OFDM: Modulation Technique for Wireless Communication

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Abstract— **Orthogonal Frequency Division Multiplexing (OFDM) has become the modulation technique for many wireless communication standards. In a wireless system, a signal transmitted into channel bounces off from various surfaces resulting in multiple delayed versions of the transmitted signal arriving at the receiver. The multiple signals are received due to the reflections from large objects, diffraction of electromagnetic waves around objects .This causes the received signal to be distorted. OFDM provides tolerance to such frequency selective channels and provides high data rates. In this paper we propose to analyze the theory of OFDM, simulate the OFDM transceiver using MATLAB and perform BER analysis.**

Keywords— OFDM, FFT, IFFT, ISI, BPSK, QPSK, AWGN, RAYLEIGH CHANNEL

I. INTRODUCTION

The progress in the semiconductor technology has made radio transmission without any physical connection possible throughout the world. The goal of future wireless communication is to provide communication with high data rates. The most popular technique in wireless communication is Orthogonal Frequency Division Multiplexing (OFDM). When the data is transmitted at high data rates over wireless radio channels, the symbols may overlap over each other which can lead to inter symbol interference (ISI). OFDM can combat the effect the ISI.OFDM is increasingly used in high mobility wireless communication systems, e.g. mobile WiMAX (IEEE 802.16e) and 3GPP's UMTS Long-Term Evolution (LTE).

The developments of OFDM systems can be divided into three parts .They are Frequency Division Multiple Access (FDMA), Multicarrier Communication and Orthogonal Frequency Division Multiplexing.

In FDMA, the available bandwidth is divided into multiple channels and then allocated to the users.

In Multicarrier Communication the signal is divided into a number of signals over a frequency range, whereas OFDM spaces the channels much closer by placing the carriers orthogonal to each other, thus using the spectrum efficiently as shown in Fig.1.

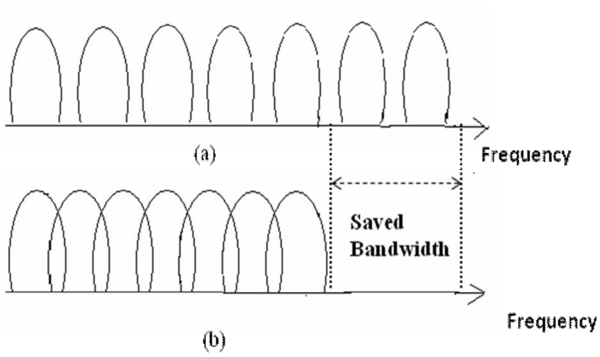

Fig.1 a.)Multicarrier Technique (FDM) b.)Orthogonal Frequency Division Multiplexing.

In 1960's, the concept of using parallel data transmission by multicarrier modulation was published. However it was not practical to implement until the discovery of using the Discrete Fourier Transform (DFT).DFT is implemented using the computationally efficient Fast Fourier Transform (FFT).

II. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

A. *Theory of OFDM*

OFDM is a multicarrier transmission technique in which the high rate single data stream is transmitted over a number of low rate parallel subcarriers. Because of the low rate parallel subcarriers, the symbol duration increases which will reduce the effect of multipath delay spread on the signal. Fig.2 shows the orthogonal subcarriers in frequency and time domain.

In a single carrier system, a single fade or interference can cause the entire link to fail, but in a multicarrier system, only a small percentage of the subcarriers will be affected.

The term orthogonal in OFDM refers to the fact that the center frequencies of the sub channel are separated by the reciprocal of the OFDM block time T. Suppose the symbol length is T, sinusoidal signals differing in frequency by 1/T,will be orthogonal over the period T.

The bandwidth upon which the channel response can be assumed to be flat is known as coherence bandwidth of the channel.

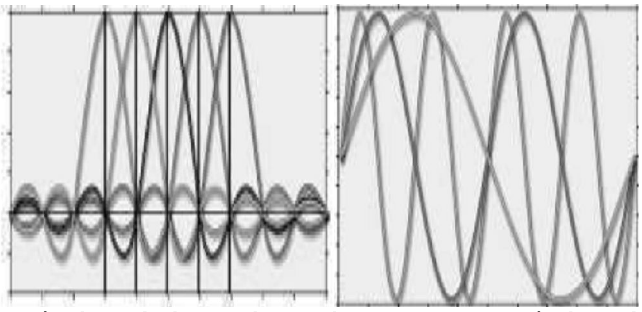

Fig.2: a) Spectrum of Orthogonal subcarriers b.)Time domain representation of orthogonal subcarriers.

If the data is transmitted at high rate, the bandwidth of the channel becomes wide and may exceed the coherence bandwidth of the channel. This distorts the signal and causes Inter Symbol Interference (ISI).

A guard interval is introduced in every OFDM symbol to eliminate ISI. Two approaches are followed in OFDM to insert guard interval. The first one is known as zero padding, where zeros are inserted between OFDM symbols .The second one is known as cyclic prefix, where a part of the end of the OFDM symbol is copied and inserted in the beginning of the next OFDM symbol in time domain.

The length of the guard interval must be at least equal to the length of the channel response to avoid the ISI.

Usage of cyclic prefix is preferred than zero padding when FFT is used. Because FFT algorithms require the signal to be periodic to produce accurate results and cyclic prefix makes the signal periodic. Fig. 3 shows the OFDM symbol with cyclic prefix.

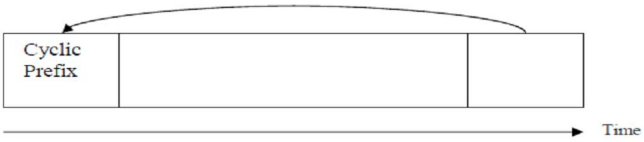

Fig. 3: OFDM symbol with cyclic prefix in time domain.

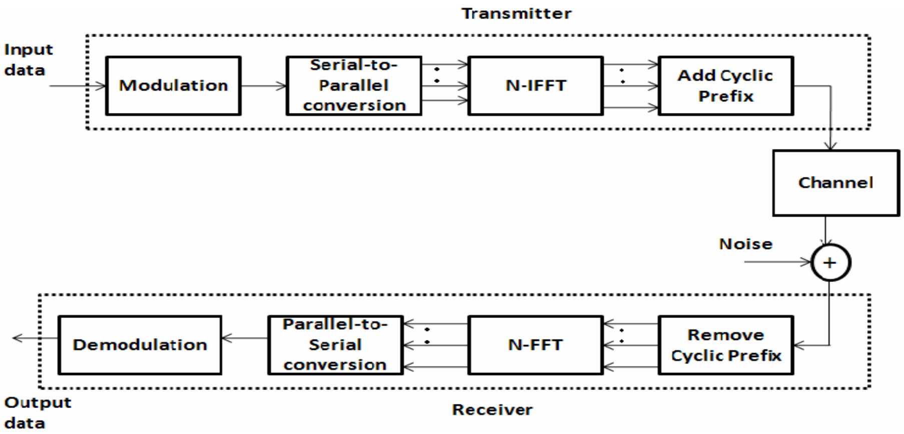

Fig. 4: Block diagram of the OFDM system

B. System Description

The block diagram of an OFDM system is represented in Fig.4.

OFDM symbols are generated as follows .The transmitter section converts the digital data to be transmitted into a mapping of the sub carrier's amplitude and phase using modulation techniques.

The modulation technique such as the BPSK, QPSK or QAM can be used. The modulated data is converted into parallel stream for faster and optimum utilization of the bandwidth.

Time domain representation of the data is created by using an Inverse Fast Fourier Transform (IFFT) which is an efficient method to implement DFT.

OFDM symbol time domain representation is extended by addition of cyclic prefix to each symbol that solves both ISI and inter carrier interference (ICI).

The time domain signal is passed through the channel.

At the receiver side, the cyclic prefix is removed and converted to frequency domain by using FFT. Finally the parallel data is converted back to serial data.

Mathematically, each subcarrier can be formulated as follows*:*

$$S_c(t) = A_c(t)e^{j|\omega_c t+\phi_c(t)|} \quad (1)$$

where Ac (t) is amplitude and ϕ c (t) is phase.
An OFDM symbol consists of many subcarriers. It is represented by:

$$S_s(t) = \frac{1}{N}\sum_{n=0}^{N-1} A_n(t)\ e^{j[\omega_n t+\phi_n(t)]} \quad (2)$$

where $\omega_n = \omega_0 + n\Delta\omega$

A_c (t) and ϕ_c (t) get different values in different symbols, but they are constant in every symbol and only depend on frequency of carriers.

In every symbol, we have,

$$\phi_n(t) \Rightarrow \phi_n\ ,\ A_n(t) \Rightarrow A_n \quad (3)$$

If the signal is sampled with 1/T where T is the duration of a symbol and substituting (3) in (2) we get,

$$S_s(kT) = \frac{1}{N}\sum_{n=0}^{N-1} A_n\ e^{j[(\omega_0+n\Delta\omega)kT+\phi_n]} \quad (4)$$

When ω_0 =0, (3) is converted to an IDFT transform.

By adding cyclic prefix in time domain, ISI can be prevented.

$$s_T(n) = \begin{cases} s(N+n), n = -N_{cp}, -N_{cp}+1, \ldots\ldots, -1 \\ s(n), n = 0, 1, \ldots\ldots\ldots\ldots, N-1 \end{cases} \quad (5)$$

where N_{cp} is the length of the cyclic prefix.

III. Simulation

In this paper, we have simulated the OFDM transceiver using the model shown in Fig.4.We have used two modulation schemes, namely BPSK (Binary Phase Shift Keying), QPSK (Quadrature Phase Shift Keying).The ofdm symbols created after taking ifft is passed through the Gaussian channel which adds additive white Gaussian noise (AWGN).Cyclic prefix does not hold any significance in AWGN channel. The demodulation is performed at the receiver.

Multipath Rayleigh fading channel is also considered for simulation. It is generated by considering sum of two random variables .Each path in the multipath scenario can be modelled as circularly symmetric Gaussian random variables with respect to time when central limit theorem is applied ,the envelope of the random variables will follow Rayleigh distribution .Hence it is known as Rayleigh fading channel.

We have plotted the Bit error rate (BER) by considering the signal-to-noise ratio for the modulation techniques specified.

An OFDM symbol is created after taking the 64 point ifft of the modulated data .An OFDM containing 64 subcarriers generated using BPSK modulation is as shown in Fig .5.

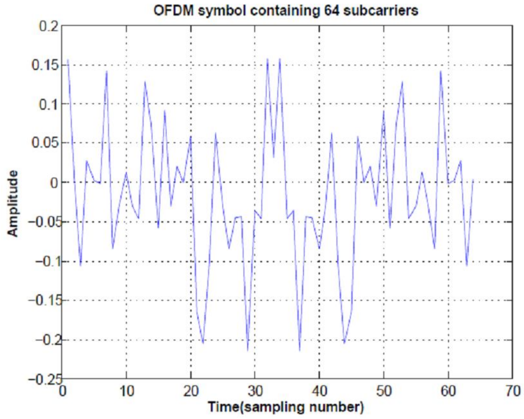

Fig. 5: An OFDM symbol of containing 64 subcarriers using BPSK modulation.

Simulated BER curves for BPSK, and QPSK in AWGN channel is as shown in Fig. 6.

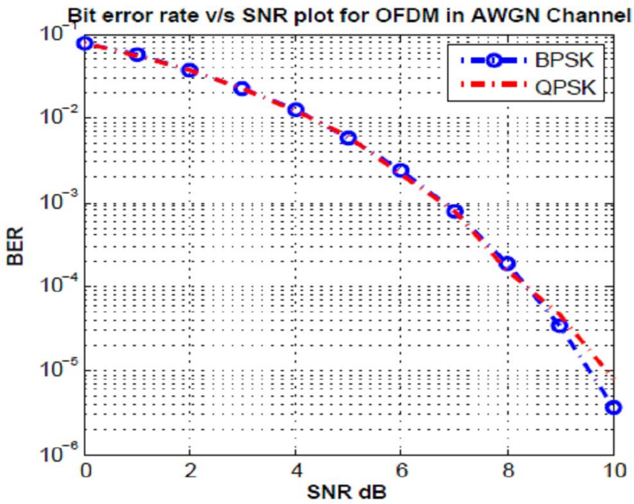

Fig. 6: BER vs. SNR plot for OFDM using BPSK, QPSK modulation techniques in AWGN channel.

Simulated BER curves for BPSK, and QPSK in Rayleigh channel is as shown in Fig. 7. A 10 tap Rayleigh channel has been considered with a cyclic prefix of length 16.Cyclic prefix is used to minimize the effect of ISI. AWGN will also have an influence in the BER value in the Rayleigh fading channel.

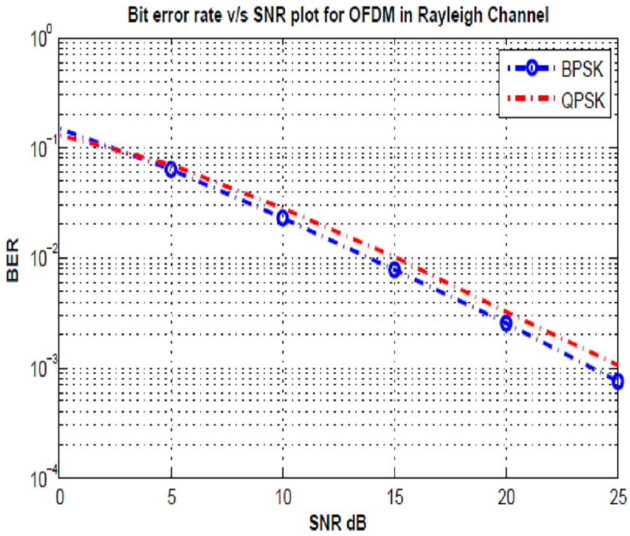

Fig.7: BER vs. SNR plot for OFDM using BPSK, QPSK modulation techniques in Rayleigh channel.

TABLE I
SIMULATION PARAMETERS

Parameters	**Specification**
FFT size	64
No of subcarriers	64
Channel Model	AWGN& Rayleigh
Signal constellation	BPSK&QPSK
No of symbols	10000
Cyclic Prefix length	16

It is observed that for a particular value of SNR, the BER for BPSK and QPSK is almost equal in AWGN channel and in Rayleigh channel. The advantage of using QPSK modulated data is that it can be transmitted as twice the data rate when compared to BPSK modulated data. However, QPSK transmitters and receivers are complicated and expensive when compared to BPSK.

IV. CONCLUSIONS

OFDM provides high data rates and is robust in frequency selective channels .It minimizes the effect of ISI. Hence it is suitable for wireless communication .Simulation was performed for OFDM using BPSK and QPSK modulation in AWGN and in Rayleigh channels. The BER performance is similar for both, but QPSK is expensive in terms of bandwidth when compared to BPSK.

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