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Simulation and Performance Evaluation of OTDM in Optical Communication System

Mary Magleena Bruno
P G Scholar, Optoelectronics and Communication Systems,
Dept. of ECE
T K M Institute of Technology
Kollam, India

Sujith Kumar V
Assistant Professor
Dept. of ECE
T K M Institute of Technology
Kollam, India

***Abstract*— There is always a need for speed and highly efficient networks which can exploit the existing fiber optic links. For this fiber optic communication technology has been massively developed along with the development of new capacity enhancing components. From time to time several promising solutions have been devised such as signal multiplexing in wavelength, polarization, frequency, code and time. Amongst many of these multiplexing methods Time Division Multiplexing has enormous transmission capability. It can be realized in two ways; one is by Electrical Time Division Multiplexing and other is by employing TDM into optical domain, Optical Time Division Multiplexing. OTDM is a very powerful optical multiplexing technique that delivers very high capacity of data over an optical fiber. The basic principle of this technology is to multiplex a number of low bit rate optical channels in time domain. In this project an optical time division multiplexing link is simulated, along with an OTDM link using MZI switching. In order to determine the maximum transmission performance the link has been designed at different data rates of 20 Gbps, 30 Gbps, 40 Gbps, using different fiber standards such as ITU G.653, ITU G.655, and different modulation formats. The Bit Error Rate for different lengths, modulation formats and fiber standards have been obtained and the performance has been analysed for the OTDM links with and without MZI switching. The effect of power on BER has also been analysed. An OTDM Passive Optical Network has also been analysed using different data rates, different number of users, direct and external modulation. The simulation is done using Optsim software.**

***Keywords* — Mach-Zehnder Interferometer (MZI); Time Division Multiplexing (TDM); Optical Time Division Multiplexing (OTDM) ; Electrical Time Division Multiplexing (ETDM);* Passive Optical Network (*PON*).**

I. INTRODUCTION

Fiber optic communication technology has been massively developed over the past era in a series of generation along with development of new capacity enhancing components. So as to emulate this there is always a need for speed and highly efficient networks which can exploit the existing fiber optic links. The increasing request for broad-band communication services demands telecommunication networks offering line capacities highly exceeding those of the existing facilities. Although, the commercially available electronic components are limited to about 10 Gbps data rate, still there is possibility to enhance the system data rate by deploying various multiplexing techniques. From time to time several promising solutions have been devised such as signal multiplexing in wavelength, polarization, frequency, code and time. Data transport in optical networks can be done mainly in two ways: wavelength division multiplexing and time division multiplexing.

Wavelength-division multiplexing (WDM) is one such promising technique that can be used to exploit the huge available bandwidth of the optical fiber. In WDM, the optical transmission spectrum is divided into a number of non overlapping wavelength bands, with each wavelength supporting a single communication channel operating at peak electronic speed. Thus, by allowing multiple WDM channels to coexist on a single fiber, the huge bandwidth can be tapped. Besides the higher capacity, WDM has also some other advantages. One advantage is the easy upgradability. By employing multiple wavelengths within the passband in the optical fiber, it is possible to reuse the same optical fiber cable without changing the in-line equipment. The potential lower cost is also another advantage. The use of wavelengths for add drop multiplexing and routing in networks is also an attractive feature in WDM. Inspite of the above mentioned advantages,
it has some disadvantages also. One such disadvantage is the appearance of fiber nonlinearities. Normally, each channel requires about 1 mW, and with the use of multiple channels, several miliwatts are injected into the fiber. Such high powers lead to the appearance of different nonlinear effects in the Scattering (SRS), Stimulated Brillouin Scattering (SBS), FourWave Mixing (FWM), and the Cross Phase Modulation (XPM). These nonlinear effects lead to the degradation of system performance.

Time Division Multiplexing (TDM) is a multiplexing technique being used traditionally. In TDM, the shared channel is divided among its user by means of time slot. Each user can transmit data within the provided time slot only. Digital signals are divided into frames, equivalent to time slots i.e. frame of an optimal size can be transmitted in a given time slot. However, TDM has a few drawbacks. One of the biggest is that the existing electronic technology allows multiplexing only up to about 10 Gbps. Thus, an alternative optical multiplexing technique such as Optical Time Division Multiplexing (OTDM), that avoids the 10 Gbps electronic bottleneck is used. OTDM is very strong contender for the next generation communication systems and networks. OTDM technique plays a significant part in all optical signal processing and passive optical networks. OTDM is employed for upgrading the bit rate at a single channel and hence it creates ultrafast signals with low speed optical sources.

II. Optical Communication Systems

The most elementary type of communication system consists mainly of three components, the transmitter, the receiver and the channel. The channel in a system can be wire, coaxial cable, air, or an optical fiber. When the telephone was invented in 1876 there was a complete revolution in the world of communications and for many years metallic cables consisting of twisted wire pairs were the media of choice. However, metallic cables had limitations and with the demand for telephone services increasing it was necessary to find an alternative medium for telephony to cope with the high demand. Eventually, the first commercial deployments of practical fiber systems were developed in 1977-78. The process of communicating using fiber-optics involves the following basic steps: Creating the optical signal involving the use of a transmitter, relaying the signal along the fiber, ensuring that the signal does not become too distorted or weak, receiving the optical signal, and converting it into an electrical signal.

A. Optical Networks

An optical network is a system that connects computers (or other devices which can produce or store data in electronic form) using optical fibers. To enable data communication, an optical system also consist of other optical devices to generate optical (electrical) signals from electrical (optical, respectively) data, to restore optical signals after transmission through fibers, and to direct optical signals through the network. Basically, optical networks are those networks in which the principal physical layer technology for transport is optical fiber. The optical networks can be opaque or all-optical, and can be single-wavelength or based on Dense Wavelength Division Multiplexing (DWDM). Optical fiber networks are used due to their possibly unlimited capabilities, as given below:

- large bandwidth (over 50 Tbps),
- little signal attenuation (as low as 0.2 dB/km), and hence offers transmission over long distances without requiring any repeaters,
- immunity to electromagnetic interference, high signal security and hence difficult to eavesdrop because of no electromagnetic radiation,
- no crosstalk and interferences between fibers in the same cable,
- low signal distortion, hence appropriate for transmitting digital information,
- need low power,
- low material usage, small space requirement, light weight, cost-effective, nonflammable
- high electrical resistance, hence harmless to use near high-voltage equipment or between different earth potential areas.

B. Multiplexing

Multiplexing is widely used in many telecommunications applications, including telephony, Internet communications, digital broadcasting and wireless telephony. Multiplexing basically involves taking multiple signals and combining them into one signal for transmission over a single medium, such as a telephone line. The input signals can be either analog or digital. The purpose of multiplexing is to enable signals to be transmitted more efficiently over a given communication channel, thereby decreasing transmission costs. Multiplexing is the process of combining multiple signals (analog or digital), commonly from slow devices, onto one very fast communication link. This sharing is achieved by a Multiplexer (MUX) and a Demultiplexer (DEMUX) which performs the multiplexing and demultiplexing function respectively. Multiplexing is done by combining a number of input lines to generate one output line i.e.(many to one).

This means that MUX has several inputs and one output. Whereas, DEMUX at the other separating the signal into several sub channels. Therefore, DEMUX has one input and several outputs. The aim of multiplexing is to share an expensive resource. The multiplexed signal is transmitted over a communication channel, which may be a physical transmission medium (e.g. a cable). Multiplexing divides the capacity of the high-level communication channel into several low-level logical channels, one for each message signal or data stream to be transferred. A reverse process, known as demultiplexing, can extract the original channels on the receiver side.

Multiplexing has opened the doors to many applications. This is important especially in the field of communication. In communication, the use of fiber optic cables allows for long distance communication at high bandwidths. It also allows operators to expand their capacity as well as set aside backup bandwidth at the same time. There are three major categories of multiplexing techniques which are Frequency-Division Multiplexing (FDM), Wavelength-Division Multiplexing (WDM) and Time-Division Multiplexing (TDM). The first two techniques are designed for analog signals and the third one is for digital signals. TDM can be realized in two ways, one is by electrical multiplexing i.e. Elecrical Time Division Multiplexing (ETDM) and other is by employing TDM in optical domain i.e. Optical Time Division Mltiplexing (OTDM).

III. Optical Time-Division Multiplexing

Optical Time Division Multiplexing (OTDM) is a scalable and powerful technique for investigating high-speed data transmission systems, associated signal processing and monitoring techniques at serial data rates far away from the bandwidth limitation of electronics. As compared to the Wavelength Division Multiplexing (WDM), only single wavelength (color) of light is used. An OTDM system includes a multiplexer at the transmission side and a demultiplexer at the receiving side. The multiplexer (MUX) brings together the bit stream with higher bit-rate from the base band streams, whereas the demultiplexer (DEMUX) rebuilds bit streams at the basic lower bit rate by bit separation in the multiplexed stream.

A. Principle of OTDM

The basic principle of time-division multiplexing and demultiplexing involves allocation of a series of time slots to all the baseband data streams on the multiplexed channel, this is shown in Figure 1. With the ever-increasing demand for higher speeds and larger capacity brought about by rapid data growth on the Internet, interest in optical time division multiplexing has been growing rapidly in recent years. OTDM also has the ability to overcome the electronic bottleneck offered by todays electronic components. In contrast to WDM, where multiplexing occurs in the frequency domain, OTDM transmits multiple data channels in the form of ultra-short duration optical pulses which are interleaved into a single high-speed data stream by accurate control of their relative delay in the time domain. At the receiving end, an optical gate is used to extract one base rate tributary from the aggregate data stream for subsequent processing. Although such systems can potentially operate at speed much higher (>100Gb/s) than that limited by electronic components, several technologies are required to realize high-speed OTDM systems.

These include high repetition rate ultra-short pulse sources, high speed demultiplexing and clock recovery. Some of these technologies are still at the research stage. OTDM is an effective way to increase the transmission capacity of a fibre system. Compared to conventional WDM transmission systems, it may offer several advantages.

- In terms of transmission performance, since only one wavelength is used in a pure OTDM system, the gain tilt problem and dispersion tilt problem associated with wide-band WDM transmission can be eliminated. Also, the major limiting nonlinear effects for WDM systems, such as Four Wave Mixing (FWM) and Stimulated Raman Scattering (SRS) can be avoided.
- OTDM is not incompatible with WDM. For point-to-point applications, OTDM can be used to increase the data rate of WDM channels to reduce the overall complexity of the system. This is also a potential approach for enhancing the spectral efficiency for WDM system.
- By manipulating data in the electrical domain, a carefully organized OTDM transmission system may provide a truly high-speed low-latency data link with maximum parallelism. This may have important applications in both the distributed computing industry and scientific data acquisition.

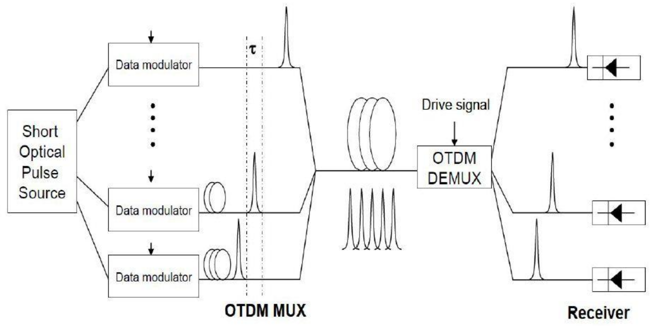

Figure 1: Principle of OTDM

IV. System Design

The simulation layout for the analysis of an OTDM link is shown in Figure 2. It mainly consists of four parts , the transmitter, control signal, Symmetrical Mach-Zehnder interferometer (SMZ) and receiver. Transmitter consists of PRBS generator, mode locked laser, electrical generator, time shifting blocks, optical multiplexer and an optical normalizer. Multiple channels from the laser are modulated with PRBS patterns and hence generate multiple output patterns, with every one dissimilar from the other one and at the same bit rate. It is designed for ten channels operating on the same wavelength 1550 nm and with dissimilar pseudo random bit sequence (PRBS) modulated with NRZ and RZ modulation. After the modulation process, every channel is delayed. Data and control signals are multiplexed and delayed signals co-propagate and time delay between two control pulses is equal to the switching window duration.

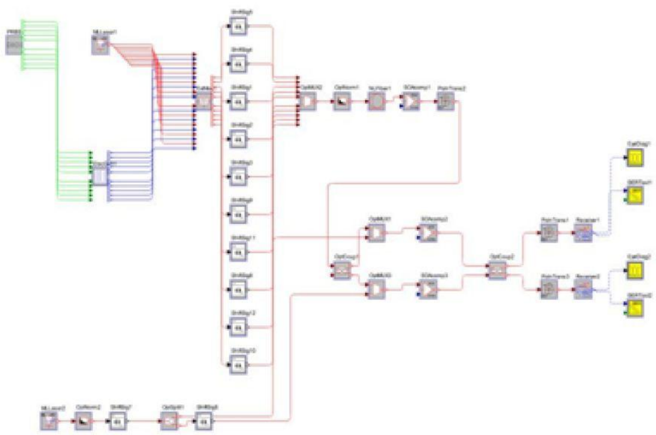

Figure 2: Simulation layout of an OTDM link

The demultiplexer used is a Mach Zehnder Interferometer switch having two arms. The working of MZI is shown in Figure 3. Each arm has optical couplers and semiconductor optical amplifiers. The outputs are switched using optical control pulses generated with suitable delays so that the desired channel is selected. Further channel and control power levels are fixed by the Optical normalizer and polarizer selects the signal with matching polarization. A polarization or wavelength filter is used at the output to reject the control signal and to pass the data signals.

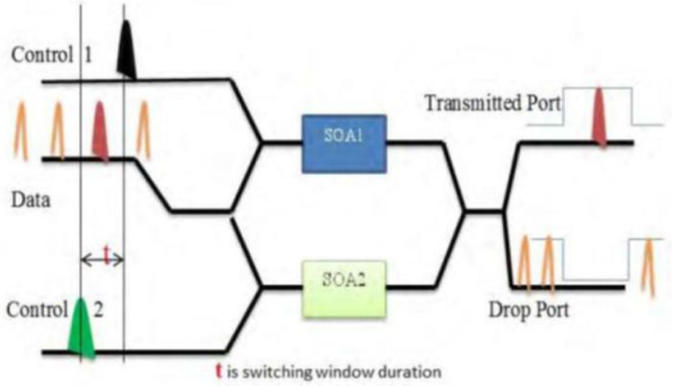

Figure 3: Working of Mach-Zehnder Interferometer

V. RESULTS AND DISCUSSION

The transmission performance and the effect of power on BER has been analysed for the link. Visual analysers such as Eye Diagram Analyser and certain parameters such as Bit Error Rate is used for the evaluation.

A. BER Analysis of OTDM Link

For the analysis of an OTDM link, different data rates of 20 Gbps, 30 Gbps, 40 Gbps, different fiber standards such as ITU G.653 and ITU G.655 and different modulation formats such as Non Return to Zero and Return to Zero are used. The Bit Error Rate obtained while using the different parameters are analysed to determine the transmission performance of the OTDM link.

TABLE I. BER RANGE AT 20 GBPS DATA RATE

Fiber Standard	BER Range	
	NRZ	***RZ***
ITU G.655	2.27e-260 to 9.66e-259	1.3e-262 to 8.66e-259
ITU G.653	5.59e-260 to 2.37e-258	2.37e-262 to 1.24e-258

TABLE II. BER RANGE AT 30 GBPS DATA RATE

Fiber Standard	BER Range	
	NRZ	***RZ***
ITU G.655	12.84e-138 to 4.23e-116	2e-138 to 2.47e-116
ITU G.653	2.27e-136 to 6.24e-116	2.44e-136 to 3.14e-116

TABLE III. BER RANGE AT 40 GBPS DATA RATE

Fiber Standard	BER Range	
	NRZ	***RZ***
ITU G.655	1.69e-81 to 1.80e-68	1.06e-81 to 1.29e-68
ITU G.653	6.45e-69 to 1.70e-68	5.93e-69 to 1.44e-68

From the above Tables I, II and III it is seen that the BER range is highest while using NRZ modulation format and ITU G.655 fiber standard at 40 Gbps, and that the BER range is lowest while using RZ modulation format and ITU G.653 fiber standard at 20 Gbps. Therefore it is concluded that the transmission performance is maximum i.e the BER is minimum while using MZI swiching in an OTDM link with RZ modulation format and ITU G.653 fiber standard at 20 Gbps.

B. Eye Diagram Analysis of OTDM Link

The eye diagram analysis of an OTDM link using Mach Zehnder Interferometer Switching is done at a distance of 2 Km, using Return to Zero modulation format, and using ITU G.653 fiber standard at different data rates of 20 Gbps, 30 Gbps and 40 Gbps. The eye diagrams obtained for different data rates are shown below:

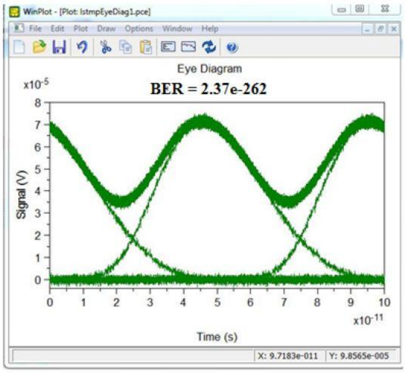

Figure 4: Eye diagram at 20 Gbps

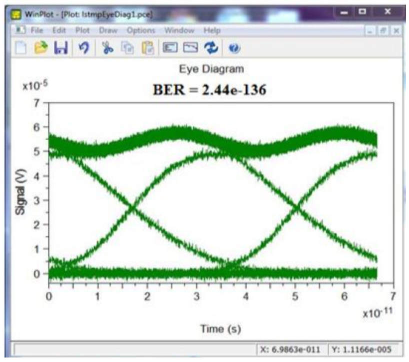

Figure 5: Eye diagram at 30 Gbps

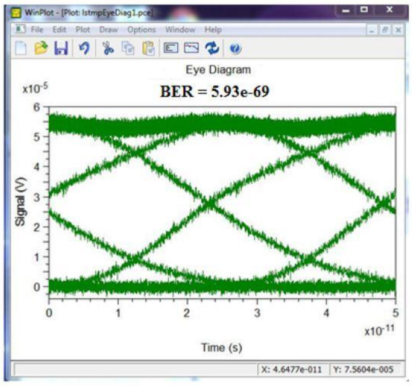

Figure 6: Eye diagram at 40 Gbps

Figure 4, 5 and 6 shows the eye diagrams obtained at different data rates of 20 Gbps, 30 Gbps and 40 Gbps respectively. From the above eye diagram analysis of an OTDM Link using MZI Switching at different data rates it is clear that the maximum eye opening i.e maximum transmission performance is obtained while using a data rate of 20Gbps.

C. Graphical Analysis of OTDM Link

For analyzing the effect of power on Bit Error Rate, the power level of the input signal and the power level of the control signal which drives the MZI Switch is varied. The graphs showing BER Vs. input signal power and BER Vs. control signal power is given below.

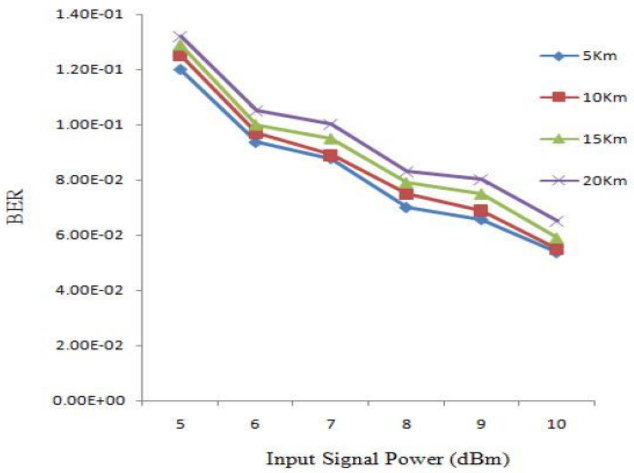

Figure 7: BER Vs. Input Signal Power

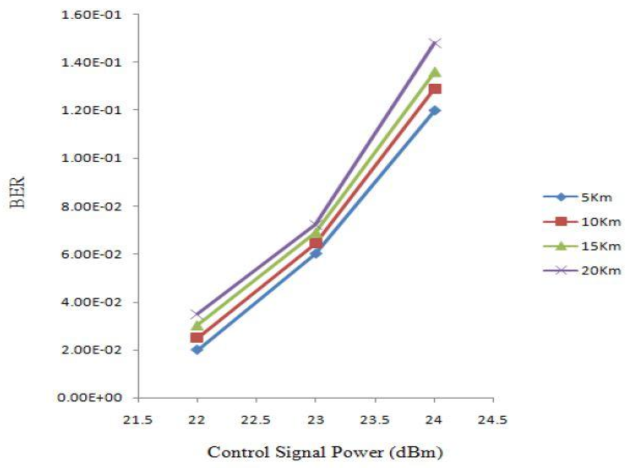

Figure 8: BER Vs. Control Signal Power

The effect of input signal power on BER is shown in Figure 7. From the graph it is seen that as the input signal power increases, the BER decreases. The reason behind this is that the BER is inversely proportional to the optical signal to noise ratio which in turn is directly proportional to the input signal power. Therefore as the input signal power increases, the optical signal to noise ratio also increases thereby decreasing the BER and improving the transmission performance. The effect of control signal power on BER is shown in Figure 8. From the graph it is seen that as the control signal power increases, the BER increases. The control signal is applied to the MZI arms. This control signal changes the refractive index of the semiconductor material, thereby causing a phase shift to the data signal. As the control signal power is increased additional phase shift occurs thereby increasing the BER and reducing the transmission performance.

VI. CONCLUSION

Optical Time Division Multiplexing (OTDM) provides a strategy for increasing the bit rate of digital optical fiber system beyond the bandwidth capabilities of the drive electronics. An OTDM link with MZI switching has been analysed and its transmission performance at different data rates, using different fiber standards and different modulation formats has been determined. The effect of input signal power and control signal power on BER has been analysed. The transmission performance of the OTDM link is found to be best while using 20 Gbps data rate, ITU G.653 fiber standard and RZ modulation format. From the analysis of the OTDM link using MZI switching it has been found that, as the input signal power increases, the BER decreases and as the control signal power increases, the BER decreases.

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