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Performance Evaluation and Simulation of OFDM in Optical Communication Systems

Mary Anjaley Josy John*, Gokul P G**
*(Department of Electronics and Communication, CUSAT, Kerala)
** (Department of Electronics and Communication, CUSAT, Kerala)

ABSTRACT
Orthogonal Frequency Division Multiplexing (OFDM) is of prime importance nowadays in long haul communication networks because of its higher spectral efficiency, immunity to multipath fading and its resilience to interference. Optical Orthogonal Frequency Division Multiplexing is considered as a promising technology to satisfy the increased demand for bandwidth in broadband services. It is of two types based on the detection techniques employed. They are direct detection and coherent detection. In direct detection OFDM, a photodiode is used while in the latter the principle of optical mixing is utilized. This paper investigates the architecture of single channel and four channel direct detection and coherent detection optical OFDM systems and carries out performance analysis based on bit error rate and Q-factor. In the case of single channels, a date rate of 10 Gbps is achieved while in 4 channel systems a data rate of 40 Gbps is achieved. Coherent Optical OFDM (CO-OFDM) is the next generation technology for the optical communications, since it integrates the advantages of both coherent systems and OFDM systems.
***Keywords* –** BER, CO-OFDM, IFFT, MZM, OFDM, QAM.

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a Multi Carrier Modulation (MCM) technique which uses many subcarriers to carry the information. The main advantage of the OFDM is its ability to overcome channel dispersion. Also, OFDM has the ability to transmit information with high data rates which has made it popular. OFDM has been used in many different applications in the RF domain such as digital audio broadcasting (DAB), digital video broadcasting (DVB), and Wireless Local Area Networking (WLAN). OFDM was introduced to optical domain in 2005, and has since been studied and investigated in two main techniques classified according to the detection scheme. The first technique is the direct detection optical OFDM (DD-OFDM) and the second technique is the coherent optical OFDM (CO-OFDM). A direct detection optical OFDM aims for simpler transmitter or receiver than CO-OFDM for lower costs. DD-OFDM has an advantage that it is more immune to impulse clipping noise. Coherent Optical OFDM (CO-OFDM) is the next generation technology for optical communications since it integrates the advantages of both coherent systems and OFDM systems. CO-OFDM provides linear detection and high spectral efficiency. The CO-OFDM system has the ability to overcome many optical fiber restrictions such as Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD). Moreover the system is resistant to inter-symbol interference (ISI) because of the cyclic prefix code.

II. SYSTEM MODELING

2.1. Direct Detection OFDM System

Fig 1 shows the basic block diagram of a direct detection OFDM transmitter. The main purpose of the optical transmitter is to convert the electrical signal to an optical signal and to launch the resulting signal into the optical fiber. The optical transmitter consists of an optical source and an optical modulator. The optical source can be a Light-Emitting Diode (LED) and the optical modulator can be direct or external modulator. An example of external modulator is a Mach-Zehnder Modulator. At the transmission block, both modulation and multiplexing are achieved digitally using an inverse fast Fourier transform (IFFT) at the OFDM modulator. The subcarrier frequencies are mathematically orthogonal over one OFDM symbol period. Quadrature modulator is used to modulate the I and Q components separately and the RF to optical up-conversion is done using a CW laser and a MZM.

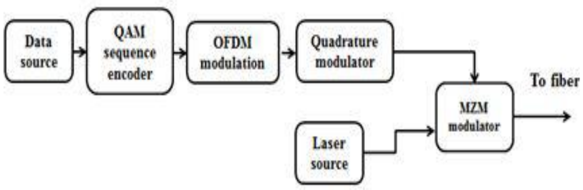

Figure 1: Basic block diagram of DD-OFDM transmitter

The optical link consists of an optical amplifier, an optical filter, and single mode fiber and loop control. An optical amplifier is used to amplify the signal and then filtered by means of an optical filter. The loop control is used to vary the fiber length.

Fig 2 shows the basic block diagram of a direct detection OFDM receiver. The main purpose of the optical receiver is to detect the signal and convert the received signal from optical back to electrical. The detection system consists of a photodiode tuned at the frequency at which the signal is transmitted which converts the optical signal to electrical signal. It is then given to a given to a quadrature modulator for demodulating the I and Q components separately and further given to QAM sequence decoder and finally to the visualizers.

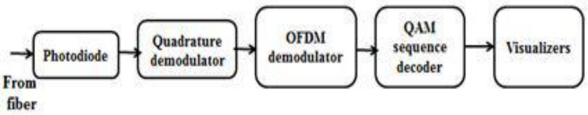

Figure 2: Basic block diagram of DD-OFDM receiver.

2.2 Coherent Detection OFDM System

Fig 3 shows the transmitter section of a coherent detection OFDM system. The bit stream to be transmitted is given by a data source which is mapped onto to symbols by a QAM encoder. The OFDM modulator then performs the IFFT operation and adds cyclic prefix. A Continuous Wave (CW) laser and two Mach-Zehnder modulators are used to up-convert the RF data to the optical domain.

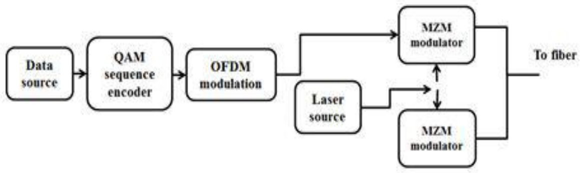

Figure 3: Basic block diagram of CO-OFDM transmitter

The transmission fiber is usually a single-mode fiber in the case of medium or long-distance transmission, but can also be a multimode fiber for short distances. In the latter case, intermodal dispersion can limit the transmission distance or bit rate. Long range broadband fiber channels can contain fiber amplifiers at certain points to prevent the power level from dropping to too low a level. Alternatively, it is possible to use a distributed amplifier, realized with the transmission fiber itself, by injecting an additional powerful pump beam which generates Raman gain. In addition, means for dispersion compensation and for signal regeneration may be employed. The latter means that not only the power level but also the signal quality is restored. This can be achieved either with purely optical signal processing, or by detecting the signal electronically, applying some optical signal processing, and resending the signal. Thus the signal from the CO-OFDM transmitter is then propagated through the optical link and becomes degraded due to fiber impairments.

Fig 4 shows the receiver section of CO-OFDM system. The main purpose of the optical receiver is to detect the signal and convert the received signal from optical back to electrical. The optical receiver consists of a photodiode, which converts the optical signal to electrical, and an electrical demodulator, which extracts the original electrical signal that was sent. A coherent receiver with a local oscillator is used to down-convert the data to the RF domain. Homodyne detection is used here where the local oscillator frequency is same as the incoming signal. Finally data is demodulated and sent to the detector and decoder for BER measurements. Coherent detection provides linearity in RF to Optical up conversion, much needed for OFDM providing high spectral efficiency and great robustness against dispersion effects.

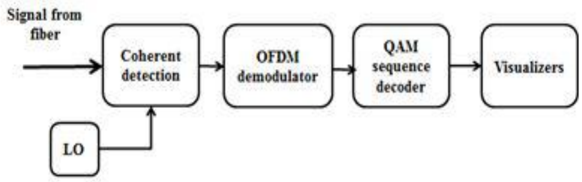

Figure 4: Basic block diagram of CO-OFDM receiver

III. SIMULATION USING OPTISYSTEM

3.1 DD-OFDM

The design model is shown in Fig 5. A PRBS bit generator is used to produce bits at a rate of 10 Gbps and its output is given to a QAM sequence encoder which maps the bits to particular symbols. Quadrature Amplitude Modulation (QAM) is a modulation scheme in which two sinusoidal carriers, one exactly 90 degrees out of phase with respect to the other, are used to transmit data over a given physical channel. Because the orthogonal carriers occupy the same frequency band and differ by a 90 degree phase shift, each can be modulated independently, transmitted over the same frequency band, and separated by demodulation at the receiver.

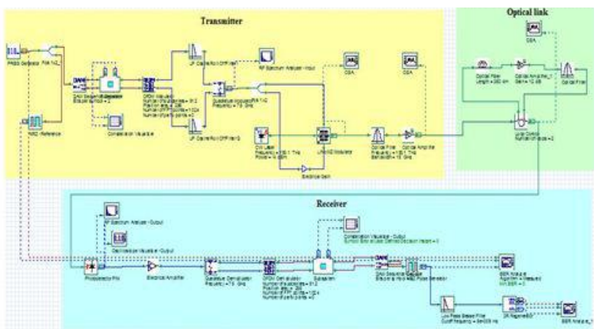

Figure 5: Single channel direct detection optical OFDM system

For a given bandwidth, QAM enables data transmission at twice the rate of standard Pulse Amplitude Modulation (PAM) without any degradation in the BER. The mapped symbols are given to a OFDM modulator where they are converted from serial to parallel order and cyclic prefix is added. The Quadrature modulator then modulates the I and Q components separately. It has a frequency of 7.5 GHz, gain 0.01 a.u. The MZM together with the CW laser operating at -4 dBm and 193.1 THz provides the RF to optical up-conversion. The output is then filtered at 193.1 THz, order 2 using an OBPF and amplified before transmission through the optical link.

The optical link consists of an optical fiber whose length is varied to carry out performance analysis, given to an optical amplifier amplifying at 12 dB and then given to an optical amplifier. All the above 3 components are given into a loop, whose number can be varied to increase the fiber length rather than increasing the fiber length on its own. The receiver section consists of a photo detector tuned at 193.1 THz so as to detect the signal transmitted using the same frequency. The main difference between coherent and direct detection is that direct detection makes use of a photo detector while coherent detection makes use of the principle of optical mixing. The converted electrical signal is then given to an electrical amplifier then to quadrature demodulator with frequency 7.5 GHz. It is then given to an OFDM demodulator with the same specifications as that of the OFDM modulator. A subsystem is used here to view the constellation diagram at receiver side. The output then obtained from a QAM sequence decoder maps the symbols back to bits and is used for BER analysis.

3.2 CO-OFDM

The design model shown in Fig 6 is a single channel coherent detection optical OFDM system. In the CO-OFDM transmitter, the bit stream is generated by a PRBS generator and mapped by a 4-QAM encoder. The resulting signal is modulated by an OFDM modulator with parameters. After that, the resulting electrical signal is modulated to optical

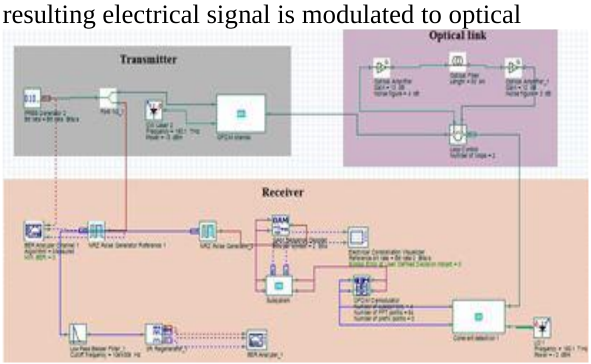

Figure 6: Single channel coherent detection optical OFDM system

signal using a pair of Mach Zehnder modulators (MZM) and a CW laser source. The optical link consists of a SMF, with dispersion coefficient of 16 ps/nm/Km, and attenuation of 0.2 dB/Km. The CO-OFDM receiver design consists of two pairs of balanced PIN photodetectors and LO to re- cover the I/Q component of the OFDM signal. The balanced detectors perform the I/Q optical to electrical conversion and helps perform the noise cancellation. Electrical amplifiers are used to adjust the signal intensity. After the balanced detectors the resulting electrical signal is amplified and then demodulated using the OFDM demodulator with guard interval removed. The demodulated signal is fed to a 4-QAM decoder followed by a BER analyzer to evaluate the various performance parameters of the signal.

IV. RESULTS AND DISCUSSIONS

4.1 Eye diagram analysis

Fig 7 and 8 shows the eye diagrams for 4-channel and 1-channel direct and coherent detection systems. It is seen that direct detection systems have a lesser Q-factor and high BER compared to coherent detection systems. A Q-factor of 20, 24, 31 and 40 is obtained for single channel and 4 channel direct detection and coherent detection systems respectively.

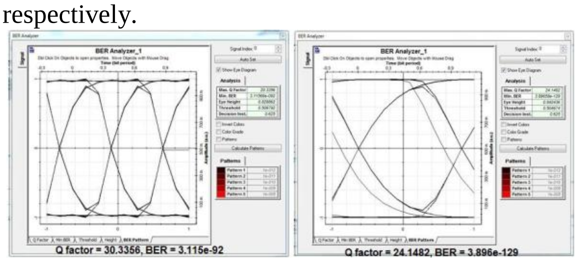

Figure 7: Eye diagram obtained for 4 channel and 1 channel direct detection systems

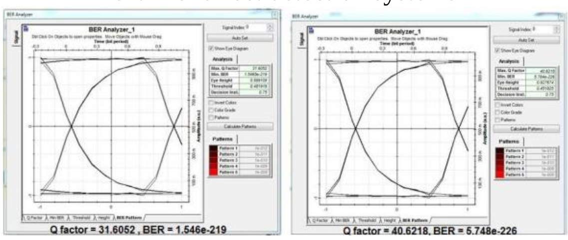

Figure 8: Eye diagram obtained for 4 channel and 1 channel coherent detection systems

4.2 Relationship between Transmission length and Q-factor

The fiber length of single channel and 4 channel direct detection and coherent detection systems are varied and the corresponding Q-factor measurements are shown in Fig 9. The fiber length is varied from 100 to 500 km and thus the Q-factor measurements are taken. The bit rate is set at 10 Gbps. From the graph it is analyzed that as the transmission length increases the Q-factor decreases, but it is higher when a single user is present. When comparing the direct detection and coherent detection systems, coherent detection have more Q-factor because it makes use of the principle of linear detection by means of the principle of optical mixing. At the receiver side, a perfectly aligned CW laser along with a pair of photodetectors and an optical hybrid helps in increasing the Q-factor by means of linear detection.

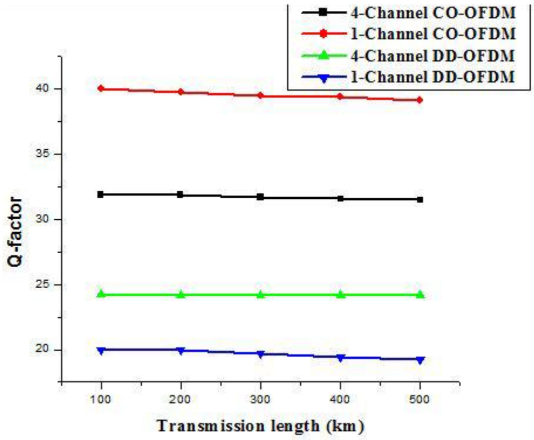

Figure 9: Q-factor versus Transmission length for optical OFDM systems

4.3 Relationship between Transmission length and BER

Fig 10 shows variation of BER with transmission distance for a single channel and 4 channel CO-OFDM system. When comparing the BER and transmission length for single channel and four channel, BER is less when a single channel is employed. But BER increases only upto a small extent. Our present need is to accommodate more

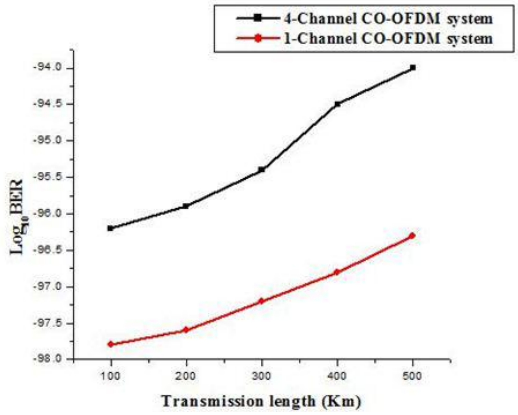

Figure 10: Log BER versus Transmission length for coherent detection systems

Number of users, so 4 channels WDM optical CO-OFDM is used which provides high Q-factor but low BER when compared to direct detection systems. Also it is seen that with increasing fiber lengths, the variation of BER is almost small. So it can be said that the OFDM systems are highly efficient and better in performance.

V. CONCLUSION

In this paper, single and four channel direct and coherent optical OFDM has been studied and analyzed. It has been found that the single channel systems have a higher Q-factor and a lower value of BER when compared to 4-channel systems. Therefore as the number of channel increases Q-factor decreases and BER increases. When comparing direct and coherent detection systems, the latter one has a better performance. The performance can further be improved by using an equalizer before the receiver section. Also 16-QAM or higher bit rates may be used as transmission length increases to improve the signal quality.

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