A Novel WDM Passive Optical Network with Bi-directional Protection

T. J. Chan, C. K. Chan, K. Chan, W. Hung, and L.K. Chen

Department of Information Engineering, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong SAR.

Tel: +852-2609-8479, Fax: +852-2603-5032, Email: *tjchan1@ie.cuhk.edu.hk*

ABSTRACT

Passive optical networks (PONs) have recently emerged to be a promising approach to enhance the penetration of fiber towards the subscriber side, thus further enables delivery of higher data-rate services to the subscribers. They feature easy network maintenance as there is no active component at the remote node (RN). However, in conventional PONs, both upstream and downstream bandwidths have to be time-shared among all optical network units (ONUs). By applying WDM technique to PONs, the total system capacity can be further enhanced. Each ONU enjoys a dedicated bandwidth and resolves the ranging problem as in PONs.

In both conventional PON and WDM-PON, little work has been done to offer protection capability though fiber fault detection methods have been extensively studied. We propose a novel network architecture for WDM-PON which offers 1:1 protection capability. In case of any fiber cut between remote node and ONUs, the affected ONU can re-route the wavelength channels via the adjacent ONU and can still maintain normal bidirectional traffic.

.

1. INTRODUCTION

The recent availability of low cost optical components has triggered the deployment of optical access networks to further deliver broadband data services to the subscribers. Thus, passive optical networks (PONs) [1] have emerged to be a promising approach to enhance the penetration of fiber towards the subscriber side. They eliminate the power requirement at the remote node (RN), however, both upstream and downstream bandwidths have to be time-shared among all optical network units (ONUs). By applying WDM technique to PON [2] [3], the total system capacity can be further enhanced. Each ONU can thus enjoy a dedicated bandwidth and can also eliminate the ranging problem as in conventional PON.

Currently, little work has been done to offer protection capability in both conventional PON and WDM-PON, although fiber-cut detection methods have been studied extensively. Whenever a fiber link from the RN to the ONU is broken, the affected ONU will become unreachable from the optical line terminal (OLT). This translates into enormous loss in data

Network Design and Management, Qian Mao, Shoa-Kai Liu, Kwok-wai Cheung,
Editors, Proceedings of SPIE Vol. 4909 (2002) © 2002 SPIE · 0277-786X/02/$15.00

and business. In this paper, we propose a novel network architecture for WDM-PON which offers 1:1 protection capability in both downstream and upstream fiber connections. In case of any fiber cut between the RN and an ONU, the "isolated" ONU can still support two-way communications with the OLT by re-routing the wavelength channels via the adjacent ONU.

2. NETWORK DESIGN

2.1 Overview

Fig. 1 shows our proposed network architecture for a WDM-PON with bi-directional protection capability. The RN comprises an array-waveguide grating (AWG) to route the wavelength channels to the ONUs. Every two adjacent ONUs are assigned to a group. Each ONU in a group is separately connected to the same output port of the AWG via a 1×2 3-dB fiber coupler. Thus a network with a $1\times N$ AWG at the RN can support $2N$ ONUs. In each group of ONU, there is a single piece of fiber connecting the two ONUs to provide an alternative path so that any isolated ONU, due to possible fiber cut between itself and the RN, can still route its upstream and downstream traffic to/from the OLT via its adjacent ONU in the same group. Thus the ONUs in each group have mutual 1:1 protection capability, that is, an ONU can protect its adjacent ONU from being isolated due to fiber cut, although each of them can still serve their respective connected subscribers in both normal and protection modes.

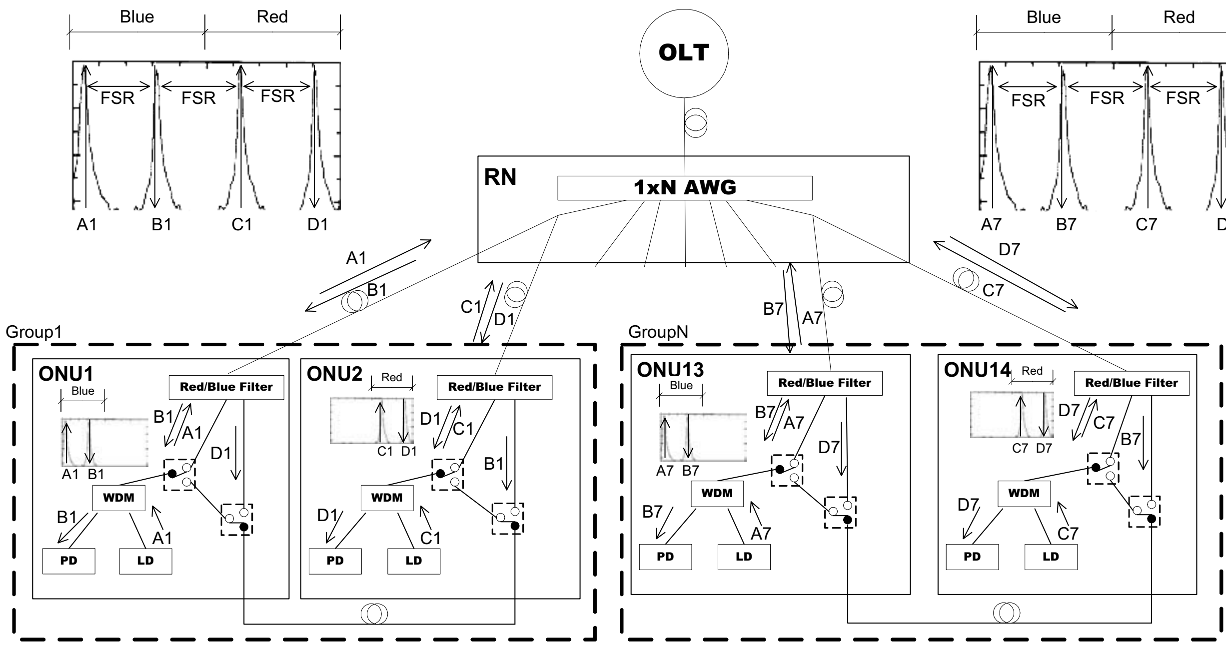

Fig.1: The proposed WDM-PON under normal operation. Insets show the corresponding optical spectra in the fiber links connecting the RN and the respective ONUs. (WDM: WDM Coupler; LD: laser; PD:photodiode)

2.2 Working Principle

Under normal operation (see Fig. 1), the downstream wavelengths, **Bi** and **Di**, are carried on the fiber link connecting to ONU(2i-1) and the same composite signal is also delivered to ONU(2i). At the front-end of ONU(2i-1), its destined downstream wavelength, **Bi**, will be filtered out by the Red/Blue filter and so is **Di** in ONU(2i). The use of the WDM coupler is to separate the upstream and downstream wavelengths within the ONU.

For upstream wavelengths, **Ai** from ONU(2i-1) and **Ci** from ONU(2i) will pass through their own Red/Blue filters and their respective fiber links. They are then combined before being fed into the same output port of the AWG. In case of fiber cut at the fiber link connecting to ONU(2i), the ONUs in the same group would be reconfigured as illustrated in Fig. 2. Both upstream and downstream wavelengths of the isolated ONU(2i) will be routed to the ONU(2i-1) via the single fiber connecting between them. These re-routed wavelengths will be multiplexed with the existing wavelengths in ONU(2i-1) so that ONU(2i) can still communicate with the OLT. Conversely, ONU(2i) protects ONU(2i-1) in a similar way. With this protection mechanism, a fast restoration of the broken connection can be achieved, with minimal affect on the existing traffic.

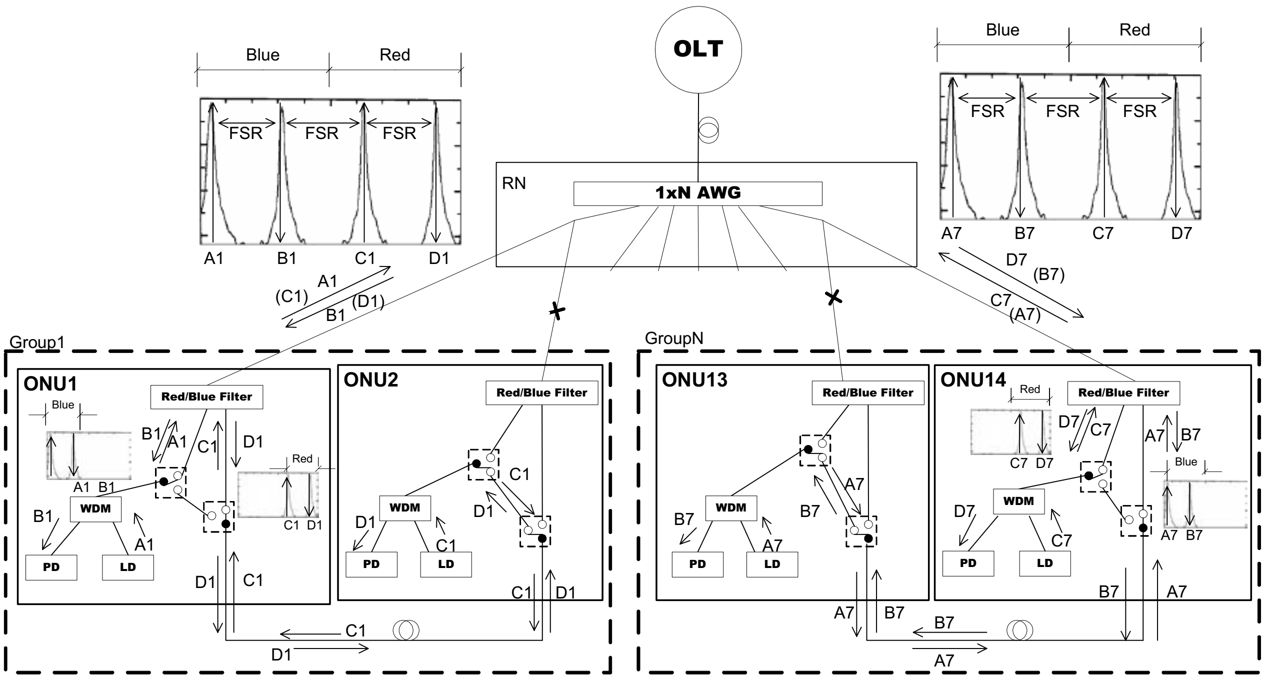

Fig. 2: The proposed WDM-PON when the fiber links connecting to ONU 2 and to ONU 13 are broken. The wavelength labels in brackets mean re-routed wavelengths.

2.3 Wavelength Assignments

For each ONU, two distinct wavelengths are assigned for upstream and downstream signals. Moreover, as two adjacent ONUs in the same group are actually connecting to the same output port of AWG at the RN, We make use of the spectral periodicity property of AWG to support the set of working and re-routed wavelengths.

To illustrate the wavelength assignment, the upstream and downstream wavelengths for ONU1 are labeled as **A1** and **B1**, respectively, while that for ONU2 (in the same group) are labeled as **C1** and **D1**. **A1** and **B1** are chosen to be spectrally-spaced by one free spectral range (FSR) of the AWG and similar rule applies to **C1** and **D1**. **C1** is also one FSR away from **B1**, thus four wavelengths (**A1**, **B1**, **C1** & **D1**) are equally spaced by one FSR as shown in the inset of Fig. 1. Using the same principle, the wavelength assignment for the other ONUs are tabulated in Table 1 as an example, assuming N=7 and with ITU-grid (100GHz) wavelengths. Note that **Ai** and **Ci** are the upstream wavelengths for ONU(2i-1) and ONU(2i) while **Bi** and **Di** are the corresponding downstream wavelengths.

Channel no	Wavelength value	Channel no	Wavelength value	Channel no	Wavelength value	Channel no	Wavelength value
A1	1532.29	**B1**	1539.37	**C1**	1546.52	**D1**	1553.73
A2	1533.07	**B2**	1540.16	**C2**	1547.33	**D2**	1554.54
A3	1533.86	**B3**	1540.95	**C3**	1548.11	**D3**	1555.34
A4	1534.64	**B4**	1541.75	**C4**	1548.91	**D4**	1556.15
A5	1535.43	**B5**	1542.54	**C5**	1549.72	**D5**	1556.96
A6	1536.22	**B6**	1543.33	**C6**	1550.52	**D6**	1557.77
A7	1537.00	**B7**	1544.13	**C7**	1551.32	**D7**	1558.58

Table 1: Wavelength assignment.

2.4 Power Budget Analysis

Assuming the transmitted powers from the LDs in the ONUs are 0 dBm, the receiver sensitivities of the photodiodes at the OLT are –24dBm (at 2.5Gb/s), the insertion losses of optical switches, AWG, Red/Blue filters and WSC are 1dB, 5dB, 1dB and 1dB, respectively; the optical power margin will be 11dB in the re-routing path of upstream traffic, and so is that in downstream traffic. Therefore, a transmission distance of more than 44km can be achieved.

3. EXPERIMENTAL RESULTS

3.1 Experiment

Fig. 3 shows the experimental setup to demonstrate the principles of the bi-directional transmission and protection operations of the proposed WDM-PON network. The laser diodes (LD) used were 2.5Gb/s, directly modulated, while each of the arrayed-waveguide gratings (AWGs) had 16 channels with 100-GHz channel spacing and had an FSR of 12.8nm. Each Red/Blue filter had a bandwidth of about 18nm in each passband. On the OLT side, EDFAs were inserted in front of the AWG in order to compensate the components' insertion losses and to achieve the required transmitted power.

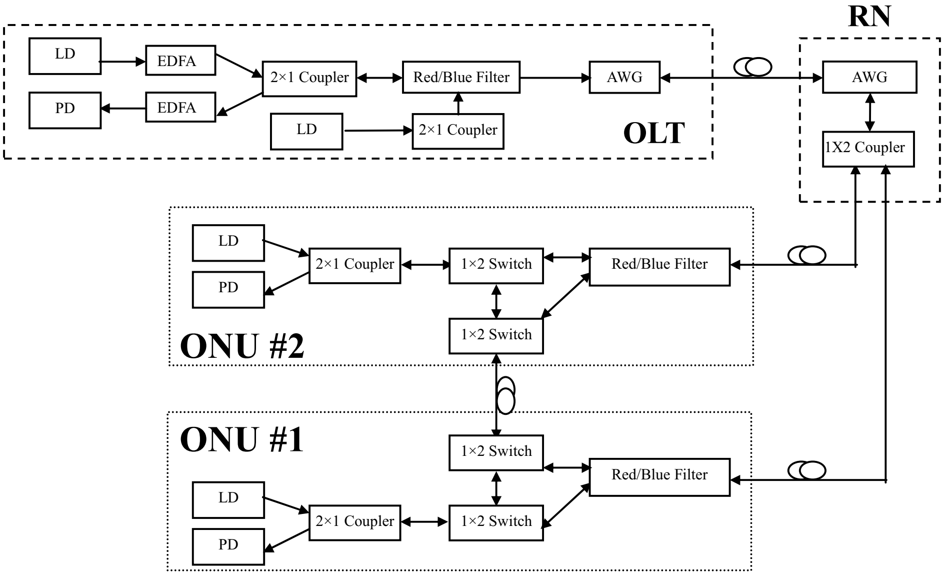

Fig. 3. Experimental setup

3.2 Results

At OLT, two DFB lasers were used illustrate the operation of the downstream side of the system. First, the two downstream wavelengths (B1 & D1) were combined by the Red/Blue filter (Fig. 4(a)), and then passed through the AWG in the OLT. Fig. 4 (a) shows the optical spectrum of output signal from OLT. The downstream signal was then passed over a piece of 18km single-mode fiber to the RN's AWG and then reached the ONU#1 and ONU#2. At ONU#1 and OLT#2, the two downstream wavelengths were separated by a Red/Blue filter and each of them was detected at the respective ONU. Figs. 4(b) and 4(c) show the optical spectra of the downstream wavelength, B1, received at ONU#1 and the downstream wavelength, D1, received at ONU#2. We have also measured the bit-error-rate (BER) performance using 2.5Gb/s $2^{23}-1$ PRBS data and the results are depicted in Fig. 5.

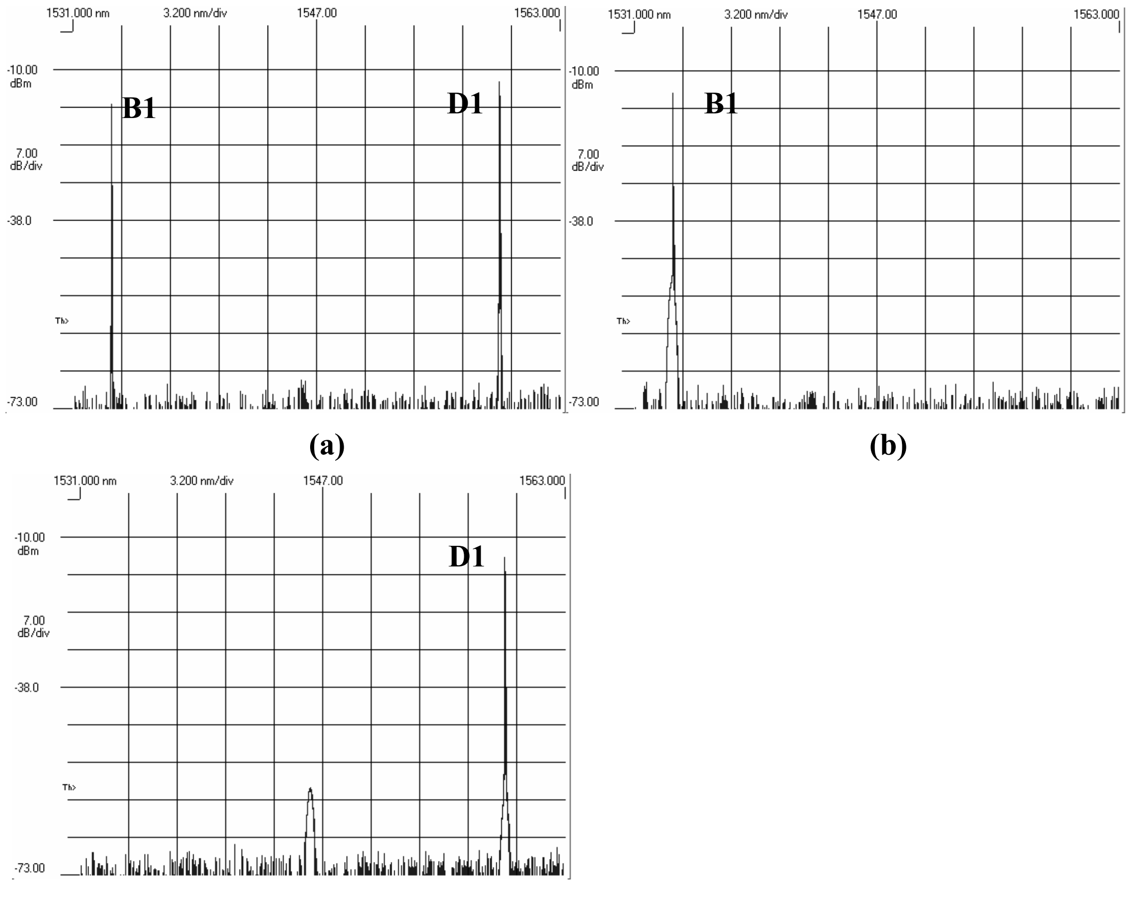

Fig. 4 (a) to (c): Optical spectra of the downstream signals at (a) output of OLT; (b) ONU#1; and (c) ONU#2.

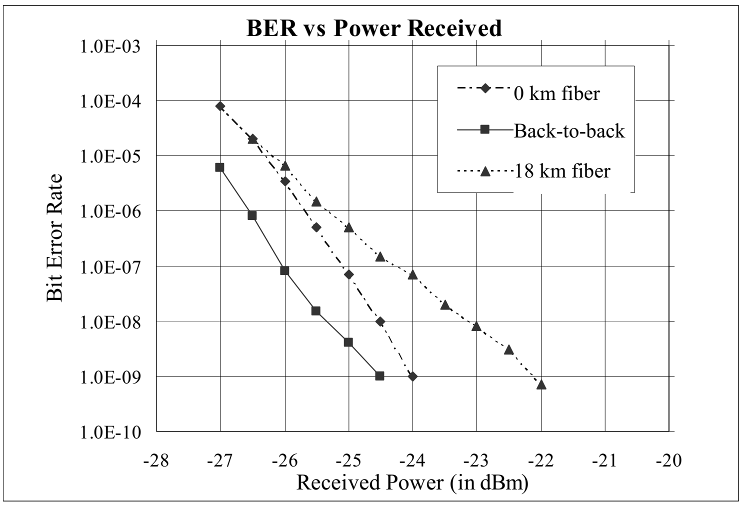

Fig. 5: BER performance of the 2.5Gb/s downstream wavelength

4. CONCLUSION

We have proposed a novel bidirectional protection scheme for WDM-PONs. By incorporating simple optical switches and optical filters into the ONUs; and by connecting two ONUs in the same group by a single piece of fiber, bi-directional signal re-routing can be achieved. Thus the isolated ONU can still communicate with the OLT in case of fiber cut. The transmission aspect of 2.5Gb/s signals was experimentally characterized. Further work on characterizing the fault detection, protection switching and data restoration are under investigation.

5. REFERENCES

1. D. W. Faulkner, et al, IEEE J. Lightwave. Technol., vol. 7, pp. 1741-51, 1989.
2. N. J. Frigo, et al, IEEE Photon. Technol. Lett., vol. 6, no. 11, pp. 1365-67, 1994.
3. P. P. Iannone, et. al, IEEE Photon. Technol. Lett., vol. 10, no. 9, pp. 1328-30, 1998.