Optical Communication with Time Division Multiplexing (OTDM) and Hybrid WDM/OTDM PON

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Abstract: ***The high speed reliable data transmission is always required in communication. The passive optical network provides very high data rates for long distance. This work provides the performance of a four users Optical Time Division Multiplexing OTDM over different length of single mode fibers (SMF) for different bit rates. The effect of utilizing Erbium Dopped Fiber amplifiers (EDFAs) is investigated for mitigating effect of performance degradations due to attenuation. In order to increase capacity of the system, a hybrid four Wavelength Division Multiplexing WDM and four OTDM system has proposed. Dispersion Compensating Fiber (DCF) is used for reducing the effect of dispersion distortion. Post dispersion compensation is applied to a four users OTDM each with bit rate of 10 and 40 Gbps in terms of data capacity per Optical Network Unit (ONU).A bit rate of 160 Gbps is obtained from the work with a BER of 10-10 over length of 352.89km. The simulation has implemented using optisystem 7 and MATLAB R2011a.***

Keywords: SMF; OTDM; DWDM; PON; DCF; BER; Q-Factor

1. Introduction

A very high speed multi-terabit/s optical core networks require optical technologies capable of managing ultra-high bit rate OTDM/DWDM (optical time division multiplexing/dense wavelength division multiplexing) channels at 160 Gbit/s or higher bit rates. OTDM (Optical Time-Division Multiplexing) is a very powerful optical multiplexing technique that delivers very high capacity of data over optical fiber. The basic principle of this technology is to multiplex a number of low bit rate optical channels in time domain. The key functionalities in ultra-high speed network nodes are all-optical wavelength conversion and demultiplexing of OTDM signals [1]

Advanced optical networking techniques (optical add-drop multiplexing and optical routing) are studied in simulations and their performance evaluated considering 160 Gbit/s OTDM/DWDM channels. Optical time-division-multiplexing (OTDM) is an important technique to overcome the electronic bottleneck and achieve single channel high bit-rate system. The commercially available electronic components are limited to around 10Gb/s data rate. The first 100Gb/s OTDM transmission experiment over a 36-km fiber link was already reported in 1993, OTDM was first demonstrated as early as 1968, primarily as means to increase the capacity of an optical link. OTDM technologies have made a lot of progress toward much higher bit rates and much longer transmission distance. For example, 160Gb/s transmission over a record length of 4320 km and on 2.56Tb/s transmission over 160-km have been reported. Overall, successful demonstration of OTDM up to 400Gb/s has brightened the future of commercial OTDM [2].

This system has the advantage of operating only on a single wavelength. It is possible of running OTDM on a number of existing WDM channels, which improves the overall data capacity. It is purely digital and compliant with the concepts of all-digital network. With rapid advancement in semiconductor technology and integration techniques, it will eventually make possible to manufacture compact, stable and higher performance components for commercial OTDM system.

Hybrid WDM/OTDM networks have been proposed to move data between WDM and OTDM networks, and various subsystems have been demonstrated at 40 Gbit/s including WDM-to-OTDM and OTDM to-WDM translators, OTDM transmitters, and OTDM add–drop multiplexers. OTDM and WDM are considered as the bases of second generation optical networks. OTDM and WDM can be used within the same network. They are complementary technologies in that a single fiber strand can be transmitting a several WDM signals. OTDM multiplexed data can be contained in each single WDM wavelength can contain.

All Optical Network (AON) uses WDM and OTDM together. AON increases the efficiency and throughput while decreases delay and errors. DWDM takes WDM, one of the second generation's optical network technologies, and takes it further. This research work investigates the performance of an OTDM-PON and hybrid OTDM/WDM-PON network during the downstream direction.

2. Optical Time Division Multiplexing OTDM System

In time-division multiplexing and demultiplexing, each of the baseband data streams is given a series of time slots on the multiplexed channel. A multiplexer (MUX) is responsible of assembling the higher bit-rate bit stream from several baseband streams while a demultiplexer (DEMUX) does the opposite job to reconstruct replica of bit streams at the original lower bit rate by separating bits in the OTDM system [3]-[4].

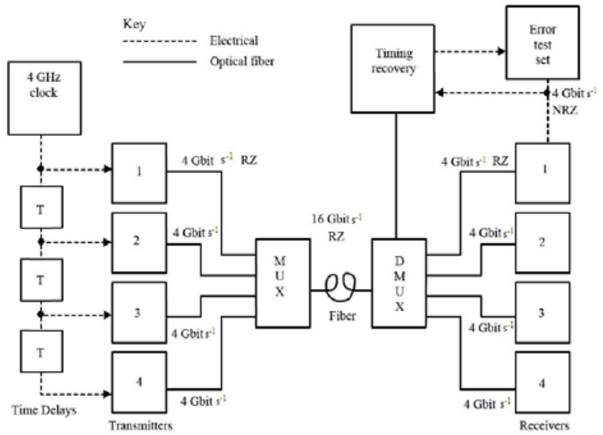

Figure 2: Block Diagram of Multiplexing OTDM (Optical Time Division Multiplexing)

3. Passive Optical Networks (Pon)

During the year 1980's only Passive optical networks (PONs) were developed. Since it is cheap way to implement, PON has received great interest. It is used as a cost effective method for haring fiber infrastructure to business premises, curb, and home etc. The PON architectures use the passive components, which potentially reduces the cost and maintenance since it is point to multi point transport network. PONs uses optoelectronics so they characterized to have low power consumption, except laser amplifiers and photo receivers. Gigabit PON GPON has found to improve bandwidth factor by four through maintenance and security issues. There are several architectures of PON using different modulation schemes like TDM, WDM and hybrid using both TDM/WDM. The TDM PON is a point to multipoint architecture. The packets were broadcasted by the Optical Line Terminal OLT in the downstream direction.

It is passed through a 1: N optical splitter and it is extracted by the designated Optical Network Unit (ONU).The data is sent in the form of packets and each user transmits after a definite time delay. The same time delay is utilized at the destination ONU to distinguish the packets meant for it. The WDM PONs has been widely researched as a potential technology. This PON uses multiple wavelengths in a single fiber to multiply the capacity without increasing the data rate. But a single wavelength is assigned for TDM PON. A TDM PON provides moderate bandwidth but more channels. The PON architecture consist of a single mode fiber which connects a Central Office CO to the network distribution unit which consist of passive optical splitters or/and Multiplexers and demultiplexer. The Optical Line Terminal OLT housed in the CO contains a set of tenable laser sources or fixed wavelength laser sources used to transmit the downstream traffic to Optical Network Unit (ONU). Each user has been assigned a fixed frequency at which the laser operates. The frequency allotment can be permanent or it can be based on the requirement of bandwidth demanded. The data is then given to a multiplexer which combines all the data together and sends it through the optical fiber of lengths varying from 20km to 100km. The Optical fiber that comes from the central office is connected to a passive WDM demultiplexer. The function of it is to split the light depending on the wavelength and to transmit the same to the corresponding ONU. The ONU is again an optoelectronic component and converts the light signal to electrical signal and the data is retrieved .multiplexed stream.

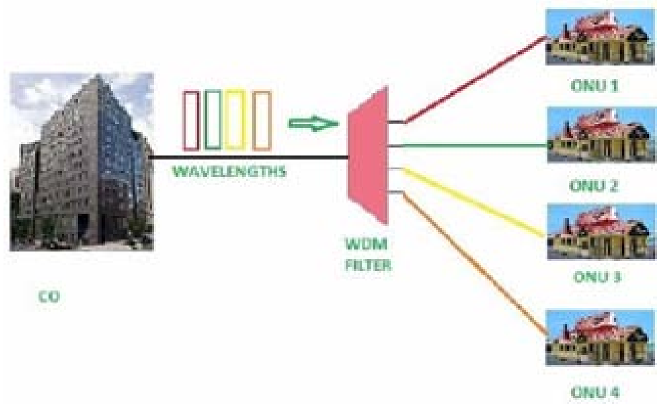

Figure 1: WDM PON MODEL

This technique is applied to optical system to multiplex and demultiplex optical signals as done in electrical systems. In schematic diagram of an *N* channel OTDM transmission system is shown. An optical pulse train from a laser diode is splitted into N paths. In each path, the pulse train is individually modulated by an electrical data signal forming in *N* optical RZ format data channels. Each of branches is delayed by a fraction of the clock period and synchronized to allow passive multiplexing to sum up an individual data stream. Here, the multiplexer is most simply implemented using passive fiber couplers with appropriate optical delays between the channels. To avoid crosstalk between these interleaved channels, the laser source must be able to generate optical pulses of duration $<1/N$ of the clock period. To multiplex an optical signal with period T ps to channel N, the required times delay Δτ for each path is:

$$\Delta = * ( ) = 1, 2 \ldots - 1$$

Where Δτi is the time delay for i[th] path.

For example, for multiplexing the optical pulse train of 10 Gbit/s to 40 Gbit/s, the period T is 25 ps, so the time delay is 3.125 ps, and the difference of the fiber length is 0.2 mm. Goal of OTDM is to increase of the aggregate rate BOTDM = NBch into the Tb/s-range (T~1ps). Where, N is the number of time-channels and Bch is the channel bit rate repetition [5].

4. Wave Length Division Multiplexing (WDM)

Wavelength-division multiplexing (WDM) gives better utilization of the large bandwidth of optical fiber and can increase the capacity of the cable network. Through WDM, signals from two or more line systems are transmitted over the same fiber. The signal from different sources which combined by a multiplexer and fed into an optical fiber, channels combined are separated in the receiver unit by a demultiplexer and detected by photo detector. The WDM devices at the transmitting unit are essentially a power combining referred to as a multiplexer. The device at the receiver unit is called a demultiplexer and should ideally separate out various channels with eligible loss and signal distortion. a large number of channels can be combined and separated with angularly dispersive multiplexing elements.

At the output of the multiplexer, these light rays become co-line and can be easily launched simultaneously into an optical fiber. At the receiver, a WDM works in exactly in the reverse fashion, directing light beams of various wavelengths from a fiber into their respective channels. A block diagram of a WDM system is shown.

The main goal in any communication system is to increase the transmission distance. Loss and dispersion are the main factor that cause signal degradations and affect fiber-optical communication being the high-capacity develops. It is easy to see that the dispersion become the major factor that restricts long distance fiber-optical transfers as the bit rate increases. Several dispersion compensation technologies were proposed. Amongst the various techniques proposed in the literature, the ones that appear to hold immediate promise for dispersion compensation and management could be broadly classified as: dispersion compensating fibers (DCF), chirped fiber Bragg gratings (FBG), and high-order mode (HOM) fiber. Optical amplifiers are used to maintain the correct signal

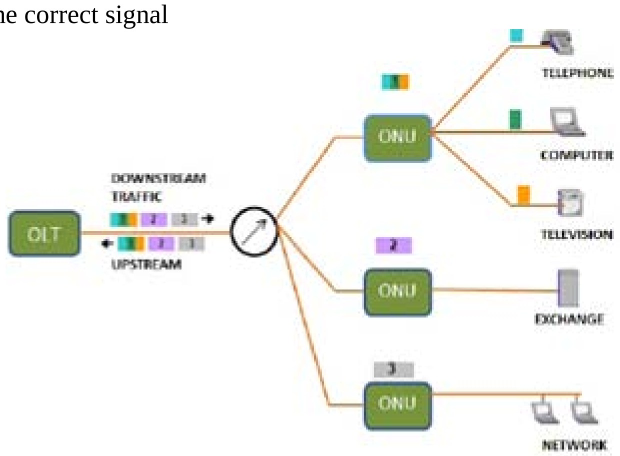

Figure 3: TDM PON MODEL

power to keep sufficient signal to noise ratio for acceptable bit-error rate. In such systems, fiber dispersion can be managed in many ways. One method is to balance the average group velocity dispersion in the whole system such that it is zero referred to dispersion management and another is to use soliton transmission techniques. The third-order dispersion will influence the transmission system seriously as the bit rate of a single exceeds 40 Gbit/s and degrades the system performance. To deal with this problem, one can use DCF to compensate both the second-order dispersion and third order dispersion of the SMF to extend the transmission distance in the system. The condition for a fiber link containing two kinds of fibers of length *L1* and *L2* to form the dispersion management is

$\beta21LSMF + \beta22LDCF = 0$
$\beta31LSMF + \beta32LDCF = 0$

Where $\beta2$ j and $\beta3$ j are second and third-order dispersion parameters for the fiber of length indicated. The third order dispersion $\beta3$ is decided by:
$\beta32 = (\beta22/\beta21)\ \beta31 = -(L_1/L_2)\ \beta31$

The resultant length due to use of DCF will be:
$L = LSMF + LDCF$ [6]-[7].

5. System Simulation and Results

The performance of OTDM system and hybrid OTDM/DWDM system will be evaluated here for different bit rates and lengths of SMF. The proposed 4 users OTDM system is shown in Figure (5). A CW laser diode with a frequency of 193.1 THz is used. The splitter divides the optical power between the four OLTs. Each subsystem included in the OLT consists of a PRBS generator at a specific rate and a RZ Machzehnder modulator. In each branch there is a time delay with time of [(1/bit rate)* i/N)] where i = 0, 1…N-1. So each user is capable of transmitting information at a specific time slot. Then combining the output from each user by the optical power combiner and sent through a single mode fiber SMF. At the end of the SMF of variable length, the multiplexed signal is amplified by an erbium dopped fiber amplifier EDFA. The emerging signal is splitted and distributed among the ONUs at the receiver side and time delay unit is used at each ONU in order to synchronous with that of the OLT. Each user is allowed to access the network at certain time slot with delay time which limits the throughput of each user. Then, the signal is detected and demodulated at each ONU to extract the original information. Table (1) lists the main parameters and settings of proposed OTDM system. Figures (5 and 6) shows the Q factor and BER variations of four users OTDM with length of SMF without any amplification for bit rates of 1, 2.5 and 4 Gbps per user which give total bit rate of 4, 10 and 16 Gbps respectively. Q factor and BER variations of four users OTDM with length of SMF with EDFA amplifier of 20 dB gain and noise figure of 4 for bit rates of 1, 2.5 and 4 Gbps per user which give total bit rate of 4,10 and 16 Gbps respectively. From the results it can be noted that as the bit rate increases the BER reduces for the same length [8]-[9].

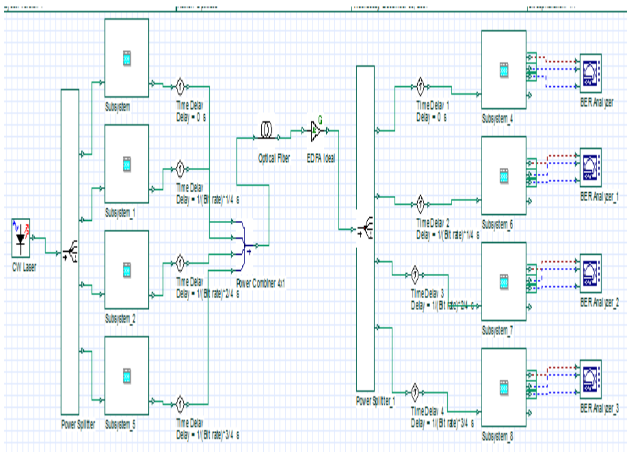

Figure 4: Proposed OTDM For User System

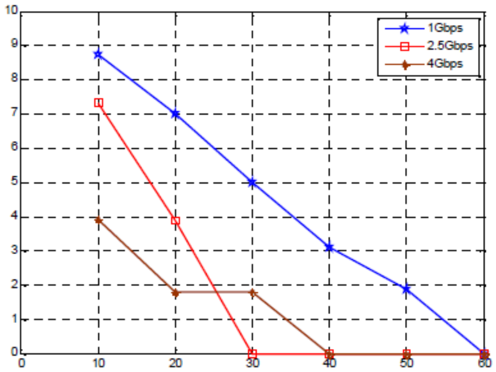

Figure 5: Q-Factor versus distance without optical amplifiers or DCF

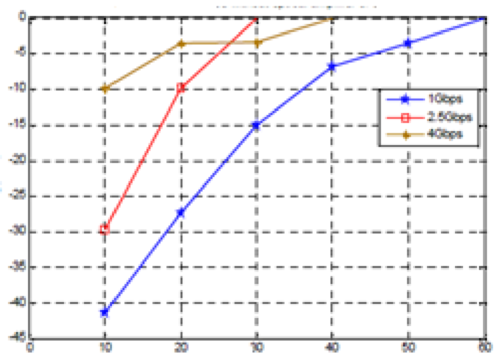

Figure 6: BER versus distance without optical amplifier

The use of EDFAs in the work improves the BER since the received optical power increased. For example, at lengths of 20 km, the BER obtained was 1.16e-18, 5e-5 and 1.3e-11 for bit rates of 1, 2.5 and 4 Gbps respectively. The BER of 10^{-9}as obtained over a length of 125, 80 and 34.45 km for bit rates of 1, 2.5 and 4 Gbps respectively with the use of EDFA of 20 dB gain. Hybrid OTDM/DWDM system is schematic diagram of a Hybrid OTDM/DWDM PON system which is a combination of OTDM and DWDM for increasing the number of users and the rate of transmission of the system.

6. Conclusions

The proposed 160 Gbps OTDM access network has been designed using four users each transmitting at 40 Gbps has been successfully evaluated in this research work. The system operated over a distance of 352.89km with a BER of 10. In OTDM, the performance depends on both bit rate and length of the fiber as the bit rate increased the BER of the system decreased. The use of the EDFAs enhances the system performance and the link length.

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