A Packet-Switched Waveband-selective PON Enabling Optical Internetworking among ONUs

Yikai Su[1], Peigang Hu[1], Weisheng Hu[1], Jingjing Zhang[1], Lufeng Leng[2], Hao He[1], Xiangqing Tian[1], Yaohui Jin[1]
[1]State Key Lab of Advanced Optical Communication Systems and Networks, Shanghai Jiao Tong University
Shanghai 200030, China, Email: yikaisu@sjtu.edu.cn
[2]New York City College of Technology, City University of New York, 300 Jay Street, Brooklyn, NY 11201, USA

Abstract *We propose and demonstrate a novel packet-switched PON with waveband selectivity in ONUs, which enables internetworking of ONUs in a group. This configuration clearly improves the latency and throughput performance by reducing the electronic bottleneck in the OLT.*

Introduction

Passive optical networks (PONs) [1] have been an attractive approach to providing broadband data communications. Conventional PONs distribute downstream traffic from the optical line terminal (OLT) to optical network units (ONUs) in a broadcast manner, while the ONUs send upstream data packets multiplexed in time to the OLT. This means that the communications among ONUs have to go through the OLT involving electronic processing such as buffering and scheduling, which inevitably introduces latency and degrades the throughput of the network. In applications such as virtual private networks (VPNs) and super-computer interconnections where the communications among ONUs are frequent, the problem is pronounced and the performance of conventional PONs may be significantly degraded due to the electronic bottleneck of the OLT. This problem also exists in wavelength-division-multiplexed (WDM) PONs, which employ multiple wavelengths to provide point-to-point connectivity between OLT terminals and ONUs. To date the inter-ONU networking issue has only been addressed by a few groups. In [2], a specific wavelength is allocated in the PON that uses a fibre Bragg grating on the feeder fibre to broadcast the packets for inter-ONU communications. However, this approach requires two transmitters and two receivers in an ONU, thus doubling the cost of the system. In [3] an N x N star coupler based PON architecture was proposed, reducing one transmitter in every ONU.

In this paper, we propose a novel waveband-selective PON that enables optical internetworking of ONUs within the same waveband (WB). In each ONU only one pair of transmitter/receiver is required. ONUs are grouped into different VPNs according to the WBs assigned to them. The architecture is compatible with conventional PONs therefore upgrade can be easily realised. The VPNs can be implemented by dynamically adjusting a WB reflector at the OLT site to achieve flexible configuration, which is not possible with previous proposals. In the following we experimentally demonstrate this WB-based PON operating at 1.25 Gb/s. A packet-switched ONU is demonstrated to receive optical packets from the VPN and the OLT simultaneously. We also carry out simulations to show the significant performance improvement in reduced latency and increased throughput compared to a conventional PON.

Architecture of the WB-selective PON

The transmitter in an ONU is assigned a specific wavelength, and adjacent wavelengths are grouped to form a WB. The receiver in an ONU is equipped with a WB filter that covers the wavelengths in the VPN. Thus, the transmitted signal from an ONU can be optically re-directed to other ONUs in the same VPN if a WB reflector is employed at the OLT site.

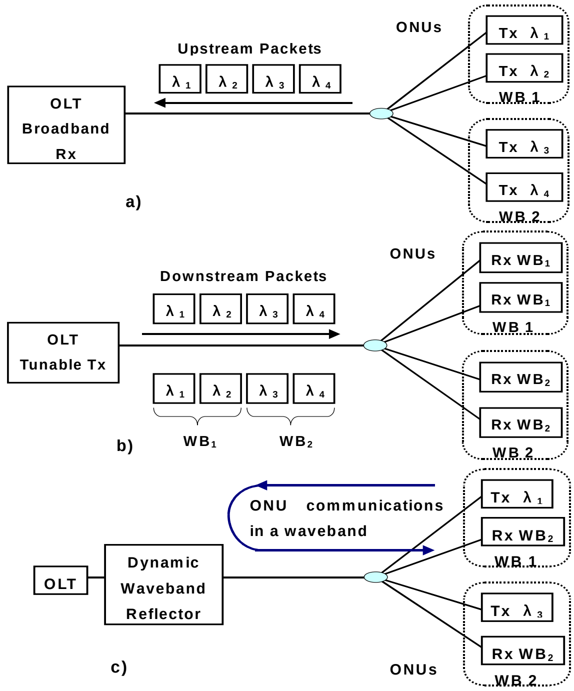

Fig. 1: Three scenarios in PON communications: a). upstream, b). downstream, c) inter-ONUs.

Here we illustrate the operation principle of the proposed WB-based PON by showing three communication scenarios in Fig. 1. The upstream traffic from the ONUs to the OLT is packet-interleaved in time as in conventional PONs but at different wavelengths (Fig 1a). At the OLT, the receiver is broadband to recover packets from all ONUs. The transmitter of the OLT is fast wavelength-tunable so the downstream data can be sent to the intended VPN (Fig. 1b). Within the same VPN the downstream traffic is received by ONUs in the group in a broadcast manner. In the case of inter-ONU communications in a VPN, we place a uni-directional WB reflector that directs the data from an ONU back to the VPN that the ONU belongs to. Therefore, intra-VPN communications can be realised by employing a WB reflector. The WB reflector can be rapidly re-configured to handle dynamic traffic. Scheduling is required with certain modifications based on conventional PONs. Note that the 1xN splitter in the network can be replaced by a low-cost WB multiplxer to reduce the loss and increase the scalability.

Experimental demonstration

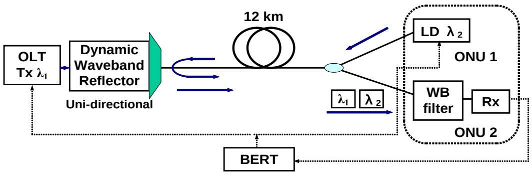

Fig. 2: Experimental setup of the WB-based PON showing its optical internetworking of ONUs.

We perform an experiment to demonstrate the optical internetworking of ONUs while simultaneously receiving the data from the OLT, as shown in Fig. 2. At the OLT site, the wavelength of the transmitter is set to 1547.0 nm, the downstream data pass through a uni-directional re-configurable reflector that reflects the packets from the ONUs and pass through the data from the OLT. Such a dynamic reflector can be in the form of a blocker [4] based on micro-electromechanical-system (MEMS), while in our experiment we simply used a wavelength de-multiplexer with a reflector connected at the proper port. The transmitter wavelength of ONU is 1547.8 nm, which is reflected back and sent downstream. In ONU2, the receiver is equipped with a WB filter having a bandwidth of ~2 nm centred at 1547.4 nm, which is capable of receiving the data from the ONU1 and the OLT. Between the OLT and a 3-dB splitter is a 12-km single mode fibre.

We test the communication from ONU1 to ONU2. To mimic the packet-switching scenario, we set the bit error rate tester (BERT) to 'zero substitute' mode with a pattern consisting of 7 bytes (56 bits) of random data followed by 72 '0's, totalling a period of 128 bits. All the 128 bits were measured to obtain the BER curve as shown in Fig.3. We follow the same procedure to study the downstream communication from the OLT to the ONU2. Similar results were observed. Compared to the back-to-back sensitivity of -23.6 dBm, a small penalty of ~0.8 dB was observed, while the difference in sensitivities tested with the OLT and the ONU is negligible. The above studies verify the feasibility of the optical internetworking of ONUs and the OLT. We also show the pattern when the packets from the ONU and the OLT are interleaved in time. Although the BER measurement cannot be performed in such configuration, we

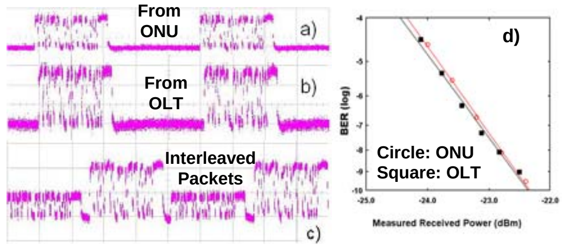

Fig. 3: Waveforms of the packets a) from ONU1, b) from OLT, c) combined, respectively. d) BER curves.

observed the signal waveforms remain unchanged as compared to before they are combined, therefore similar BER performance can be expected.

To show the benefits of inter-ONU communications, we perform simulations to compare this PON with a conventional PON in terms of the latency and the throughput performance as defined in [5]. We assume there are 16 ONUs in the PON, which is a typical scenario in today's access networks. The 16 ONUs are grouped to 4 VPNs each containing 4 ONUs. The traffic demand among ONUs [5] in the same VPN is randomly assigned from 1 slot to a variable '*load*', while the rest of the traffic (OLT to ONUs, communications between ONUs that do not belong to the same VPN) is evenly distributed between 0 and 10 slots. We run the simulation 1000 times and average the results. Fig. 4 shows that with increasing the intra-VPN traffic, the performance of the proposed PON significantly outperforms the conventional PON. This is primarily attributed to the fact that the optical internetworking eliminates the electronic bottleneck at the OLT, thus greatly reduces the latency and increases the throughput.

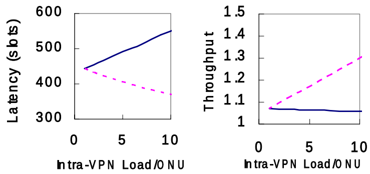

Fig. 4: Improved performance of the proposed PON (dashed) relative to a conventional PON (solid).

Conclusion

We propose and experimentally demonstrate a novel packet-switched PON with ONUs grouped in WBs to form VPNs. An ONU node is demonstrated to receive data packets from another ONU and from the OLT. The significant improvement in latency and throughput is shown through simulations.

Acknowledgement

This work was supported by NSFC 60407008 /90304002, Shanghai Optical Science & Technology 04dz05103, and Shanghai Rising Star 04QMX1413.

References

1 C. Chan and C. Lin, APOC 2003, invited 5282-41.
2 C. Chae et al. PTL, Vol.11 (1999), pp.1686-1688.
3 E. Wong et al. PTL, Vol.16 (2004), pp.2195-2197.
4 R. Ryf et al. JLT, Vol.23 (2005), pp.54-61.
5 Y. Jin et al. ECOC 2004, We4.P140.