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Orthogonal Frequency Division Multiplexing in Wireless Communication Systems: A Review

Sandeep Kaur, Gurpreet Bharti

Abstract— **As more and more people started using the communication equipments, the demand for high data rate increased quickly. Orthogonal Frequency Division Multiplexing (OFDM) is one of the latest modulation techniques used in order to combat the frequency-selectivity of the transmission channels, achieving high data rate without inter-symbol interference. The basic principle of OFDM is gaining a wide spread popularity within the wireless transmission community. Furthermore, OFDM is one of the main techniques proposed to be employed in 4th Generation Wireless Systems. Therefore, it is crucial to understand the concepts behind OFDM. In this paper it is given an overview of the basic principles on which this modulation scheme is based and compared with basic communication system.**

Index Terms— **Orthogonal Frequency Division Multiplexing (OFDM); Inter Symbol Interference (ISI), Inter Carrier Interference (ICI)**

I. INTRODUCTION

With the rapid growth of digital communication in recent years, the need for high speed data transmission is increased. Moreover, future wireless systems are expected to support a wide range of services which includes video, data and voice. Orthogonal Frequency Division Multiplexing (OFDM) is a promising candidate for achieving high data rates in mobile environment because of its multicarrier modulation technique [1]. Due to its high capacity transmission, and multi carrier modulation technique it was chosen for digital audio broadcasting (DAB), terrestrial digital video broadcasting TV (DVB-T), asymmetric digital Subscriber Lines (ADSL), ultra-wideband system. The IEEE 802.11a standard for wireless local area networks (WLAN) and IEEE 802.16 standard is also based on OFDM [2].

The basic principle of OFDM is to split a high rate data-stream into multiple lower rate data streams that are transmitted simultaneously over a number of sub carriers. OFDM sends multiple high-speed signals concurrently on orthogonal carrier frequencies. This results much more efficient use of bandwidth as well as robust communications during noise and other interferences. With OFDM, it is possible to have overlapping sub channels in the frequency domain, thus increasing the transmission rate. In order to avoid a large number of modulators and filters at the transmitter and complementary filters and demodulators at the receiver, it is desirable to be able to use modern digital signal processing techniques, such as fast Fourier transform (FFT). After more than forty years of research and development carried out in different places, OFDM is now being widely implemented in high-speed digital communications. In a basic communication system, the data are modulated onto a single carrier frequency. The available bandwidth is then totally occupied by each symbol. This kind of system can lead to inter-symbol-interference (ISI) in case of frequency selective channel. 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 rest the paper is organized as follows: In section II, literature review has been described. In section III, block diagram of OFDM system has been described. In section IV, the principle of OFDM has been described. In section V, the operation of OFDM has been described.

II. LITERATURE REVIEW

The origins of OFDM development started in the late 1950's with the introduction of Frequency Division Multiplexing (FDM) for data communications. In 1966 [3] Chang patented the structure of OFDM and published the concept of using orthogonal overlapping multi-tone signals for data communications. In 1971 Weinstein and Ebert [4] introduced the idea of using a Discrete Fourier Transform (DFT) for implementation of the generation and reception of OFDM signals, eliminating the requirement for banks of analog subcarrier oscillators. This presented an opportunity for an easy implementation of OFDM, especially with the use of Fast Fourier Transforms (FFT), which are an efficient implementation of the DFT. This suggested that the easiest implementation of OFDM is with the use of Digital Signal Processing (DSP), which can implement FFT algorithms [5]. It is only recently that the advances in integrated circuit technology have made the implementation of OFDM cost effective. The reliance on DSP prevented the wide spread use of OFDM during the early development of OFDM. It

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Sandeep Kaur, *University College of Engineering, Punjabi University Patila, Patiala, India, 9815206662,*
Gurpreet Bharti, *Yadawindra College of Engineering, Punjabi University Patiala, Patiala, India,9478805009,*

wasn't until the late 1980's that work began on the development of OFDM for commercial use [6], with the introduction of the Digital Audio Broadcasting (DAB) system. Cyclic prefix (CP) or cyclic extension was also first introduced by Peled and Ruiz in 1980 [7] for OFDM systems. In 1985, Cimini introduced a pilot-based method to reduce the interference emanating from the multipath and co-channels [8]. In the 1990s, OFDM was exploited for wideband data communications over mobile radio FM channels, high-bit-rate digital subscriber lines (HDSL; 1.6 Mbps), asymmetric digital subscriber lines (ADSL; up to 6 Mbps), very-high-speed digital subscriber lines (VDSL; 100 Mbps), digital audio broadcasting (DAB), and high definition television (HDTV) terrestrial broadcasting [2].

III. BLOCK DIAGRAM OF OFDM SYSTEM

At the transmitter, the user information bit sequence is first subjected to channel encoding to reduce the probability of error at the receiver due to the channel effects. Usually, convolution encoding is preferred. Then the bits are mapped to symbols. Usually, the bits are mapped into the symbols of either 16-QAM or QPSK. The symbol sequence is converted to parallel format and IFFT (OFDM modulation) is applied and the sequence is once again converted to the serial format. Guard time is provided between the OFDM symbols and the guard time is filled with the cyclic extension of the OFDM symbol. Windowing is applied to the OFDM symbols to make the fall-off rate of the spectrum steeper. The resulting sequence is converted to an analog signal using a DAC and passed on to the RF modulation stage. The resulting RF modulated signal is, then, transmitted to the receiver using the transmit antennas. Here, directional beam forming can be achieved using antenna array, which allows for efficient spectrum reuse by providing spatial diversity. At the receiver, first RF demodulation is performed. Then, the signal is digitized using an ADC and timing and frequency synchronization are performed. Synchronization will be dealt with in the later sections. The guard time is removed from each OFDM symbol and the sequence is converted to parallel format and FFT (OFDM demodulation) is applied. The output is then serialized and symbol de-mapping is done to get back the coded bit sequence. Channel decoding is, then, done to get the user bit sequence.

IV. THE PRINCIPLE OF OFDM

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier transmission technique, which divides the bandwidth into many carriers; each one is modulated by a low rate data stream. In term of multiple access technique, OFDM is similar to FDMA in that the multiple user access is achieved by subdividing the available bandwidth into multiple channels that are then allocated to users [9]. However, OFDM uses the spectrum much more efficiently by spacing the channels much closer together. This is achieved by making all the carriers orthogonal to one another, preventing interference between the closely spaced carriers. The figure shows the difference between the conventional non-overlapping multicarrier technique and overlapping multicarrier modulation technique. As shown in figure 2, by using the overlapping multicarrier modulation technique, we save almost 50% of bandwidth. To realize the overlapping multicarrier technique, however we need to reduce crosstalk between subcarriers, which means that we want orthogonality between the different modulated carriers.

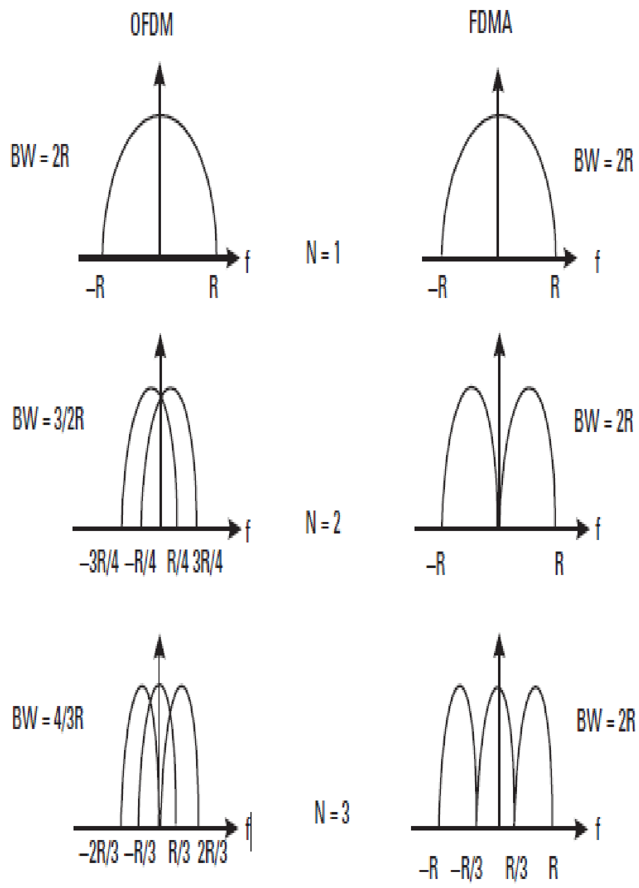

Fig 2: Concept of OFDM Signal: Orthogonal Multicarrier Technique Versus Conventional Multicarrier Technique [5]

The orthogonality of the carriers means that each carrier has an integer number of cycles over a symbol period. Due to this, the spectrum of each carrier has a null at the center frequency of each of the other 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).

V. THE OPERATION OF OFDM

As stated above OFDM is a multi-carrier modulation technology where every sub-carrier is orthogonal to each other. The "orthogonal" part of the OFDM name indicates that there is a precise mathematical relationship between the frequencies of the carriers in the system. It is possible to arrange the carriers in an OFDM Signal so that the sidebands of the individual carriers overlap and the signals can still be received without adjacent carrier's interference. In order to do this the carriers must be mathematically orthogonal. If the integral of the product of two signals is zero over a time period, then these signals are orthogonal to each other. Since the carriers are all sine/cosine wave satisfy this criterion. If a sine wave of frequency m is multiplied by a sinusoid (sine or cosine) of a frequency n, then the product is given by

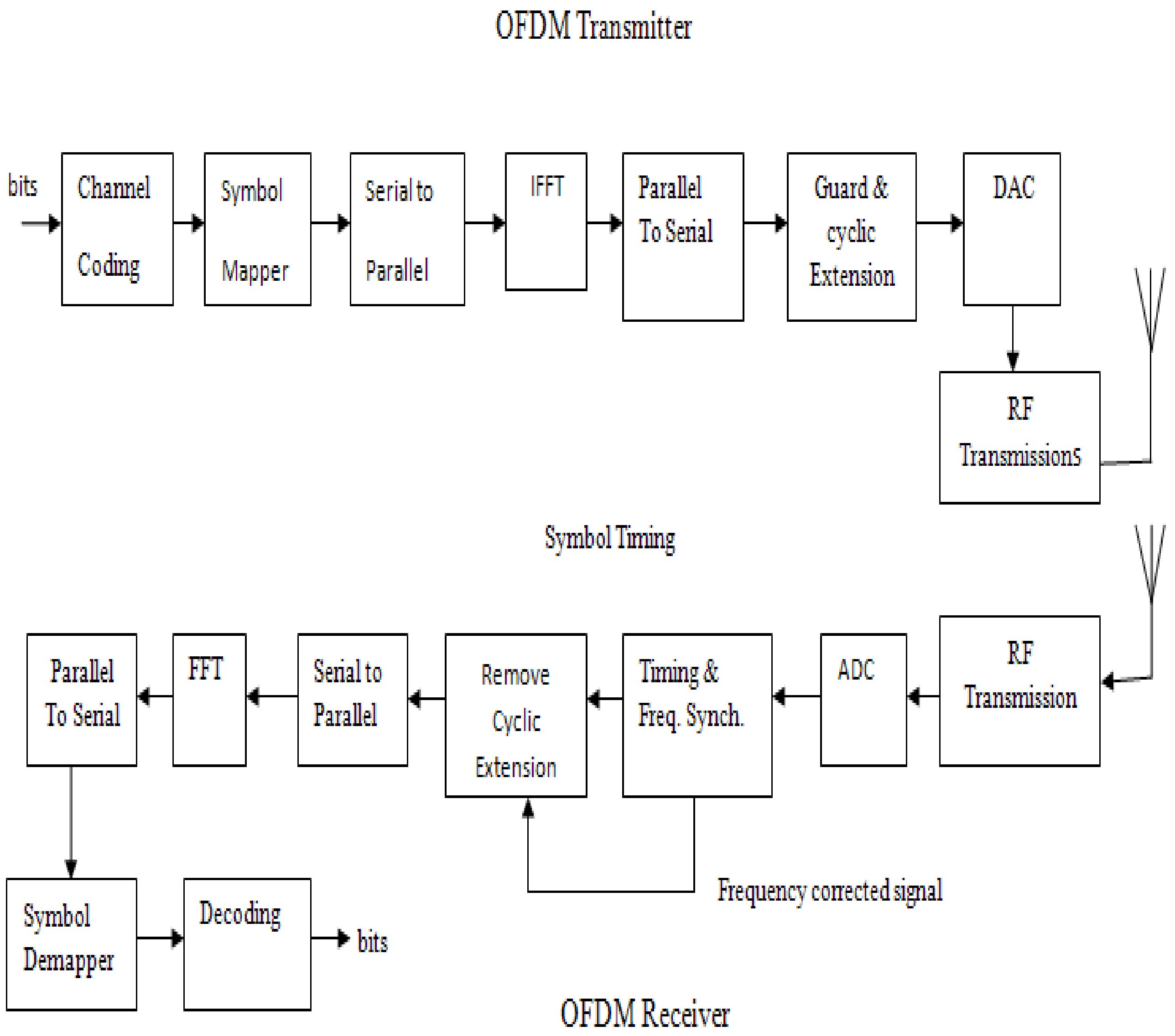

Figure 1: OFDM System Block Diagram

$$f(t) = \sin mwt * \sin nwt \qquad (1)$$

Where both m and n are integers. By simple trigonometric relationship, this is equal to a sum of two sinusoids of frequencies $(n-m)$ and $(n+m)$, since these two components are each a sinusoid, the integral is equal to zero over one period. The integral under this product is given by

$$f(t) = \int_0^{2\pi} \frac{1}{2}\cos(m-n) - \frac{1}{2}\cos(m+n)wt \qquad (2)$$

So when a sinusoid of frequency *n* multiplied by a sinusoid of frequency *m*, the area under the product is zero. In general for all integers' *n* and *m*, $\sin mx$, $\cos mx$, $\cos nx$, $\sin nx$ are all orthogonal to each other. These frequencies are called harmonics.

As the sub carriers are orthogonal, the spectrum of each carrier has a null at the center frequency of each of the other carriers in the system. This results in no interference between the carriers, allowing them to be spaced as close as theoretically possible. The orthogonality allows simultaneous transmission on a lot of sub-carriers in a tight

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frequency space without interference from each other. So in the receiver side easily we can extract the individual sub-carriers. But in traditional FDM systems overlapping of carriers are not possible, rather a guard band is provided between each carrier to avoid inter-carrier interference.

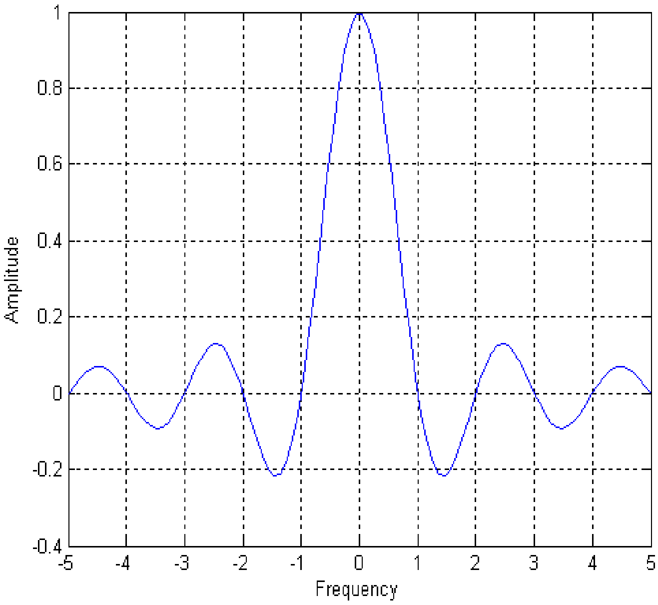

Figure 3: Single Carrier of OFDM Signal

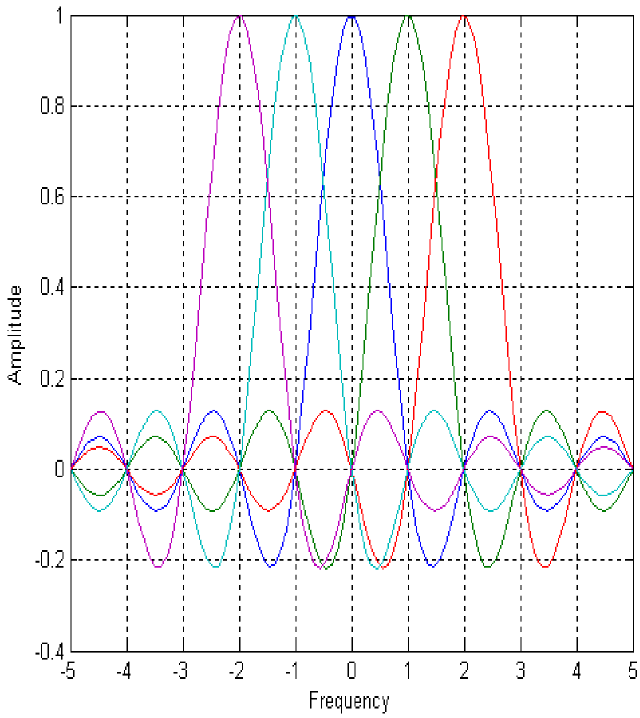

Figure 4: Multi Carriers of OFDM Signal

VI CONCULSION

In this paper we summarized the review of OFDM in wireless communication system. Then we compared the use of OFDM with basic communication system. OFDM solves the problem of ISI through use of a cyclic prefix due to high data rates. It also provides other advantages like high spectral efficiency, Low implementation complexity etc. Some of the major applications of OFDM include digital audio broadcasting digital video broadcasting, local area networks, WiMax etc. Despite of all these advantages and applications the carrier frequency offset (CFO) and high peak to average power ratio (PAPR) are major disadvantage of OFDM. This disadvantage needs to be addressed properly to allow further widespread use of OFDM.

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Authors Profile:

Sandeep Kaur: Miss**.** Sandeep Kaur is currently pursuing M.TECH (final year) in department of Electronics and Communication Engineering at University College of Engineering, Punjabi University, Patiala. She has done her B.TECH. in trade electronics and communication engineering from Yadavindra College of Engineering, Punjabi University, Patiala. Her areas of interest are Wireless communication and MATLAB. She has to her credit many papers in international journals and national and international conferences.

Gurpreet Bharti: Gurpreet Bharti is currently Assistant Professor at Yadavindra College of Engineering Talwandi sabo (Bathinda) Punjabi University, Patiala, India. She has completed his B.Tech from Rayat Institute of Engg. & information Techonology College Ropar and M.Tech. from Yadavindra College of Engineering Talwandi sabo (Bathinda) Punjabi University, Patiala, Punjab, India. Mrs. Gurpreet has 4 years of academic experience. Her areas of interest are Optical communication, OPTSIM, Matlab. She has to his credit many papers in national and international conferences.