Journal of Advances in Science and Technology
Vol. 17, Issue No. 1, March-2020, ISSN 2230-9659

A Study of Orthogonal Frequency Division Multiplexing

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Abstract - The multi-carrier modulation system known as Orthogonal Frequency Division Multiplexing (OFDM) makes effective use of available bandwidth and is resistant to the effects of time-dispersed channels. This article discusses self-interference or the corruption of the intended signal by itself in OFDM systems, and the fundamental system model for OFDM-based systems. Basically a study mainly discussed about Historical Perspectives of OFDM, OFDM Principle, OFDM Orthogonality, Optical-OFDM, Optical-OFDM Signal Processing, OFDM basics, Block System Representation of OFDM

Keyword – Frequency, Division Multiplexing

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INTRODUCTION

The rising popularity of mobile applications and other wired and wireless devices is placing strain on communication networks to expand their capacity to accommodate the rising demand for bandwidth-intensive applications. Gaining such systems requires a feeder network with the ability to function at higher carrier frequencies and set a benchmark with larger user population densities. For this reason, optical communication systems for long-distance channel transmission are now fundamental to modern life. The higher the carrier frequency, the smaller the radio cell size, but the more expensive the radio system will be to instal and maintain, making higher bandwidth silica fiber impracticable for use in residential and commercial settings. For both short- and long-haul transmission at extremely high data rates, OFDM has been shown to be an exceptional and promising technology, leading to greater system flexibility and coverage without significantly increasing system cost or complexity. Because of its scarcity and high value, devices must learn to cohabit peacefully while sharing the airwaves. Throughput optimization in modern systems is focused on signal identification algorithm improvements and minimizing the effects of different practical limitations in wireless system design. Because of the low population density and high cost of installation in rural regions, the telecommunications sector is increasingly challenged in meeting the needs of its customers. Therefore, in order to provide adequate coverage, it is necessary to use large cell sizes, which leads to significant signal path loss and lengthy delay periods during multipath signal transmission. Thanks to WDM technology, fibers may now propagate more than one wavelength at once.[1]

Advanced multi carrier modulation methods have been used in optical communication as the need for high information rates across a dispersed optical transmission medium has grown. Since it makes good use of the resources at hand and serves as a model application of digital signal processing (DSP) methods, orthogonal frequency division multiplexing (OFDM) is often held up as an efficient method among these others. The use of digital signal processing (DSP) in a wireless channel implementation of OFDM to counteract the effects of inter-symbol interference (ISI) and multipath fading has led to widespread optimism about the viability of this technology in the optical realm. As a result of its application to optical communication, a potential solution for dispersion correction has been developed to meet the needs of high-speed requirements. Optical Orthogonal Frequency Division Multiplexing (O-OFDM) has become popular because it can support large bit rates across a dispersive optical transmission medium while also being immune to transmission defects such as polarization mode dispersion (PMD) and chromatic dispersion (CD). Additionally, cyclic prefix is introduced to reduce inter-symbol interference (ISI) and inter-carrier interference (ICI) caused by chromatic dispersion (ICI). The latest technological advancements in digital signal processing (DSP) and VLSI (very large scale integrated) circuits have allowed the implementation of OFDM to overcome all the difficulties by lowering the structural complexity, making it more efficient. The analogue difficulty of implementing transmitters and receivers has given way to the digital complexity of implementing them. As a consequence of spectrum overlap between orthogonal carriers, performance is maximized and spectral efficiency is increased.[2]

The introduction of noise and interference, such as inter symbol interference, rises with the data rate (ISI). If you want to prevent errors caused by interference, you need to make sure that each symbol lasts longer than the channel's impulse response. This has the unintended side effect of slowing down the transfer of data, which is an essential component of modern technology. As a result, researchers faced a formidable obstacle in trying to achieve the seemingly unachievable goal of reducing the symbol rate without affecting the data rate. A solution to this problem is OFDM. It belongs to a subset of multi-carrier techniques in which the input data stream is split into many parallel subcarriers that operate at a reduced data rate. Digital modulation methods like as quadrature amplitude modulation (QAM) and quadrature phase shift keying (QPSK) are then applied to each of them separately prior to transmission. Although it has certain similarities with Frequency Division Multiplexing (FDM), its uniqueness stands in the orthogonality of its parallel subcarriers. Until recently, it has only been used in wireless and copper applications, but now it is now being used in optical communications with great success. The first implementation of OFDM in an optical system was shown by Pan and Green.[3]

Historical Perspectives of OFDM

In the 1870s, Frequency Division Multiplexing (FDM) was developed for the first time. Frequency Division Multiplexing (FDM) was briefly investigated in the 1870s as part of research on telegraph systems capable of transmitting data across several channels. Orthogonal frequency-division multiplexing (OFDM) is a method of transmitting and receiving digital data that was first introduced by Chang in 1966. Saltzberg published his patent for OFDM in 1967. In 1969, FFT was introduced as a method for generating orthogonal signals. It wasn't until 1980 that the concept of a cyclic prefix was established. As early as 1985, OFDM was developed by Bell Labs' Cimini specifically for use in wireless communication. Coded OFDM was first implemented for radio transmission in response to a 1987 presentation by Lassalle & Alard on the need of forward error correction (FEC) with OFDM. Thus, OFDM gained notoriety for military uses and served as the foundation for numerous telecommunications standards, including the discrete multitude low-bit-rate (DSL) standards (DMT). By using DFT, Weinstein was able to get a patent for OFDM signal production and reception in 1971, doing away with the need for large banks of analogue subcarrier oscillators. OFDM was first developed in the 1980s for commercial usage with DAB to create DVB-T. Although research on OFDM in the RF domain spanned four decades, it wasn't until the late 1990s that researchers began focusing on how the technique might be used to optical communication. In 2001, a patent was issued for optical frequency division multiplexing (OFDM) used for wireless optical communications. A proposal for using OFDM in optical fiber communication was made in 2005. As of late 2009, research on using OFDM for long-distance transmission was underway. As a result, for more efficient use of the spectrum and increased receiver sensitivity in low-power, short-range applications Direct Detection Optical Frequency Division Multiplexing (DDO-OFDM) and Coherent Optical OFDM are the two most prominent variants that emerged (CO-OFDM). A publication in terms of the (LTE) long-term evolution for the fourth-generation mobile standard was released in 2009. [4]

OFDM Principle

Transmission in OFDM is based on the notion of symbol time period being longer than channel impulse response by breaking a serial high data rate bit stream into many low rate parallel sub-streams. These independent streams are orthogonal to one another because they are modulated onto separate sub-carriers using distinct modulation methods including quadrature amplitude modulation (QAM) and quadrature phase shift keying (QPSK). It employs a mechanism analogous to FDM, and hence functions similarly. OFDM, like FDM, transmits parallel sub-carriers across a single channel to increase spectral efficiency, but does so under tighter control. This is only one of many ways in which it differs from FDM. FDM is a method of data transmission that uses multiplexing to send signals from various sources across a range of frequencies while maintaining enough spacing between them. There is no connection, coordination, or synchronization between the signals' carriers, and each is sent separately. For an OFDM system to function properly, the individual sub-channels of information from a single data source must be mutually orthogonal. The same frequency division multiplexing (FDM) concept is used to broadcast each of these sub channels. All of the subcarriers are in sync with one another in terms of both timing and frequency, allowing for precise management of intercarrier interference. When using FDM, a guard band of a certain frequency must be placed between the channels to prevent interference from reducing the overall spectral efficiency. The major reason for the widespread use of orthogonal frequency-division multiplexing (OFDM) is the fact that its overlapping sub-carriers do not result in inter-carrier interference (ICI), and that this overlap in turn increases OFDM's spectral efficiency. Compared in Figure 1.8, FDM and OFDM have certain key distinctions.[5]

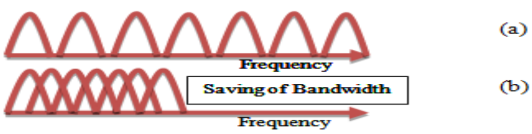

Figure 1 : Bandwidth Utilization for FDM and OFDM Multi Carrier Modulation

However, tolerance from chromatic and polarization mode dispersion, compatibility with DSP algorithms and high spectral efficiency makes OFDM attractive choice for optical communication systems.[6]

OFDM Orthogonality

Multiple sub-carrier transmission is accomplished by OFDM. An essential property of orthogonal frequency-division multiplexing is that the subcarriers remain orthogonal to one another. When the integration over a certain time period of the product of two signals approaches to zero, we say that the signals are orthogonal. If the two sinusoidal functions' frequencies are integral multiples of a fundamental frequency, then they are said to meet this condition. As a result, we may define orthogonality as:

$$\int_0^{T_s} \cos(2\pi i f t).\cos(2\pi j f t)dt = 0 \qquad i \neq j$$

Two numbers, I and j; the fundamental frequency, f; the symbol period, Ts, When using orthogonal frequency division multiplexing (OFDM), the subcarrier spacing, Δf, must be adjusted to 1/NTs in order to preserve orthogonality between overlapping sub-carriers. Subcarrier count N and symbol rate 1/Ts are indicated here.[7]

Time-domain and frequency-domain analyses both provide orthogonal results. If the difference between neighboring subcarriers is exactly one cycle in the time domain, then the subcarriers are said to be orthogonal to one another. To be orthogonal in a frequency domain, the subcarrier spacing must be adjusted to 1/NTs, and the subcarrier peak must be at the subcarrier's own centre frequency, while being zero in the centers of other subcarriers. What this means is that, as illustrated in Figure 1.9, the peak of one carrier occurs at the null of the other. There is no interference even when the sub-carriers are tightly spaced or even overlapped. If these conditions are not met, the orthogonality of the two subcarriers is broken.

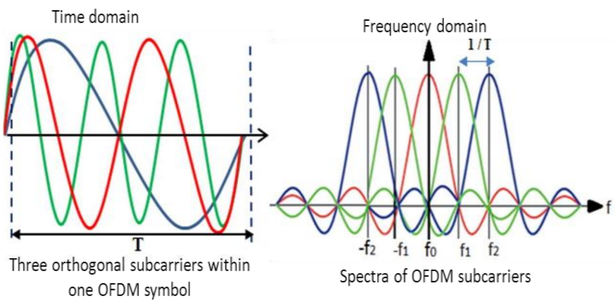

Figure 2: Orthogonality in Time and Frequency Domain

For orthogonality, the inner product is zero for two orthogonal functions with different symbols i.e. zero inter-symbol interference (ISI) and inner product is also zero for orthogonal functions with different subcarriers i.e. zero inter-carrier interference (ICI).

Optical-OFDM

In spite of its relative newness to the field of optical communications, orthogonal frequency division multiplexing (OFDM) is receiving considerable interest from researchers due to its promising performance in the optical channel for dispersion correction and high data rates. It's a powerful tool against color shifts in glass and other optical materials. Utilizing digital signal processing (DSP) technology, OFDM becomes a powerful method for handling information. This causes transmission rates to rise annually; many Tb/s have been seen experimentally. Linearity between the IFFT input at the transmitter and the FFT output at the receiver is crucial to the proper operation of the OFDM system. Multi-mode fiber systems, which can transmit several optical modes, and single-mode fiber systems, which can only transmit a single optical mode, are the two primary types of optical systems. Intensity modulation is often used to build multi-mode fiber systems, where the many modes of the transmitted signal are linear with respect to intensity. RF-OFDM signals are bipolar (having both positive and negative values), however intensity modulation does not accommodate bipolar signals. [8]

All electrical OFDM systems use a bipolar electrical signal to transfer data. Alternatively, information in optical OFDM systems is often modulated in line with the light signal's intensity, which can only be positive (unipolar). Therefore, the OFDM signal must be transformed to a real and positive signal before it can be sent via an IM/DD connection using an optical carrier. Biased orthogonal frequency division multiplexing (B-OFDM) and clipped orthogonal frequency division multiplexing (OFDM) are two solutions that have been developed for this purpose (C-OFDM). In B- OFDM, a non-negative signal may be formed by combining an OFDM signal with a bias component (often a dc bias) of a big enough magnitude. However, the huge PAPR of an OFDM signal causes only a tiny fraction of the negative component to be clipped, which in turn causes distortion. Bias components are included into the OFDM signal in C-OFDM to zero-clip the negative part of the OFDM signal. Linear field modulation, in which the signal is represented by optical field and this form of the signal may also be called as an unclipped-OFDM, on the other hand, can be simply implemented in single mode fiber systems (U-OFDM).[9]

Optical-OFDM Signal Processing

Five functional blocks make up an optical OFDM system: an OFDM transmitter that generates the OFDM signal from bit streams, an RF to optical up converter that converts an RF (electrical) signal to optical by modulating a light with an RF signal, optical media that carries the optical signal through the channel, an optical to RF down converter that converts an optical signal to RF using a photodiode, and an OFDM receiver that detects the original bit streams from the OFDM signal. Figure 1.10 shows a block diagram of the most fundamental components of an optical OFDM (O-OFDM) system.

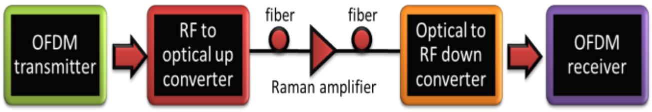

Figure 3: Optical-OFDM System

The conceptual diagram of the O-OFDM system, including all the functional blocks, is shown in Figure 1.11. Using orthogonal frequency division multiplexing (OFDM) modulation, high bit rate data streams can be transmitted by dividing them into multiple low rate streams, each of which is modulated using a different modulation format, such as binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), or quadrature amplitude modulation (QAM) (4QAM, 16QAM, 64QAM, etc.).

OFDM Basics

The unique class of Multiplexing and Multicarrier Modulation (MCM) method that OFDM employs is well-known. OFDM's othogonality between subcarriers is what sets it apart from other types of multicarrier transmission systems. Multi-user applications that need bidirectional communication in OFDM have seen less development than their one-way counterparts, such as DAB and DVB-T, which only transmit data from a base station to end users. Some examples of where this technology has been put to use include in wireless modems, WLANs, WLLs, mobile phones, and HSDPA-enabled mobile internet. The purpose of this thesis is to examine the use of orthogonal frequency division multiplexing (OFDM) in such contexts, and to assess the benefits and drawbacks that emerge as a consequence. As a broadcasting and multiuser system, OFDM may be greatly enhanced by the methods presented in this thesis. A multiuser OFDM system is shown, along with adaptive modulation and user allocation algorithms. All three of these aspects of signal transmission—spectral efficiency, frequency offset, and signal quality—are enhanced by these methods. The public and commercial sectors are both expected to increase their need for a wireless multimedia broadband system, making multimedia essentially an infrastructure technology. As a result, this thesis also explores strategies for facilitating multimodal exchanges while on the go. Frequency division multiplexing is a method of transmitting a signal in which the signal is divided into many parts, or "subcarriers," each of which operates at a different frequency (FDM). In order to get an accurate FDM signal, it is necessary to modulate these subcarriers using a certain modulation structure. In FDM transmission, the receiver is able to separate and reassemble each subcarrier. Spectrum overlap may increase spectral efficiency by making these subcarrier signals orthogonal to one another. Consequently, we refer to this method as "orthogonal frequency division multiplexing" (OFDM).[10]

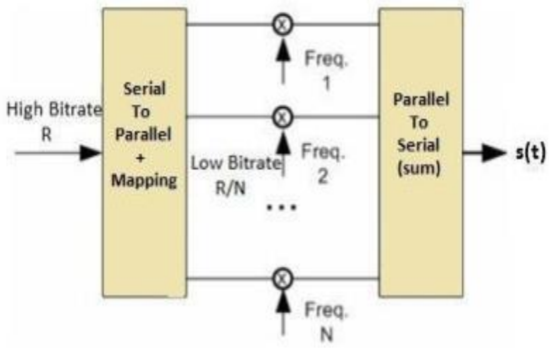

Figure 4: Schematic OFDM modulation

Fig. 1.15 depicts a simplified model of an OFDM modulation system. A total of N parallel channels, each operating at a different frequency, transport data at bitrate R, The total bit rate shared by all channels is split proportionally based on the ratio of the bit rate to the number of parallel channels, denoted as (R/N). Here, information signals are represented by data maps, and those maps are multiplied by their associated frequencies in each channel. These simultaneous information symbols combine to produce an OFDM symbol, hence the duration of an OFDM symbol is denoted in terms of symbol time., Ts= N/R.

Block System Representation of OFDM

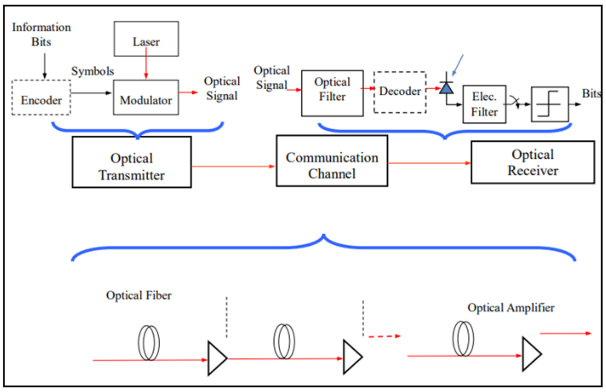

Figure 5: Block diagram OFDM

Optical amplifiers' "Amplified Spontaneous Emission" (ASE) noise, In 2002, we set a record for capacity with 40 Gb/s/channel across 64 channels and 4000 metres with a BER < 10-12. The next generation of light wave systems, using distributed photon counting and amplitude modulation (DPSKAs), is on the cusp of development, so the current operating wavelength window, the conventional wavelength window known as C-band, which is from 1530nm-1565nm, is not providing better results at the user end. Thus, the primary focus has been on the L-band (1570nm-1610nm) and S-band (1.6-2.8 GHz) extensions of the wavelength range (1485nm-1520nm). Second, efforts have been undertaken to boost the data rate of each channel. However, the advent of OFDM and other forms of multicarrier modulation has been a significant setback for the advancement of optical communication systems. These modulation techniques offer a robust foundation for the transfer of digital information across both wireless and wired networks. Research into minimising interference between closely spaced channels led to the first notion of OFDM technology being explored in the 1960s and 1970s. There was a rise in the number of research that stressed the need of achieving error-free data transmission despite interference and selective propagation. At first, OFDM's high processing needs made it impractical for widespread use. Digital terrestrial broadcasting was an early adopter of OFDM due to the reliability it offered in data transfer under varying signal path circumstances. One such example is DAVB-T digital radio, which was initially launched in Europe and other regions on June 1, 1995, with the Norwegian Broadcasting Corporation NRK launching the first terrestrial service. The digital television industry also made use of OFDM. As a consequence, OFDM was taken into consideration for the 4G mobile communications systems that began to be implemented around 2009 due to the increase in processing power afforded by the increasing integration levels. OFDM is now used in many wireless communications systems, including Wi-Fi. OFDM is a kind of multicarrier modulation. Overlapping frequency division multiplexing is characterised by a large number of modulated carriers with small intervals between them. Sidebands radiate outward from a carrier when it is modulated in any way, whether by speech, data, or anything else. In order to demodulate information from a transmission, a receiver has to pick up the complete signal. Thus, a guard band and enough spacing are required when transmitting signals in close proximity to one another so that the receiver may distinguish between them using a filter. Unfortunately, OFDM is not like this at all. Due to their orthogonality, the overlapping sidebands from each carrier may be received without creating interference. The multiplexing and modulation techniques in which it figures prominently as one of the most promising developments have broad practical implications. Understanding how OFDM works requires a look at the receiving end. It's like a sea of demodulators, bringing every carrier down to direct current. Data from a carrier is recovered by integrating the resultant signal across its symbol period. This is because all of the carriers may be demodulated by the same demodulator. When the carrier spacing is a whole number of cycles less than the symbol period, there is no interference since the total of the carrier contributions is zero.

CONCLUSION

In various experimental and simulated situations, OFDM over optical power has attained a feasible data rate in the region of 100 Gbps across 100's of kilometers of fiber length; nonetheless, practical development still has a long way to go. The writers of this study have taken a number of difficulties and real-world considerations into account while creating the suggested system. Because an MMF employs a light-emitting diode (LED) or a vertical-cavity surface-emitting laser (VCSEL) as its light source, commercial multimode fibers (graded index) connections are optimized for those specific wavelengths. When compared to LED, VCSEL is able to produce more power, making it ideal for applications requiring a high data transfer rate. Light sources for single-mode fibers are typically continuous-wave (CW) lasers operating at 1310 nm or 1550 nm. CW lasers are suitable due to their short line width and minimal source noise. The optical power that can be launched from a CW laser is on the order of a few milli watts to a few watts. The purpose of this paper is to present an optical OFDM system that may be used with a variety of currently deployed optical fibre networks. The proposed system uses a continuous-wave (CW) laser with a central wavelength of 1550 nm. The performance of MMF is simulated with these settings and analyzed. In order to make the suggested system function with both MMF and SMF networks, this is the initial step.

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