Design and Performance Analysis of Time and Wavelength Division Multiplexed Passive Optical Network (TWDM-PON)

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Abstract – Recent years, enormous deployment of Passive Optical Network (PON) happened worldwide due to high demand of network operators to serve their customer's requirements. Operators are hoping for an improvement and capability in terms of bandwidths and service support. In addition, they required an enhanced performance of access nodes and supportive equipment connected to their current PON networks. The direction of PON evolution is a main key problem for the telecommunication commerce. In April 2012, The Full Service Access Network (FSAN) announce Time and Wavelength Division Multiplexing (TWDM) became one of superlative resolutions NG-PON2 implementation. Network operators deliberate TWDM-PON to have more advantages than other methods because it is not much of risk and troublemaking and more cheaper system as it reuses current components and technologies. In this project, a design of TWDM that meet the requirement of NG-PON2 constructed on International Telecommunication Union/ Telecommunication Standardization Sector (ITU-T) was proposed. The design achieves the minimum requirements of standard ITU-T G.989 and was simulated using Optisystem Simulation Software. This project implements NG-PON2 systems at 4x10Gbps using four different wavelengths range 1596 – 1603 nm, fiber link of 40 km and varied the value of power optical splitter from 1:2, 1:4, 1:8, 1:16 and 1:32. The results indicate that the suitable number of customers that can be served for this TWDM network is 60 based on simulation result for received power is -27.5 dBm, excess power margin of 12 dB and maximum fiber span of 100 km.

Index Terms—FTTX; FSAN; ITU-T G.989; NG-PON2; PON; TWDM; Optisystem

I) INTRODUCTION

Passive Optical Networks (PON) evolution passed since first ATM/Broadband PON (APON/BPON) [1, 2] to Gigabit-PON (GPON) and Next Generation GPON (XG-PON) with data rates for both Upstream (US) and Downstream (DS) route progressively increasing from 155Mbps to 10Gbps. For current marketing of PON, the main point is to encounter demand by reducing cost and bandwidth per subscriber. Likewise, another revolution of PON have improved from the original requirement split ratio of 1:16 and 1:32 to current split of 1:64 along with maximum 20 km fiber distance [3]. However, due to unceasing demand of high data rates presented by Telecommunication's Service Providers to their subscribers, it is necessarily needed to increase data rates and split ratio. The fundamental of the PON architecture are optical line terminal (OLT), optical distribution network (ODN) and optical network unit (ONU) as in Figure 1. OLT occasionally known as PON head-end and normally located at service provider's site called Central Office (CO). The ONU normally located at the user sites ODN which consist of fiber and passive optical splitters is located in between OLT and ODN.

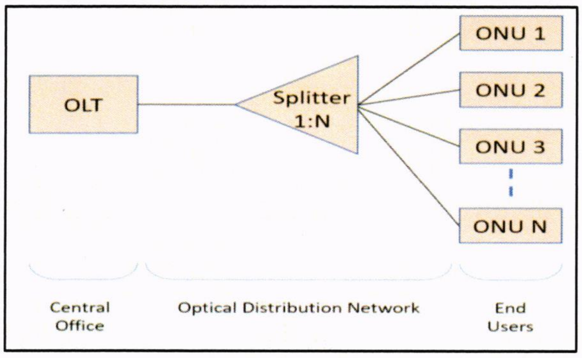

Figure 1: PON architecture and elements

In 2011, consider of above specified requirements from NG-PON, FSAN proposed NG-PON2 as the following evolution which empower a capacity of 10Gbps [4]. Amongst the requirements is higher capability equipped or larger than 40Gbps at 40 km range and split ratio of 1:64 and not more than 1Gbps access rate per customer [4, 5]. NG-PON2 systems necessitate elasticity to balance a compromise in data speed, fiber range, and power splitter ratio for numerous applications. The contestant technology possibility for NG-PON2 included Wavelength Division Multiplexed PON (WDM-PON), Time Division Multiplexed PON (TDM-PON), Time and Wavelength Division Multiplexed PON (TWDM-PON), Code Division Multiplexed PON (CDM-PON) and Orthogonal Frequency Division Multiplexed PON (OFDM-PON). In 2012, FSAN nominated TWDM-PON as NG-PON2 technology due to a consideration of technical and economic parts. TWDM-PON arise as one of the utmost capable PON resolutions to run high capacity of bandwidth for broadband services whereas each wavelength is shared among several ONUs by using TDMA mechanism [6].

TWDM-PON system is designed, implemented and tested against many wavelengths plans. All wavelengths that transmit over the optical fiber link are disseminated using optical splitter to all the subscriber and exit the schedule of the time slots to the MAC layer [9]. In addition, the ONUs should be colorless and tunable by using a RX optical filter altered at a definite wavelength, to transmit data in upstream direction, the tune lasers are implemented [8]. The TWDM-PON network architecture can provision several users on a single wavelength using wavelength elasticity of WDM-PON. It can happen by allowing wavelengths to be dedicated to users or applications. TWDM-PON can used up to eight wavelengths of 10G each to distribute capacity of 80G. Nevertheless, preliminary equipment solutions only use four wavelengths of 10G each to distribute capacity of 40G. Figure 2 illustrates the TWDM-PON architecture which coexistence of GPON and XG-PON1 (TWDM-PON) without necessitating changes to the existing ODN [7].

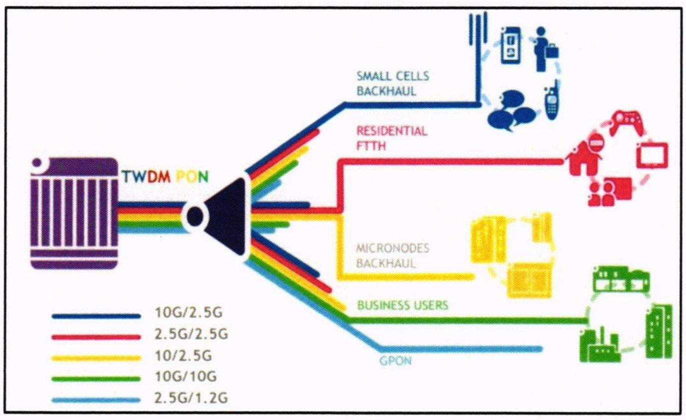

Figure 2: Current TWDM-PON Architecture

In TWDM-PON, the OLT is in a central office (CO) and function to control two-way direction of data transmission and integration through the ODN. An OLT is be able to support up to 20km of transmission distances among the ODN and nowadays should be more with added of Erbium-doped Fiber Amplifier (EDFA). In the downstream path, OLT is operated to collect voice signal, data, and video traffic from a long-haul system and transmit through ODN before distributing to all available ONU. In the upstream direction, ONU will distributes all the data traffic to be transfer back to OLT for allocation [1, 12].

TWDM-PON ONT Transceiver is described as an optical connectivity to the PON on the upstream path and to interface electrical signal to the customer equipment on the downstream side. Naturally, ONT provisions a combination of telecommunication services, as well as several Ethernet rates, telephone connections, ATM interfaces and digital and analog video formats depends on the communication requirements of the customer. To accommodate the desires of various levels of request, multiple of ONT practical plans and frame configurations are presented [1].

In this paper, an optimized TWDM is proposed. The design of an TWDM-PON model is focused on downstream direction only that meet the requirement of NG-PON2 constructed by International Telecommunication Union (ITU-T) as describe in ITU-T G989. The design is employed using multiplexer, demultiplexer and four power splitters. A four wavelength 40 Gbps. TWDM is proposed. Further explanation is as stated in the next section.

II) PRINCIPLE DESIGN

The simulation design consists of four different value of wavelengths for downstream path correspondingly with frequency spacing of 100GHz. It is complied with the recommendation of ITU-T standard for the Physical Layer of NG-PON2 which specifies minimum and maximum channel spacing of 50GHz and 200GHz respectively [16]. The four wavelength values chosen for this project are within the standard range and using frequency spacing of 100GHz. The wavelength plan for the simulation of downstream is shown in Table 1.

Table 1: Wavelength for the simulation of downstream path

Channel	Wavelength (nm)	Frequency Equivalent (THz) (100GHz spacing)
Channel 1	1596.34	187.8 THz
Channel 2	1597.19	187.7 THz
Channel 3	1598.04	187.6 THz
Channel 4	1598.89	187.5 THz

This design is used to determine the performance of 40Gbps TWDM-PON at fixed value 40 km of fiber distance varying the number of optical splitter to investigate their performance and maximum number of customers that can fulfil ITU-T G.989 standard. The design is using four wavelength range of 1596 – 1603 nm in L-band. Optisystem Simulation Software is used to design and simulate the model. It is an authoritative software tools which qualifies for design, testing, and simulate practically all sort of fiber optic link in the transmission layer of optical network. To obtain an ideal system design and simulation, there are several parameters need to be considered. The proposed simulation design of downstream path is shown in Figure 3.

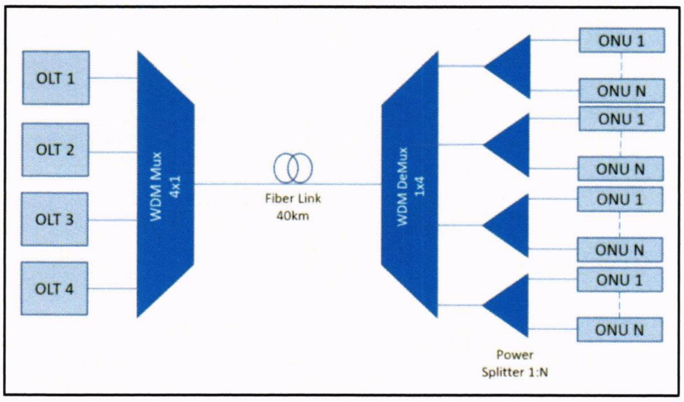

Figure 3: Proposed design of TWDM

The OLT located in the Central Office contains of four subsystems. The Pseudorandom Binary Sequence (PRBS) Generator provides data to be transmitted. It generates binary pulses of 128 bits and the formed data is transit to the laser bias input via non-return-to-zero (NRZ) pulse generator. NRZ pulse generator will generate electrical pulses coded signal that was encoded from PRBS generator using NRZ encoding technique. The continuous wave (CW) laser produces an unremitting laser signal, and its optical output is connected to the optical input of MZ modulator. Each OLT will have four different wavelengths of 1596.34, 1597.19, 1598.04 and 1598.89 nm that will be set at CW laser with the constant power of 10 dBm. The MZ modulator function to differ concentration of light source from CW laser depends on the output of NRZ pulse generator. 30 dB extinction ratio and -1 of k factor has been set to MZ modulator to make it zero chirp. Zero chirp means an ideal intensity modulator. Data stream from PRBS will modulate the optical signal and transmit into an optical fiber link.

The multiplexed signal is carried out to be transmit over an optical fiber with an attenuation of 0.2 dB/km. Then it will be separated using a demultiplexer. Each wavelength will pass through a splitter that will be distributed to each ONU. A multiplexer and demultiplexer are used to reduce power losses due to optical splitter. The signal is applied to an optical splitter of 1:2, 1:4, 1:8, 1:16 and 1:32 with having an attenuation loss of 3, 6, 9, 12 and 15 dB. Then, the signal is distributed to each corresponding ONUs. The wavelength detected by the receiver at each ONU is selected using a tunable filter. Table 2 shows the parameters used for simulation in this design.

Table 2: Simulation Parameters

Component	Parameter	Value
PRBS Generator	Bit Rate	10Gbps
CW Laser	Input Power	10dBm
Pulse Generator	Line Coding	NRZ
MZM External	Extinction Ratio	30 dB
Mux/Demux	Bandwidth Insertion Loss	10Ghz 1 dB
Optical Fiber	Span Loss coefficient	40km 0.2 dB/km
Splitter 1 x N	Attenuation Loss	10 log (1/N) dB
Photodetector	Responsivity Dark Current Sensitivity	1A/W 10Na -28 dBm
Global Parameter	Bit Sequence	128 bits

III) SIMULATION VALIDATION

In evaluating the performance of TWDM-PON model, various parameters are measured such as optical spectrum, number of customer, optimum received power over sensitivity, excess power margin and maximum fiber span. Figure 4 shows the optical spectrum of the downstream signal showing the four wavelengths 1596.34, 1597.19, 1598.04 and 1598.89 nm represented in frequency value as 187.8THz, 187.7THz, 187.6 THz and 187.5THz, respectively. The transmitted power for each OLT is +10 dBm.

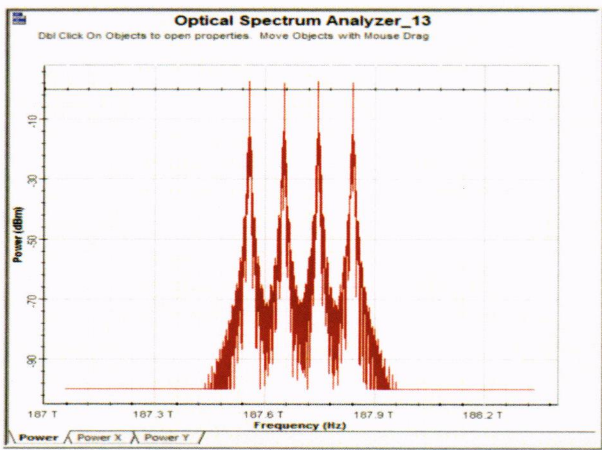

Figure 4: The four wavelengths of the downstream signal

Figure 5 shows the amplitude of received power at ONU using power meter and OSA for the downstream signal at wavelength 1596.34 nm versus number of customer. Received power was observed after the Bessel filter using two devices, optical power meter and Optical Spectrum Analyzer (OSA).

The power decreased when the number of customer increased. This is happened due to high insertion loss of optical splitter resulting from using different number of splitter. The lowest amplitude of -34.6 dBm spotted at 128 customers using power meter and -36.6 dBm using OSA. The highest amplitude detected at 8 customers with the value of -10.1 dBm and -13.4 dBm, respectively. Referring to ITU-T G.989.2 standard for TWDM-PON, the minimum receiver sensitivity is -28 dBm [6]. Using the power meter, based on the receiver sensitivity of -28 dBm, the maximum number of allowed customer with power received of -27.5 dBm stipulated at 60 customers. The result using power meter is chosen for defining 60 customers because in real telecommunication industry, power meter is used to test power result at end to end of fiber route. Meanwhile, OSA is likely used for lab test.

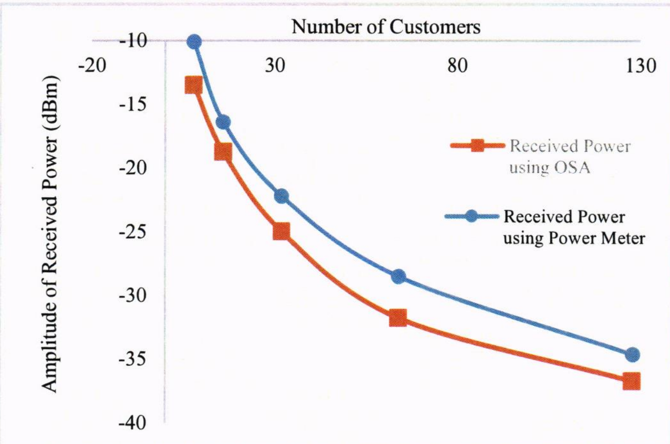

Figure 5: Amplitude of received power at ONU using power meter and OSA for the downstream signal at wavelength 1596.34 nm versus number of customers

Power margin is the difference between power transmit at the beginning of system design with link losses occurred during transmission and minimum achievable optical power required at receiver for a certain level of performance. To ensure the system design in correct operation, link's Power Budget (PB) and Power Margin (PM) need to be calculated. Power Transmit (PT) at OLT is 10 dBm which is the recommended value between range +7 until +11 dBm based on ITU-T G.989.2 at 10Gbps downstream direction. Receiver Sensitivity (PR) is the minimum power level at receiver which can demodulated data and detect the RF signal. In this case, PR of -28 dB is used [6]. Power Budget (PB) is given by:

$$PB\ (dB) = PT\ (dBm) - PR\ (dBm) \quad (1)$$

Therefore, power budget for this project is 38 dB. After calculating a link's power budget, PM is calculated by subtracting PB value with all available link loss (LL) value and Safety Margin. The formula used is

$$PM\ (dB) = PB\ (dB) - LL\ (dB) - \text{Safety Margin}\ (dB) \quad (2)$$

The TWDM-PON design is analyzing for different number of splitters used at wavelength 1596.34 nm. In the loss budget calculation, all active and passive elements of the design should be considered. Fiber loss, connector loss, splice loss, and losses involved with couplers or splitters in the link are categorizes as passive loss. Active components consist of system gain, wavelength, transmitter power, receiver sensitivity, and dynamic range. For link loss value, each component loss is considered. Insertion loss for multiplexer, demultiplexer and fiber is set at 1 dB. Attenuation loss for fiber is 0.2 dB/km, therefore for fiber link length of 40 km, the total attenuation loss is 8 dB. Power splitter is calculated using formula 10 log (1/N) whereas N is the number of splitter. The loss for splitter 1:2, 1:4, 1:8, 1:16 and 1:32 are 3, 6, 9, 12 and 15 dB. Another loss that should take into consideration is connector loss and splice loss at both transmitter and receiver point. Connector and splice loss of 0.02 dB and 0.05 dB is considered. Finally, the typical safety margin ranges of 3 dB is used in this design. The total link loss for splitter 1:2, 1:4, 1:8, 1:16 and 1:32 is 17.14, 20.14, 23.14, 26.14 and 29.14 dB.

By using different value of splitter, the calculated excess power margin for splitter 1:2, 1:4, 1:8, 1:16 and 1:32 is 20.86, 17.86, 14.86, 11.86 and 8.86 dB respectively. As we calculate, by using splitter number up to 32, the excess power margin is above zero. The calculated PM is larger than zero, signifying that the optical fiber link has appropriate power to broadcast and does not surpass the maximum input power at receiver. Figure 6 shows the excess power margin in dB versus no of customers. Refer to the result of excess power margin, the number of customers that can be served are 128 customers. However, considering the factor of minimum received power of -28 dBm, the suitable number of customers that can be served are 60.

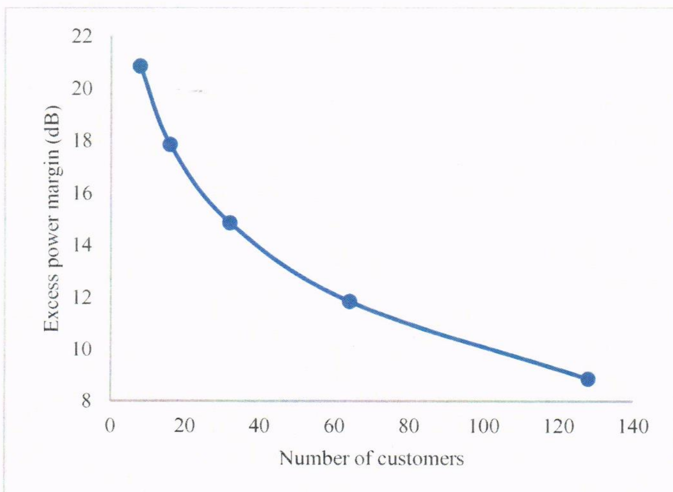

Figure 6: Excess power margin versus no of customers

Maximum fiber span is the maximum distance of fiber cable can convey a signal deprived of using an amplifier otherwise repeater. This fiber span is restricted by the attenuation loss and dispersion of pulse widening of the optical fiber. Optical pulse widening caused by fiber dispersion is the other significant boundary on optical fiber's maximum span distance without using an amplifier. Firstly, the maximum distance of optical link be subject to the superiority of the fiber used as a transmission medium and the insertion losses occurred end to end of the link. The maximum attainable transmission fiber span may depend on various factors such as type of the fiber, electrical data rate, electro-optic modulation format and optical launch power. From the excess power margin calculation, the maximum fiber span for the network can be calculated. Figure 7 displays the maximum fiber span versus number of customers. Fundamentally, the fiber span decrease with the increase number of optical splitter. This is due to high insertion loss occurred. Refer to ITU-T standard, the maximum fiber distance for TWDM is only 40 km, therefore this value can be improved using forward error correction (FEC). This FEC is beneficial for forthcoming employment of extended range of fiber link TWDM-PON. In practice, fiber link distance can be extended by using fiber amplifiers and dispersion compensators. The maximum fiber span that can be achieved for splitter 1:2, 1:4, 1:8, 1:16 and 1:32 is 144.3 km, 129.3, 114.3, 99.3 and 84.3 km. At 60 number of customers, we can reach up to 100 km of fiber span.

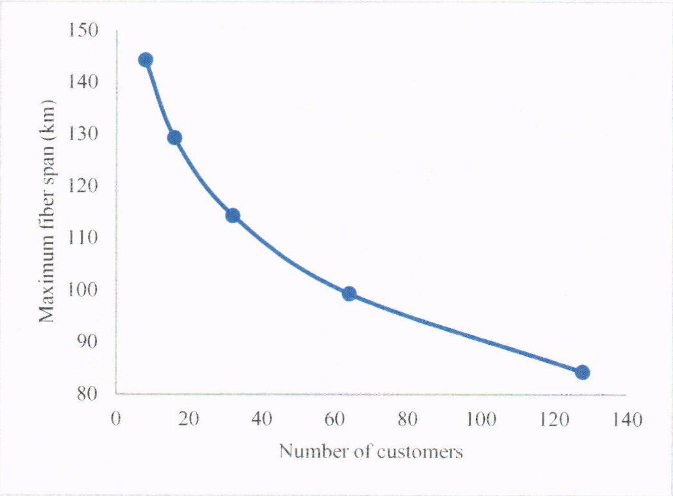

Figure 7: Maximum fiber span versus number of customers

IV) CONCLUSION

These days, the high-speed broadband dissemination and current evolution of the Internet traffic flow between clients have been placing a huge bandwidth demand on the telecommunication network. TWDM-PON empowers the study and technology deployment in PON revolution industry in using four XG-PONs to grasp a cumulative admission rate of 40Gbps. In place of key resolution to NG-PON2 system, TWDM-PON poises the system elevation in telecommunication industry. Intended for network operators, TWDM-PON releases new paths in the direction of increased revenue, profit, cost reducer and lower risk. TWDM-PON developments is helping operators to produce extra profits by combining several services into single fiber. The service providers capital expenditure and operational expenditure cost can be reduced by increased the operative proficiency and if access to viable co-investment possibilities. TWDM will also help operators reserve their current fiber funds. In this project, the basic design of TWDM-PON is simulated for downstream signal and several features were analyzed refer to ITU-T G.989 for NG-PON2 requirements. TWDM-PON system is designed, implemented and tested using Optisystem Simulation Software at 4 different wavelengths of 1596.34, 1597.19, 1598.04 and 1598.89 nm at a distance 40 km. The results of modular design for downstream path were discussed based on optical spectrum, received power, excess power margin and maximum fiber span. In conclusion, the suitable number of customers that can be served for this TWDM network is 60 based on simulation result for both amplitude received power and excess power margin. For 60 customers, we got the value of amplitude received power -27.5 dBm, excess power margin 12 dB and maximum fiber span of 100km. These results have a wide range of advantages that make it as the best resolutions meant for following generation of optical access networks. TWDM-PON, uniting the TDM-PON and WDM-PON advantages, derives into being the far-most advanced Passive Optical Network technology. TWDM-PON will plays a main key role in the optical communication networks in these few years as they able to provide higher bandwidth, higher data rates in downstream and upstream and competitive cost.

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