40Gbit/s λ-tunable stacked-WDM/TDM-PON using dynamic wavelength and bandwidth allocation

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Abstract: This paper proposes a configuration and a dynamic wavelength and bandwidth allocation for the upstream signal in 40Gbit/s λ-tunable stacked-WDM/TDM-PON. An upstream transmission experiment with 10Gbit/s burst-mode receivers and fast-switching tunable filters is first demonstrated.

OCIS codes: (060.2330) Fiber optics communications, (060.2340) Fiber optics components

1. Introduction

Passive optical network (PON) systems are now being installed throughout the world for high-speed optical access networks. 10Gbit/s-class PON systems, namely 10G-EPON and XG-PON systems, have already been standardized as next-generation PON systems. Various approaches are being studied for future PON systems including high-speed time division multiplexing (TDM)-PON, wavelength division multiplexing (WDM)-PON, and WDM/TDM-PON [1-2]. However, the generation that will replace 10Gbit/s-class-PON requires more than just high speed. Not all users will require high speeds and bandwidth needs will reflect lifestyles. It is likely that heavy users and light users will congregate in different PON systems. Therefore, we must improve the bandwidth utilization efficiency by accommodating several conventional PON systems in one optical line terminal (OLT), and ensuring the flexible allocation of bandwidth to meet the various users' needs. To satisfy this requirement, a λ-tunable stacked-WDM/TDM-PON system has been proposed, and the feasibility of its downstream signal demonstrated [3]. This system bundles several PON branches with WDM technology and provides flexible bandwidth allocation by using wavelength tunability and the dynamic wavelength and bandwidth allocation (DWBA) algorithm.

This paper proposes a configuration and a DWBA of the upstream signal for 40Gbit/s λ-tunable stacked-WDM/TDM-PON system to increase the number of accommodated ONUs per OLT and improve the bandwidth utilization efficiency, and clarifies the feasibility of the λ-switching/receiving function of the upstream signal. We first conduct an upstream transmission experiment that uses fast-response 10Gbit/s-class burst-mode receivers (B-Rxs) and fast-switching tunable filters (TFs) to realize the DWBA operation.

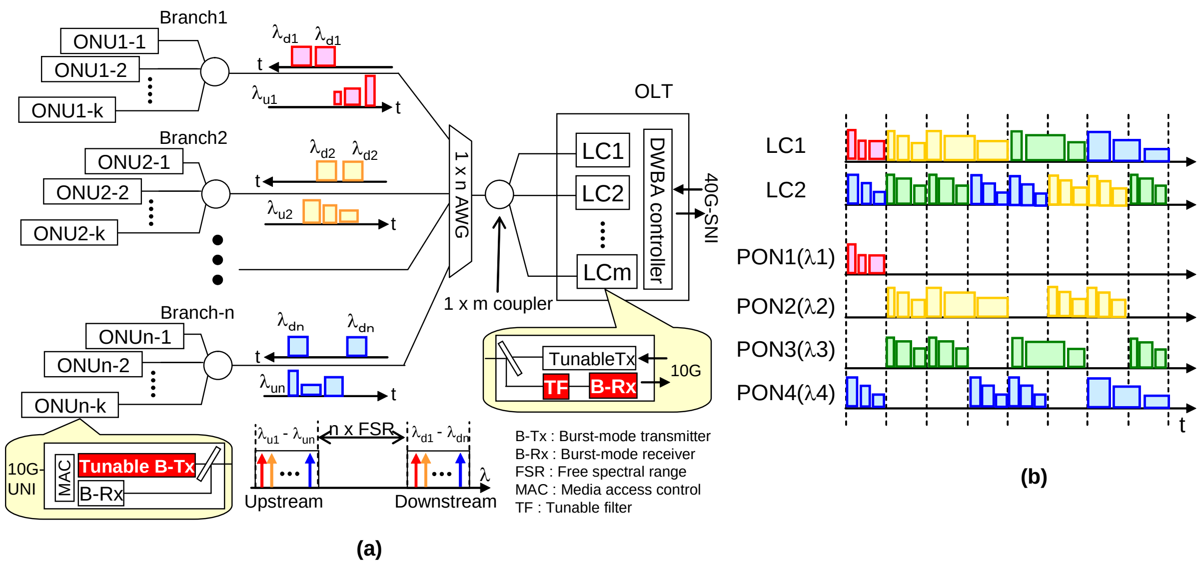

Fig. 1 (a) Configuration of λ-tunable stacked-WDM/TDM PON (b) DWBA operation.

2. Proposed PON system and DWBA

Fig.1 (a) shows the configuration of the proposed PON system and the DWBA operation. The OLT is equipped with line cards (LCs) that output downstream signals and receive upstream signals at several wavelengths and a DWBA controller. A 1 x *m* coupler and a 1 x *n* arrayed wavelength grating (AWG) connect *m*-LCs to *n*-PON branches. An optical network unit (ONU) is equipped with a λ-tunable burst-mode transmitter to realize a colorless function and a burst-mode receiver. Different wavelengths (λu1-λun/λd1-λdn) are assigned to each PON branch (1-n). The ONUs in the PON branch output the assigned wavelengths and their upstream signals are multiplexed in the time domain. Upstream signals with different wavelengths from those of each PON branch are multiplexed by the 1 x *n* AWG, divided by the 1 x *m* coupler, and input into the LCs. A tunable filter (TF) in each LC changes the transmitting wavelength according to the λ-switching signal from the DWBA controller, and the upstream signal is received by the burst-mode receiver.

The DWBA controller calculates the wavelength and bandwidth allocation that balances the load between LCs to satisfy requests from ONUs. It assigns a sending time to each ONU and a receiving wavelength and time to each LC. Fig. 1 (b) shows an example of DWBA operation with 2-LCs and 4-PON branches. DWBA observes the requests from the ONUs and sets the wavelength and time matrices of LC1 and LC2. After LC1 receives λ1 from PON branch1, in which the traffic demand is small, LC1 and LC2 receive λ2, λ3 and λ4 to meet requests from PON branch2, PON branch3, and PON branch4 equally; these 3 PON branches have heavy data traffic demands.

In this system, the number of accommodated ONUs can be easily increased without any loss budget degradation, because the PON branches are bundled by the AWG. The number of LCs can be minimized due to the flexible load balance between the LCs achieved by the DWBA.

3. Experiment

(1) Fast switching tunable filter

The proposed system requires a fast switching time to avoid any degradation in the bandwidth utilization efficiency and a low loss to avoid any reduction in the loss budget in the TF. Fig. 2 (a) and (b) respectively show the configuration and characteristics of our TF, which can meet these requirements. Some SOAs used as gating switches are sandwiched between two AWGs. The controller in the TF adjusts the current of the SOA of the transmitting wavelength according to the λ-switching signal, which includes the λ information and the λ-switching trigger. The gross gain and noise figure (NF) of the TF including the AWGs are shown in Fig. 2 (b). The static gain and NF are 6.5 and 10 dB, respectively.

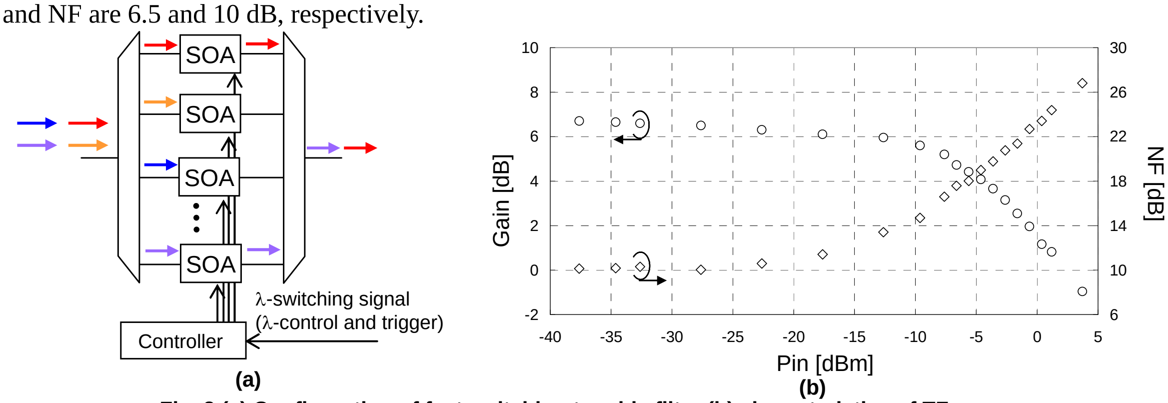

Fig. 2 (a) Configuration of fast switching tunable filter (b) characteristics of TF.

(2) Upstream transmission

Fig. 3 shows our experimental setup, which emulates the case of 2-LCs and 4-PON branches to confirm the feasibility of realizing fast λ-switching/receiving characteristics for the upstream signal. The tunable burst-mode transmitter (B-Tx) consists of a tunable laser diode (TLD), an LN modulator for 10-Gbit/s-data signals, and an acousto-optic modulator (AOM) for the burst mode. The extinction ratio (ER) of the upstream signal was 10 dB. The four wavelengths used in this experiment were 1546.9, 1547.3, 1547.7 and 1548.1 nm. Our 10-Gbit/s-class B-Rx has a high sensitivity, a wide dynamic range, and an instantaneous response [4].

Fig. 4 shows input and output waveforms of LC1. Burst-mode signals with wavelengths of λ1 and λ2 were input into LC1 in a 1-μs period, with a 15-ns guard time and a 6-dB difference in optical power. The λ-switching trigger was input into LC1 in the guard time. The λ-switching time was less than 20 ns and the amplitude of the output signal from the B-Rx was recovered within 40 ns. Fig. 5 shows characteristics of the bit error rate (BER) of the payload of the received signal with λ1 and λ2. The transmitted burst pattern consisted of blocks comprising a 410-ns preamble and a 640-ns payload with 2^{31}-1 PRBS. For the λ1-signal, the optical received power at BERs of 10^{-3} and 10^{-12} were -34.2 and -24.5 dBm, respectively. The slope of the BER curve with the TF was smaller than that without the TF, because the gain of the TF improved the BER of 10^{-3}, and the increasing NF around the -25 dBm input power degraded the BER.

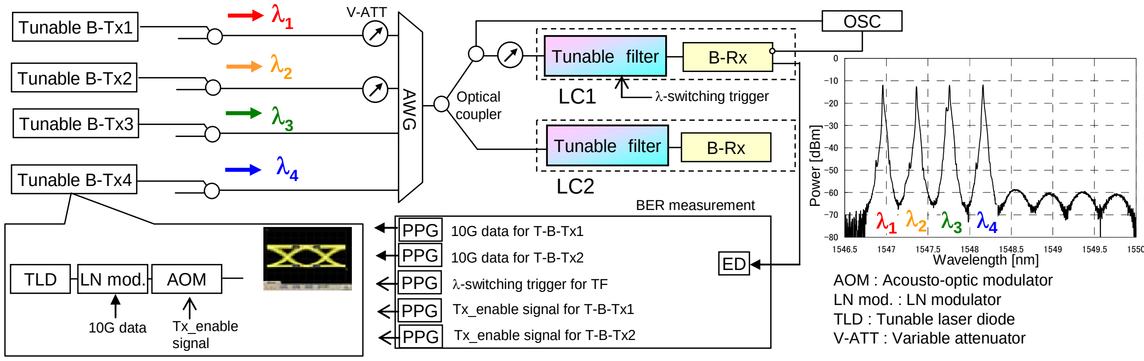

Fig. 3 Experimental setup.

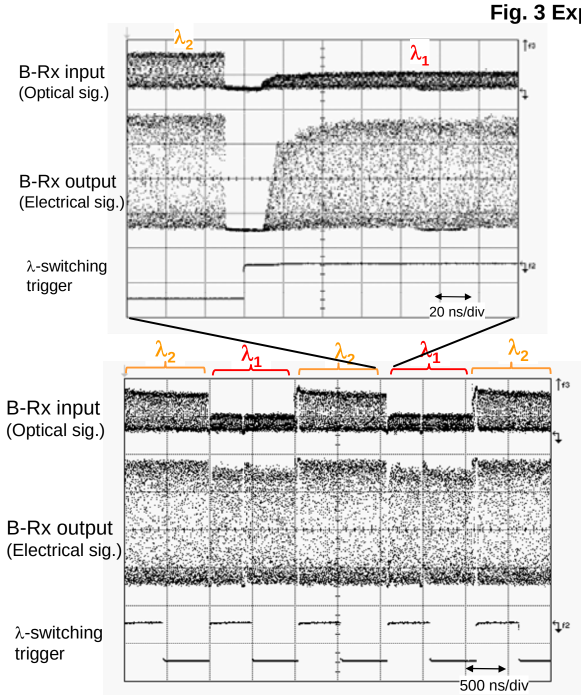

Fig. 4 Waveforms of received signal.

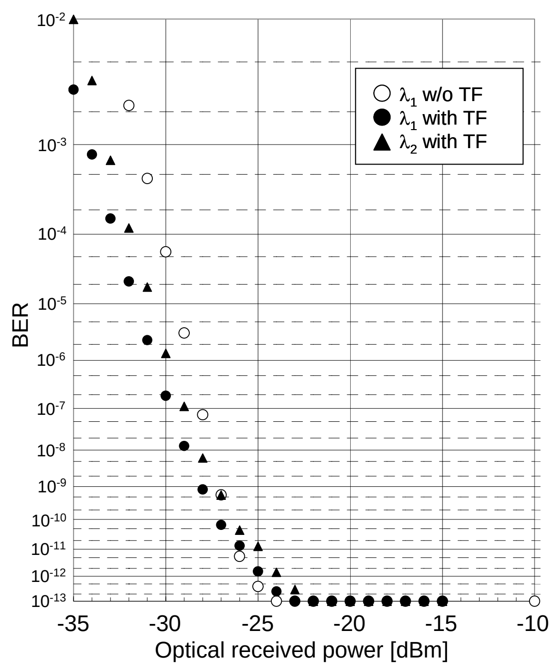

Fig. 5 BER characteristics of received signal.

5. Summary

This paper proposes a configuration and a DWBA of the upstream signal for a 40Gbit/s λ-tunable stacked-WDM/TDM-PON. We first conducted an experiment using fast-response 10Gbit/s B-Rxs and fast-switching TFs and the demonstrated the feasibility of the λ-switching function to realize the DWBA operation. It was clarified that the λ-switching/receiving time was within 40ns and the receiver sensitivity is -34.2 dBm at BER of 10^{-3}. This system can realize cost-effective and high capacity PON systems by increasing the number of the accommodated ONUs and providing the flexible load balance.

References

/1/ J. Kani, *et al.*, "A WDM-Based Optical Access Network for Wide-Area Gigabit Access Services," *IEEE Commun. Mag.*, Vol. 41, s43-s48, Feb. 2003.

/2/ Y-L. Hsueh, *et al.*, "Success-DWA : A highly scalable and cost-effective optical access network," *IEEE Opt. Commun*, s24-s30,2004.

/3/ K. Hara, *et al.*, "Flexible load balancing technique using DWBA toward 100Gbit/s-class- WDM/TDM-PON," ECOC2010, Tu.3.B.2, 2010.

/4/ K. Hara, *et al.*, "New AC-coupled burst-mode optical receiver using transient-phenomena cancellation techniques for 10 Gbit/s-class high-speed TDM-PON systems," *J. Lightwave Technol.*, vol. 28, pp. 2775-2782. 2010.