Optical VPN in PON Based on DPSK Erasing/Rewriting and DPSK/IM formatting using a Single Mach-Zehnder Modulator

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Abstract *We demonstrate a novel PON scheme enabling optical VPN functionality using DPSK/IM format. DPSK is used for downstream and upstream traffic, while IM is superimposed on the DPSK signal for VPN traffic.*

Introduction

Passive Optical Network (PON) has been an attractive solution to providing broadband access. Optical-layer virtual private network (VPN), as a promising approach to meeting a wider range of service demands, implements direct optical connections among optical network units (ONUs) so that the throughput is effectively increased and the latency is reduced compared with conventional PONs [1]. Optical VPN also provides enhanced security for ONU users. Recently, several optical VPN configurations were reported [1]-[3]. However, in all these demonstrations at least one laser is required at each ONU, and intensive scheduling is necessary for upstream, downstream and VPN traffic. In this paper, we propose and demonstrate a novel optical VPN in a PON using orthogonal differential phase shift keying/intensity modulation (DPSK/IM) format. At the ONU, the downstream data in DPSK format is erased and then the upstream data is rewritten on the optical carrier. Simultaneously, the VPN data is superimposed on the DPSK signal by modulating its intensity. The downstream DPSK erasing, the upstream data rewriting, and the VPN data superimposing are all implemented by the use of a single Mach-Zehnder modulator (MZM). The proposed scheme possesses several attractive features: no laser is needed at the ONU side, which reduces the cost of the VPN/PON; a single standard MZM is employed for DPSK erasing/rewriting and DPSK/IM formatting, which is cost-effective; finally scheduling can be greatly simplified by employing orthogonal DPSK/IM data format for upstream and VPN traffic.
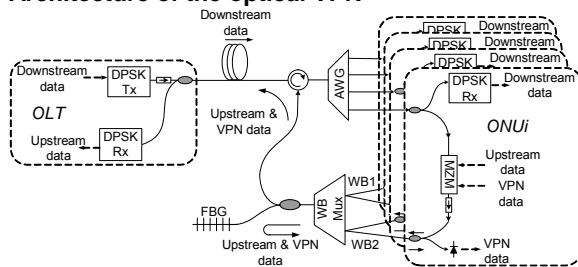
Architecture of the optical VPN

Fig. 1 The architecture of an optical VPN in a PON. WB: waveband.

Fig. 1 shows the architecture of the proposed optical VPN based on a waveband PON [3]. The downstream packets are sent from the OLT to the ONUs at a wavelength λ_i in DPSK format, selected by the corresponding ONU and subsequently demodulated. The upstream signal, which contains upstream and VPN data, is split into two parts by a 1x2 coupler. One is transmitted through a circulator to the OLT, while the other is reflected by a fiber Bragg grating (FBG) next to the coupler and broadcasted within the VPN.
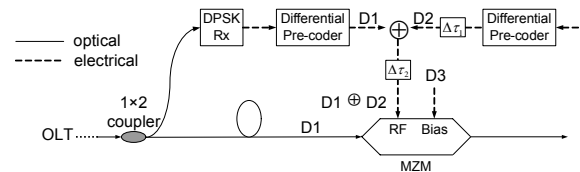

Fig. 2 Simultaneous DPSK erasing/rewriting and DPSK/IM formatting using a single MZM, D1: downstream data, D2: upstream data, D3: VPN data.

Fig. 2 illustrates the operation of the MZM in the ONU for DPSK erasing/rewriting and DPSK/IM formatting. Before re-modulation, a pre-coded data $D1 \oplus D2$ is obtained through an XOR logic operation on the demodulated downstream data D1 and the upstream data D2, both differentially pre-coded. The operation of $D1 \oplus D2$ on the input data D1 when the MZM is biased at a null point results in $(D1 \oplus D2) \oplus D1$, which is D2. Frame synchronization is necessary between D1 and $D1 \oplus D2$, which can be controlled by an electronic buffer or a phase shifter. The VPN data D3 is superimposed onto the DPSK signal by modulating the bias point of the MZM between the null point and a small fraction of V_π [4].
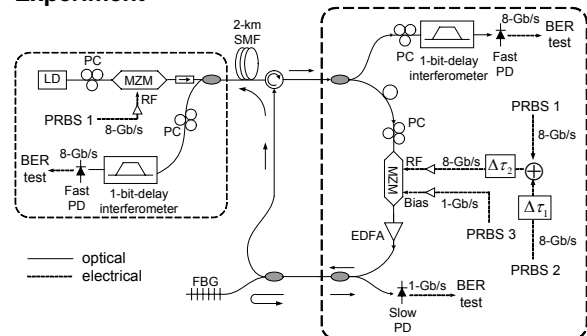
Experiment

Fig. 3 Experimental setup. PC: polarization controller.

To verify the operation principle of the optical VPN in the PON, we performed simultaneous transmission of upstream and downstream signals, as well as VPN internetworking.

As shown in Fig. 3, two non-return-to-zero (NRZ) data streams with a pseudo-random bit sequence (PRBS) length of 2^{31}-1 are used to drive the respective MZMs to generate the downstream and upstream DPSK signals at a data rate of 8-Gb/s, to match with the 1-bit delay interferometer that is available. Note that differential pre-coding is not necessary for PRBS data. The VPN traffic is a 1-Gb/s NRZ data stream with a PRBS length of 2^{7}-1. An electronic phase shifter is employed for synchronization between the upstream and the downstream data. The upstream data is demodulated at the OLT side by a DPSK receiver with a 10-Gb/s photo detector (fast PD), and the VPN data is received at the ONU side by a 2.5-Gb/s receiver (slow PD). For the VPN data, the peak driving voltage at the bias port of the MZM is chosen such that the ratio of level '1' to '0' is 2:1. The particular modulator driver used in this demonstration cannot provide an output swing of $2V_\pi$, therefore we did not demonstrate simultaneous IM and DPSK modulation. Instead, the upstream and the intra-VPN traffic are transmitted separately, and in this case scheduling is needed to avoid contention between the non-VPN and intra-VPN traffic. If a high-output-power driver as in [4] were available, simultaneous modulation and data transmission would be achievable, thus eliminating the need for scheduling. For proper erasing/rewriting, the optical power sent to the DPSK demodulator at the ONU should be high enough to ensure the downstream transmission free of error, judging from the BER curve shown in Fig. 4. To avoid differential pre-coding, the downstream electrical PRBS instead of the decoded optical signal is employed for DPSK erasing/rewriting.
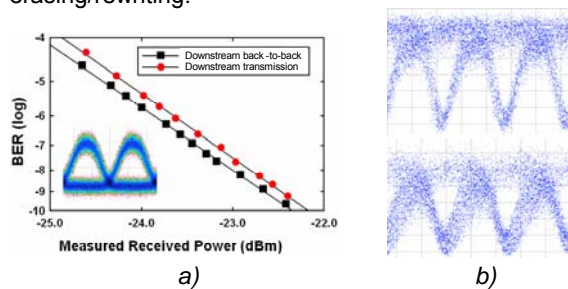

a)   *b)*

Fig. 4 (a) Measured BER performance for downstream transmission, (b) eye diagrams of the downstream signal (upper) and the upstream signal after rewriting (lower). Inset in a: eye diagrams of downstream signal after the interferometer.

Fig. 4b shows the measured eye diagrams for the downstream DPSK signal before the interferometer and the upstream signal after rewriting. The upstream DPSK signal shows more residual amplitude modulation, which may be attributed to slight misalignment between the downstream and the upstream data. The BER measurement and the eye diagram after DPSK decoding for upstream transmission are provided in Fig. 5a.
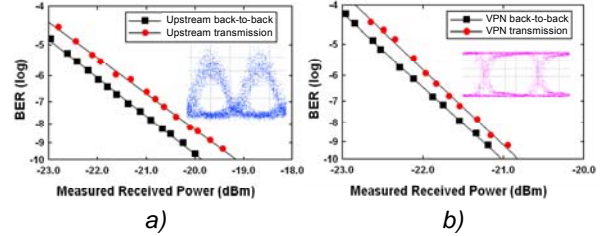

a)   *b)*

Fig. 5 Upstream transmission (a), and VPN traffic (b). Insets: upstream eye diagrams after the interferometer (in a), and demodulated VPN traffic (in b).

For intra-VPN data encoding, the RF port of the MZM is held at "0" level, therefore no erasing/rewriting operation is performed but only IM is superimposed on the downstream data. The 2.5-Gb/s PD for VPN demodulation filters out the residual amplitude modulation of the 8-Gb/s DPSK signal. Fig. 5b shows the BER curves for back-to-back operation and after transmission, with an inserted electrical eye diagram of the VPN data after the PD.

The experiment proves the feasibility of an optical VPN in a PON using DPSK erasing/rewriting and orthogonal DPSK/IM formatting by a single MZM. Such a potentially low-cost and simple architecture of VPN/PON enables high throughput and low latency [3]. It is expected that the cost of each ONU can be further reduced if a narrowband Gaussian shaped fiber Bragg grating filter is employed as the DPSK demodulator instead of a 1-bit-delay interferometer, which has been demonstrated in [5].

Conclusions
We have proposed and experimentally demonstrated a novel cost-effective scheme of optical VPN in PON, which is based on DPSK erasing/rewriting and orthogonal DPSK/IM format. Only a single MZM is employed and no laser is needed in each ONU.

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