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Virtual Private Group Formation in a WDM Passive Optical Network

Qiguang Zhao and Chun-Kit Chan
Department of Information Engineering, The Chinese University of Hong Kong, Shatin, N. T., Hong Kong SAR, China
Tel: +852-2609-4325, Fax: +852-2603-5032, Email: qgzhao5@ie.cuhk.edu.hk

Abstract
We propose and demonstrate a multiple virtual private group (VPG) formation scheme for ONUs over a WDM-PON. By employing the novel remote node design, multiple independent ONU-VPGs can be realized with identical inter-ONU transmitters in the optical layer.

1 Introduction

With the increasing demand of the community networking and corporate networking, internetworking communication among optical network units (ONUs) has emerged as an access network design consideration in wavelength-division-multiplexed passive optical network (WDM-PON). Conventional strategies supporting inter-ONU communication would consume the bandwidth of both the downstream and the upstream signals [1]. Therefore, it is highly desirable to offer flexible and arbitrary formation of virtual private groups for ONUs (ONU-VPGs) in WDM-PONs. Electronic code-division multiple access (E-CDMA) technique [2] and subcarrier multiplexing (SCM) technique [3] were utilized to support multiple ONU-VPGs. However, these previous schemes required additional electronic techniques to distinguish among different ONU-VPG traffic and require the processing at higher layers. Moreover, these schemes multiplexed more than one data traffic on the same carrier. Thus the system may suffer from interference, which limits the transmission data rate for the inter-ONU traffic.

In this paper, a novel scheme is proposed and experimentally demonstrated to realize ONU-VPG formation in the optical layer. Compared with other schemes providing ONU-VPG configuration, our scheme can support high data rate up to 2.5-Gb/s for inter-ONU traffic in the optical layer with identical inter-ONU transceivers at all ONUs.

2 Proposed architecture and operation principle

Fig.1 illustrates our proposed architecture of multiple ONU-VPGs over a WDM-PON with N users, where N=8 for illustration. Similar to the conventional WDM-PON architectures, N downstream transceivers in the 1.55μm waveband are designated at the optical line terminal (OLT). The 1×2N (say 1×16) array-waveguide grating (AWG1) is employed at the OLT to multiplex and demultiplex the downstream and the upstream carriers, respectively. A formation example of two ONU-VPGs (ONU-VPG1 & ONU-VPG2) in the network is shown in Fig. 1(b), where five ONUs (ONU1-5) are involved in the ONU-VPG1 and the other three ONUs (ONU6-8) belong to the ONU-VPG2. At the remote node (RN), one 5×5 star-coupler and one 3×3 star-coupler are employed

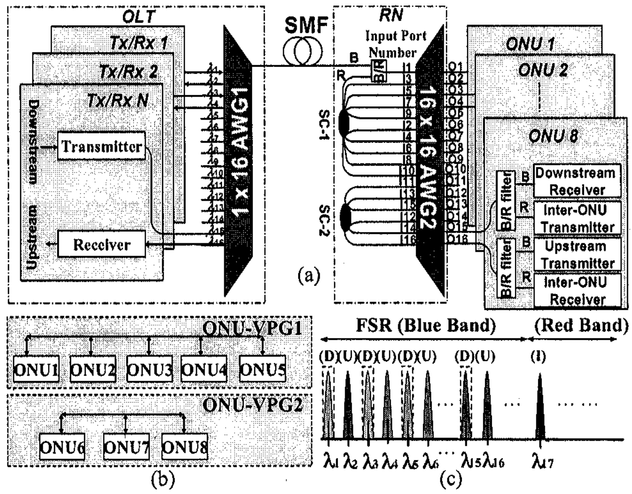


Fig.1.(a) Schematic diagram of proposed WDM-PONs with two ONU-VPGs configuration. (b) Logical connections of an example of two ONU-VPGs in a WDM-PON. (c) Wavelength assignment plan.

to duplicate and broadcast the inter-ONU traffic signals, via the 2N×2N AWG2 (say 16×16) within their respective ONU-VPGs. The connection patterns between the star-couplers and the AWG2 are consistent with the ONU-VPGs configuration. For ONU-VPG1, the input ports of the 5×5 star-coupler are connected to the I1, I3, I5, I7, I9 ports of the AWG2, while their output ports are connected to I2, I4, I6, I8, I10 ports of the AWG2, respectively. Similarly, the connection pattern for the ONU-VPG2 is illustrated in Fig. 1(a). At the ONU, two transceivers are assigned for normal up-/downstream traffic transmission and inter-ONU traffic transmission, respectively. Fig. 1(c) illustrates the wavelength assignment plan. The downstream and the upstream carriers are in the blue-band free-spectral range (FSR) of the AWG2, while the inter-ONU traffic carriers are assigned as the first wavelength λ_{2N+1} (say λ_{17}) in the red-band FSR of the AWG2. Therefore, Blue/Red (B/R) filters are utilized to combine and separate the inter-ONU carrier at the RN and the ONUs, respectively.

The formation of the ONU-VPGs is realized by flexible setting of the star-couplers configuration at the RN. λ_{17}, as shown in Fig. 1(c), is the first wavelength channel in the red-band FSR of the AWG2, and it is assigned as the inter-ONU traffic carrier for all ONUs in the network. A suitable media access protocol, such as carrier-sense multiple access, is assumed to coordinate the data transmission by all ONUs among themselves. According to the wavelength routing principle of the AWG2, λ_{17} has a special correspondence feature between the input port and the output port of the AWG2. That is, when λ_{17} is fed into the k^{th} input port of the AWG2, it would be routed to its k^{th} output port. Hence, when the star-couplers are employed to broadcast this inter-ONU carrier within their respective ONU-VPGs, this special correspondence feature of the AWG2 supports flexible and arbitrary formation of ONU-VPGs by simply connecting the output ports of the star-coupler to the input ports of the AWG2 whose corresponding output ports are connected to the destined inter-ONU receivers in the same ONU-VPG. Under this configuration, the inter-ONU traffic sent from ONU1 would be broadcasted to ONU1, ONU2, ONU3, ONU4, and ONU5 only in ONU-VPG1, while that sent from ONU6 would be broadcasted to ONU6, ONU7 and ONU8 only in ONU-VPG2.

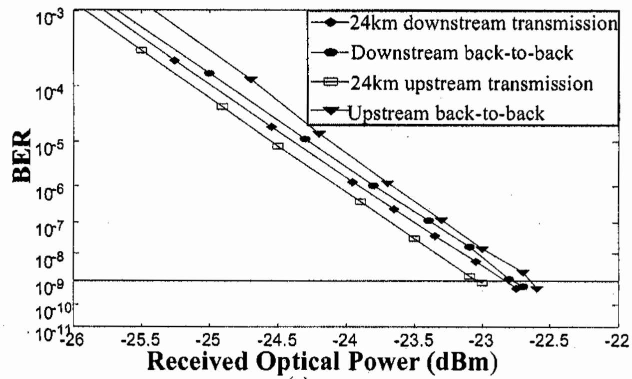
3. Experimental demonstration

The experimental setup was similar to Fig. 1 so as to investigate the functionality and transmission performance of ONU-VPGs formation. Two DFB laser diodes directly modulated by 2^{31}-1 pseudorandom bit sequence (PRBS) non-return-to-zero (NRZ) data at 2.5-Gb/s were employed as the downstream and the upstream transmitters. The upstream signal was received by a p-i-n receiver at the OLT. Two 16×16 AWGs, with an FSR of 12.8 nm and 100-GHz channel spacing, were employed as the AWG1 at the OLT and the AWG2 at the RN. They were connected by a piece of 20-km standard single-mode fiber (SMF), as the feeder fiber. A 4×4 star-coupler was used at the RN, with its first input port connected to the Red/Blue filter (18-nm passband) while the others were directly connected to the designated input ports of the AWG2. The distribution fiber between the RN and the ONU was 4-km SMF. At the ONU, a tunable laser, lasing at 1529.2nm and externally modulated by 2.5-Gb/s NRZ 2^{31}-1 PRBS, was employed as the inter-ONU traffic transmitter, due to component availability. The downstream signal and the inter-ONU traffic signal were received by a 2.5-Gb/s p-i-n receiver and a 2.5-Gb/s avalanche photodiode (APD) receiver, respectively.

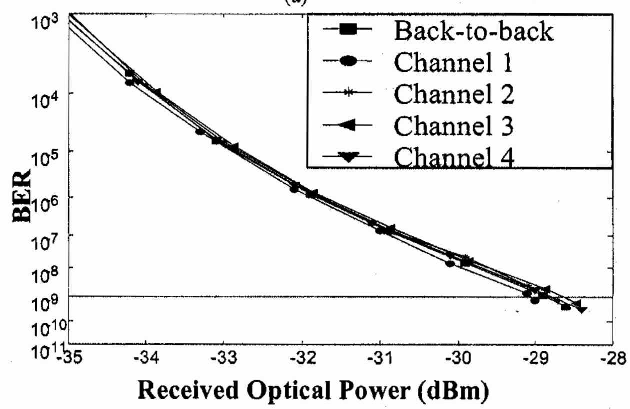
The bit-error-rate (BER) measurement results for the upstream, the downstream as well as the inter-ONU traffic are depicted in Fig. 2. Compared to the back-to-back measurement, the negligible power penalty was less than 0.5 dB for both the downstream and the upstream traffic after 24-km SMF transmission, as depicted in Fig. 2(a). This could be attributed by the fiber chromatic dispersion. The receiver sensitivities at BER=10^{-9} for the downstream and the upstream signals were measured as within -22.5 dBm and -23 dBm. Besides, the broadcasting transmission performance of inter-ONU traffic was also investigated in all four output channels of the star-coupler. As depicted in Fig. 2(b), error free operation was achieved in all cases, with the receiver sensitivities at about -28 dBm.

4 Discussion

The loss budget for the inter-ONU traffic signal was about 22 dB, which include the round-trip transmission between the OLT and the RN via the AWGs (10 dB). Thus it can provide more than 7-dB power margin at the receiver sensitivity of -28 dBm at 2.5-Gb/s, assuming the output optical power of inter-ONU traffic transmitter is 1 dBm. When the commercial AWGs with low insertion loss (3 dB) are employed in practical network deployment, the loss budget can be further reduced by 4 dB. Therefore, our proposed scheme can support up to sixteen ONUs within each ONU-VPG.



(a)



(b)

Fig.2.BER measurements of (a) 2.5-Gb/s upstream and downstream transmission; (b) 2.5-Gb/s inter-ONU traffic transmission, measured at RN.

5 Summary

We have demonstrated a novel ONU-VPGs formation scheme in optical layer for WDM-PONs. The ONU-VPGs formation is realized by the special wavelength assignment and the star-couplers at the RN, where a cyclic AWG is employed. The connection patterns between the star-couplers and the AWG physically partition the network into multiple ONU-VPGs. It is compatible with the conventional WDM-PONs architectures and provides a flexible solution to upgrade it to the WDM-PONs with ONU-VPGs formation capability. This project is partially funded by a research grant from Hong Kong Research Grants Council (Project No. CUHK4142/06E).

6 References

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