Design and Performance Analysis of OFDM-Based 40Gbps TWDM-PON System

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Abstract
Recently, a TWDM-PON system has gained significant attention to support high data rate transmission. To overcome the several dispersion effects occurring in optical transmission, OFDM has been introduced to improve the overall performance of the system. In this paper, OFDM-based 40Gbps TWDM-PON system is designed and its various performance parameters like launched spectrum, received spectrum, eye diagram and electrical spectrum etc. are analyzed. BER and Q factor performance of the downstream signals is also evaluated w.r.t. launched power over 500Km SMF.

Keywords
Orthogonal Frequency Division Multiplexing (OFDM), Quadrature Amplitude Modulation (QAM), Single Mode Fibre (SMF), Time-Wavelength Division Multiplexing (TWDM).

I. Introduction

In recent years, various optical access systems have been designed to meet the increasing demand in bandwidth requirements [1]. These requirements could not be met by the conventional Time DivisionMultiplexing (TDM) Passive Optical Network (PON). So, in 2012 the Full Service Access Network (FSAN) group proposed Time and Wavelength Division Multiplexing PON (TWDM-PON) as a solution to the demand of higher data rates and high quality of service [2-4]. The PON evolution has occurred in two stages: The next generation PON1 (NG-PON1) and NG-PON2. The first generation includes the serial 40G TDM-PON and OFDM-PON while the second generation includes TWDM-PON and OFDM-PON [4-5].

TWDM-PON is a multiple wavelength PON system in which each wavelength is shared between multiple Optical Network Units (ONUs) by employing TDM and multiple access mechanisms. It is a very reliable technique as it coexists with Gigabit PON (G-PON) and 10 Gigabit PON (XG-PON) systems. This technique offers a range of bit rates to end users (from 2.5 to 10Gbps), support symmetrical or asymmetrical bandwidth allotment and assign different bandwidth to different wavelengths. Hence, TWDM-PON has been selected as the mainaccess network for NG-PON2. Also, it uses existing ONU with less destruction and capital investment. But it requires tuneable transmitters and tuneable receivers in the ONUs.

The already existing TWDM-PON systems make use of On-Off Keying (OOK) modulation technique [6-8] where it is difficult to upgrade the data rate per wavelength to meet the growing demand in bandwidth requirements. Also, the chromatic dispersion limits the transmission rate and maximum transmission reach. Here, Orthogonal Frequency Division Multiplexing (OFDM) has been introduced to support long reach access. OFDM is a spectrally efficientadvanced modulation format which provides more resistance to frequency selective fading as compared to a single carrier transmission system [9].

In this paper, we have demonstrated a 4-wavelength 40Gbps downstream bitrate by introducing OFDM in TWDM-PON system where the OFDM symbols are continuously broadcasted to all ONUs and each one selects its own wavelength and then selects packet according to the address. ONU contains a combination of PIN diode and an OFDM receiver [10]. By using the four different wavelengths i.e. 1549.5, 1550.5, 1551.5 and 1552.5nm, we could be able to easily transmit our signal over 500 Km SMF distance with less attenuation.

II. System Architecture

Due to the topology of PON, the transmission mode for upstream (i.e. from ONU to Optical Line Terminal (OLT)) and downstream (i.e.from OLT to ONU)are different [2]. For downstream transmission, the OLT broadcasts optical signal to the ONUs in a continuous mode (CM), i.e. the downstream channel always contains the optical data signal. Whereas, in upstream channel, ONUs cannot transmit optical data signal in the same mode. Use of CM for upstream data transmission would result in all the signals transmitted from the ONUs converging (with attenuation) into one fiber by the power coupler, and overlapping. The particular ONU only transmits optical packet when it is allocated a time slot and it needs to transmit [3]. The output spectrum is observed by an optical spectrum analyzer (OSA) having 0.06 nm resolution. Four 10GHz Directly Modulated Lasers (DMLs) employing 4-QAM and OFDM modulation are employed to achieve 4×10 Gbps downstream transmission rate in this experiment [6].

The basic architecture of the OFDM based TWDM-PON system is as shown in Fig. 1.

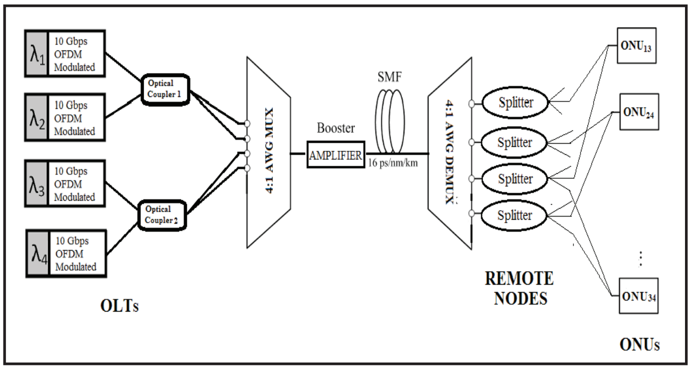

Fig. 1: Architecture of OFDM based TWDM-PON [2]

Four C-Band wavelengths (1530-1565nm) λ_1, λ_2, λ_3 and λ_4 used in the system are OFDM modulated. These OFDM symbols are transmitted in different time slots. The data rate per wavelength can be upgraded to 10 Gbps using OFDM with high order mapping. Two 2×2 Optical Coupler (OC) and a 4×1 Arrayed Waveguide Grating (AWG) are used to connect the four downstream wavelengths for signal traffic and then boosted by the Optical Amplifier (OA). After fiber transmission, the downstream signal is distributed to all ONUsby a 1×4 AWG De-multiplexer and four splitters. The ONUs areequipped with tunable receivers which can be tuned to any of the four downstream wavelengths using tunable filters. Here, the tunable filters are Bessel filters having better gain performance and the centralized frequency can be set according to our requirement.

III. Simulative Analysis

A complete simulation model of the OFDM based TWDM-PON system using OPTSIM (version 5.2) is shown in Fig. 2.

In this measurement, the value of cyclic prefix (CP) is 0.25. The 4-QAM OFDM formats have 8 number of subcarriers, with FFT size of 64.These subcarriers occupy bandwidth from 1.95 MHz to 2.50 GHz. Hence, it can generate 10Gbps data rate for downstream traffic, and the downstreamsignal is received by a 2.5 GHz PIN receiver at each ONU.

Fig. 3 and 4 show the launched spectrum and received spectrum respectively.The figures show thereceiver sensitivities of -11, -18, -25 and -25.5 dBm over 500Km SMF transmission.Here, the power penaltyof almost 20dBm w.r.t. launched power is observed for each wavelength.These spectra showed the transmitted and the received power in dBm at the four wavelengths. Some losses have been occurreddue to long distance coverage and dispersion characteristics of fiber.

The pre-emphasis can arrange the electrical power of each subcarrier toobtain better Signal to Noise Ratio(SNR) withinthe bandwidthunder 500 km SMF. Four wavelengths (1548.5, 1549.5,1550.5 and 1551.5 nm) in theC-band are well separated by 1nm and these downstream signals are produced by temperature controlled lasers.

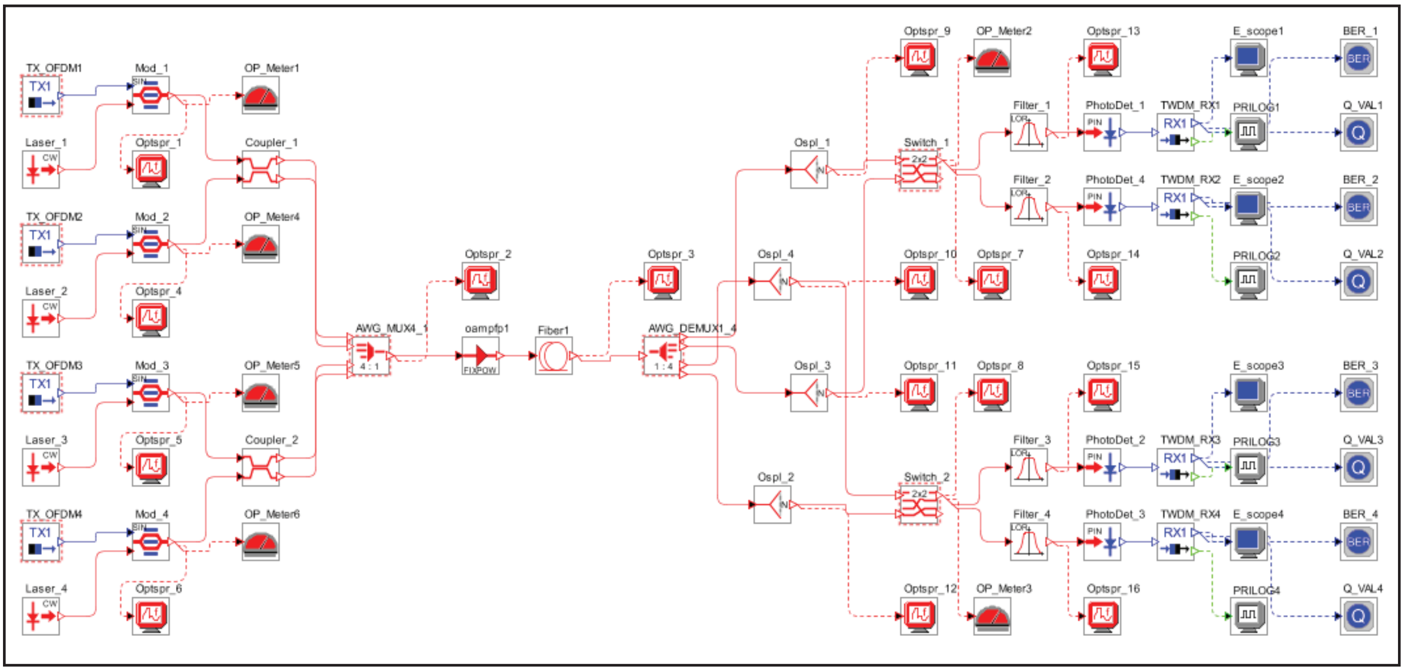

Fig. 2: Simulation Model of OFDM-Based TWDM-PON Architecture

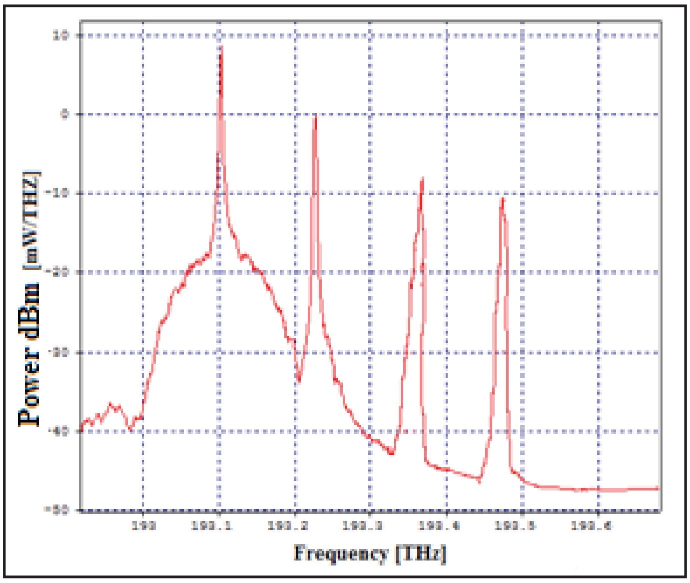

Fig. 3: Launched Spectra for four wavelengths in OFDM-TWDM-PON system.

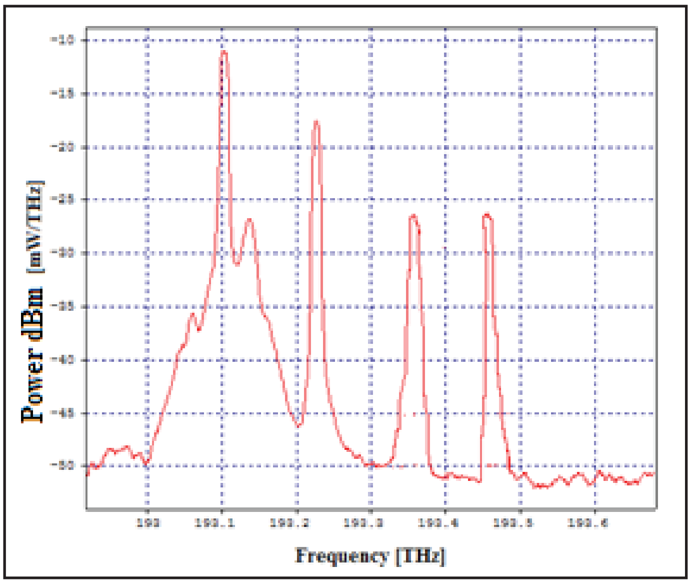

Fig. 4: Received Spectra after 500Km SMF.

Besides, the 1×4 AWG with crosstalk level of −30 dBcan be used and we believe that thecrosstalk from adjacent channel is very small.

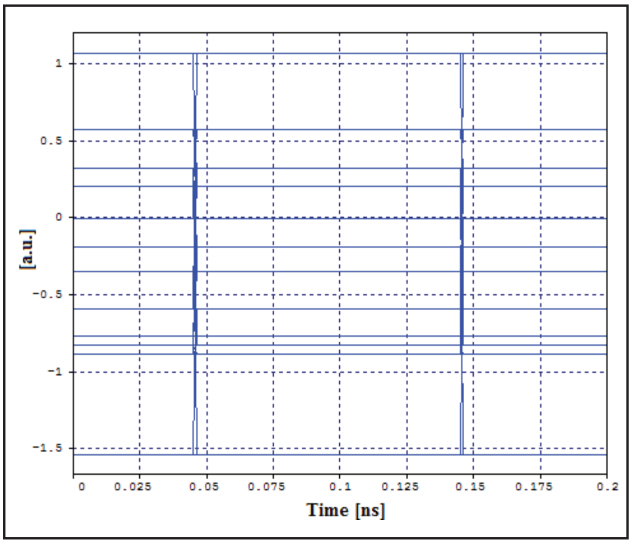

Fig. 5: Eye Diagram.

Fig. 5 shows the Eye Diagram (in Auxiliary Unit [a.u.]) of the first wavelength 1549.5 nm and the respective electrical spectrum is shown in figure 6. In eye diagram,the eye threshold is almost 1V and the value of jitter is 0.0032 ns. In general, this value is completely sufficient because Voice over Internet Protocol (VoIP) required maximum jitter value of 150 ms. The electrical spectrum presentsthe electricalpower in dB for different frequencies when an injection power of -10dBm is launched for the wavelength 1549.5 nm.Figure 7 shows the bit error rate (BER) measurement of four 10 Gbpsdownstream signalsutilizing 4-QAM

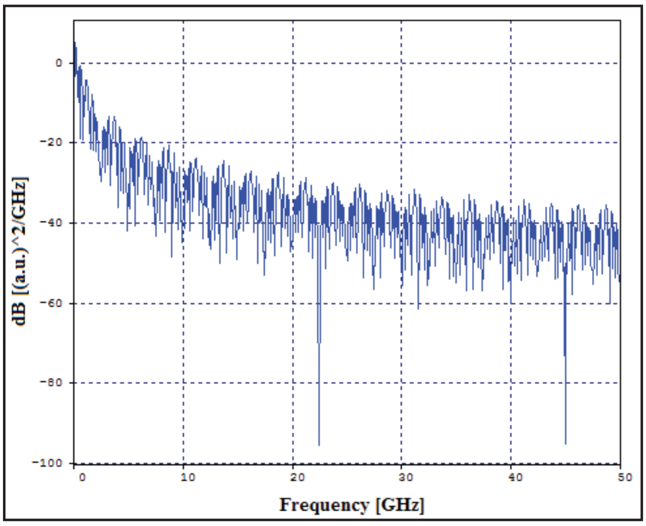

Fig. 6: Electrical Spectrum

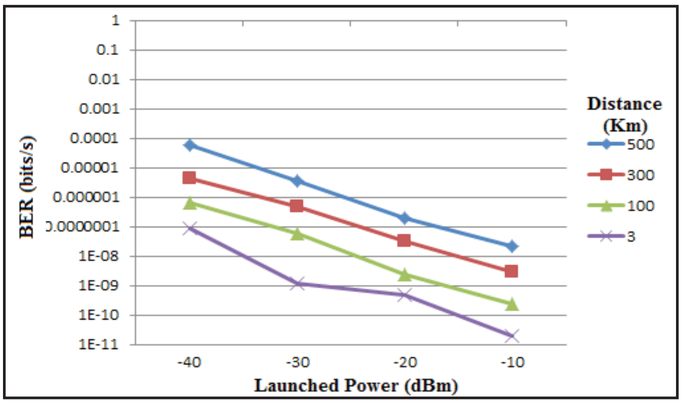

Fig. 7: BER Measurement of the OFDM Based TWDM-PON System

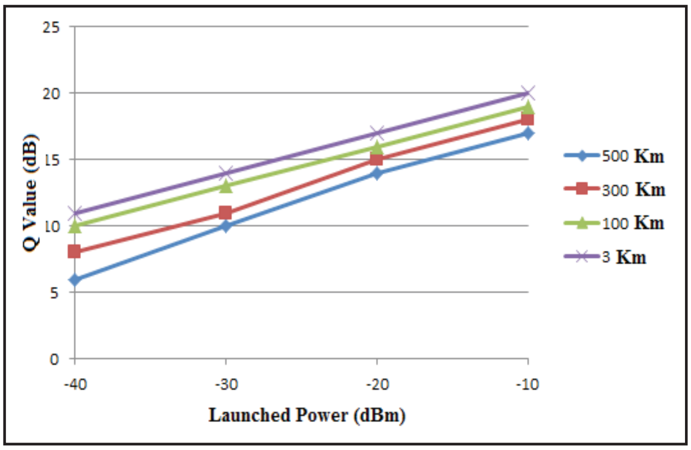

Fig. 8: Q Value Measurement of 10Gbps Downstream Signal

OFDM modulation with pre-emphasis at thevarious SMF transmission distances of 3, 100, 300 and 500Km respectively. As we can observe that with the increase in launched power, BER decreases and we obtained BER of 2.23×E-008 for 500 Km SMF distance with launched power of -10 dBm. Further, figure 8 shows the measurement of Q Value of a single 10Gbps downstream channel for the same set of SMF distances. The minimum value of Q factor for 500 Km is 11 dB and maximum value is 20 dB for the launched power of -40 and -10 dBm respectively, which shows that the system has a good Quality factor even after 500 Km distance.

IV. Conclusion

In this paper, a reliable downstream 40 Gbps OFDM based TWDM-PON access architecture is demonstrated. A fine BER performance and Q Values for the system have been observed after 500Km SMF distance. Here, 4×10Gbps OFDM downstream traffic is achieved by using four 10GHz Directly Modulated Lasers (DMLs) in the Optical Line Terminal(OLT).

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