Optical VPN Connecting ONUs in Different PONs

Yue Tian, Xiangqing Tian, Lufeng Leng*, Tong Ye, Yikai Su
State Key Lab of Advanced Optical Communication Systems and Networks, Department of Electronic Engineering
Shanghai Jiao Tong University, 800 Dongchuan Rd, Shanghai 200240, China, yikaisu@sjtu.edu.cn
** New York City College of Technology, City University of New York, Brooklyn, NY 11201 USA*

Abstract: We demonstrate optical-layer virtual private networking in a new super-PON architecture using a dynamic wavelength reflector. The optical VPN enables communications among different PONs.

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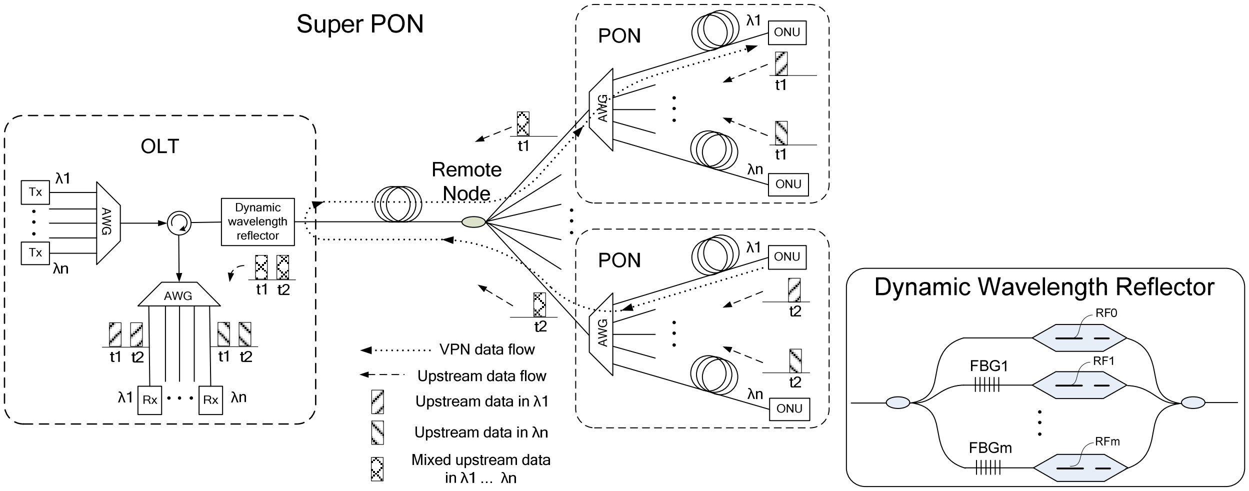
1. Introduction

All optical virtual private network (VPN) in a passive optical network (PON) provides dedicated optical channels to connect VPN users. It is an effective technique to increase the throughput and reduce the latency of the network [1], while providing enhanced security for users. Several schemes [1-4] based on waveband or wavelength reflection in a PON have been reported recently, and other proposals [5-9] used star couplers for inter-connecting optical network units (ONUs). In these demonstrations, the optical VPN connects ONUs within the same PON. In practice, however, there exist applications where an optical VPN is desired to connect ONUs in different PONs, in order to provide more efficient access service covering a wider area. To the best of our knowledge, however, this issue has not been studied to date.

In this paper, we propose and demonstrate optical VPN communications among different PONs at 10 Gb/s. These PONs are connected in a two-stage tree topology, leading to a super-PON architecture [10]. The lower stage consists of conventional wavelength-division multiplexed (WDM) PONs operating in burst mode to interleave the upstream and VPN traffic. They are combined by a passive coupler and directed to an optical line terminal (OLT) through a feeder fiber. The ONUs of the same color in different PONs are grouped into a VPN. A dynamic wavelength reflector is placed at the OLT side, which can be configured to reflect the VPN traffic back to the ONUs belonging to the same group, thus linking the ONUs in different PONs. We experimentally demonstrate both the conventional and the VPN communications in such a super-PON.

2. Optical VPN in the Super-PON with TDM and WDM multiplexing



a) b)

Fig. 1. a) Architecture of the hybrid super-PON using TDM and WDM multiplexing. b) Configuration of the dynamic wavelength reflector.

Fig. 1a shows the architecture of the proposed optical VPN in a super-PON. A 1xN coupler at the remote node broadcasts the downstream traffic to each PON, where an arrayed waveguide grating (AWG) router separates the WDM channels so that point-to-point connections to each ONU are established. Since the PONs share the same group of wavelengths, upstream data originating from ONUs of the same color has to be time-division multiplexed (TDM). When the dynamic wavelength reflector is switched on, the transmitted packets from an ONU can be optically redirected back to the remote node and subsequently broadcast among all the ONUs using the same wavelength channel in different PONs. Thus, an optical VPN is formed for these ONUs in a broadcast-and-select manner. The optical VPN within the same PON can also be implemented additionally by combining this architecture and the previously proposed scheme [2,3].

Fig. 1b illustrates the structure of the dynamic wavelength reflector. It consists of two 1xm star-couplers connected by a set of optical paths of equal lengths, with a Mach-Zehnder modulator (MZM) and one or more optional fiber Bragg gratings (FBG) embedded in each path. By driving the MZMs between the peak and the null of the transmission curve with radio frequency (RF) signals, as shown in Fig. 1b, data packets entering the dynamic wavelength reflector can be blocked, transmitted, or reflected. In each path, one or more FBGs can be installed to reflect one or more wavelengths. When a MZM is in the transmission mode, the downstream/upstream traffic falling into the FBG bandwidth is reflected, while the rest goes through. Therefore, by selecting the through paths, reflection of multiple wavelengths is possible. The OLT should schedule the state of the dynamic wavelength reflector to pass the regular upstream and downstream traffic and redirect the optical VPN data in their corresponding time slots. The number of optical paths is flexible and can be determined by the specific network scheduling. Optical amplification may be employed at the wavelength reflector to increase the scalability.

3. Experiment

To verify the operation principle of the super-PON with optical VPN function, we performed an experiment to demonstrate downstream and upstream transmissions and inter-ONU optical networking. Fig. 2 shows the experimental setup with the optical VPN enabled. The pulse pattern generator (PPG) was set to “zero substitute” mode to generate a packet consisting of 948 bits of random data followed by 76 '0's, totalling a period of 1024 (2^{10}) bits at 10 Gb/s. The dynamic wavelength reflector was controlled by a pair of complementary electrical on-off signals, as plotted in Fig. 2a.

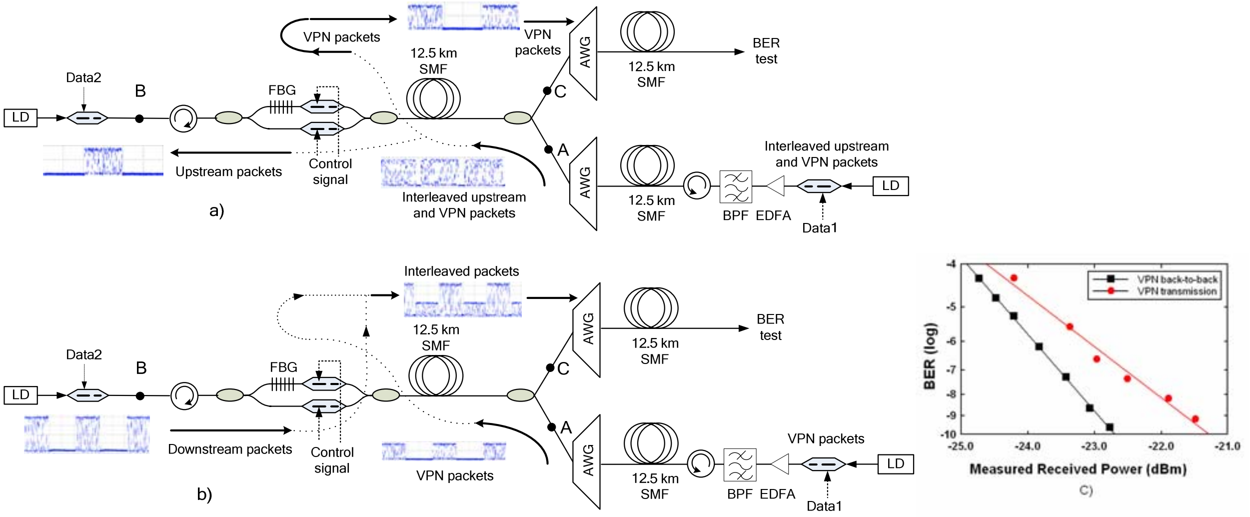
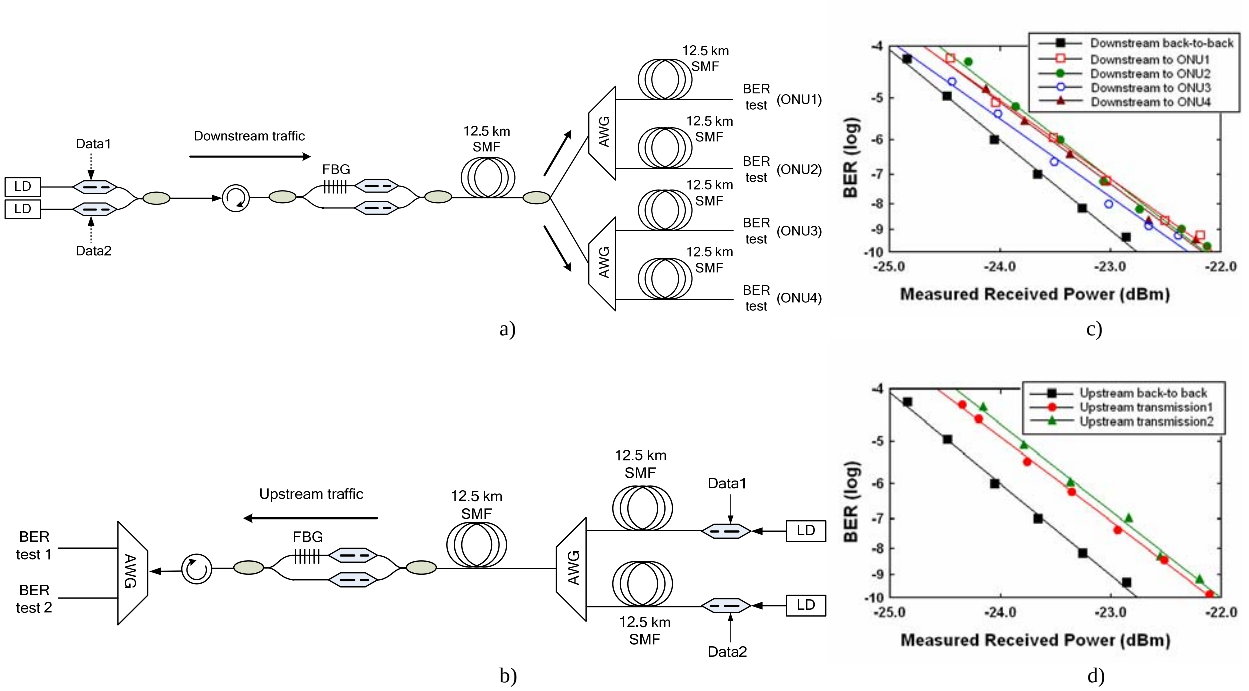


Fig. 2. Experimental setup (a) an ONU sends upstream packets and VPN data, and (b) an ONU receives data packets from the OLT and the VPN traffic from another ONU. (time scale: 20 ns/div) c) BER measurement for VPN traffic

We firstly demonstrate the optical VPN operation for the ONUs in different PONs by dynamically configuring the wavelength reflector. In Fig. 2a, the ONU keeps sending the upstream and the VPN traffic interleaved in time, and the waveforms at points A, B, and C are monitored. The waveforms in Fig. 2a confirm that, by controlling the state of the reflector on-the-fly, the upstream packets pass through the reflector and reach point B while the VPN packets are redirected to point C. We further show that the contention between the downstream and the VPN traffic can be avoided by proper scheduling. To achieve that, the OLT and the ONU were set to transmit the downstream and VPN packets, respectively, in separate time slots, as shown in Fig. 2b. The results in Fig. 2b exhibit no contention between the VPN and the downstream packets at point C. The bit error rate (BER) performance is shown in Fig. 2c, which indicates degraded receiver sensitivity compared to the non-VPN transmissions shown in Fig. 3. This may be attributed to the round-trip transmission.

The setups in Fig. 3 correspond to the downstream and upstream transmissions. For the downstream case (Fig. 3a), two 10-Gb/s non-return-to zero (NRZ) data streams are generated at 1559.78 nm and 1558.31 nm, respectively, and are received by the four ONUs distributed in the two PONs. The state of the dynamic wavelength reflector is adjusted to pass the data traffic with minimal loss. For the upstream case (Fig. 3b), two transmitters in a PON are sending packets at different wavelengths simultaneously to the receivers in the OLT. The BER measurements are provided in Fig. 3c and d. Compared to the back-to-back performance, a penalty of less than 1dB is observed for both the downstream and upstream traffic.



a) c)

b) d)

Fig. 3. Experimental setups of (a) downstream and (b) upstream case, and BER measurements for (c) downstream and (d) upstream transmission

4. Conclusion

We have proposed and demonstrated a new optical VPN in a two-stage super-PON operating at 10 Gb/s, which enables optical VPN communication among the ONUs in different PONs. A fast dynamic wavelength reflector located at the OLT can be scheduled to avoid the contention between the conventional traffic and the VPN communication.

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References:

[1] Yikai Su *et al.*, "A Packet-Switched Waveband-selective PON Enabling Optical Internetworking among ONUs," ECOC 2005, We4.P95 (2005).
[2] Yikai Su *et al.*, "Optical VPN in PON Using TDM-FDM Signal Format," OFC 2006, OTuJ5 (2006)
[3] Yue Tian *et al.*, "Optical VPN in PON Based on DPSK Erasing/Rewriting and DPSK/IM formatting using a Single Mach-Zehnder Modulator," ECOC 2006, Tu4.5.6 (2006).
[4] Chang-Joon Chae *et al.*, "A PON System Suitable for Internetworking Optical Network Units Using a Fiber Bragg Grating on the Feeder Fiber," IEEE PTL 11, 1686-1688 (1999).
[5] Nishaanthan Nadarajah, Elaine Wong and Ampalavanapillai Nirmalathas, "Implementation of Multiple Secure Virtual Private Networks Over Passive Optical Networks Using Electronic CDMA," IEEE PTL 18, 484-486 (2006)
[6] Elaine Wong, and Chang-Joon Chae, "CSMA/CD-Based Ethernet Passive Optical Network with Optical Internetworking Capability Among Users," IEEE PTL 16, 2195-2197 (2004).
[7] Nishaanthan Nadarajah *et al.*, "A Novel Local Area Network Emulation Technique on Passive Optical Networks," IEEE PTL. 17, 1121-1123 (2005).
[8] An V. Tran, Chang-Joon Chae and Rodney S. Tucker, "Bandwidth-Efficient PON System for Broad-Band Access and Local Customer Internetworking," IEEE PTL 18, 670-672 (2006).
[9] Qiguang Zhao *et al.*, "A Novel Internetworking Scheme for WDM Passive Optical Network based on Remodulation Technique," OFC 2006, JThB67 (2006).
[10] Giuseppe Talli and Paul D. Townsend, "Hybrid DWDM–TDM Long-Reach PON for Next-Generation Optical Access," IEEE JLT 24, 2827–2834 (2006).