Research Article

Wavelength Tuning Free Transceiver Module in OLT Downstream Multicasting $4\lambda \times 10$ Gb/s TWDM-PON System

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We propose a new architecture of dynamic time-wavelength division multiplexing-passive optical network (TWDM-PON) system that employs integrated all-optical packet routing (AOPR) module using $4\lambda \times 10$ Gbps downstream signal to support 20 km fiber transmission. This module has been designed to support high speed L2 aggregation and routing in the physical layer PON system by using multicasting cross-gain modulation (XGM) to route packet from any PON port to multiple PON links. Meanwhile, the fixed wavelength optical line terminal (OLT) transmitter with wavelength tuning free features has been designed to integrate with the semiconductor optical amplifier (SOA) and passive arrayed waveguide grating (AWG). By implementing hybrid multicasting and multiplexing, the system has been able to support a PON system with full flexibility function for managing highly efficient dynamic bandwidth allocation to support the $4\lambda \times 10$ Gb/s TWDM-PON system used to connect 4 different PON links using fixed wavelength OLT transceivers with maximum 38 dB link loss.

1. Introduction

FSAN has selected TWDM PON system as the most suitable technology to be deployed in the NG-PON2 system. This technology combines the benefits of wavelength-division multiplexing-PON (WDM-PON) and time-division multiplexing-PON (TDM-PON) technologies in order to offer high throughput bandwidth allocation and support more users. This is achieved by stacking approach in NG-PON2 where multiple 10 G XG-PONs stacked onto wavelength domain resulting in a more bandwidth system with up to 40 Gb/s downstream and 10 Gb/s upstream [1].

In order to support current legacy PON network, most of the proposed designs deploy broadcast and select (B&S) architecture [2] or dynamic WDM/TDM PON [3] to maintain optical splitter at remote node side to broadcast the signal, while optical network unit (ONU) features must be added with filtered wavelength to select a specific wavelength belonging to them and ONU identification (ID). SUCCESS-dynamic wavelength allocation (DWA) [4] architecture PON, proposed by Stanford University, deploys WDM-PON to

support flexible migration from legacy TDM-PON to WDM by maintaining ODN infrastructure. The NTT ANSL Lab has studied the PON architecture deploying hybrid WDM and TDM PON [5, 6] to allow flexible packet routing to support the incremental demand of bandwidth between each PON link and PON port while maintaining legacy EPON/GPON ODN infrastructure. The same architecture under hybrid WDM/TDM PON has also been studied by Kourtessis et al. [7] to support dynamic multiwavelength, using tunable lasers in both upstream and downstream to allow multi-PON port interacting with multiple PON links. However, in order to achieve flexible packet routing between multiple PON ports and multiple PON links, the proposed system requires high speed tunable transceiver in both OLT and ONU to reduce average packet delay in downstream signal. This function is even more critical in OLT, which requires a very fast wavelength tuning laser [8], thus increasing the time delay (band gap delay plus tuning delay) between downstream packets transmitted between different PON links. Furthermore, the usage of tunable transceiver in the proposed design will lessen the attractiveness of the PON system, which is able

FIGURE 1: The proposed OLT module design with integration of AOPR module.

FIGURE 2: The proposed high speed wavelength Select CW signal as a probe for XGM module.

to broadcast and multicast packet limited to only a single PON link. Instead of using AWG, another paper presented by Fujiwara et al. [9] proposed all broadcasting concepts to replace AWG with optical splitter at the OLT. However, this design needs high power budget to support high loss produced by both $N \times N$ optical splitters located in CO and in remote node (RN). Another issue encountered in this design is that unfiltered amplified spontaneous emission (ASE) generated by SOA, which is used to compensate the loss,

caused the signal-to-noise ratio (SNR) to degrade by the ASE noise [9]. Another approach to support flexible design without using TLS in OLT transmitter module is by using (laser diode) LD array as proposed by [10]; however, this design needs multiple arrays of LD with different wavelengths at each OLT port, and this will increase the number of transmitters in a single OLT port.

In this paper, we propose an AOPR TWDM PON system architecture utilizing a single fixed wavelength transceiver

FIGURE 3: TWDM PON wavelength router architectures using (a) tunable laser source (TLS) OLT module, (b) AOPR WTF OLT module using wavelength selected switch (AOPR-WSS module) using fixed laser source (FLS), and (c) AOPR WTF OLT module broadcasting and multicasting (AOPR-B&M module).

at OLT. The proposed architecture is designed to support flexible packet routing in downstream signal connected to multiple PON links. Wavelength tuning free (WTF) effect was proposed using integrated multicasting XGM with OLT transmitter to eliminate wavelength tuning delay system while maintaining broadcast and multicast functionality to all PON links that are connected to the OLT PON port.

This study proposes a new architecture of all-optical packet routing (AOPR) TWDM-PON system architecture. Figure 1 shows a generic AOPR OLT module used in the proposed system architecture. Under the same existing fiber plant, each PON link can route its packet to any PON destination link. In this design, each PON port could handle up to N (number of PON links) $\times$ 64 customers using a single PON port and K (number of PON ports) $\times$ PON port into a single PON link for 64 customers. The downstream signal from each PON link transmits a different wavelength in TDM mode. It is broadcasted to 64 customers in a single PON link. In the upstream direction, each ONU will transmit

specific wavelength according to the AWG routing path to OLT PON port. This wavelength is predefined by OLT, which will provide additional granting message, for example, wavelength ID to each ONU. This wavelength ID is specified by OLT to all ONU at all PON links to avoid packet collision in upstream data and also to allow flexibility of packet to be transmitted according to any ODN PON link to any OLT PON port at the OLT system.

AOPR OLT module consists of subcomponents such as multiple ports of PON chipset, wavelength converter module based on semiconductor optical amplifier (SOA), multiple-wavelength continuous wave (CW) probe laser, array waveguide grating (AWG), fiber delay line (FDL), optical coupler, and controller. A processor (or controller) controls the multiple PON port chipsets as well as other components in the module.

Figure 2 shows two types of CW pump probe signal on cross-gain modulation (XGM) module with the function to generate wavelength routing, multicasts, and broadcast signal

FIGURE 4: Experimental setup of TWDM AOPS PON system configuration.

FIGURE 5: BER performance of 4 different downstream channels at 10 Gb/s with 4 multicast wavelengths.

from any OLT PON port to any PON link. In this case, SOA is used as a high speed ON/OFF switch. As a result, wavelength tuning can be performed in nanoseconds (ns) duration [11], eventually allowing packet distribution to any AWG port without affecting the system average time delay. Alternatively, similar transmission can also be achieved by ensuring all wavelength CW pump probes in the always ON condition to allow all OLT PON ports to broadcast to all PON links that are connected to the system.

Figure 3 shows a comparison of downstream packet delivery in TWDM-PON wavelength router architecture with the new proposed AOPR TWDM-PON system architecture. Figure 3(a) shows that TLS OLT module is used in OLT system to deliver downstream signal to two different PON links using a single OLT PON port. Using TLS OLT transmitter,

the packet routing from any PON port to any PON link will cause tuning delay time, caused by TLS, to tune the wavelength of the original frequency to another frequency. This design will also cause each packet to only be capable of performing broadcasting or multicasting function only in each individual PON link. Figures 3(b) and 3(c) show that AOPR wavelength tuning free (WTF) OLT module was used to eliminate tuning delay time and at the same time to perform broadcasting or multicasting (B&M) to any PON link in the system using a single OLT PON port.

2. Experimental Setup

Figure 4 illustrates the experimental setup of XGM modulation to emulate the proposed AOPR TWDM-PON system

using different types of SOA. The experiment was measured using optical spectrum analyzer (OSA), optical power meter (PM), and Agilent PXI 10 Gbps bit error rate tester (BERT) with a pseudo-random bit sequence (PRBS) length of $2^{31}-1$. The first type of SOA is Alphion SAC 11b with a peak gain at 13.9 dB, average noise figure at 6.2 dB, and power saturation at +13.3 dBm representing a booster type (low gain). The second type is known as Alphion SAC20b which is specified with a peak gain at 25 dB, average noise figure at 6.9 dB, and power saturation at +13.3 dBm representing the inline type (high gain). A Finisar transmitter with an output power range from -1 to +3 dBm, extinction ratio at 8.2, side mode suppression ratio (SMSR) at 30 dB, and relative intensity noise (RIN) at -130 dB/Hz is used to emulate a fixed wavelength OLT transmitter at 1541.48 nm. A Finisar receiver with a receiver sensitivity of -24 dBm at 9.95 Gb/s is used as an ONU. To route the signal from any PON port to any PON link, the 16×16 AWG with 100 GHz spacing, insertion loss average at 5.5 dB, ripple at 0.5 dB, polarization dependence loss (PDL) at 0.4 dB, chromatic dispersion (CD) at ± 10 ps/nm, and PDM at 0.5 ps is used as a passive router. A CW pump probe signal is used as a seeding source to carry OLT data onto a new CW wavelength. It is transmitted at a different power level with a wavelength of 1545.47 nm using Agilent multichannel DFB laser source. In this design, the first SOA (pre-amp) is designed to support wavelength conversion, and the second SOA (post-amp) is introduced to increase power margin between OLT and ONU by placing it between AWG and 20 km fiber. The integration of the two types of SOA and AWG can be related to the effect of XGM to be used as an all-optical packet router in the OLT system.

3. Result and Discussion

Figure 5 shows the comparison of BER line performance of downstream signal using TLS OLT module, AOPR-WSS module, and AOPR-B&M module as shown in Figure 2. The results show that received signals generated by TLS OLT module have more received sensitivity at -27 dBm compared to AOPR-WSS and AOPR-B&M module at -21 dBm at BER 10^{-9} . The 6 dB power margin difference is caused by ASE noise generated by SOA in AOPR-WSS, and AOPR-B&M OLT module affects the OSNR of the downstream signals. However, the total link loss result shows that the AOPR-WSS module has the best BER performance compared to AOPR-B&M module, whereby each system was able to support 38 dB and 34 dB at BER 10^{-3} link loss margin, respectively, compared to conventional TLS OLT module that is able to support a maximum 24 dB link loss in the same BER 10^{-9} .

Figure 6 shows the BER performance comparison of 4 channels' optical spectrum downstream signal, from channel 1 (1545.32 nm) to channel 4 (1547.71 nm). Each channel demonstrates different BER values as each signal undergoes different PON link via $N \times N$ AWG port. The figure shows that AOPR-WSS module provides better downstream performance for all PON links and this system proves to be able to support up to 38 dB link loss margin at BER 10^{-3} compared to AOPR-B&M module that supports up to

FIGURE 6: BER performance of 10 Gbps downstream AOPR TWDM PON using AOPR-B&M module and AOPR-WSS module in 4 different PON links.

33 to 35 dB link loss margin at BER 10^{-3} . The 2 dB margin difference in AOPR-B&M module is due to the fact that, in AOPR-B&M module, 4 different channels experience a different number of four-wave mixing (FWM) order [12], as compared with AOPR-WSS module that only has 2 input signals to XGM module.

Figure 7 shows optical spectrums of multicasting four downstream channels at BER $10e^{-9}$. Channel 1 begins at the wavelength of 1545.32 nm, channel 2 at 1546.11 nm, channel 3 at 1546.91 nm, and channel 4 at 1547.71 nm, with frequency spacing of 100 GHz between each two channels. Figure 7(a) shows the optical spectrum of all four CW probe channels and OLT transmit signal in comparison with each optical spectrum. Figure 7(b) shows four optical spectrums at each point. Point A represents signal after XGM module, point B is the signal after being filtered by AWG, point C is after the postamplifier, before it is transmitted to the ODN fiber input, and point D is the ONU received signal. Figure 7(c) shows a 30 dB loss margin between OLT AOPR transmitted at +5 dBm and ONU receivers received at -25 dBm. Figure 7(d) shows the optical spectrum for the first channel that passes through PON link 1 to ONU receiver. The result shows that the signal gain of the postamplifier is amplified by +12 dB and the AWG loss is around 5.3 dB.

4. Conclusions

We have proposed and demonstrated experimentally a new architecture of AOPR TWDM-PON system. By using integrated multicasting XGM in AOPR OLT module, the proposed architecture is capable of supporting the full degree of flexibility in managing highly efficient dynamic bandwidth allocation to support low bandwidth and high bandwidth

FIGURE 7: Optical spectrum signal of downstream signal for 4 multicasting channels with 30 dB link loss margin.

demand on the network. The proposed system also shows the capacity of the system to reduce the numbers of aggregation L2 in uplink PON layer by implementing this function in the physical layer, using all-optical packet routing apparatus. By using fixed wavelength laser source at OLT transceivers, it will eliminate the inventory issue and mismanagement of optical transceiver during OLT installation. The result revealed the system's capability to carry 4 channels of 10 Gbps multicasting PON system with up to 30 dB total loss margin at BER of 10^{-9} . By using FEC and super-FEC [13, 14], the system is able to give 36 dB link loss margin at BER 10^{-4} . As a result, the total number of users at 20 km radius is 4096 users supported by a single OLT port in 4 different PON ODN links.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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References

- [1] Y. Luo, X. Zhou, F. Effenberger et al., "Time- and wavelength-division multiplexed passive optical network (TWDM-PON) for next-generation PON stage 2 (NG-PON2)," *Journal of Lightwave Technology*, vol. 31, no. 4, Article ID 6289432, pp. 587–593, 2013.
- [2] A. Dixit, B. Lannoo, G. Das, D. Colle, M. Pickavet, and P. Demeester, "Evaluation of flexibility in hybrid WDM/TDM PONs," in *Proceedings of the 5th IEEE International Conference on Advanced Networks and Telecommunication Systems*, vol. 1, pp. 1–6, December 2011.
- [3] J. Kani, "Enabling technologies for future scalable and flexible WDM-PON and WDM/TDM-PON systems," *IEEE Journal on Selected Topics in Quantum Electronics*, vol. 16, no. 5, pp. 1290–1297, 2010.
- [4] Y. Hsueh, M. S. Rogge, S. Yamamoto, and L. G. Kazovsky, "A highly flexible and efficient passive optical network employing dynamic wavelength allocation," *Journal of Lightwave Technology*, vol. 23, no. 1, pp. 277–286, 2005.
- [5] K. Hara, H. Nakamura, S. Kimura et al., "Flexible load balancing technique using dynamic wavelength bandwidth allocation (DWBA) toward 100Gbit/s-class-WDM/TDM-PON," in *Proceedings of the 36th European Conference and Exhibition on*

- Optical Communication (ECOC '10)*, pp. 3–5, Torino, Italy, September 2010.
- [6] Y. Senoo, S. Kaneko, S. Kimura, and N. Yoshimoto, “Wavelength router for energy efficient photonic aggregation with large-scale λ -tunable WDM/TDM-PON,” in *Proceedings of the 18th Asia-Pacific Conference on Communications: Green and Smart Communications for IT Innovation (APCC '12)*, pp. 350–354, October 2012.
 - [7] P. Kourtessis, Y. Shachaf, C.-H. Chang, and J. M. Senior, “PON topologies for dynamic optical access networks,” in *Proceedings of the 10th Anniversary International Conference on Transparent Optical Networks (ICTON '08)*, pp. 131–134, Athens, Greece, June 2008.
 - [8] C. Bock, J. Prat, and S. D. Walker, “Hybrid WDM/TDM PON using the AWG FSR and featuring centralized light generation and dynamic bandwidth allocation,” *Journal of Lightwave Technology*, vol. 23, no. 12, pp. 3981–3988, 2005.
 - [9] M. Fujiwara, K. Suzuki, K. Taguchi et al., “Effective accommodation for users located in long / short distance areas through PONs with dual stage splitter configuration using ALC burst-mode optical amplifier,” in *Proceedings of the Optical Fiber Communication Conference and Exposition and the National Fiber Optic Engineers Conference (OFC/NFOEC '11)*, March 2011.
 - [10] N. Cheng, L. Wang, D. Liu, and B. Gao, “Flexible TWDM PON with load balancing and power saving,” in *Proceedings of the 39th European Conference and Exhibition on Optical Communication (ECOC '13)*, pp. 1–3, London, UK, September 2013.
 - [11] K. A. W. A. Rohit, M. K. S. X. J. M. Leijtens, T. deVries Y, M. J. R. Heck L, R. Notzel, and D. J. Robbins, “Monolithic multi band nanosecond programmable wavelength route.pdf,” *IEEE Photonics Journal*, vol. 2, no. 1, pp. 29–35, 2010.
 - [12] B. H. L. Lee, R. Mohamad, and K. Dimyati, “Performance of all-optical multicasting via dual-stage XGM in SOA for grid networking,” *IEEE Photonics Technology Letters*, vol. 18, no. 21, pp. 2215–2217, 2006.
 - [13] R. P. Davey, D. B. Grossman, M. Rasztoivits-Wiech et al., “Long-reach passive optical networks,” *Journal of Lightwave Technology*, vol. 27, no. 3, pp. 273–291, 2009.
 - [14] D. P. Shea and J. E. Mitchell, “A 10-Gb/s 1024-way-split 100-km long-reach optical-access network,” *Journal of Lightwave Technology*, vol. 25, no. 3, pp. 685–693, 2007.