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Bit Error Rate Performance Analysis of OFDM System Over AWGN Channel

[1]Dr. Sunil R. Gagare, [2]Arun E. Kachare and [3]Haribhau A. Shinde

[1&2]Assistant Professor, Department of Electronics & Telecommunication Engineering,
Amrutvahini College of Engineering, Sangamner (Maharashtra), India, 422605.
[2]Research Scholar, Oriental university, Indore (M.P.), India.
Corresponding Author: Dr. Sunil R. Gagare

Abstract

The basic requirements of next generation communication system are high data rates, less inter carrier interference, less inter symbol interference and to save the bandwidth. The orthogonal frequency division multiplexing (OFDM) system is suitable for wireless communication to fulfill these requirements. In his paper, the performance of OFDM system is analyzed by calculating the BER versus signal to noise ratio (SNR) with Additive white Gaussian noise (AWGN), channel. The simulation work is carried out to cover OFDM transmitter chain like binary data source, data mapping, IFFT, CP insertion. This time domain data is passed through AWGN channel. The OFDM receiver consists of CP removal, FFT, data de mapping and decoding of the same data. Thus OFDM system over an AWGN channel is a uses OFDM modulation to transmit digital data over a channel that is affected by AWGN. The AWGN adds noise to the transmitted signal, which can cause errors in the received signal. To mitigate the effects of the noise, the receiver of the OFDM system uses error correction coding and decoding techniques to detect and correct errors in the received signal.

Keywords-OFDM, SNR, BER, QPSK, AWGN

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a digital multi-carrier modulation scheme that extends the concept of single subcarrier modulation by using multiple subcarriers within the same single channel. Instead of transmitting a high speed data with a single subcarrier, OFDM makes use of a large number of closely spaced orthogonal subcarriers that are transmitted in parallel with FFT mechanism. Each subcarrier is modulated with a conventional digital modulation scheme (such as BPSK, QPSK, QAM, etc.) at low symbol rate[3]. However, the combination of many subcarriers enables data rates similar to conventional single-carrier modulation schemes within same band width. It is important to evaluate the performance of parameters of OFDM system over AWGN channel. The performance of data transmission over wireless channels is studied by analyzing BER in accordance with signal to noise ratio (SNR) at the receiver [1]. In OFDM system, it divides a communications channel into a number of equally spaced frequency bands. A subcarrier carrying a portion of the user information is transmitted in each band. Each subcarrier is orthogonal (independent of each other) with every other subcarrier; and it is different from the commonly used frequency division multiplexing (FDM). The Bit Error Rate (BER) for orthogonal frequency division multiplexing (OFDM) under different channels condition is an important parameter in digital communication.

II. MULTICARRIER CONCEPT

The total bandwidth B into N sub-bands of bandwidth B/N subcarriers are placed at

….-B/N, 0, +B/N…..

Signal si(t) *corresponding to the ith subcarrier is given as*,

$$Si(t) = Xie^{j2\pi fit} = Xie^{j2\pi fi\,(B/N)t}$$

there are total of N data streams. The bandwidth of multicarrier signal is given in fig.1.

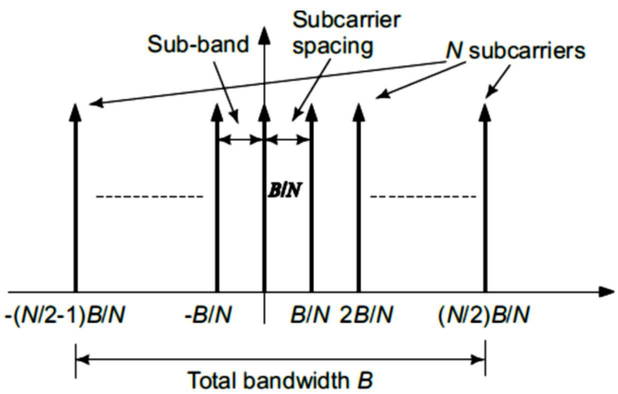

Figure 1: Bandwidth of multicarrier signal

Fig. 2 shows the most important advantage of OFDM system over FDM system is to save the bandwidth[5]. The frequency spectrum of multicarrier OFDM system is shown in fig. 3.

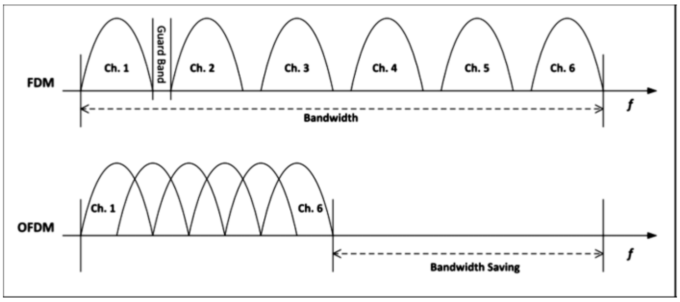

Figure 2: Difference between FDM & OFDM system.

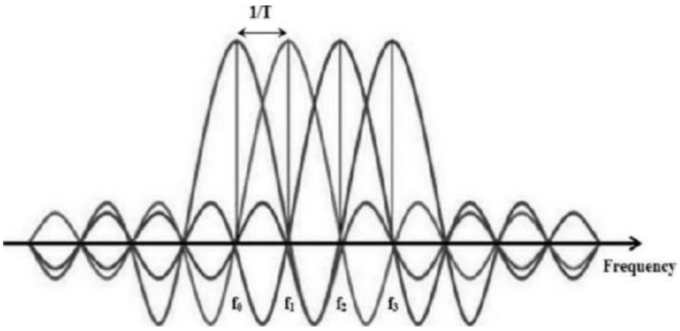

Figure 3: Frequency domain multicarrier OFDM system.

III. MULTICARRIER TRANSMISSION

Multicarrier transmission refers to a technique used in communication systems, particularly in Orthogonal Frequency Division Multiplexing (OFDM), where data is transmitted simultaneously over multiple carriers.

In OFDM, the frequency band is divided into multiple subcarriers, each of which is modulated with a data signal. The subcarriers are orthogonal to each other, meaning that they are spaced such that they do not interfere with each other, and each subcarrier is modulated with a portion of the data signal [1].

The advantage of multicarrier transmission is that it can provide high data rates and robustness against frequency-selective fading and interference, which can affect single-carrier transmission techniques. Additionally, OFDM can be efficiently implemented using Fast Fourier Transform (FFT) algorithms, which can simplify the implementation of the receiver.

OFDM is used in various wireless communication standards, including Wi-Fi, digital television broadcasting, 4G and 5G cellular networks etc.

The transmitted multicarrier signal is given as, Si(t),

$$Si(t) = \sum Xi e^{j2\pi fit}$$

The equation of received output signal is given as,

$$Y(\text{t}) = Si(t) = \sum_{i=0} Xi\, e^{j2\pi fit}$$

The right-hand side of given equation is the Fourier series representation of Si(t), corresponding to the fundamental frequency f_0= (B)/ N and the various Xi representing the Fourier coefficients.

The received signal, y(t) with h parameter and added noise, can be expressed as:

$$Y(\text{t}) = = Si(t) * \text{h(t)} + \text{n(t)}$$

where:
h(t) is the channel impulse response and n(t) is the added noise.
Here $Si(t)$ and Y(t) are function of time t.
where, X_l is the Fourier coefficient corresponding to the frequency $f_l = l\, f_0$

IV. OFDM SYSTEM WITH AWGN CHANNEL

The concepts used in the simple analog OFDM implementation can be extended to the digital domain by using digital signal processing such as a combination of Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT). These transforms are important from the OFDM perspective because they can be viewed as mapping digitally modulated input data (data symbols) onto orthogonal subcarriers. In this process, the IFFT takes frequency-domain input data (complex numbers representing the modulated subcarriers) and converts it to the time-domain output data of OFDM symbol [8].

The block diagram of OFDM system is given in fig. 4.

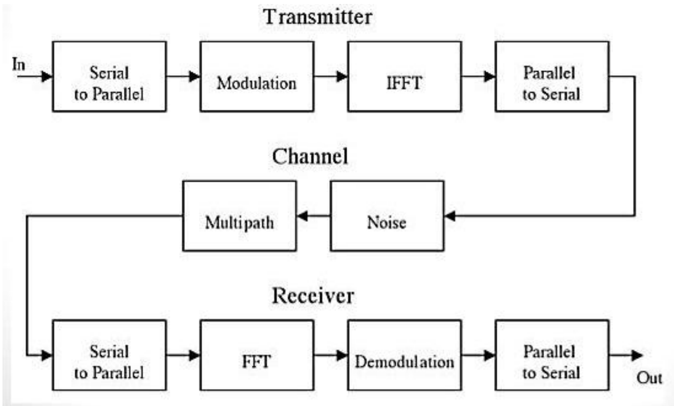

Figure 4: OFDM system over AWGN channel

V. DIGITAL OFDM SYSTEM USING FFT TRANSFORMS

In a digitally implemented OFDM system shown in fig 5, the input bits are grouped and mapped to source data symbols that are a complex number representing the modulation constellation point (e.g., the BPSK or QAM symbols that would be present in a single subcarrier system). These complex source symbols are treated by the transmitter as though they are in the frequency-domain and are the inputs to an IFFT block that transforms the data into the time-domain. The IFFT takes N source symbols at a time where N is the number of subcarriers in the system [9]. Each of these N input symbols has a symbol period of T seconds. Remember that the output of the IFFT is N orthogonal sinusoids. These orthogonal sinusoids each have a different frequency.

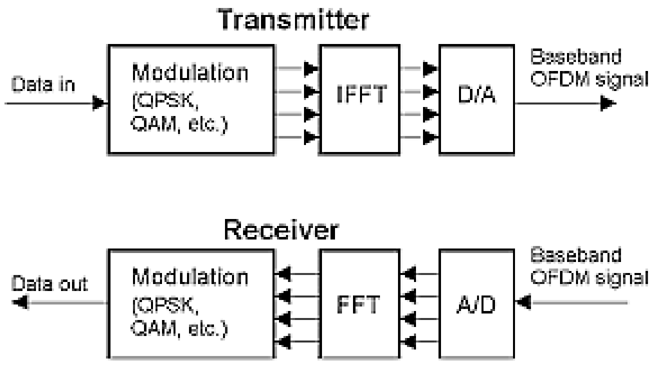

Figure 5: OFDM transceiver system with IFFT and FFT

In an OFDM system, the IFFT (Inverse Fast Fourier Transform) and FFT (Fast Fourier Transform) are used to convert the time-domain signal to the frequency-domain signal and vice versa.
The system is operated by following way,
Transmitter: The data to be transmitted is divided into several parallel streams. Each stream is modulated using some form of modulation (such as QPSK or 16-QAM) to generate complex symbols. The complex symbols are then grouped into blocks, each block containing N symbols.
An IFFT is performed on each block of N symbols to convert it from the frequency domain to the time domain. The resulting time-domain signals are then concatenated to form a single time-domain signal that is transmitted over the channel.
Receiver: The received signal is first passed through a channel that introduces distortion and noise. The distorted signal is then converted to the frequency domain using an FFT. The frequency-domain signal is then demodulated to recover the complex symbols. An IFFT is performed on each block of N symbols to convert it back to the time domain. The resulting time-domain signals are then combined to form the original transmitted signal.
The use of IFFT and FFT in OFDM provides several advantages over other modulation techniques. For example, it allows for efficient use of the available bandwidth and provides robustness against frequency-selective fading. The input symbols are complex values representing the mapped constellation point and therefore specify both the amplitude and phase of the sinusoid for that subcarrier. The IFFT output is the summation of all N sinusoids. Thus, the IFFT block provides a simple way to modulate data onto N orthogonal subcarriers. The block of N output samples from the IFFT make up a single OFDM symbol. After some additional processing, the time-domain signal that results from the IFFT is transmitted across the radio channel. At the receiver, an FFT block is used to process the received signal and bring it into the frequency domain which is used to recover the original data bits.
The equations for the time-domain representation of the FFT and IFFT for OFDM are given as:

FFT equation: $x(k) = 1/\text{sqrt}(N) * \sum[xn * \exp(-j*2\pi nk/N)]$

where:
x(k) is the kth frequency-domain sample of the signal
N is the total number of time-domain samples
xn is the nth time-domain sample of the signal
k is the index of the frequency-domain sample, ranging from 0 to N-1

IFFT equation: $xn = 1/\text{sqrt}(N) * \sum[x(k) * \exp(j*2\pi nk/N)]$

where:
xn is the nth time-domain sample of the signal
x(k) is the kth frequency-domain sample of the signal
N is the total number of time-domain samples
k is the index of the frequency-domain sample, ranging from 0 to N-1

The FFT and IFFT equations are essentially the same, but with a different sign in the exponent of the exponential term. This is because the FFT converts from the time domain to the frequency domain, while the IFFT converts from the frequency domain to the time domain.
The Additive White Gaussian Noise (AWGN) is a noise that affects the transmitted signal when it passes through the channel. It contains a uniform continuous frequency spectrum over a particular frequency band while in Rayleigh fading has no LOS path exists in between transmitter and receiver, but only have indirect path than the resultant signal received at the receiver which will be the sum of all the reflected and scattered waves. Noise exists in all communications systems operating over an analog physical channel, such as radio. The main sources are thermal background noise, electrical noise in the receiver amplifiers, & inter-cellular interference. In addition, this noise can also be generated internally to the communication system as a result of Inter-Symbol Interference [5][6], Inter-Carrier Interference & Inter-Modulation Distortion. These sources of noise decrease the Signal to Noise Ratio (SNR) & thus limiting the spectral efficiency of the system. This noise has a uniform spectral density & a Gaussian distribution in amplitude. Thermal & electrical noise from amplification, primarily have white Gaussian noise properties, allowing them to be modelled accurately with AWGN. Also most other noise sources have AWGN properties due to the transmission being OFDM. OFDM signals have a flat spectral density & a Gaussian amplitude distribution provided that the number of carriers is large, because of this the intercellular interference from other OFDM systems have AWGN properties.

VI. NEED OF CYCLIC PREFIX IN OFDM SYSTEM

Cyclic prefix (CP) is an essential component of OFDM systems that is used to mitigate the effects of inter-symbol interference (ISI) and inter-carrier interference (ICI) caused by multipath propagation in wireless communication channels.
In an OFDM system, data is transmitted in the frequency domain using multiple subcarriers. Each subcarrier is modulated with a portion of the data, and the modulated subcarriers are combined to form the OFDM signal. However, when the OFDM signal is transmitted through a multipath channel, the different paths may have different propagation delays, which can cause ISI and ICI.
To mitigate these effects, a cyclic prefix is added to each OFDM symbol. The cyclic prefix is a copy of the last part of the OFDM symbol, which is inserted at the beginning of the symbol. This

creates a guard interval between the OFDM symbols, which helps to reduce ISI and ICI.

The cyclic prefix allows the receiver to remove the effects of the channel by using a time-domain equalizer, which is based on a matched filter. The matched filter uses the cyclic prefix to estimate the channel impulse response and compensate for the channel distortion.

Therefore, the cyclic prefix is an important component of OFDM systems that helps to improve the robustness and reliability of wireless communication in multipath channels [12].

Consider following example of time domain signal fig. 6, showing two OFDM symbols in sequence.

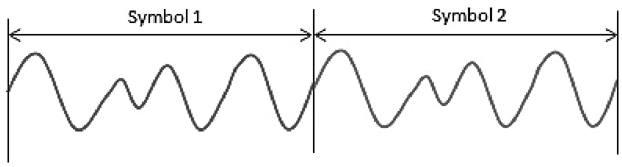

Figure 6: Sequence of OFDM symbol

In ideal case, there is no problem with this signal, but if the first symbol is delaye[4]. Here, the ending part of the first symbol is spill over into the following symbol time and interfere the next symbol as shown below. This kind of interference between different symbols are called 'Inter Symbol Interference (ISI) shown in fig.7.

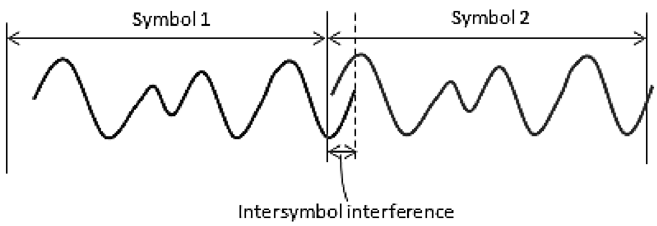

Figure 7: Symbol with ISI interference

It is required to prevent the signal from getting delayed. But it is not possible because we have no control over the radio channel itself (physical medium itself). The solution is to design our system to handle this type of problem. One simple solution is to create some time gap, fig. 8, between symbols so that one symbol would not spill into next symbol even when it get delayed.

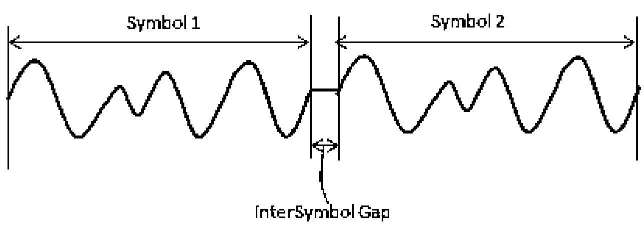

Figure 8: Delayed OFDM symbol

With this gap, the system tolerates delay and inter symbol interference issue to a certain degree, by copying a part of signal from the end and paste it into this gap. This copied portion prepended at the beginning is called 'Cyclic Prefix'.

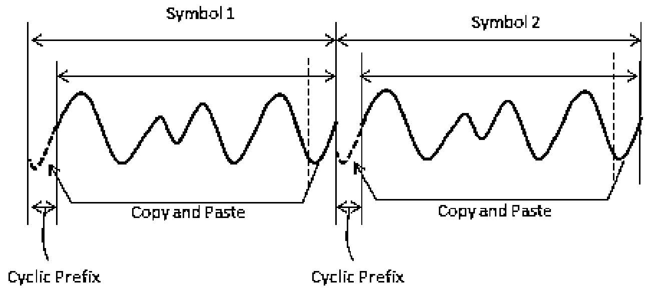

Figure 9: OFDM symbol with cyclic prefix

The main purpose of cyclic prefix is to reduce ISI (Inter Symbol Interference

VII. DESIGN PARAMETERS OF OFDM SYSTEM

Table 1: OFDM System Design Parameters

Number of subcarrier channel	64 to 128
Number of bits per channel	M=4
Total number of bits to be transmitted at the transmitter	N=256
Size of each OFDM block to add cyclic prefix	16
Length of the cyclic prefix	0.1 * Block size
modulation	QPSK
Type of channel	AWGN

VIII. RESULTS AND DISCUSSIONS

By using a Matlab simulation we can implement an OFDM system. Using the simulation we can change the values of S/N ratio and change the multi propagation effects on the transmission. After analyzing the results of each transmission, the BER is changed. A. This implementation is used to transmit a binary data form modulated by OFDM and 16-QAM modulation. At the end of the transmission, when the receiver receives the data, a comparison of the transmitted and the received messages is done in order to calculate the Bit Error Ratio (BER). The simulated results of OFDM system are shown in following figures.

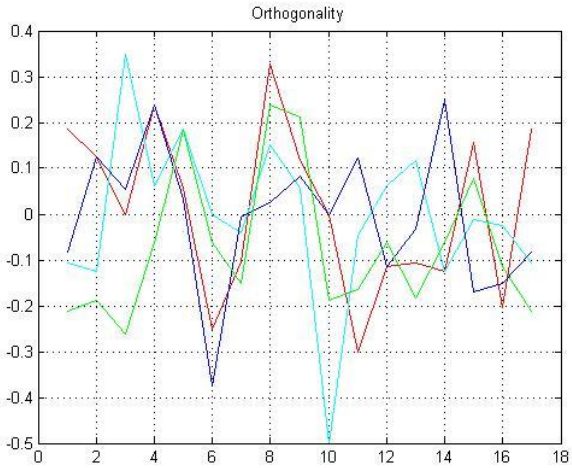

Figure 10: Generated OFDM Signal

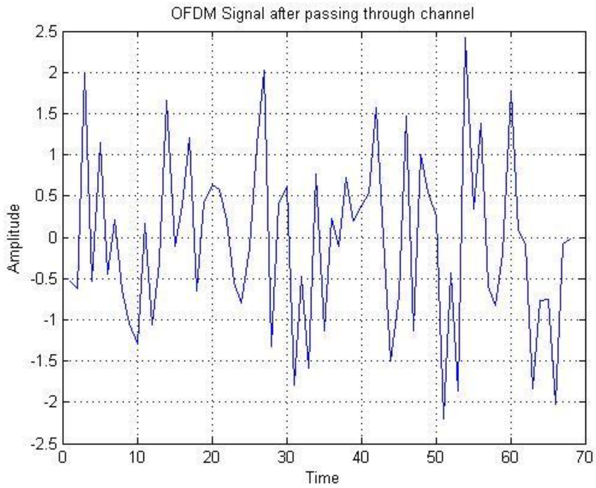

Figure 11: OFDM Signal after passing through AWGN Channel

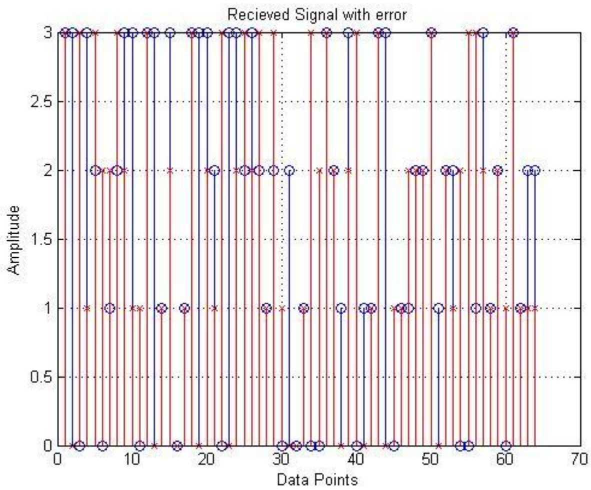

Figure 12: Received signal with error

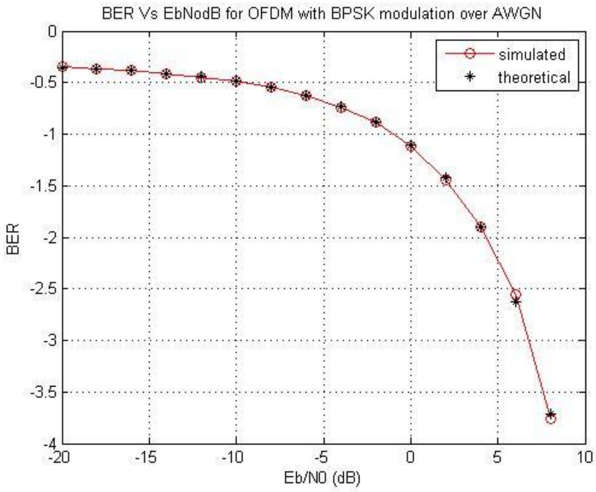

Figure 13: Performance of BER vs SNR

IX. CONCLUSION

In this work, the performance of OFDM system is analyzed by calculating the BER versus signal to noise ratio (SNR) with Additive white Gaussian noise(AWGN), channel. The simulation of OFDM system over AWGN channel is performed. In multicarrier OFDM signal cyclic prefix is added at the transmitter to reduce the inter symbol interference It is observed that the bit error rate is decreases according to increase in signal to noise ratio. In an OFDM system, the IFFT and FFT are used to convert the time-domain signal to the frequency-domain signal and vice versa.

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