Upstream Multi-wavelength Shared TDM-PON using RSOA based Directly Modulated Tunable Fiber Ring Laser

Zhengxuan Li, Lilin Yi*, Yan Zhang, Shilin Xiao and Weisheng Hu
State Key Lab of Advanced Optical Communication Systems and Networks, Shanghai Jiao Tong University, Department of Electronic Engineering, Shanghai 200240, China
*lilinyi@sjtu.edu.cn

ABSTRACT

We have proposed to use a directly modulated tunable fiber ring laser based on reflective semiconductor optical amplifiers(RSOA) and tunable optical filter (TOF) as an upstream source in multi-wavelength shared(UMWS) time division multiplexing-passive optical network (TDM-PON) configuration. Downstream signal is broadcasted in TDM way while upstream signals are multiplexed in hybrid time/wavelength division multiplexed way, which upgrades the upstream capacity greatly. Bidirectional transmission of downstream data at 10-Gb/s and upstream data at 1.25-Gb/s per wavelength over 25-km single mode fiber (SMF) is demonstrated with a power penalty of ~0.5 dB at both ends. A stable performance is observed for the upstream wavelength tuned from 1530 nm to 1595 nm.

Keywords: Upstream multi-wavelength shared, tunable fiber laser, RSOA, TDM-PON

1. INTRODUCTION

With the rapid development of Internet applications such as Internet protocol television (IPTV), high-definition television (HDTV), and video upload/sharing, the upstream bandwidth demand of each user in access network increases accordingly. The traditional time division multiplexed-passive optical network (TDM-PON) has an upstream capacity of 1 Gb/s or 1.25 Gb/s which is shared by all the users in TDM way resulting in only several Mb/s bandwidth owned by each user, cannot fulfill the increasing requirement effectively. However, upgrading the upstream capacity by employing a high speed burst mode transmitter in each optical network unit (ONU) is impractical due to its high cost. Upstream multi-wavelength share (UMWS) has been considered as a promising solution to upgrade the upstream capacity in TDM-PON configuration, where the upstream signal is tuned to another wavelength when the assigned time slot is not sufficient for users [1-4]. In this case, the expensive high speed burst mode transceiver can be avoided. In the UMWS TDM-PON configuration, the upstream tunable laser source is a key component with the properties of wide wavelength tuning range, high output power, low power ripple, high side mode suppression ratio (SMSR) and low cost.

Self-seeding [1-2] and injection-locking [3] Fabret–Perot laser diode (FP-LD) have been proposed as the upstream tunable laser source. The wavelength tuning range is less than 20 nm limited by the spectral width of the FP-LD, and the tuning step is around 1nm limited by the spacing between two neighboring modes, which is not strictly compatible with the ITU-T channel. Special and strict cavity-length design of the FP-LD is required to meet the ITU-T channel requirement. Moreover, the power ripple among different channels is ~6 dB, which put a restriction on the upstream power budget. Compared with FP-LD, reflective semiconductor optical amplifier (RSOA) is a better candidate due to its wider wavelength tuning range, flexible tuning step and higher output power. In the ever proposed architecture, centralized laser sources at optical line terminal (OLT) are injected to RSOA in each ONU through a power splitter, and a tunable optical filter (TOF) in ONU is employed to select the upstream wavelength [4].In this case the wavelength

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number and tuning flexibility are determined by the centralized laser bank, which increases the cost of OLT. Besides, Rayleigh backscattering and back reflection induced crosstalk will degrade the upstream signal performance in the centralized light source case [5-6].

In this paper, we propose to use a RSOA and TOF based directly-modulated tunable fiber ring laser to construct an UMWS ONU in the traditional TDM-PON configuration. Experimental results have shown that the proposed laser source can operate within the entire gain bandwidth of the RSOA from 1530 nm to 1595nm with SMSR larger than 60 dB, output power higher than 2 dBm and power difference less than 1 dB. Therefore, the proposed upstream laser source features wide wavelength tuning range, high SMSR, high output power and low cost, which perfectly meets the requirement of the UMWS ONU. Bidirectional transmission of downstream data at 10 Gb/s and upstream data at 1.25 Gb/s per wavelength over 25-km single-mode fiber (SMF) has been demonstrated with a power penalty of ~0.5 dB at both ends. By tuning the central wavelength of the TOF, the operating wavelength of the ONU can be tuned to another one when the upstream data traffic is overloaded, which can significantly increase the upstream capacity of the traditional TDM-PON without updating the network configuration.

2. PROPOSED SCHEME AND EXPERIMENTAL DEMONSTRATION

The configuration of the UMWS TDM-PON using the proposed RSOA and TOF based directly-modulated tunable fiber ring laser as upstream source is shown in Fig.1. For the users with a higher upstream bandwidth demand, an upgraded ONU is needed while others maintain the traditional ONU structure. The upgraded ONU consists of a coupler, a TOF, two optical circulators (OC), a downstream optical receiver, and an RSOA. Each upgraded ONU can operate at its unique wavelength by controlling the central wavelength of the TOF. Distributed Bragg reflectors based micro-machined vertical cavity filters with fast tuning responses and wide wavelength tuning range can be used for the TOF [7]. Upstream signal is obtained by directly modulating data on the RSOA. At the OLT side, a 10-Gb/s burst mode transmitter is used to generate a downstream broadcasting signal through the splitter to each ONU in a TDM way. Upstream signal from the feeder fiber is launched into an arrayed waveguide grating (AWG) through OC1 and then divided into n receivers for detection according to upstream wavelength scheduling. The receiver could be a standard photo-receiver if the corresponding upstream wavelength is specially assigned to one user with extremely high upstream bandwidth requirement. Otherwise the receivers in OLT should be 1.25-Gb/s burst mode receivers which detect the upstream signals from different users sharing the same wavelength. Therefore in the viewpoint of downstream configuration, the UMWS TDM-PON is a pure TDM-PON; while in the viewpoint of upstream configuration, it is more like a hybrid WDM/TDM PON. Note that with the help of OC2 and OC3, the upstream and downstream signals are transmitted in opposite directions, which can prevent the downstream signal and the back-reflected upstream signal from launching into the RSOA for reamplification therefore the crosstalk can be suppressed.

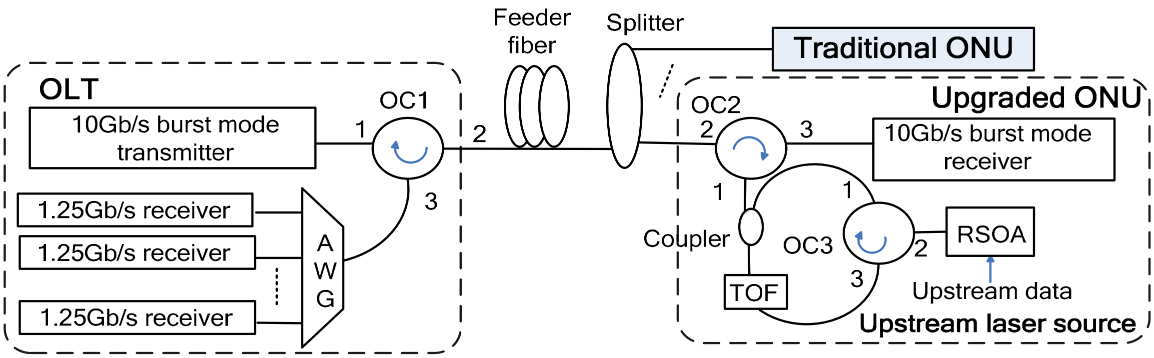

Fig.1 The proposed UMWS TDM-PON schematics

We set up an experiment to demonstrate the single-fiber bidirectional transmission UMWS TDM-PON employing the proposed tunable fiber ring laser as upstream source, and the experimental setup is shown in Fig.2. A distributed feedback laser-diode (DFB-LD) performs as the downstream laser source, and after passing a polarization controller (PC), the laser was modulated by a 10-Gb/s pseudo-random bit sequence (PRBS) data using a Mach-Zehnder modulator (MZM).Then the downstream signal passes through an optical circulator (OC1) and launched into a 25-km SMF fiber for transmission. After transmission, a variable optical attenuator (VOA) is used to attenuate the optical power and imitate the function of a power splitter. Finally the signal passes through OC2 and detected by the receiver. As for the upstream link, the coupler launches 80% of the tunable laser output into the transmission fiber as the upstream source through OC2.The split ratio of the coupler has been investigated taking the properties of upstream signal sensitivity and output power for consideration, and a 20/80 split ratio has been proved to be the best choice. By tuning the bias current of the RSOA at its saturation region, the RSOA based tunable fiber ring laser can be directly modulated [8]. We modulate the tunable fiber ring laser using a 1.25-Gb/s PRBS data as the upstream data. After the 25-km SMF transmission, the upstream signal was launched into OC1 and finally detected by the receiver.

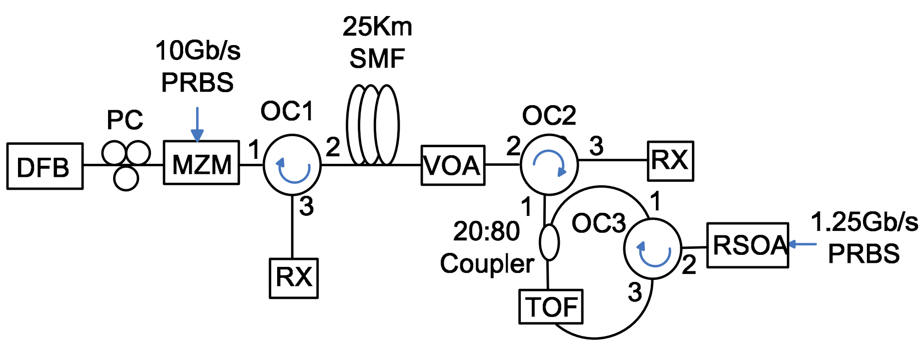

Fig.2 Experimental setup

3. EXPERIMENTAL RESULTS

Firstly, we experimentally investigate the properties of the proposed laser source at ONU. The TOF has a 3-dB bandwidth of ~0.4 nm. Figure 3 shows the output spectra of the laser module from 1530 nm to 1595 nm with a tuning step of 5 nm. When the central wavelength of the TOF was tuned shorter than 1530 nm or longer than 1595 nm, laser cannot be generated due to the gain characteristics of the RSOA. Within the entire tuning range, the laser features SMSR higher than 60 dB, output power higher than -1 dBm and power fluctuation less than 2 dB, which enables a sufficient upstream power budget.

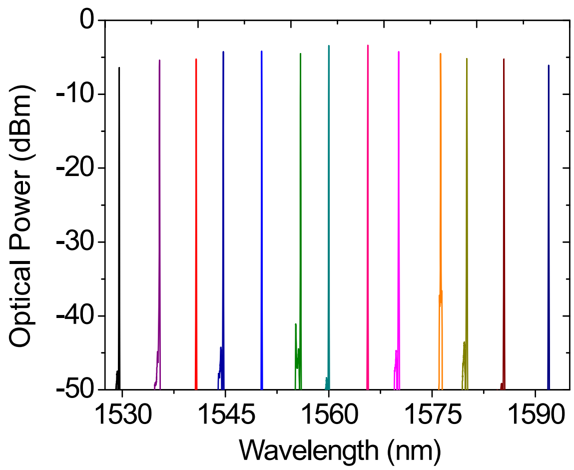

Fig.3 Optical spectra of the laser output

We then tested the property of the proposed laser source by measuring the bit-error rates (BERs) of the upstream signal both in BtB case and after 25-km SMF transmission. When the wavelength tuned from 1530 nm to 1595 nm, the sensitivities of the signal are almost the same, and no power penalty is observed after the 25-km SMF transmission, verifying a stable performance within the whole tuning range of the laser source. We only take 1530 nm, 1555 nm and 1595 nm as examples in Fig.4. We also change the bandwidth and filtering-shape of the TOF to evaluate the tunable laser performance and it is found both the BtB and transmission performance are not degraded when the filter bandwidth is tuned from 0.3 nm to 5 nm and the filtering-shape is varied from flat-top to Gaussian-shape. When the bandwidth is less than 0.3 nm, the increased insertion loss of the TOF will degrade the laser performance. This evaluation proves the laser performance has no strict requirement on the TOF therefore it is quite easy to implement.

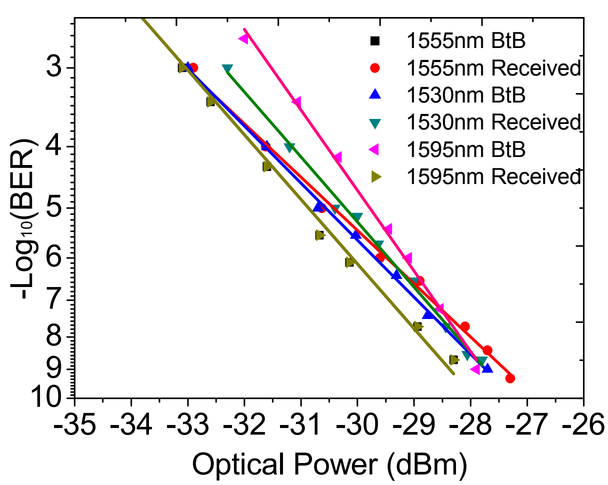

Fig.4 BER measurement of upstream laser

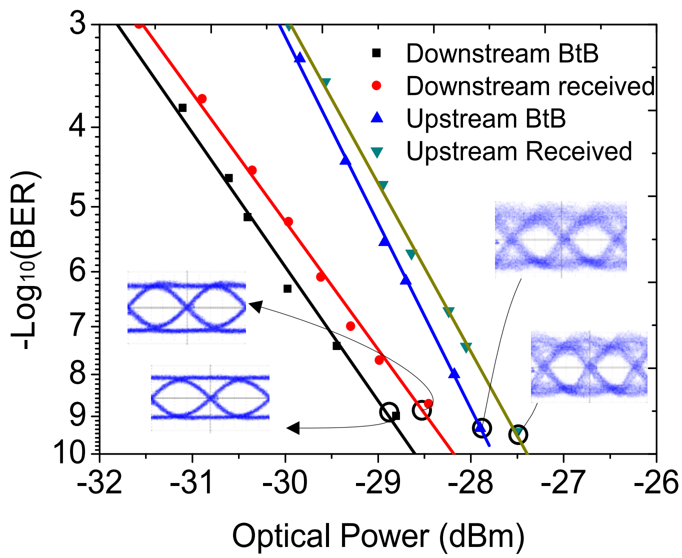

Fig.5 BERs and eye diagrams measurement

Finally, we evaluate the system performance of the proposed UMWS-PON by measuring the BERs and eye diagrams of the downstream and upstream signals in 25-km single-fiber bidirectional transmission case. The sensitivities of signals at both ends in BtB case and after 25-km SMF transmission are measured，the results are shown in Fig.5 taken 1550 nm as an example. The extinction ratio (ER) of the downstream 10-Gb/s data is around 13 dB and that of the upstream 1.25-Gb/s data is around 8 dB. The ER of the upstream laser can be improved by using a RSOA with higher linear gain. The eye diagrams of the downstream/upstream signals before and after transmission are shown as the inset of Fig. 5. After transmission, a ~0.5-dB power penalty was observed in both directions compared with the BtB case, proving the feasibility of the proposed UMWS TDM-PON configuration using RSOA and TOF based tunable fiber ring laser as an upstream source.

We also estimate the power budget of the proposed PON architecture, meaning the maximal number of users that could be supported in the system. The total loss of the system is 10 dB, including the insertion loss of an AWG, the 25-km SMF and two OCs. Taking the lowest output power of -1 dBm and the worst sensitivity of the received upstream signal of -27 dBm for calculation，the upstream power budget is ~16 dB，corresponding to a 1/40 split ratio in the RN. By using a high linear gain RSOA, the output power of the upstream laser source can be further improved therefore enhancing the supported users' number.

4. CONCLUSION

We have proposed to use a directly modulated tunable fiber ring laser based on RSOA as the upstream source to realize a UMWS TDM-PON configuration. This scheme upgrades the upstream capacity by introducing multiple wavelengths without changing the existing TDM-PON configuration. The operating wavelength of the upgraded ONU can be tuned to another one by tuning the central wavelength of the TOF when the assigned wavelength is overloaded. The output performances of the proposed upstream laser source at ONU are experimentally investigated. Bidirectional transmission of downstream data at 10 Gb/s and upstream data at 1.25 Gb/s per wavelength over 25-km SMF is demonstrated with a power penalty of ~0.5 dB at both ends, and a stable performance was observed when the upstream operating wavelength tuning from 1530 nm to 1595 nm, which proves the feasibility of the proposal.

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