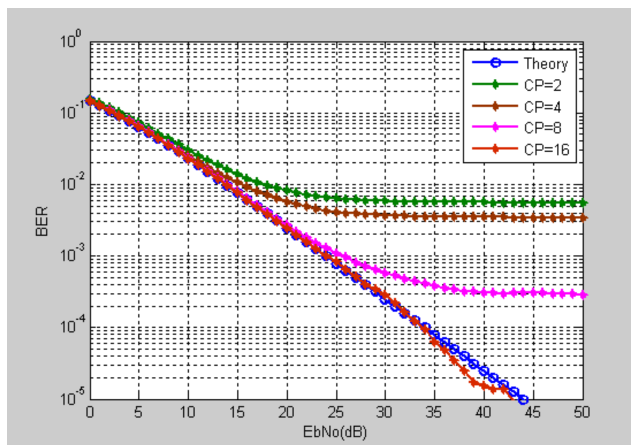

Figure 7. BER Vs. Eb/No for OFDM over Rayleigh channel with different CP

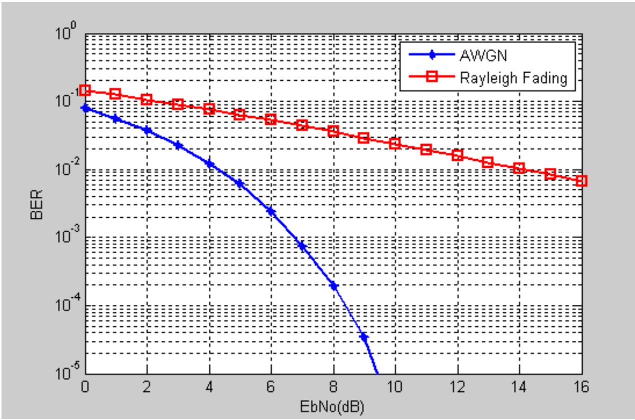

Figure 8. BER Vs. Eb/No Simulation Comparison for OFDM over AWGN & Rayleigh channel

VII. CONCLUSIONS

This paper analyzed the effect of different cyclic prefix length on OFDM in terms of bit error rate probability for AWGN and fading channel. In case a communication channel is only affected by an AWGN the length of CP not influence the performances of the OFDM systems. Furthermore, the results of the simulations overlap with the theoretical results, also due to the fact that in an OFDM system which is affected only by AWGN there is no multipath propagation. Whereas, for high value of the CP, performances are better in Rayleigh fading channel as compared to AWGN channel. Therefore, once the prefix length decreases, the effect of the inter-symbol interferences over the BER is significant, leading to a degrading the system performance.

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