All Optical Packet Routing using SOA and AWG to Support Multi Rate 2.5 Gbps and 10 Gbps in TWDM PON System

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Abstract: A new architecture of time and wavelength division multiplexed (TWDM) passive optical network (PON) systems using all optical packet routing (AOPR) is proposed in this paper. This architecture is designed using cross-gain modulation (XGM) to support wavelength conversion using an integrated semiconductor optical amplifier (SOA) and array waveguide grating (AWG) component in an OLT system as a part of the OLT transmitter module. This study demonstrates that using an existing fixed wavelength of 2.5 Gbps and 10 Gbps OLT transceivers, the system is able to support flexible routing functions between multiple PON port OLTs with multiple PON optical distribution node (ODN) links to maximize the utilization of the GPON and XG-PON OLT cards in the system. This paper concludes with an analysis and discussion based on an experimental laboratory setup to determine the gain saturation effect using low- and high-gain SOA components integrated with an AWG impact the development of integrated AOPR OLT transceiver

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1. Introduction

In optical access networks, there are two common systems: the point-to-point (P2P) system and the point-to-multipoint (P2MP) system. Both of these technologies have their own advantages. Metro Ethernet typically uses P2P fiber connectivity from a central office to the customer's premises. To reduce fiber connectivity in XDSL technology, direct fiber is commonly used to connect DSLAMs located in the central office with remote DSLAMs located close to the customer area network using the concentration switch concept. However, as new technologies use all passive components in the access network, a passive optical network (PON) system is viewed as the most promising technology for deployment in access networks (Kramer & Pesavento, 2002)(Kazovsky et al.,2007).

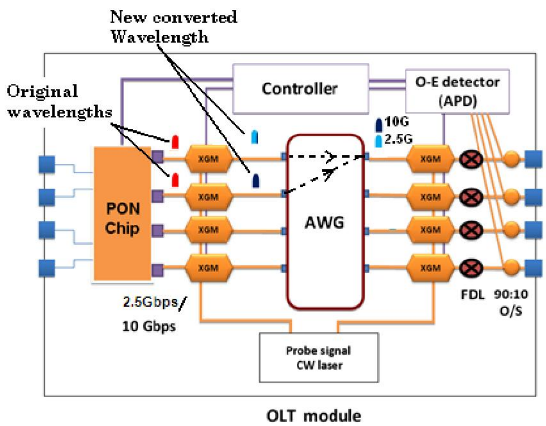
IEEE and ITU-T have proposed a roadmap to define standards for future requirements of supporting more bandwidth while maintaining most of the existing network design to leverage the network infrastructure in which telecommunication service providers have invested. ITU-T, which is under the Full Service Access Network (FSAN) group, defines 2.5GPON [ITU-T G.984] and 10GPON [ITU-T G.987], and IEEE defines GEPON [IEEE P802.3] and 10GEPON [IEEE P802.3av]. According to the standard, objective of 10GEPON is to support P2MP access networks using optical fiber with 10 Gbps downstream and 1 Gbps upstream and split ratios of 1:16 or 1:32 at distances up to 20 km. For XG-PON or 10GPON, FSAN working group under Next-Generation Passive Optical Network (NG-PON)–aims to provide carrier class solutions capable of smooth migration between system generations and the reuse of the "legacy" fiber plant. ITU-T is focused on additional features and tools for extending the capability of XG-PON technology [3]. "NG-PON2″ used as a new term for the extension of NG-PON1. FSAN working group start to analyze and investigate on upcoming technologies with higher bandwidth utilization that are able to solve the issues encountered in the deployment of 1GPON and 10GPON technology.

To accommodate high demands for bandwidth from the access network of the future (Salleh & Manaf, 2012). This paper proposed the new AOPR TWDM PON system architecture. This proposed architecture was designed to increase bandwidth per user using a stacking XG-PON system into multiple existing GPON ports to support multiple PON links. This approach provides fll flexibility for both PON systems to co-exist in a single network and is able to utilize the number of XGPON OLT cards to support high-burst traffic bandwidth demand in the network

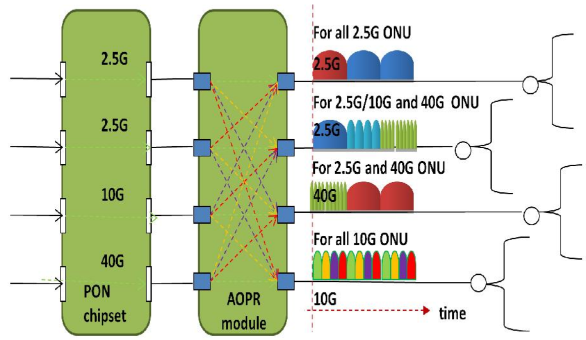
2. WDM PON System Architecture Design

This study proposes a new AOPR TWDM PON system architecture. Figure 1 presents the generic AOPR OLT module in the proposed system architecture. By using the same existing optical distribution node (ODN), each PON link capable to route their packet to any PON destination link. In this proposed design, each PON port could handle up to $N\times64$ customers using a single OLT PON port to broadcast or multicast the signal and $K\times$PON ports into a single PON link to multiplex the multiple wavelength signals for 64 customers. The downstream signal from each PON link transmits a different wavelength in TDM mode. This signal is distributed to 64 customers through a single PON link. In the upstream each ONU support tunable wavelength to direct upstream packet into OLT PON port.

The AOPR OLT module consists of such



address read by the O-E detector, each packet will be directed to each PON port by converting the original 1310 nm wavelength to the new wavelength taken from the OLT wavelength table. According to the time slot given by the OLT, each ONU will receive its packet at a specific time allocation. Based on the ONU ID at each PON link, the OLT will instruct the controller at the XGM module to change the original wavelength to the new wavelength as stated in the OLT learning table. In this design, each PON port can transmit not only to their original PON link but also to any other PON link, thus allowing packets to be transmitted from to any PON port to any PON link in the OLT system. Figure 2 presents the scenario of co-existence of 2.5, 10, and 40 Gbps streams in the same PON system.



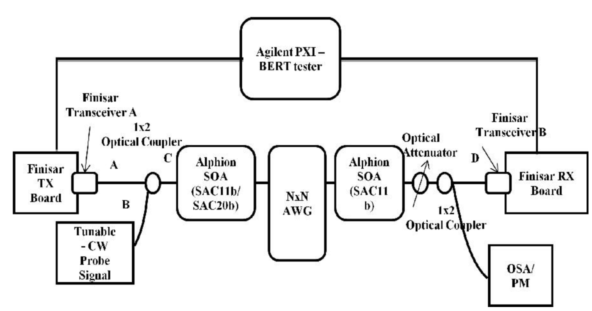


Fig. 3: Experimental setup of the TWDM AOPS PON system configuration

Figure 3 illustrates the experimental setup of XGM modulation to emulate the proposed AOPR TWDM PON system using different types of SOA. The Alphion SAC 11b represents the booster type (low gain), and the Alphion SAC20b represents the inline type of SOA (high gain). Using the Agilent 10G BERT tester, the quality of the signal (e.g., bit error rate (BER) curves) can be determined to correlate with the SOA received input power, SOA output power, and fiber distance, which all affect the system performance. Point A determines the transmit data power; this point represents the data signal from the OLT to the ONU as a downstream signal. Point B is the output probe power, which represents a new wavelength as a new carrier for the downstream signal. Point C represents the total input power to the SOA (Data power + Probe power), and point D represents the signal received power of the ONU receiver. A Finisar transmitter with an output power range of -1 to +3 dBm, extension ratio of 8.2, SMSR of 30 dB, and RIN of -130 dB/Hz was used to emulate the OLT transmitter fixed at 1541.48 nm. For the ONU, the Finisar receiver was used with received sensitivity of -24 dBm at 9.95 Gbps with an optical center wavelength at 100 GHz.

To route the signal from any PON port to any PON link, the 16×16 AWG was used as a passive router with a 100 GHz spacing, an insertion loss average of 5.5 dB, a ripple of 0.5 dB, a PDL of 0.4 dB, a CD of +/-10 ps/nm, and a PDM of 0.5 ps. The CW pump probe signal is used as a seeding source to carry the OLT data onto the new CW wavelength; the signal is transmitted at a different power at the 1545.47 nm wavelength using an Agilent multichannel DFB laser source. In this design, the first SOA (the pre-amp SOA) was designed to support wavelength conversion, and the second SOA (the post-amp SOA) was introduced to increase the power margin between OLT and ONU by placing this module between the AWG and 20 km fiber. Based on the integration of two types of SOAs and AWGs, the study focuses on the effect of XGM to perform as an all-optical packet router module in an OLT system. The primary target for these experiments is to establish a proposed architecture to comply with the ODN loss budget specified in G.9842 and G.987.2 and shown in Table 1.

Table 1. Loss budget defined in G.984.2 and G.987.2

	G-PON			XG-PON			
	B+	C	C+	N1	N2	E1	E2
Max loss (dB)	13	15	17	14	16	18	20
Min loss (dB)	28	30	32	29	31	33	35

4. Results and Discussion

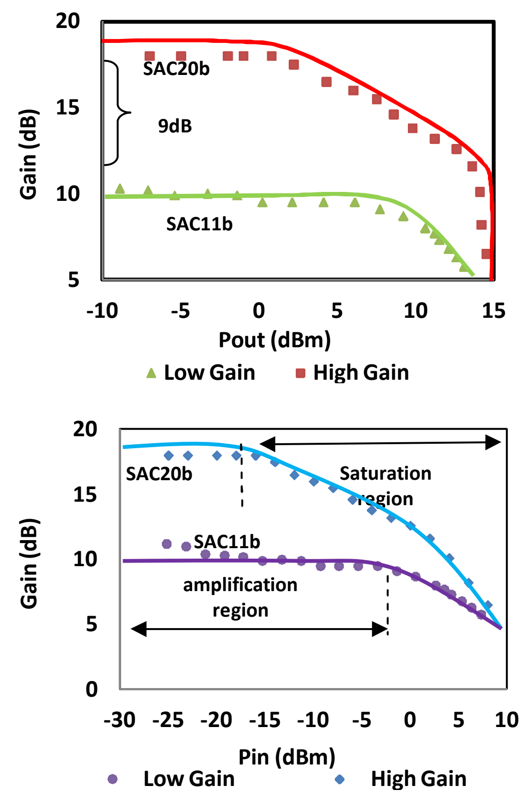


Figure 4: SOA SAC20b and SAC11b gain profiles versus input/output

Figure 4 presents two types of SOA profiles; both figures display gain versus input power for a booster-type and inline-type SOA. The objective of this characterization of the SOA is to compare the SOA gain profile between SAC11b (low-gain SOA) and SAC20b (high-gain SOA). This result is important to demonstrate that the initial study based on these two types of SOA profiles satisfies the expected characteristics and performance of the proposed SOA.

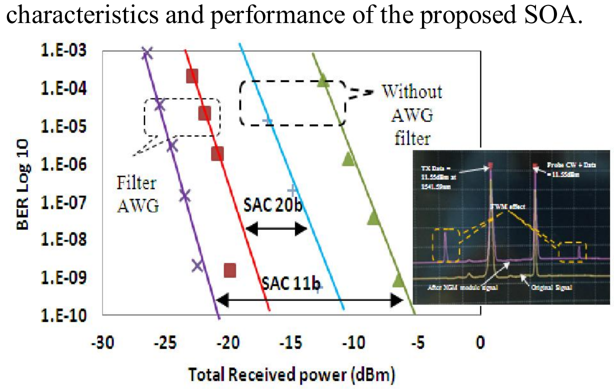


Figure 5: Comparison between the total received power using a booster SOA and an inline SOA before and after AWG filtering at 2.5 Gbps in XGM

Figure 5 compares two SOA gain profiles before and after filtering using an AWG. The graph illustrates that a lower received signal with a low BER can be achieved using SAC20b compared with SAC11b, but after filtering by the AWG, SAC11b provides a better sensitivity power margin compared to SAC20b. This value corresponds to the theory that the receiver is able to receive a low received power with a higher OSNR value using SAC11b. Through this result, we select SAC20b as a post-amp to obtain the low input power to affect the XGM at the saturation region, and we select SAC11b as a post-amp AOPR to exploit the high OSNR output signal toward the ONU receiver.

Figure 6 shows the marginal difference of the total link loss between the systems using SAC11b and SAC20b as the post-AOPR SOA and the integration of both SAC20b and SAC11b as pre- and post-AOPR amplifiers, respectively. This result demonstrates that by implementing a hybrid system with SAC20b and SAC11b as the pre and post amplifiers in the AOPR OLT module, an almost 13 and 5 dB power margin can be obtained, respectively.

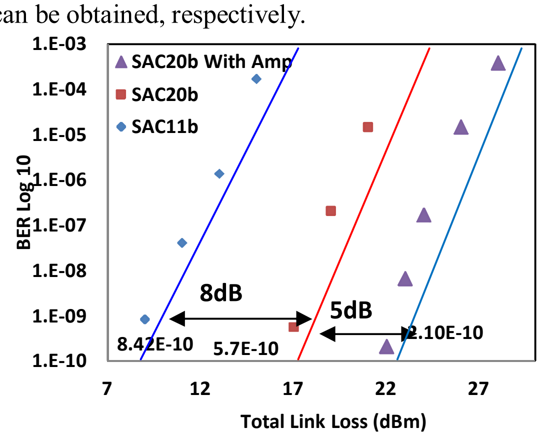


Figure 6: Performance of the system at 2.5 Gbps with and without the post amplifier at the OLT AOPR module

Figure 7 presents the BER result corresponding to the total link loss at 1.25, 2.5, and 10 Gbps. The results demonstrate that the 1.25 and 2.5 Gbps modes have almost the same BER performance, providing the maximum total link loss at a 23 dB loss margin with a BER of 10^{-9}. For 10 Gbps, the BER margin is decreased to 3 dB. Nevertheless, all systems comply to support 20 km with a 1×64 splitting ratio using the FEC or super FEC, as reported in (Davey et al., 2009)(Shea & Mitchell, 2007). To support a higher splitting ratio and comply with all classes of ODN path loss depicted in Table 1, the measurements were performed to find the best correlation power between the downstream signal power driven at 2.5 Gbps with PRBS 2^{31}-1 and the CW pump power at a different transmitted power for both the incoming signals into the first SOA (SAC20b) (with a DC value of 390 mA bias current). In this setup, the post-amp SOA (SAC11b) was set at 60 mA. Using a 10 G BER tester and the OSA, the BERs were measured by varying the optical attenuator to obtain the ONU minimum received sensitivity and the total link loss margin of the proposed system. Using a similar experimental setup and component parameters and characteristics, we extend the study using VPI simulation tools to simulate a 40 Gbps PON toward the proposed system.

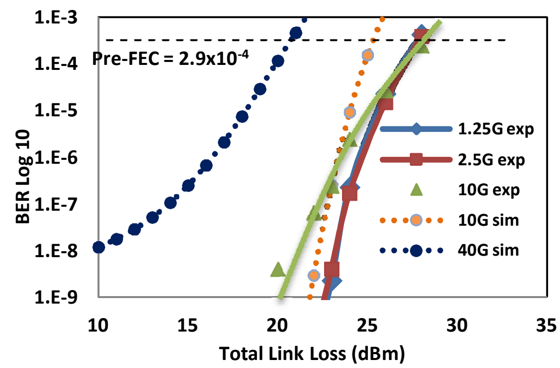


Figure 7: Performance of EPON, GPON, and XGPON in the proposed system

Figures 8 (a), (b), and (c) present the CW pump probe transmit power corresponding to the OLT downstream transmitting at +4, +6, and +8 dBm transmit power, respectively. By varying the CW pump probe transmit power from +7 to -4 dBm, the BER performance of the system compared with the back-to-back BER and total loss margin of the system were observed. Furthermore, the receiver sensitivity of the ONU is better for lower values of the CW transmit power.

However, these results did not correspond to the total loss margin of the system, where the lowest received power did not yield the maximum loss margin. These results are illustrated in Figures 9(a-d). To support a Class A GPON, the OLT transmit power was set to +2 dBm and the CW pump power was set between -2 and 2 dBm; for Class B+, the transmit OLT power was set to +4 dBm with the CW transmit power range between -4 and +3 dBm; for Class C, the transmit OLT power was set to +6 dBm with the CW transmit power between 0 and 5 dBm; for Class C+, the OLT transmit power was set to +8 dBm with the CW transmit power set between +2 and 6 dBm.

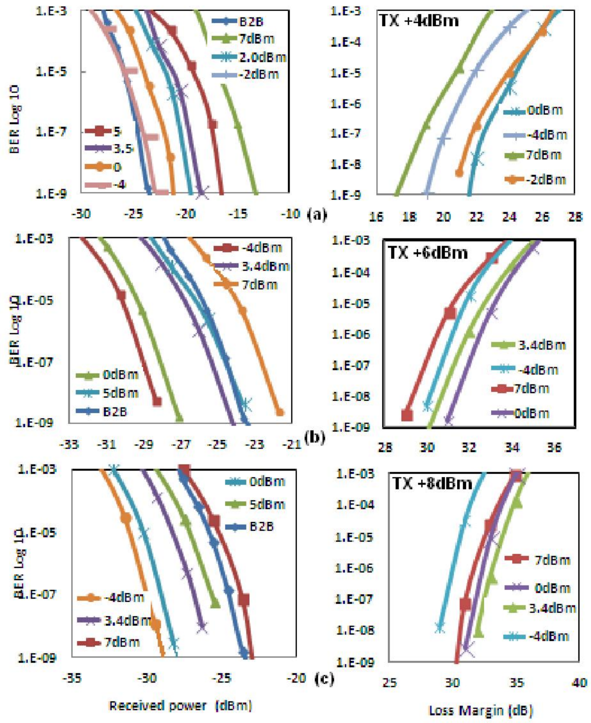


Figure 8: BER line of the 2.5 Gbps OLT downstream transmits a signal using SAC20b with a transmit power of +4, +6, and +8 dBm: (a) ONU average received power and (b) total link loss margin

4. Conclusions

This work presents the study of a new architecture of an AOPR TWDM PON system. The proposed architecture provide more flexibility of data delivery for each PON port to any PON link to support the co-existence of 2.5 Gbps and 10 Gbps and to prepare for an open platform for 40 Gbps and 100 Gbps PONs. Using an experimental setup, this work proposed a high-gain SOA to integrate with the AWG and the post-amp SOA in an AOPR OLT module that presents the best performance to support the proposed system. This work proves the capability of the system to perform wavelength conversion using XGM, and the results demonstrate that the system is capable of supporting the 2.5 Gbps system to achieve a maximum total loss margin of up to 33 dB with a -29 dBm ONU received sensitivity at a BER of 10^{-9}. Using FEC and Super FEC, as proposed by (Davey et al.,2009)(Shea D and Mitchell J., 200&), both 2.5 Gbps and 10 Gbps are expected to comply with all ODN class specifications in G.984.2 (GPON) and G.987.2 (XG-PON). In addition to using a tunable PON transmitter in the OLT system, this AOPR module was able to support multicasting and multiplexing by leveraging the integration of the SOA and AWG using a multiple pump probe signal to support multicasting XGM. This concept and the experimental results will be discussed in future papers.

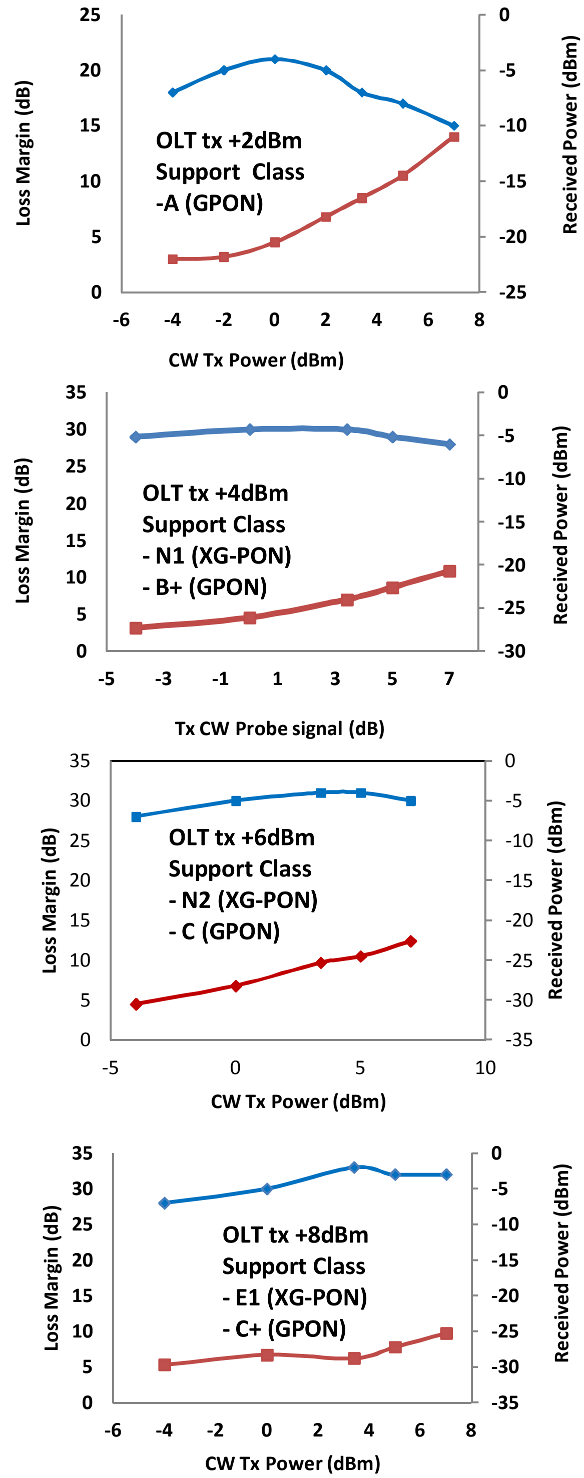


Figure 9: Summary BER10^{-9} line at the 2.5 Gbps OLT downstream transmit signal using the SAC20b transmit power supporting different classes of ODN PON systems

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