An OFDMA-PON architecture supporting flexible all-optical VPN with source-free ONUs

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Abstract— **We propose and experimentally demonstrate a new orthogonal frequency division multiple access-based passive optical network (OFDMA-PON) architecture supporting flexible all-optical virtual private network (VPN) with source-free optical network units (ONUs). In our scheme, variable-bit-rate VPN communications are achieved. Moreover, based on optical sideband reuse at the ONU side and optical carrier suppression (OCS) at the optical line terminal (OLT), the ONUs are source-free and components for the operation of frequency shift are eliminated.**

Keywords- Orthogonal frequency division multiple access (OFDMA), passive optical network (PON), virtual private network (VPN), optical carrier suppression (OCS).

I. INTRODUCTION

The growing demand for various service communications, especially the rapid growth of bandwidth-intensive multimedia services, has recently led to the emergence of orthogonal frequency division multiple access-based passive optical network (OFDMA-PON) as an attractive candidate for the next-generation optical access [1, 2]. All-optical virtual private network (VPN) [3, 4] is an approach to offering dedicated optical channels to connect end users. Orthogonal frequency division multiplexing (OFDM) provides desirable features [5] such as service transparency, high spectral efficiency, and superior tolerance against various fiber degradation effects. Therefore, OFDMA-PON is believed to be a good platform for flexible all-optical VPN with high throughput and low latency. Ref. [6] used sub-band allocation to realize all-optical VPN and inter-communications among optical network units (ONUs) in OFDM PON. However, owing to high precision requirement in spectrum to separate adjacent sub-bands of the OFDM signal, the comb optical filter (COF) employed in the scheme is currently unavailable.

In this paper, a novel OFDMA-PON scheme supporting flexible all-optical VPN communications with source-free ONUs is proposed and experimentally demonstrated. In our approach, the flexibility lies in the fact that variable-bit-rate VPN communications are achieved. Based on optical sideband reuse modulation technology, light sources and wavelengths management are not required at the ONUs. Besides, optical carrier suppression (OCS) technique at the optical line terminal (OLT) eliminates components for the operation of frequency shift at the ONUs. Therefore, the cost and energy consumption of the system are reduced. 16-quadrature amplitude modulation (16-QAM) OFDM is used for the downlink and combined signals. The combined signal comprises both the uplink and VPN data. We successfully demonstrate the OFDMA-PON transmission of 5-Gb/s downlink signal and 5-Gb/s combined signal over 25-km standard single mode fiber (SSMF).

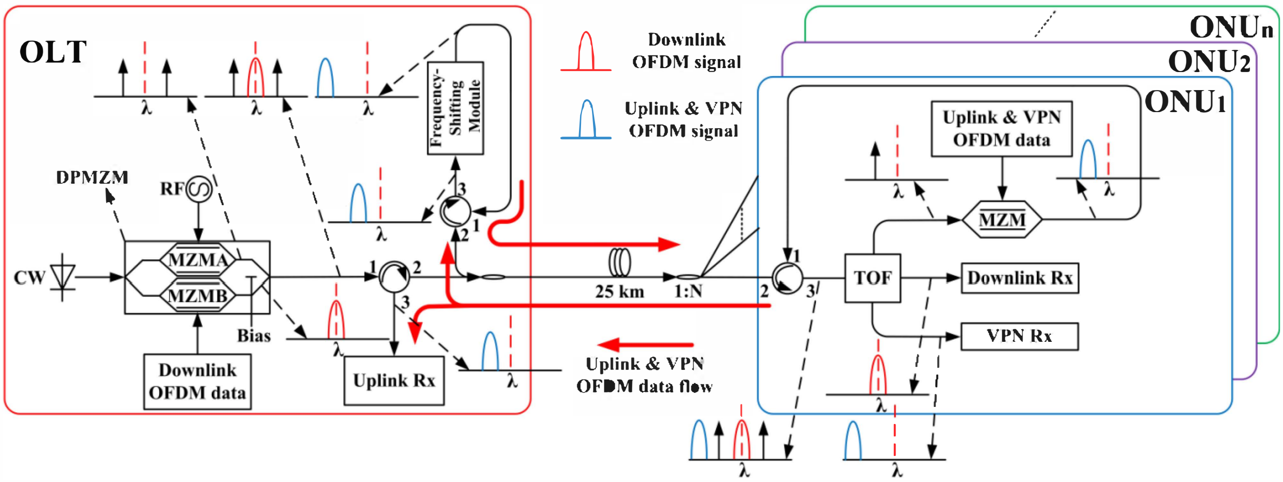

Fig. 1. Schematic diagram of the proposed all-optical VPN in OFDMA-PON (TOF: tunable optical filter).

II. PRINCIPLE

Figure 1 illustrates the schematic diagram of our proposed all-optical VPN in OFDMA-PON system. At the OLT, a continuous-wave (CW) is launched into a dual-parallel Mach-Zehnder modulator (DPMZM) [7], which comprises two sub-MZMs (MZMA, MZMB) nested within the main modulator. MZMA is utilized to generate an OCS signal, while MZMB is employed to generate the downlink OFDM signal modulating on the original optical carrier. By adjusting the bias of the main MZM, the two optical signals are added constructively to form a downlink three-tone signal. The three-tone signal is transmitted to remote node (RN) over 25-km SSMF and split by a 1:N splitter. At the ONUs, after filtered out by a tunable optical filter (TOF), the downlink OFDM signal is detected by a downlink receiver. Meanwhile, the left tone of the downlink signal depicted in the insets of Fig. 1 is selected and fed into a single-drive MZM, which is biased at the quadrature point and driven by the combined electrical OFDM signal. The combined signal consists of the uplink and VPN data. At the OLT, an uplink receiver is used to retrieve the uplink data for each corresponding ONU. Meanwhile, the combined signal is frequency shifted using a frequency-shifting module to avoid spectral overlapping with the downlink signal. Subsequently, the frequency-shifted signal is combined with the downlink signal and sent back to each ONU, where it is detected by a VPN receiver.

III. EXPERIMENTAL SETUP AND RESULTS

We perform a proof-of-concept experiment to verify the feasibility of our proposed all-optical VPN in OFDMA-PON system as shown in Fig. 2. At the OLT, a CW light from a tunable laser at 1549.75 nm is launched into a 10-GHz DPMZM. MZMA is biased at the null point and driven by a 10-GHz clock signal, while MZMB is biased at the quadrature point and driven by the downlink electrical OFDM signal. The OFDM signal is generated offline by Matlab and output by an arbitrary waveform generator (AWG Tektronix 7122C) at a bit rate of 5 Gb/s. The total subcarrier number is 256 with 64 data-bearing sub-carriers. 16 QAM is used for symbol mapping. Real numerical output data is generated by conducting 256-point IFFT with Hermitian symmetry. By adjusting the bias of the main MZM, a three-tone downlink signal is generated at the output of the DPMZM, whose spectrum is shown in Fig. 3(a). An erbium-doped fiber amplifier (EDFA) is used to amplify the downlink signal and a following TOF is utilized to suppress amplified spontaneous emission (ASE) noise. At the ONU side, a 1:8 splitter is emulated by a 9-dB attenuator. A fiber Bragg grating (FBG) is utilized to select the left tone of the signal. Fig. 3(b) and (c) provide the spectra of the passing and reflected parts from the FGB, respectively. The optical

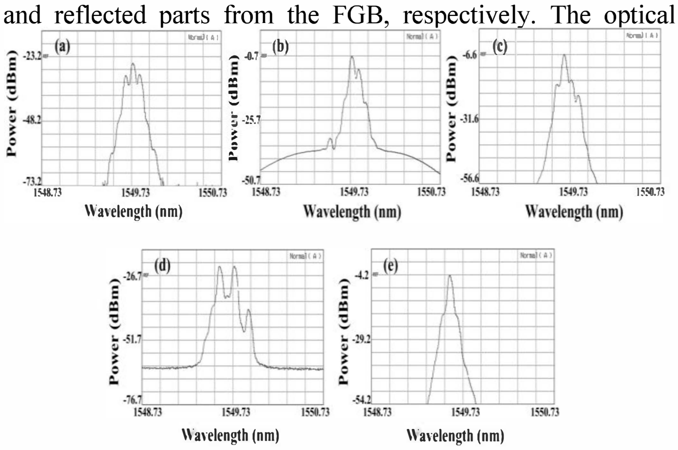

Fig. 3. Optical spectra taken at different positions as indicated in Fig. 2. Spectral resolution: 0.07 nm, X-axis scale: 0.2 nm/div, Y-axis scale: 5 dB/div. (a) downlink three-tone signal, (b) passing part from the FBG, (c) reflected part from the FBG, (d) frequency-shifted combined signal, (e) single-tone frequency-shifted combined signal.

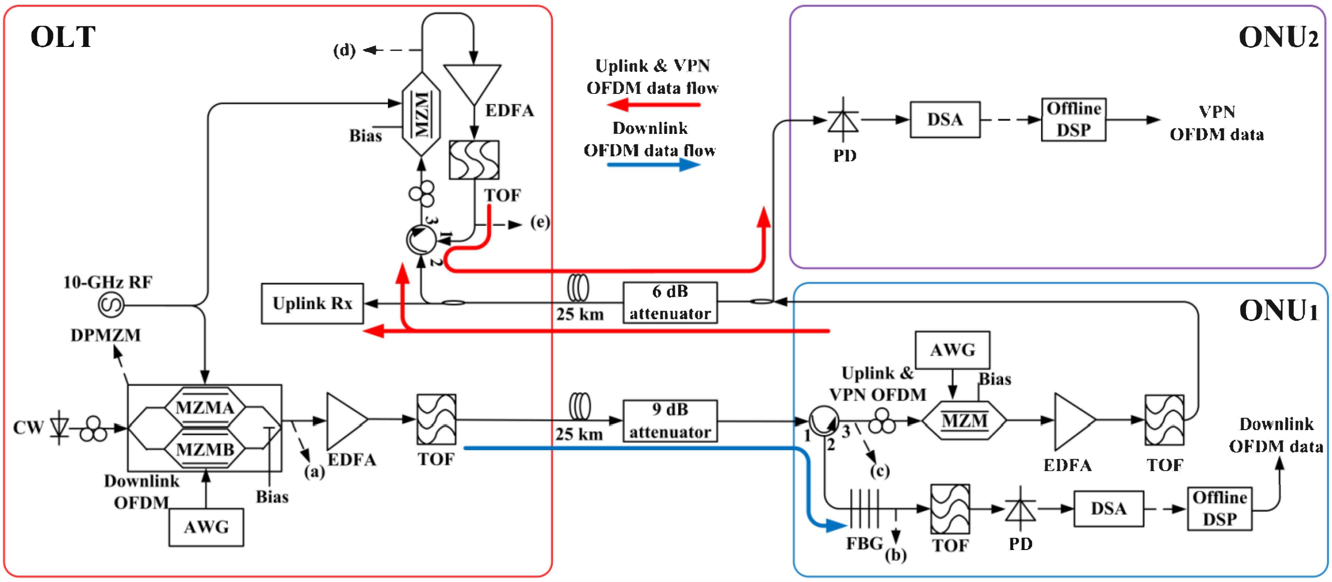

Fig. 2. Experimental setup of the proposed all-optical VPN in OFDMA-PON. (a)-(e) correspond to the optical spectra shown in Fig. 3.

carrier carrying the downlink OFDM signal is selected by an optical filter (Alnair BVF 200) and then detected by a 10-GHz photo detector (PD). The combined electrical OFDM signal is modulated on the reflected left tone from the FBG. The 5-Gb/s combined 16-QAM OFDM signal contains both uplink data and VPN data. Here, three cases are considered: 1) 5-Gb/s uplink data; 2) 3.75-Gb/s uplink data and 1.25-Gb/s VPN data; 3) 1.25-Gb/s uplink data and 3.75-Gb/s VPN data. In case 1, there is no VPN communication between ONU_1 and ONU_2, and 64 sub-carriers are all assigned to the uplink data. In case 2, the traffic demand of VPN communication is low. 48 and 16 sub-carriers are allocated to the uplink and VPN data, respectively. In case 3, the traffic demand of VPN communication is high, 16 and 48 sub-carriers are allocated to the uplink and VPN data, respectively.

At the OLT, the combined signal is split into two parts using a 50:50 optical coupler. One part is detected by a 10-GHz PD to recover the uplink data, while the other part goes through a loop for frequency shift as depicted in Fig. 2. The MZM is biased at the null point and driven by a 10-GHz clock signal to generate an OCS combined signal. The spectrum of the output of the MZM is provided in Fig. 3(d). The separation of the two tones of the OCS combined signal is 20 GHz. The right tone is removed by a TOF to generate a frequency-shifted combined OFDM signal, whose spectrum is provided in Fig. 3(e). Subsequently, the frequency-shifted signal is sent to ONU_2, where it is detected by a 10-GHz PD and the VPN traffic is retrieved. In our experiment, after detected by 10-GHz PDs, the downlink and combined OFDM signals are sampled by a Tektronix real-time oscilloscope (DSA 70804), and processed offline.

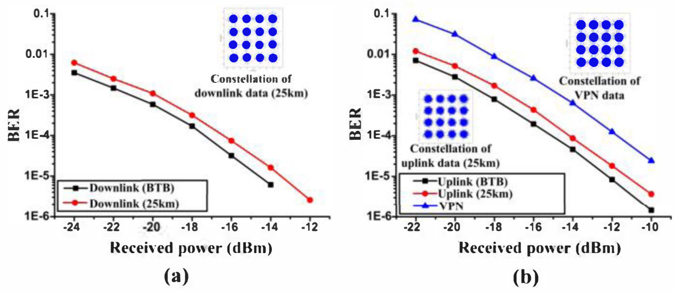

Fig. 4. BER curves and constellations of (a) the downlink OFMD data, (b) the uplink and VPN OFDM data in case 2.

The measured bit error rate (BER) curves and corresponding constellations of the downlink, uplink and VPN OFMD data are shown in Fig. 4. The BER curves of the uplink and VPN data in all the three cases show little difference. Fig. 4(b) depicts the BER curves of the uplink and VPN data in case 2. After transmission of the 25-km SSMF, error-free performance can be obtained with forward error correct for the downlink and uplink signals with 1.1-dB power penalty. For the VPN signal, compared to the uplink signal in the 25-km fiber transmission case, the power penalty is 2.8 dB.

IV. CONCLUSION

We have proposed and demonstrated a novel scheme to support flexible all-optical VPN in OFDMA-PON with source-free ONUs. In our scheme, each ONU is source-free and the bit rates of VPN traffic can be varied. The feasibility of our proposal is experimentally demonstrated.

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REFERENCES

[1] D. Qian, N. Cvijetic, J. Hu, and T. Wang, "A novel OFDMA-PON architecture with source-free ONUs for next-generation optical access networks," IEEE Photon. Technol. Lett., Vol. 21, no. 17, pp. 1265-1267, Sep. 1, 2009.

[2] Y. Lin, P. Tien, M. C. Yuang, S. Lee, J. Chen, S. Chen, Y. Huang, J. Shih, and C. Hsu, "A novel optical access network architecture supporting seamless integration of RoF and OFDMA signals," in European Conference on Optical Communication, paper P6.13, 2009.

[3] Y. Su, Y. Tian, E. Wong, N. Nadarajah, and C. Chan, "All-optical virtual private network in passive optical networks," Laser Photon. Rev., Vol. 2, no. 6, pp. 460–479, Sep. 24, 2008.

[4] X. Hu, L. Zhang, P. Cao, G. Zhou, F. Li, and Y. Su, "Reconfigurable and scalable all-optical VPN in WDM PON," IEEE Photon. Technol. Lett., Vol. 23, no. 14, pp. 941-943, Jul. 15, 2011.

[5] J. L. Wei, C. Sánchez, R. P. Giddings, E. Hugues-Salas, and J. M. Tang, "Significant improvements in optical power budgets of real-time optical OFDM PON systems," Opt. Exp., Vol. 18, no. 20, pp. 20732–20745, Sep. 27, 2010.

[6] C. Zhang, J. Huang, C. Chen, and K. Qiu, "All-optical virtual private network and ONUs communication in optical OFDM-based PON system," Opt. Exp., Vol. 19, no. 24, pp. 24816–24821, Nov. 21, 2011.

[7] Q. Chang, H. Fu, and Y. Su, "Simultaneous generation and transmission of downstream multiband signals and upstream data in a bidirectional radio-over-fiber system," IEEE Photon. Technol. Lett., Vol. 20, no. 3, pp. 81-183, Feb. 1, 2008.