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A Study of Real and Unipolar Orthogonal Frequency Division Multiplexing for Optical Fiber Channel

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Abstract - Orthogonal frequency division multiplexing (OFDM) is a widely used modulation and multiplexing technology that has become an important part of telecommunications standards in many areas of the world. The literature has also referred to OFDM as Multi-carrier and Fourier Transform, both historically and now. OFDM is essentially the transmission of lower-rate data across multiple carriers using the IFFT orthogonal principle to deliver a continuous series of data in parallel. To ensure the carriers are mutually orthogonal, their frequency separation is carefully calibrated. Study discusses and compares basic OFDM frame structures and input conditions for a real and unipolar OFDM signal generation and the study are also the discussed and explanation about the idea of time compression in ACO-OFDM. Removal of subcarriers with zero value reduces the OFDM symbol length. Simulation results for proposed time compressed ACO-OFDM and conventional ACO-OFDM are compared. Interest in using orthogonal frequency division multiplexing (OFDM) in the optical domain for high-speed optical fiber transmission has grown in recent years owing to the technique's spectrum efficiency. Modern cable and wireless communications rely heavily on orthogonal frequency division multiplexing (OFDM). Optical orthogonal frequency division multiplexing (OFDM) has been shown to be an effective method for significantly increasing spectral efficiency in a high-speed optical fiber line, all while increasing tolerance for polarization mode dispersion (PMD).

Keyword - OFDM, unipolar

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INTRODUCTION

In the 21st century, wireless networks that can transfer massive amounts of data quickly and efficiently will be critically important. Since multimedia content is intended to be available whenever and wherever the user wishes, this is the case. Bandwidth in radio frequency bands that offer sufficient spatial coverage, however, is a limiting factor. That's why lots of researchers are looking into whether or not light can actually supply the bandwidth that modern communications systems need. Light that has been modulated could be used as a carrier instead of radio waves because of its theoretically infinite bandwidth, cheap transmitters and receivers, and lack of adverse health effects. As a corollary, it is impossible to eavesdrop on conversations taking place inside opaque materials because light waves cannot pass through them. An intruder would have a difficult time (discreetly) picking up the signal from anywhere other than the immediate vicinity of the transmitter and receiver.

One could argue that the optical medium is complementary to the radio medium rather than a direct competitor. Optical frequencies exhibit wave propagation characteristics distinct from those of radio and microwave ranges. Light is typically only able to travel a short distance from the transmitter because most building surfaces are opaque at optical wavelengths. And most surfaces, unlike those with a glossy finish, diffuse rather than secularly reflect light (as from a mirrored surface). Although diffraction plays a significant role in radio transmission, it is negligible at infrared frequencies due to the fact that the diameters of most architectural structures are typically several orders of magnitude larger than the wavelength. Due to these and other fundamental differences between the sending and receiving devices, researchers have developed channel models and communication ideas for wireless infrared optical systems.

Modern networking technologies are based on the transmission and processing of enormous amounts of data and rely on a wide range of resources and complex, geographically dispersed network architectures. As the Internet of Things (IoT) and cloud computing continue to gain popularity, programmable network administration and control have become increasingly crucial. With the rise of SDN and NFV, service providers are better able to manage their customers' networks. The future of 5G will be challenging in terms of standardization and installation because of the need for high connection density in a tiny cell structure, low latency on the order of one millisecond, and an average user's data traffic expectation of up to 50 Exabyte's per month. Miniature cells need an optical fiber backbone for widespread deployment with minimal time to market. In addition to being essential for the efficient and smooth connectivity of many different network topologies at a reasonable cost, optical networks are also essential for the following reasons.[1-3]

Orthogonal Frequency Division Multiplexing

The modulation and multiplexing technique known as orthogonal frequency division multiplexing (OFDM) is now a regular component of communications infrastructure in many parts of the globe. OFDM is also known as Multi-carrier and Fourier Transform in the literature. In essence, OFDM is the simultaneous delivery of a continuous stream of data at a reduced data rate over a number of carriers utilizing the IFFT orthogonal concept. The frequency spacing of the carriers is meticulously tuned to guarantee they are orthogonal to one another. Multicarrier systems, such as frequency division multiplexing (FDM) and wavelength division multiplexing (WDM), split the spectrum into sub-bands in order to provide numerous carriers in concurrently. A large number of low-data-rate carriers were pooled together to form a single, high-data-rate communication network. [4]

Applying OFDM to Optical Signals

Electrical OFDM signals often exhibit both positive and negative peaks. A bias must be provided to the electrical OFDM signal in such a manner that negative peaks are turned into positive optical powers in order to properly modulate a radio frequency OFDM signal onto an optical carrier. The approach is insensitive because it requires high mean optical powers in relation to the signal content. Compared to non-return-to-zero modulation, return-to-zero modulation often causes a sensitivity loss of more than 6 dB at the receiver. Here, we've compared two different ways of thinking about this problem:

- To ensure an accurate optical OFDM signal is generated from an electrical OFDM signal, any fluctuations below the signal's mean level must be removed. This kind of transmission is known as "Asymmetrically-Clipped Optical OFDM." Distortion products in the OFDM signals are a foregone conclusion when ACO-OFDM is used, as predicted by elementary Fourier theory. However, we have shown that the distortion only occurs at even frequencies of the OFDM sub-carrier grid, and that it may be entirely rejected at the receiver if only odd-frequencies are used. The OFDM spectrum (of bandwidth C) may be up converted by a frequency C, making the lowest frequency >C, hence improving signal quality per unit optical power. This causes "clipping noise" on the received subcarriers, which is a band effect. We have proved that the receiver sensitivity is 1.8 dB greater than NRZ utilizing analytical and simulated approaches.

- In order to suppress the optical carrier, a strong bias is utilized during the optical modulation process. During the process of image identification, clipping noise is also created due to the mixing of subcarriers. The solution is to repeatedly do an up conversion on the OFDM frequency band. An alternative involves removing the optical carrier altogether from the transmitter and reinjection it at the receiver, however this requires a "coherent" receiver design that is not affected by polarization. Suppressing one optical sideband in both systems is preferred because it prevents substantial nulls in the baseband spectrum after photo detection owing to fiber dispersion.

OFDM System Model

OFDM permits spectral overlapping among sub-carriers because orthogonality assures sub-carrier separation at the receiver, while a steep band pass filter degrades spectral efficiency. Before the serial data stream is delivered to the QAM modulator for parallel-to-serial signal conversion, guard intervals are included to protect against inter-symbol interference (ISI). For the purpose of signal time division multiplexing (TDM), a digital-to-analog converter (DAC) is used. In the receiver, the guard bands are read and transformed to digital form. Using a QAM decoder and a quick Fourier transform, we can perform demapping and the parallel-to-serial conversion. [5]

LITERATURE REVIEW

Tian Zhang ; Yue Zou ; Jianing Sun ; Shuang Qiao (2018) To reduce the peak-to-average power ratio in visible light communication (VLC) systems based on asymmetric clipping optical orthogonal frequency division multiplexing (ACO-OFDM), we provide an improved linear nonsymmetrical transform (ILNST) here (PAPR). The emission power conservation principles are applied to the compression coefficient to get the enlarge coefficient. The transfer characteristic of commercial light-emitting diodes (LEDs) with a 5 mm diameter is described for the purpose of performance estimate in VLC systems. By reducing the pseudo-average power ratio (PAPR) and enhancing the bit error ratio (BER), simulation results show that the proposed iINST method is preferable than the traditional linear nonsymmetrical transform (LNST) approach.[7]

Yufa Chen ; Ming Jiang ; Lin Zhang ; Xianyu Chen (2018) Popular technologies that allow for high-speed visible light communication (VLC) systems include optical orthogonal frequency division multiplexing (O-OFDM) and color shift keying (CSK). In this work, we present a novel modulation strategy for O-OFDM based VLC systems: polarity modulation (PM) assisted complex color shift keying (CCSK). In the proposed PM-CCSK system, the binary data sequence is divided and modulated by two separate CSK modulators into the real and imaginary portions of complex information symbols, as opposed to the traditional CSK scheme where information bits are mapped to real-valued CSK symbols. The novel PM-CCSK constellation has a greater average Euclidean distance than regular CSK constellations because the signs of the real/imaginary sections are determined by extra polarity bits.[8]

Pu Miao ; Dongmei Jiang ; Lenan Wu ; Peng(2018) Chen In this research, we present a unique hybrid strategy to reducing the peak-to-average power ratio (PAPR) in OFDM-based optical communication systems by integrating multi-band Jacket matrix spreading (MB-JS) with the clipping and filtering. Through theoretical analysis, we determine the PAPR performance of the proposed system by calculating the SNR of the received signals in each of the sub-bands that have been separated out. In order to assess the performance of the system and draw comparisons to other well-known PAPR reduction strategies, we use the case of 50 m step-index (SI) polymer optical fibre (POF) transmission based on offline processing as a special instance. By using this technique, we can cut the PAPR by at least 2.57 dB compared to the original OFDM transmission and cut the power consumption by at least 4 dBm. It is shown that the suggested technique provides a superior trade-off between PAPR reduction, bit error rate, and computational complexity, leading to improved system performance.[9]

Zhenyu Na ; Yuyao Wang ; Mudi Xiong ; Xin Liu ; Junjuan Xia (2018) To boost the capabilities of 5G mobile communications, visible light communication (VLC) is a potent addition. The use of relays and orthogonal frequency division multiplexing (OFDM) may significantly improve the efficiency of a VLC network. In this study, we suggested an innovative relay-assisted very-low-latency communications (VLC) system for 5G networks based on asymmetrically clipped direct current biassed optical OFDM (ADOOFDM). In the suggested setup, the source terminal's signals are sent via an amplify-and-forward relay, which also transmits its own signals. It is common practice to assign even subcarriers to signals coming from the source terminal and odd subcarriers to those coming from the relay terminal. The resulting ADO-OFDM signals consist of the union of these two signal components. The ADO-OFDM system uses noise estimation to get rid of interference from even-subcarrier signals to odd-subcarrier signals.[10]

Shanshan Li ; Mengfan Cheng ; Lei Deng ; Songnian Fu ; Minming Zhang ; Ming Tang ; Ping Shum ; Deming Liu (2018) We propose and show experimentally a secure key distribution technique for an OFDM passive optical network system. The training symbol (TS) is created by using a chaotic sequence similar to noise for the purposes of time synchronization and channel estimation. Safe keys are encoded using the TS's redundancy. Data at 7.64 Gb/s with 16-quadrature-amplitude-modulation OFDM and keys at 28.4 Mb/s are successfully broadcast across a 25-kilometer-long standard single-mode fiber in an experiment. The findings point to a viable key distribution approach for physically layer secure optical communication.[11]

Suseela Vappangi ; V. V. Mani (2018) LEDs' ability to serve dual purposes as a source of light and communication has propelled the development of Visible Light Communication (VLC), a potential new technology that might one day replace RF transmissions. VLC's major goal is to improve network performance, particularly for indoor use cases, by allowing for higher data rates. Now is a good time to use Fast Optical Orthogonal Frequency Division Multiplexing (FOOFDM) to boost ISD. In this study, we use a number of different channel estimating techniques to assess FOOFDM's effectiveness, and we create a Probability of Error expression for the resulting system models. Studies of channel estimation in DC-biased optical OFDM (DCO-OFDM) are also conducted, with the results highlighting that FOOFDM is better than DCO-OFDM in terms of power efficiency and spectral efficiency.[12]

João L. Rebola ; Adolfo V. T. Cartaxo (2017) When evaluating the effect of in-band crosstalk on the efficiency of direct-detection OFDM optical communication systems, the Gaussian method (GA) is often utilized. The results of the GA are compared to the bit error probability (BEP) and crosstalk penalty estimations produced from a Monte Carlo (MC) simulation. Using the GA, we found that BEP estimates were less precise than before. In contrast, the GA showed high accuracy (less than 0.5 dB compared with the crosstalk level calculated via MC simulation) while calculating the 1 dB crosstalk penalty for 16-quadrature amplitude modulation (QAM) and 64-QAM mappings in the OFDM subcarriers. The GA produces widely varying estimates of the cost of excessive crosstalk. [13]

Manish Sharma ; D. Chadha ; Vinod Chandra (2014) In this research, we provide an investigation of the performance of a spatially multiplexed Multiple-Input Multiple-Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) Free Space Optical Communication system in the presence of turbulence-induced fading channels. Combining MIMO with OFDM improves the FSO system's throughput and performance. Utilizing spatial multiplexing significantly expands the system's carrying capacity. For a 3 dB improvement in Eb/N0, the capacity of a 22 or 88 MIMO system grows from

2 bits/sec/Hz to 16 bits/sec/Hz, respectively. We have tested QPSK, 8 QAM, and 16 QAM and have discovered that QPSK provides the best overall performance. We also demonstrate how the bit error rate using QPSK modulation technology varies depending on the antenna arrangement. In an effort to simplify the system Detection is performed using V-BLAST.[14]

Morteza H. Shoreh ; Reza Ghanaatian ; Jawad (2015) Long-distance communication systems based on Coherent Optical Orthogonal Frequency Division Multiplexing (CO-OFDM) are the focus of this study, in which we present an iterative block equalizer. The suggested method is an iterative block equalizer based on a soft Minimum Mean-Square Error (MMSE) metric. The two main approaches to channel estimation are also covered. Furthermore, the suggested iterative equalization and channel estimation methods are analyzed for their performance and computational complexity. By almost two orders of magnitude, the iterative equalizer beats the linear equalizers, as seen by the BER performance attained.[15]

Mohamed E. Khedr (2014) This study offers an all-optical orthogonal frequency division multiplexing for use in wireless optical communications to achieve both a high bit rate and the elimination of inter-symbol interference. The overall architecture is described, along with the design standards that should be followed when settling on values for the individual parameters. The system is put through its paces in a realistic wireless optical channel environment, with the error probability being calculated analytically. Overall, the proposed approach shows promise as a high-speed optical wireless channel.[16]

L.A.Abdul Rahaim et al.,(2015) designed a CO-OFDM network that makes use of QPSK and QAM modulation formats to increase speed and range at 40 and 100Gb/s bit rates. The input signal was simulated using PDM, CO-OFDM, and QPSK at 100Gb/s, resulting in an optical signal bandwidth of 25GHz. With the same bit rate, this system has a bandwidth of 12.5GHz and uses 16-QAM. Non-linearity is less of an issue with the PDM CO-OFDM QPSK signal compared to the PDM CO-OFDM 16-QAM signal. Increased spectral efficiency is a benefit of 16-QAM modulation, however the trade-off of lower maximum range and optimal input power is lower electrical bandwidth. The author also has the option of looking at the construction of a PDM CO-OFDM system that uses QPSK and 16-QAM modulation formats, has a data rate of 100Gb/s, and operates at a frequency of 25GHz. These simulation findings for PDM-based long-distance transmission demonstrate the technique's potential for both high data rates and efficient use of the radio spectrum. With equal bit rates, the PDM CO-OFDM QPSK signals have a lower OSNR than 16-QAM.[17].

Fahad Almasodi et al., (2013) Using the OptiSystem modelling programme, we looked at the effect of the OFDM approach on RoF in PONs of 100 km, 140 km, and 288 km in length, all of which made use of single mode fiber. This system was used to model the OFDM-PON network, and it allows for a high data throughput at the last mile of wireless networks while being cost efficient via the use of 4-QAM modulation on a 7.5GHz carrier frequency with a 10Gb/s transmission bit rate. This research also reveals the inner workings of an RF spectrum analyzer as well as an optical frequency analyzer. The results showed that the RoF-OFDM-PON was efficient. The constellation diagram reveals the 4-QAM modulation, proving that RoF significantly enhances signal quality..[18]

Veneetha Nair et al., (2013) analyzed the bit error rate (BER) of direct-detection and coherent-detection systems for QAM and DPSK optical OFDM. This system was simulated at 50Gb/s over a 1000-kilometer SMF link. Here, the success of 4-QAM CO-OFDM is on par with that of QAM with coherent detection at the same bit rate of transmission. When compared to QAM modulation, the performance of the OOFDM in the RoF model is superior. Through simulation, we see that CO-OFDM in the RoF system network achieves superior performance with QAM modulation and sub-carrier enhancement of BER value. When comparing direct detection to OFDM's coherent detection, the Q-Factor of the latter increases by about 9 dB. Polarization diversion modulation (PDM) is used to significantly boost CO-performance, OFDM's keeping the BER at about 10-5.[19]

Yoon-Khang Wong et al., (2012) The focus of this article is on the modulation used by the OFDM-RoF system to transmit the QAM-OFDM signal in OptiSystem. Optical and electrical signal processing have been working with the system identification method to boost performance and quality. Today's wireless communication networks may benefit greatly from the suggested model's enhanced performance and signal quality gains. This simulation model, on the other hand, makes use of fiber optic distribution and an optical OFDM signal, which has a number of benefits in microcellular setups. By avoiding the complexities of antenna technology, the adapted wireless communication system may provide a great cost-effective means of sending a broad range of applications across a wide frequency range.[20]

METHODOLOGY

To ensure the suggested system architecture is feasible, simulation results and error performance graphs were shown. Optical Fiber Overlapping Frequency Division Multiplexing Literature Review. The authors have described the many phases of OFDM's growth in the optical domain, as well as its most notable aspects, and have conducted a research on the modifications to the RF OFDM signal that are necessary prior to its transmission in the optical domain. The authors of this study used a direct detection (DD) OFDM system in order to describe the circumstances under which a real-world signal would be generated. We'll go through the differences between systems like DCO-OFDM, ACO-OFDM, and Flipped OFDM, all of which are used to ensure that the optical signal used for intensity modulation (IM) is unipolar. The paper analyses and contrasts the most fundamental OFDM frame structures and input requirements for the synthesis of real and unipolar OFDM signals, and it explains the concept of time compression in ACO-OFDM. The length of an OFDM symbol may be shortened by omitting subcarriers having a zero value. The simulation results for the proposed time-compressed ACO-OFDM and the more traditional ACO-OFDM are compared. The proposed ACO-OFDM will be tested for its BER performance at both 10 Gbps and 40 Gbps data rates and with QPSK and QAM-16 modulation formats. For ACO-OFDM, we additionally simulate a method proposed by its developers, which entails inverting the simulated negative samples. This analysis explains how to generate flipped OFDM frames twice as compressed and compares their performance to that of a single OFDM frame.

It was determined that the proposed dual frame OFDM system, as well as the optical phase conjugation (OPC) and phase conjugated sub-carrier coding (PCSC) methods, were effective in reducing the negative effects of fiber nonlinearity. Over existing OFDM and the proposed time-compressed and flipped OFDM frames, PCSC is implemented. The effectiveness of the proposed dual frame OFDM in mitigating nonlinearity and dispersion in multimode fibred is compared to that of PCSC. In this work, we model 2*2 MIMO transmission and reception using TDM and WDM algorithms over MMF and offer a summary of our simulation findings. Both single-input, single-output (SISO) and multiple-input, multiple-output (MIMO) modes of transmission were compared in terms of their performance.

DATA ANALYSIS

In Fig 3.16, we have a simplified illustration of the two possible approaches for implementing the incorporation of negative samples into the final positive frame. The suggested system's unique selling point is that it combines the features of both traditional ACO-OFDM and F- OFDM. The fundamental OFDM signal is created in the same way as ACO-OFDM, i.e. by loading all the even subcarriers with zeros, but without Hermitian symmetry. This results in an intricate bipolar antisymmetrical signal. Upconversion is used to create the real signal, and the inversion of the bipolar signal creates the unipolar signal. Two methods exist for doing this: one involves time-compressing the positive frame, followed by the time-compressed inverted negative frame, while the other involves inserting the negative samples between the positive ones. This results in the formation of two actual frames, each of which is unipolar. In order for the optical modulator to function, these frames must be converted into electrical input. The optical modulator performs direct frame modulation on these segments. At the other end of the cable, optical signals are picked up. Similarly to how the aggregate information of numerous receivers in a MIMO structure might provide better results, using two separate envelope detectors in the case of single-frame flipped OFDM can yield better results. The simulation environment in which the study was conducted is shown in Fig.1. Matlab 2016b is used to model the digital signal processor (DSP) unit responsible for OFDM creation and demodulation, and the resulting data is then used to mimic the electrical signal input to an optical MZM modulator. Optsim is used to simulate the processes of optical modulation, transmission via an optical fiber, and detection at the optical receiver. Matlab routines are used to record the data in the electrical domain and then decode the data afterwards. The frequency spectrum of the electrical input signal to the MZM modulator is seen in Fig. 2. This is for a variety of OFDM frame frequencies. Each OFDM frame's optical output and corresponding received optical signal at the receiver are shown in Fig. 3.

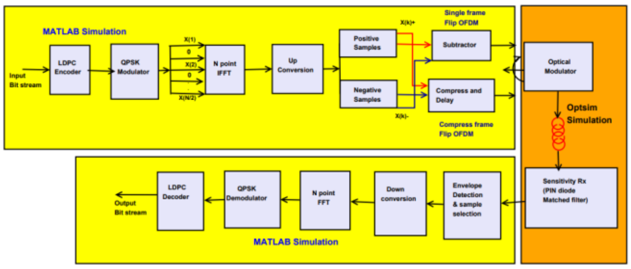
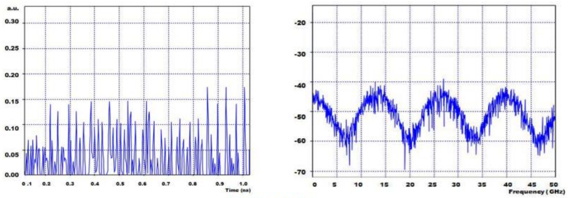
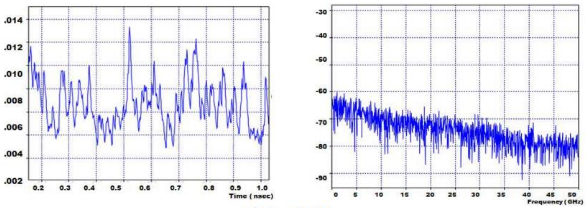


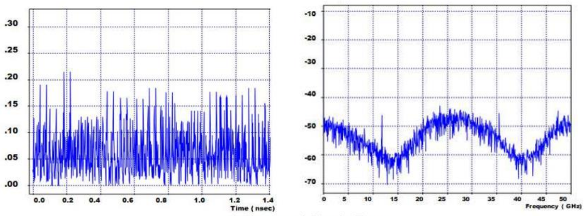
Figure 1: Simulation set up for the proposed Flipped ACO-OFDM system



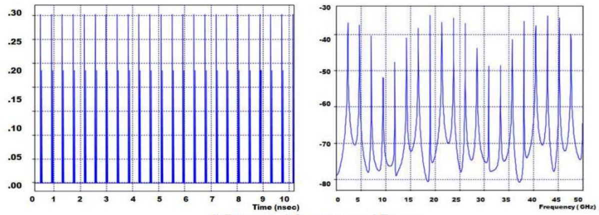
a) Clip OFDM



b) Flip OFDM

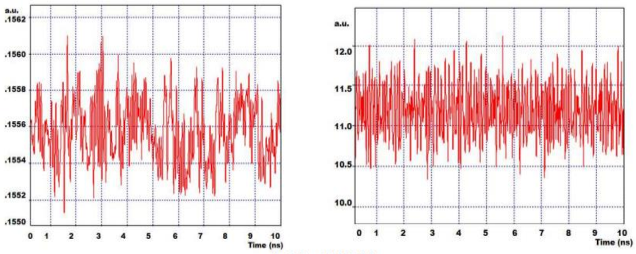


c) Proposed Single Frame

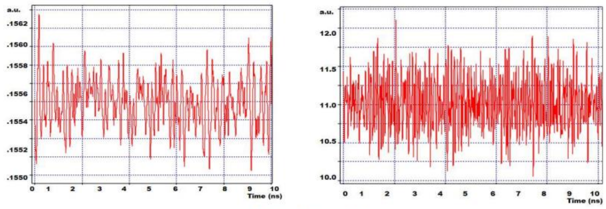


d) Proposed Compressed Frame

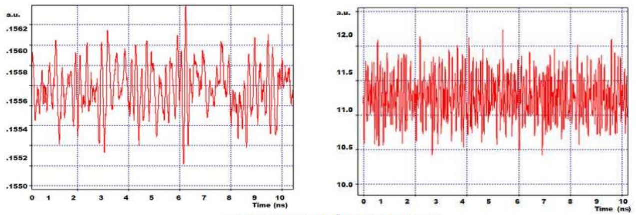
Figure 2: Simulation waveforms (left) Electrical input [X axis: time in n sec.] and (right) Frequency spectrum [X axis: frequency in GHz] for optical modulator in Fig. 4.10



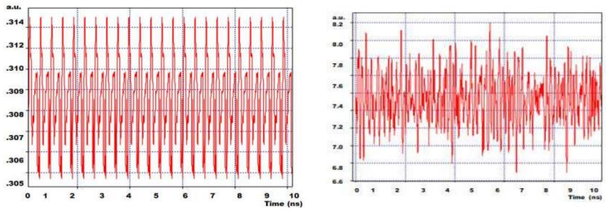
a) Clip OFDM



b) Flip OFDM



c) Proposed Single Frame



d) Proposed Compress Frame

Figure 3: Simulation waveforms (left) optical modulator output (right) received optical signal [X axis: time in n sec.]

The forward check en- coder uses a low density parity check (LDPC) code to effectively encode a binary data stream at 10 Gbps, making it suitable for use with OFDM in low signal-to-noise ratio (SNR) environments. QPSK modulation is used for symbol mapping. The symbol error probability PE may be expressed in terms of the SN R (Eb /N0) for a QPSK modulated system, where Eb is the average bit energy and N0 is the noise power spectral density:

$$P_E = 2 * Q\sqrt{2 * E_b/N_0}[1 - 2 * Q\sqrt{2 * E_b/N_0}]$$

An essential factor in the error performance of any communication connection is the total transmitted power and the signal bandwidth. Increasing the transmitted power may improve the bit error rate (BER), but optical fiber complicates things. For high optical power, optical fiber acts as a non-linear channel, and for a multi-wavelength system, estimating the channel becomes an even greater challenge. The proposed frame architectures are time-compressed to increase both bit rate and throughput in a given period of time. Since the optical channel acts as a low pass filter, time-compressed frame structures with a power maximum at DC are an advantageous characteristic.

Table 1: Simulation Parameters for different OFDM frames

Simulation Parameter	Value
Bit rate	10 Gbps
Modulation	QPSK
Nuber of Subcarrier FEC Encoder	10/40/100/200
	LDPC (32400,64800)
SMF Length	20 km
SMF Nonlinearity Coefficient SMF Attenuation Const. SMF Dispersion Coefficient MMF Attenuation Const. MMF Dispersion Coefficient Simulation B/W	1.26677 W^{-1}/km 0.2dB/km
Center wavelength	16 ps/nm/km

Table 2: Simulation Parameters for different OFDM frames

Parameter	Cllpped	Fllpped	Single Frame	Compressed Frame
Data array size	72900	145800	72900	72900
Max. Power	70.14	141.76	283.52	283.52
PAPR	43.54 dB	46.6 dB	46.6 dB	46.6 dB

CONCLUSION

Orthogonal frequency division multiplexing (OFDM) has gained popularity in recent years due to its spectrum efficiency, making it a viable option for high-speed optical fibre transmission. Orthogonal frequency division multiplexing is a crucial technology in today's cable and wireless communications (OFDM). The spectral efficiency of a high-speed optical fibre line may be considerably improved by using optical orthogonal frequency division multiplexing (OFDM), which also improves the line's tolerance for polarisation mode dispersion (PMD). The OOFDM- RoF system has gained a lot of interest as a potential future standard for gigabit broadband wireless and cable communication. The signal must be modified in RF OFDM before it can be sent in the optical domain. This research lays out the necessary steps for creating real-world signals using a direct detection (DD) OFDM system. The need for a unipolar optical signal for intensity modulation (IM) and the operation of various systems, such as Direct Coded Orthogonal Frequency Division Multiplexing, Adaptive Coded Orthogonal Frequency Division Multiplexing, and Flipped Orthogonal Frequency Division Multiplexing, are described in detail. To produce an authentic and unipolar OFDM signal, this chapter examines and compares the basic OFDM frame structures and input conditions. In an Orthogonal OFDM over Fiber (OOFDM-RoF) system, OFDM modulation is embedded inside a Radio over Fiber (RoF) infrastructure. RoF systems make use of the enormous capacity of an optical network without sacrificing the mobility of a wireless one, and OFDM can transport data across a large number of subcarriers spaced out at precise frequencies with overlapping bands. This indicates that OOFDM-RoF technology can be used for high-rate transmissions across both large and short distances. Because of this, the system's flexibility is enhanced without a commensurate rise in cost or complexity.

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