AN EXPERIMENTAL STUDY TO IMPLEMENT OFDM AND ANALYZE THE CHARACTERISTICS OF OFDM SIGNAL TRANSMISSION AND RECEPTION IN AN AWGN CHANNEL

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ABSTRACT:

Orthogonal frequency division multiplexing (OFDM) is a type of multicarrier transmission and frequency division multiplexing. It involves sending a single data stream across multiple lower-rate subcarriers that are orthogonal to each other. OFDM is increasingly being used as a modulation technique for wireless communications due to its ability to deliver high data rates with an optimal bit error rate and strong resistance to radio channel impairments [9]. The aim of this project is to implement the core signal processing components of an OFDM system using MATLAB [1]. This basic implementation benefits from reduced processing time and complexity. It covers all the essential elements of an OFDM system. In our project, we used a specific modulation technique, regardless of the data type being transmitted, such as BPSK or QPSK [10] and constellation diagram of transmitted and received data/ image both are also compared. However, it is possible to explore techniques that allow different modulation schemes to be applied based on the type of data being transmitted.

Keywords:

OFDM, orthogonal, sub-carriers, Inverse Fast Fourier Transform, MATLAB

I. Introduction:

Orthogonal Frequency Division Multiplexing (OFDM) is a unique type of multicarrier modulation especially suited for transmission over channels that cause signal dispersion. In OFDM, the different carriers are orthogonal [4], meaning they are completely independent of each other. This wideband modulation scheme is designed to address issues related to multipath reception by dividing a wideband frequency-selective fading channel [8] into many narrow-band sub channels. When there are enough sub channels, each one can be considered flat. This is achieved by transmitting numerous narrowband overlapping digital signals in parallel within one wide band. By increasing the number of parallel transmission channels, the data rate for each individual carrier is reduced, which in turn extends the symbol period. OFDM is ideal for high data rate applications [2] and is currently utilized in various wired and wireless communication systems. It involves transmitting a single data stream across multiple subcarriers to enhance robustness against frequency-selective fading or narrowband interference [13]. OFDM is ushering in a new era of digital transmission and is becoming the preferred modulation technique globally. This process examines the performance of different modulation schemes by analysing the transmitted and received OFDM frames, frequency spectrum, and constellation diagrams [5] to eliminate noise and signal interference. Frequency Division Multiplexing (FDM) has long been utilized to transmit multiple signals over a single telephone line. FDM works by splitting the channel bandwidth into several sub channels, each carrying a separate, relatively low-rate signal on a distinct carrier frequency. To prevent overlap between signals in adjacent sub channels, a guard-band is left between them. However, this guard-band results in inefficiencies. To address the issue of bandwidth efficiency, orthogonal frequency division multiplexing (OFDM) was introduced, utilizing carriers that are orthogonal to each other. This allows for overlapping sub channels in the frequency domain, thereby increasing the transmission rate [6]. The carrier spacing in OFDM ensures optimal spectral efficiency. Today, OFDM has become the most popular communication system for high-speed communications and is the preferred modulation technique for wireless communications. OFDM offers high data rates and is robust against radio channel impairments.

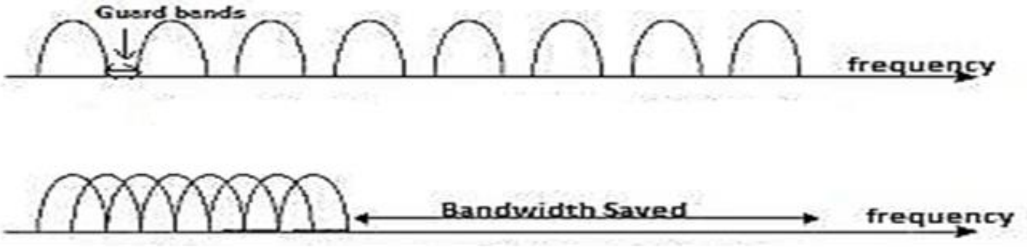

Figure 1: Conventional Frequency Division Multiplexing vs orthogonal frequency division multiplexing.

Figure 1: (a) A Regular-FDM single carrier
(b) Orthogonal-FDM

OFDM combines both modulation and multiplexing techniques. Typically, multiplexing involves combining independent signals from different sources. In OFDM, this concept is applied to independent signals that are subsets of a single main signal. The main signal is first divided into multiple independent channels, each modulated with data, and then re-multiplexed to form the OFDM carrier. OFDM is a specific form of Frequency Division Multiplexing (FDM). In an OFDM system, a large number of orthogonal, overlapping, narrow-band subcarriers are transmitted simultaneously. These subcarriers share the available transmission bandwidth, with their spacing designed for highly efficient spectral utilization. As an analogy, an FDM channel is like water flowing from a faucet, where a large volume of water comes out in a single stream. In contrast, an OFDM signal is like water from a shower, where the same amount of water is delivered through many smaller streams. In the faucet analogy, all the water is concentrated in one big stream and cannot be subdivided, while the the OFDM shower consists of numerous tiny streams. The key difference between the two is that by placing our thumb over the faucet hole, we can stop the water flow, which isn't possible with the shower. Although both methods perform the same function, they react differently to interference. Both carry the same amount of data. However, with OFDM, interference affects only a portion of the data streams. These data streams, when viewed as signals, are known as sub-carriers in an OFDM system, and they need to be orthogonal for the system to function correctly. The independent sub-channels can be combined using frequency division multiplexing (FDM), known as multi-carrier transmission, or using code division multiplexing (CDM), known as multi-code transmission. The core principle of OFDM is the orthogonally of the sub-carriers. The term "orthogonal" in OFDM signifies a specific mathematical relationship between the carrier frequencies in the system. This arrangement allows the sidebands of individual carriers to overlap without causing interference between adjacent carriers. For this to work, the carriers must be mathematically orthogonal, meaning their spacing must be a multiple of 1/Ts, where Ts is the symbol duration. This orthogonally is achieved through the use of Fourier transform techniques. The OFDM system transmits numerous narrowband carriers that are closely spaced. Importantly, at the central frequency of each sub-channel, there is no crosstalk from other sub-channels.

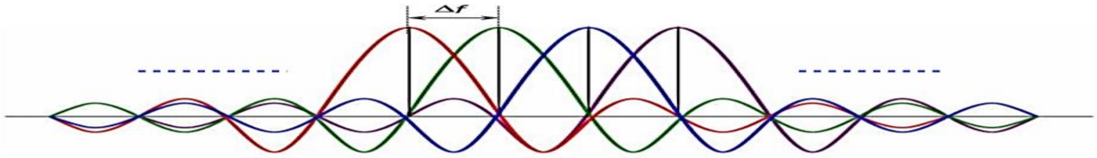

Figure 1: Example of OFDM spectrum for 4 orthogonal carriers where =1/Ts

Two signals are considered orthogonal to each other if the integral of their product over a specific time period is zero. This criterion can be met by two sinusoids whose frequencies are integer multiples of a common frequency. Thus, orthogonally is defined by the following condition:

$$\int_0^T COS\ (2\pi n\, f_0 t)\ COS\ (2\pi m f_0 t) dt = 0, (n \neq m)$$

where n and m are two different integers, f_0 is the fundamental frequency, and T is the period over which the integration is performed. In the context of OFDM, T represents one symbol period, and f_0 is set to 1/T for optimal performance. Orthogonally enables the simultaneous transmission of multiple sub-carriers within a narrow frequency range without causing mutual interference [14]. This is similar to CDMA, where codes are used to make data sequences independent (also orthogonal), allowing many independent users to transmit in the same frequency space successfully.

II.Technology and Methodology

OFDM System Using MATLAB Simulation

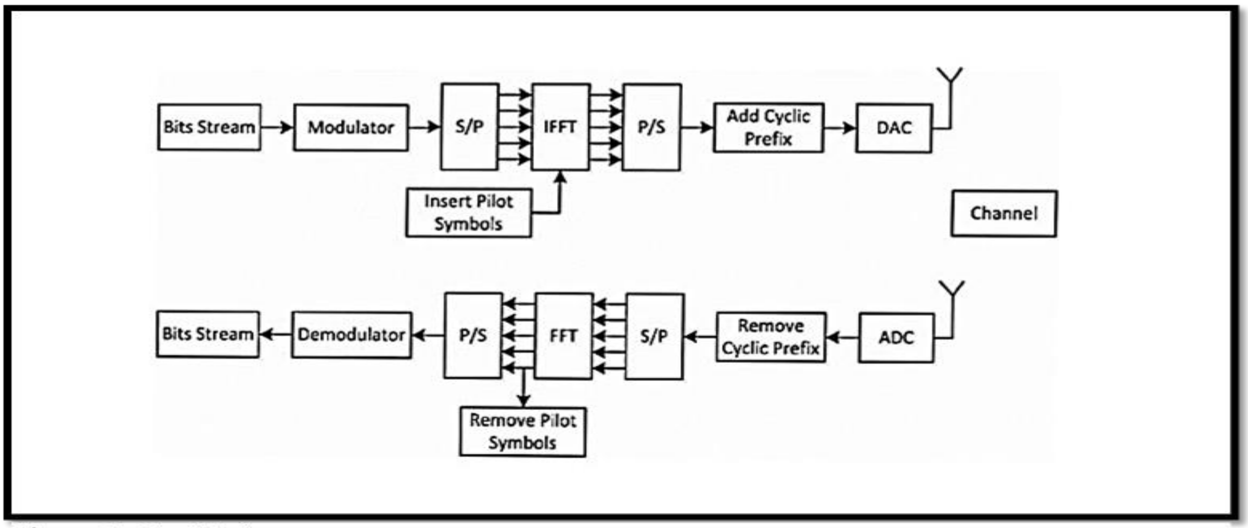

Figure 1: OFDM System

The following subsections will provide a concise overview of the various components that make up the OFDM (Orthogonal Frequency Division Multiplexing) system.

Transmitter

The primary components of the OFDM transmitter are illustrated in Figure 4. It comprises four processing stages: a serial-to-parallel converter, OFDM modulation, an Inverse Fast Fourier Transform (IFFT), and a parallel-to-serial module [7]. The input OFDM symbols are initially fed into the transmitter block in a serial manner. Subsequently, they pass through a serial-to-parallel converter, which divides the total spectrum into several sub-channels. The number of sub-channels determines the number of bands into which the spectrum is split. Following this, the signals are directed to the IFFT module, where a Pilot symbol is inserted to differentiate between various message signals. A Pilot symbol is a full OFDM symbol with predefined values for each subcarrier, known to both the transmitter and receiver. The IFFT's primary function is to convert the signal from the frequency domain to the time domain. Implementing the Cyclic Prefix (CP) technique is beneficial in multipath channels, as it completely eliminates inter-symbol interference (ISI) by appending a guard band to each data block.

Serial to Parallel Conversion:

In an OFDM system, each channel can be divided into multiple sub-carriers. Utilizing these sub-carriers maximizes the efficiency of the frequency spectrum but also necessitates extra processing by both the transmitter and receiver. This extra processing involves converting a serial bit stream into several parallel bit streams, which are then allocated to individual sub-carriers. Each sub-carrier is modulated as if it were a separate channel, and then all channels are recombined and transmitted as a single signal. The receiver reverses this process by separating the incoming signal into its respective sub-carriers, demodulating them individually, and reconstructing the original bit stream.

Modulation with the IFFT:

The data is modulated into a complex waveform during the Inverse Fast Fourier Transform (IFFT) stage of the transmitter. At this stage, the modulation scheme can be selected independently of the specific channel and tailored to meet the channel requirements. Each sub-carrier can even use a different modulation scheme if needed. The IFFT's function is to modulate each sub-channel onto its respective carrier [11].

Cyclic Prefix Insertion:

Wireless communication systems are prone to multi-path channel reflections, which can cause inter-symbol interference (ISI). To mitigate this, a cyclic prefix is added. This cyclic prefix [15] is a copy of the beginning section of a symbol that is appended to the end. It is crucial because it allows the multi-path reflections of the original signal to diminish, preventing interference with the following symbol.

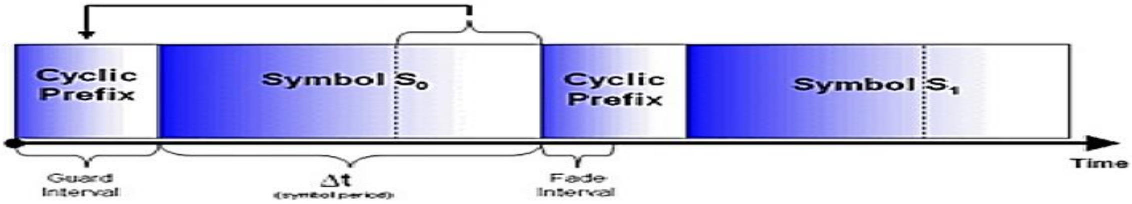

Figure 2: Cyclic Prefix Insertion

Parallel to Serial Conversion:

After adding the cyclic prefix to the sub-carrier channels, they need to be transmitted as a single signal. This is achieved through the parallel-to-serial conversion stage, which involves summing all the sub-carriers and merging them into one signal. Consequently, all sub-carriers are transmitted simultaneously and perfectly synchronized.

Digital to Analog (DAC) conversion:

On the transmitter side, a DAC chip is used, and on the receiver side, an ADC chip is used. This is necessary because the output of the Inverse FFT is a complex signal (i.e., I + jQ), which is split into an in-phase (I) component and a quadrature (Q) component, each transmitted through separate DAC channels. The challenge then is how to use a single laser to transmit both signals. There are several methods to achieve this. One method involves using an electrical analog I/Q modulator to combine the two signals into one. In this case, the receiver can use a single electrical analog I/Q demodulator. There is a way to avoid the need for two DACs and ADCs. The Fourier transform of a real number sequence has conjugate symmetry. Therefore, when QAM symbols are applied to an Inverse FFT, they are mapped to half of the entire set of subcarriers, with the other half being the conjugate of this set. This process is illustrated in Figure [Figure reference]. By using the conjugate symmetry method, a single DAC on the transmitter side and a single ADC on the receiver side can be used.

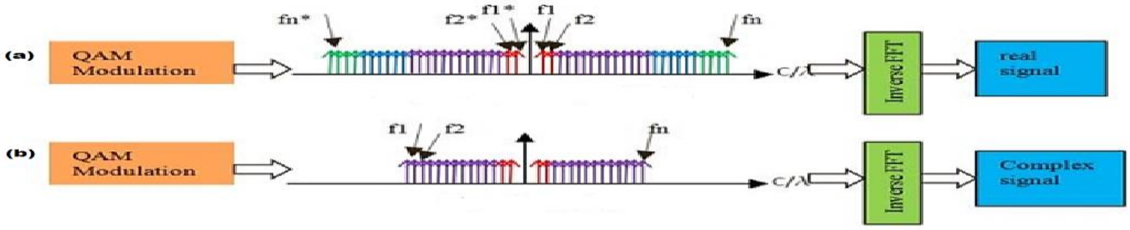

Figure 3: (a) Conjugate Symmetry Mapping (b) Normal Mapping

Receiver:

The OFDM receiver performs the reverse operations of the OFDM transmitter, which include a serial-to-parallel converter, FFT, OFDM demodulation, and a parallel-to-serial process. The incoming signal first goes through a serial-to-parallel converter. After the cyclic prefix (CP) is removed, the received signal is passed through an N-point Fast Fourier Transform (FFT) to convert it from the time domain to the frequency domain. The phase angle of each transmission carrier is then assessed and demodulated to retrieve the original data words [3]. Finally, these data words are combined back to their original size. A pilot symbol [12] is inserted to differentiate between message signals. It is a full OFDM symbol with predefined values for each subcarrier, known to both the transmitter and receiver. Initially, the data subcarriers are used for transmitting data. Next, pilot subcarriers are employed for channel estimation and synchronization. Lastly, some subcarriers are designated as null subcarriers, serving as guard bands.

III. Result and Discussions:

We conducted a MATLAB simulation for OFDM Signal Transmission and Reception in AWGN Channel using the following parameters: number of bits to process (n) = 256, a random binary data stream x, signal constellation size (m) = 16, number of bits per symbol k = log2(M), and a total of 64 subcarriers. The simulation produced a plot of the OFDM transmitted signal, the OFDM spectrum, and a comparison between the original message and the recovered message.

Output

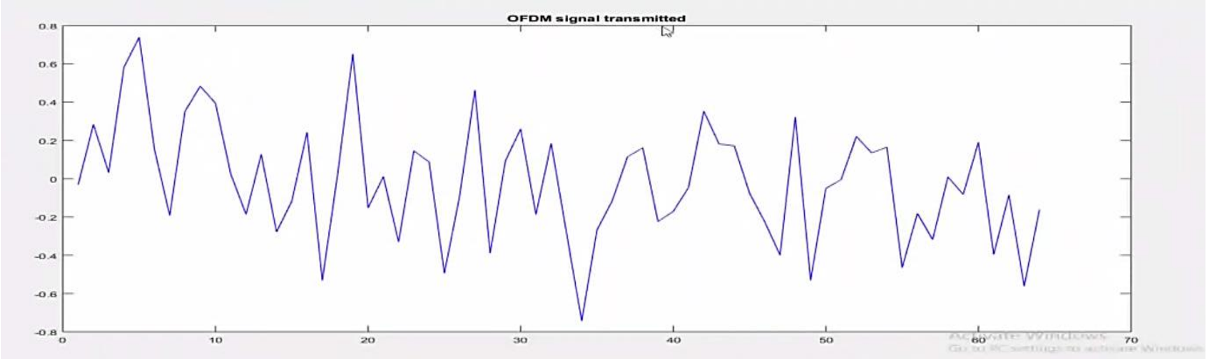

Figure 4: OFDM signal transmitted

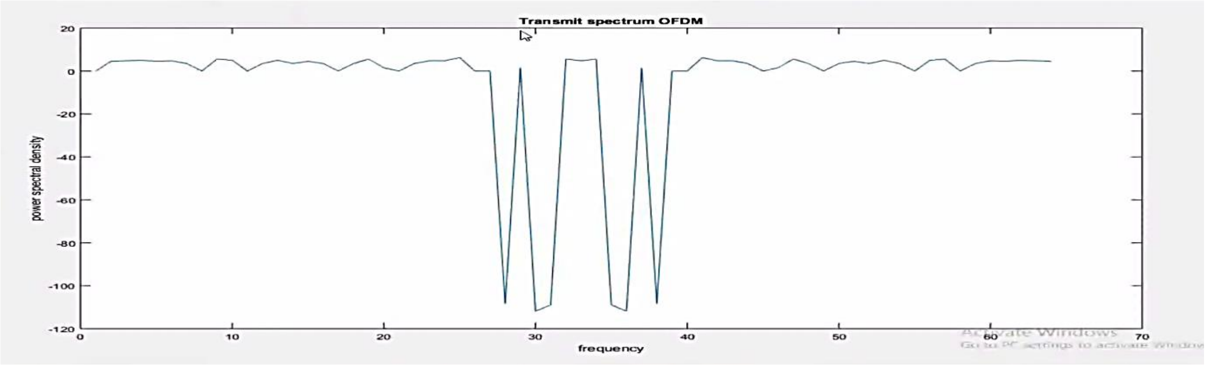

Figure 5: Transmit Spectrum of OFDM

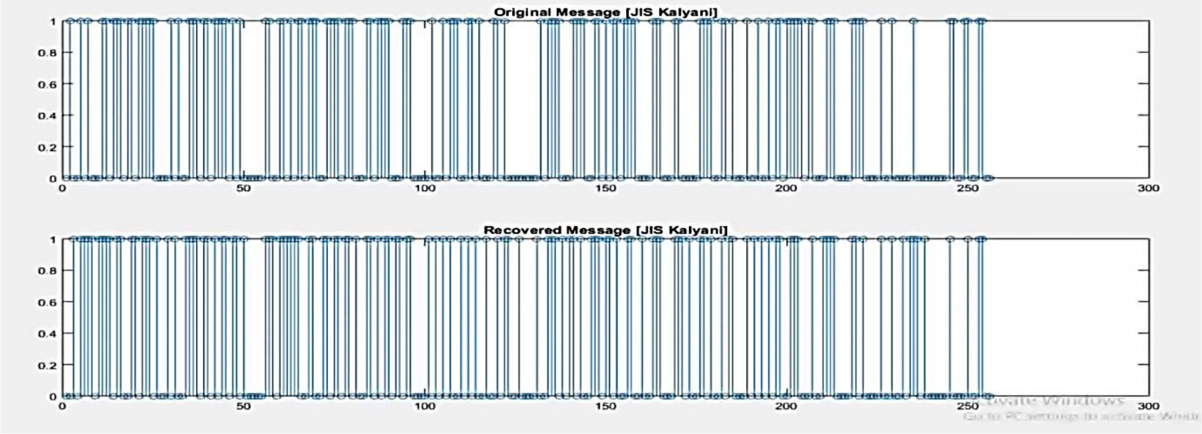

Figure 6: Original Message vs Recovered Message

IV. Future Scope of the project

As an advancement of this project, we can work in future as: i) The spectral efficiency can be increased by increasing the number of subcarriers. ii) The problem of Peak-to average ratio can be reduced by using power amplifier with wide linear range at the front end transmitter. iii) Some other methods like Clipping, Peak Cancellation can be used. iv) Synchronization can be achieved by using cyclic extension and Training Sequences.

V. CONCLUSION

This project was basically concentrated on OFDM and the study of transmission and reception in AWGN channel, it's performance measurement. Using MATLAB software, the performance of the OFDM system was evaluated with two digital modulation techniques: BPSK and QPSK. The simulation results showed that BPSK improves the bit error rate (BER) in noisy channels, but at the expense of maximum data transmission capacity. In contrast, QPSK supports higher transmission capacity but has a slightly higher probability of error due to its use of two bits per symbol, making it more susceptible to noise. Therefore, QPSK requires greater transmit power. The results suggest that OFDM with QPSK is advantageous for short-distance transmission, while OFDM with BPSK is more suitable for long-distance transmission.

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