

# All-Optical Virtual-Private-Network in Access Networks

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**Abstract:** We present four schemes to realize all-optical virtual-private-network (VPN) in access networks, particularly in passive optical networks (PONs). The all-optical VPN improves the network performance and enhances the security.

## 1. Introduction

In access areas, passive optical network (PON) has become an attractive architecture for providing services over large coverage area with low cost. A PON consists of multiple optical network units (ONUs) connected to an optical line terminal (OLT) in the central office by an optical distributed network (ODN). The ODN typically contains a single optical fiber and a passive star coupler. Recently, there arise demands for supporting private communications for the ONUs in a PON. Users in different locations may need to communicate with each other as if they were in a same local area network. However, the traditional PON is inefficient to provide services for the private communications due to the fact that the ONU-ONU traffic suffers the electronic processing in the OLT, and the round-trip propagation delay. Also, the security of private ONU-ONU communications is vulnerable because of the broadcasting nature of the PON in the downstream direction. In virtual private network (VPN) applications where the ONU-ONU communication is frequent, the problems are pronounced and the network performance is significantly degraded. Therefore, in these applications, all-optical interconnection among the ONUs is desired to provide ‘express and private’ paths for ONU communications.

To meet the emerging VPN-application demands, we proposed all-optical VPN in PONs at the physical layer to provide improved network performance and enhanced security. We introduce a waveband-selection technique in the traditional PONs. A collection of the ONU users in a same group are assigned a set of wavelengths in a same waveband associated with an optical VPN, and they are connected all-optically (Fig. 1). We have proposed and demonstrated four physical-layer schemes [1-4] to realize the all-optical interconnection of the ONUs in VPNs, so that the new architectures possess some features including: a) high-speed interconnection: the electronic processing in the OLT is avoided; b) parallel data-transfer: parallel scheduling of multiple data streams is allowed; c) security enhancement: the VPN traffic in different VPNs is isolated and the security is improved.

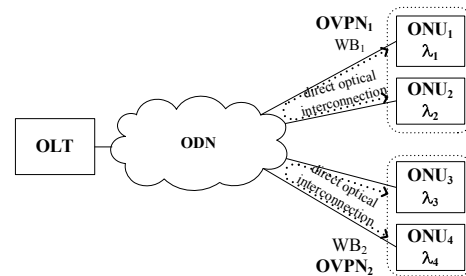


Fig. 1: All optical connection of ONUs.

## 2. Implementations of all-optical VPN in PONs

A PON should be able to support different types of traffic, including downstream traffic, upstream traffic, regular ONU-ONU traffic, and VPN traffic. We use a waveband-selection technique to partition the ONUs into different VPNs. Here, each ONU is assigned a wavelength, and a collection of adjacent wavelengths define a waveband. Based on such waveband partition of the wavelengths, the ONUs are grouped into different VPNs, where the ONUs are all-optically interconnected. Hence, in a PON, multiple OVPNs can coexist by employing the waveband-selection technique.

### *Waveband-Reflector based WSPON (WR-WSPON) [1]*

A WR-WSPON is shown in Fig. 2. A dynamic waveband reflector is installed at the OLT for each VPN. The reflector has two states: *Pass Through* and *Reflect*. When the reflector of a VPN is in the state of *Pass Through*, the OLT and the ONUs in the corresponding OVPN can exchange the non-VPN data. If there are several reflectors in this state, the upstream transmission should be packet-interleaved in time as in traditional PONs but at different wavelengths, since there is only one broadband receiver in the OLT to receive the data from all ONUs.

### *Time-Division-Multiplexed-Frequency-Division-Multiplexing (TDM-FDM) based WSPON (TF-WSPON)[2]*

The WR-WSPON may show several drawbacks, such as traffic contention and poor security. In this part, we propose another architecture, called TF-WSPON, where a TDM-FDM modulation format is used in each ONU to enable the simultaneous transmission of the upstream data and VPN data.

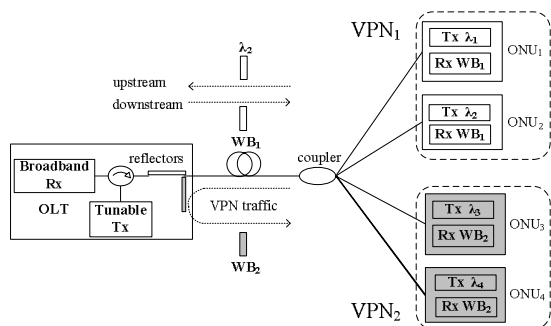


Fig. 2: Waveband-reflective VPN.

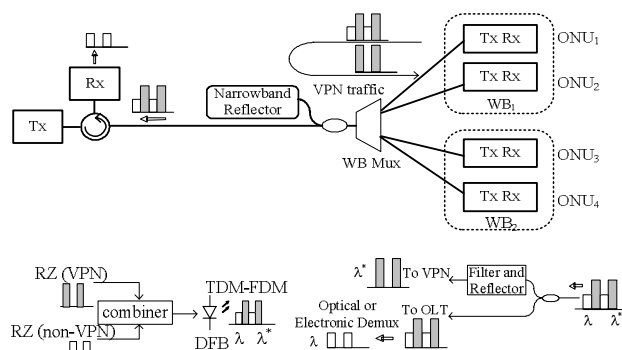


Fig. 3: VPN based on TDM-FDM format.

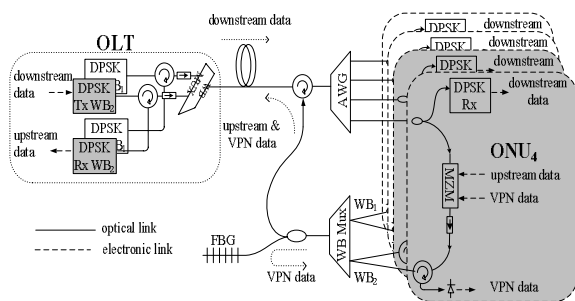


Fig. 4: ASK modulation (VPN data) on top of DPSK format (downstream and upstream re-modulation).

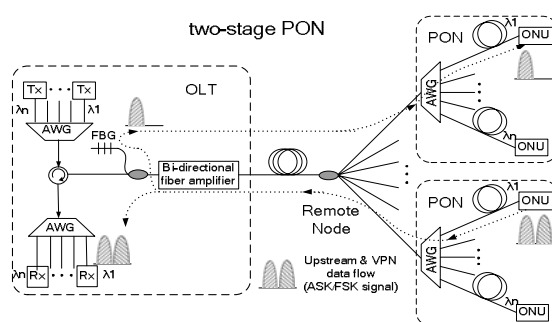


Fig. 5: FSK format (VPN) on ASK modulation (upstream).

The TDM-FDM format (Fig. 3) is typically generated by directly driving a semiconductor laser diode (LD). The driving signal to the LD is multiplexed in time from two-tributary data for the VPN traffic and non-VPN traffic, respectively. The two TDM tributaries possess different amplitudes, which cause certain frequency difference and result in an FDM signal. Therefore we term this format as TDM-FDM.

#### Hybrid Modulation (HM) based WSPON (HM-WSPON)[3]

The third scheme is proposed to remove the contention among different types of traffic in a same OVPN. In this scheme, the contention between the VPN data and non-VPN data in a same OVPN is removed by using an orthogonal Differential Phase Shift Keying/Intensity Modulation (DPSK/IM) format in the ONU as shown in Fig. 4. Particularly, the DPSK format is used for the non-VPN traffic and the IM format for the VPN traffic. Thus a WSPON employing this hybrid modulation (HM) format is termed HM-WSPON.

#### Scalable WSPON using ASK/FSK Format for VPN in different PONs[4]

To enable optical VPN service in different access networks, we have demonstrated a scalable optical VPN in a two-stage TDM-WDM PON. In Fig. 5, at the OLT, a bidirectional fiber amplifier is used to amplify the upstream and downstream signals. By using an orthogonal amplitude-shift keying/frequency-shift keying (ASK/FSK) modulation format in each ONU to simultaneously transmit the VPN and upstream traffic, only a single fiber Bragg grating (FBG) is needed in the OLT to reflect back the VPN signals from the ONUs in the same VPN.

### 3. Conclusion

We have proposed and experimentally demonstrated four all-optical VPNs in PONs. The VPN implementations increase the network performance and enhance the security. The author would like to thank Yue Tian and Tong Ye for the significant contributions. This work was supported by the NSFC (60407008), the 863 High-Tech program (2006AA01Z255), the key project of Ministry of Education (106071), and the Fok Ying Tung Fund (101067).

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