A Survivable WDM PON with Alternate-Path Switching

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Abstract: We propose and demonstrate a survivable WDM PON with simple ONUs. By employing our proposed alternate-path switching scheme, traffic can be restored promptly under feeder and distribution fiber link failures as well as the AWG failure in the RN simultaneously.

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1. Introduction

The ITU-T Recommendation on passive optical networks (PON) (G.983.1) [1] has suggested four possible fiber duplication and protection switching scenarios for reliable data delivery. Recently, we have proposed two wavelength division multiplexing (WDM) PON network architecture [2-3] to provide protection against fiber link failures. In this paper, by duplicating the AWG in the remote node (RN), we propose and investigate a survivable WDM PON with simple optical network units (ONUs). By using the spectral periodicity of the AWG, a novel wavelength assignment plan is proposed and a simple alternate-path switching scheme is employed for protection against both feeder and distribution fiber link failures, as well as the AWG failure at the RN simultaneously.

2. Network Topology and Wavelength Assignment

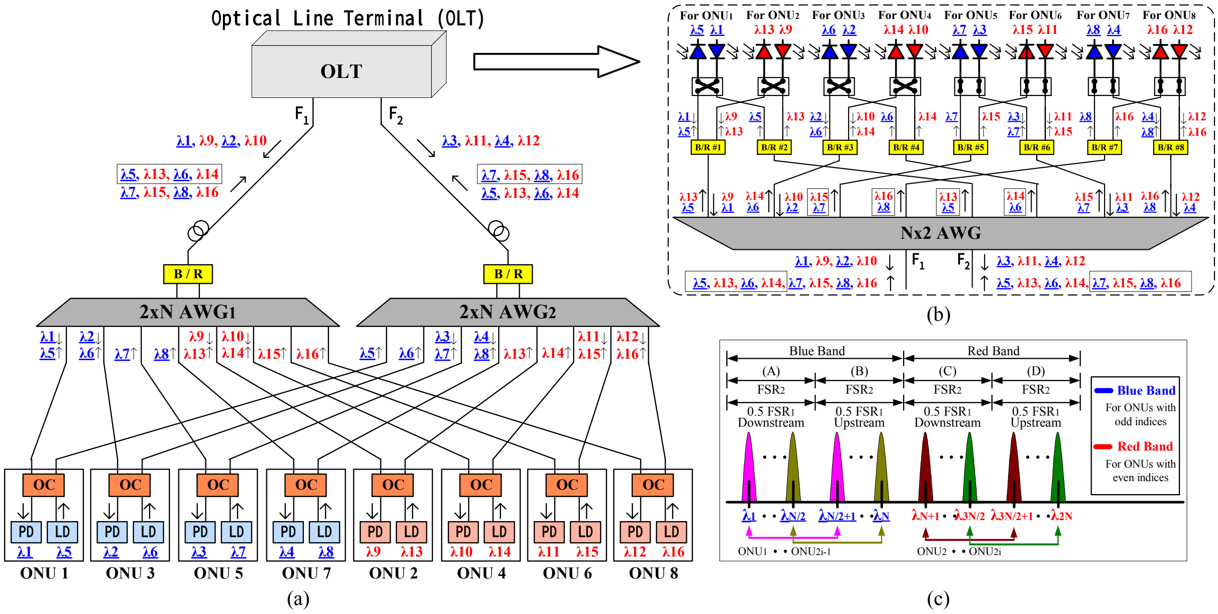


Fig. 1 (a) Proposed WDM-PON Architecture; (b) OLT configuration under normal operation; (c) wavelength assignment plan. B/R: Blue Red filter; OC: optical coupler. Note FSR$_1$ stands for free-spectral range of the N×2 AWG at the OLT; while FSR$_2$ stands for that of both AWG$_1$ and AWG$_2$ at the RN. The wavelengths quoted in boxes are the working upstream wavelengths and the wavelengths in blue band are underlined.

Fig. 1(a) shows our proposed WDM PON architecture with N ONUs, where N = 8, for example. At the OLT, the downstream signals are multiplexed through an N×2 AWG and routed either to the AWG$_1$ in the RN through feeder fiber F$_1$ or to the AWG$_2$ through feeder fiber F$_2$. The ONUs with odd indices are connected to the first N/2 output ports of the AWG$_1$ and the AWG$_2$ via 2×2 couplers; while those with even indices are connected to the last N/2 output ports of the AWG$_1$ and the AWG$_2$, as shown in Fig. 1(a). Fig. 1(c) illustrates the proposed wavelength assignment plan. For index i=1,…,(N/2), the wavebands A (λ_i) and B ($\lambda_{N/2+i}$) in the blue band are allocated for the downstream and the upstream wavelength channels of the ONUs with odd indices (ONU$_{2i-1}$), respectively, while the wavebands C (λ_{N+i}) and D ($\lambda_{3N/2+i}$) in the red band are for the downstream and the upstream wavelength channels of the ONUs with even indices (ONU$_{2i}$), respectively. Besides, the free-spectral range (FSR$_2$) of AWG$_1$ and AWG$_2$ at the RN is half of the FSR$_1$ of the AWG at the OLT. The wavelength λ_i is separated from λ_{N+i} by one FSR$_1$ of the AWG at the OLT; while the downstream and the upstream wavelengths assigned to each ONU are separated by half of the FSR$_1$. Under normal operation, each downstream wavelength originated from the OLT is destined for its respective ONUs through either the AWG$_1$ or AWG$_2$ at the RN. In contrast, the upstream wavelengths are duplicated by 2×2 couplers in each ONU and traverse towards the OLT through both AWGs at the RN, as illustrated in Fig. 1(a).

3. OLT Configuration and Protection Mechanism against Fiber Link Failures

As shown in Fig. 1(b), the OLT consists of an N×2 (N=2^n) AWG and M (M≦N) transceivers. Each transceiver, designated for a particular ONU, is associated with a 2×2 optical switch and a Blue/Red filter. Every two adjacent transceivers form a group and communicate with their respective ONUs, one with odd index (2i-1) and the other with even index (2i), respectively. Under normal operation, the 2×2 optical switches associated with ONU_1, ONU_2, …, $ONU_{N/2}$ are in cross states; while those associated with $ONU_{N/2+1}$, $ONU_{N/2+2}$, …, ONU_N are in bar states to balance the traffic on the AWG_1 and the AWG_2 at the RN. For ONU_{2i-1} (say ONU_1), the transmitter with downstream wavelength λ_i (say λ_1) and the receiver with upstream wavelength $\lambda_{N/2+i}$ (say λ_5), both of which are in the blue band, are connected to the respective blue-band ports of the two Blue/Red filters (say B/R#1 and B/R#2) in the same group, respectively, as depicted in Fig. 1(b) and Fig. 1(c). Similarly, for ONU_{2i} (say ONU_2), the transmitter with downstream wavelength λ_{N+i} (say λ_9) and the receiver with upstream wavelength $\lambda_{3N/2+i}$ (say λ_{13}), both of which are in the red band, are connected to the respective red-band ports of the two Blue/Red filters (say B/R#1 and B/R#2) in the same group, respectively. In general, the combined port of the B/R#(2i-1) (say B/R#1) and that of the B/R#(2i) (say B/R#2) are connected to the i^{th} (say 1^{st}) and the $(N/2+i)^{th}$ (say 5^{rd}) input ports of the N×2 (say 8×2) AWG, respectively. The spectral transmission peaks of the two output ports of the AWG are spaced by half of its FSR_1, and each of them are connected to the either feeder fiber F_1 or F_2. The downstream wavelengths for the first N/2 ONUs (ONU_1 to $ONU_{N/2}$) will be propagating through AWG_1 at the RN; while those for the last N/2 ONUs ($ONU_{N/2+1}$ to ONU_N) will be propagating through AWG_2 at the RN. At the RN, each of the feeder fibers F_1 and F_2 are connected to a Blue/Red filter, which is connected to input ports of 2×N AWG_1 and AWG_2, respectively. The spectral transmission peaks of those ports are spaced by half of its FSR_2. Thus, the wavelengths in blue band will be transmitted to the first N/2 output ports; while those in red band will be transmitted to the last N/2 output ports. Since the FSR_2 of the AWGs in the RN is half of the FSR_1 of the AWG at the OLT, the downstream and the upstream wavelengths for each ONU will be transmitted through the same output port of the AWGs at the RN. At each ONU, the upstream will be sent out via both AWG_1 and AWG_2, thus two copies of the upstream wavelengths originating from all ONUs will reach the N×2 AWG, where they are demultiplexed and routed towards the transceivers at the OLT, via the respective Blue/Red filters and 2×2 optical switches. One of the copies of the upstream wavelengths traverses through the path which the corresponding downstream wavelength passes would reach their respective upstream receivers; while the other copy of the upstream wavelengths would reach the transmitters where they would be blocked by the built-in optical isolators of all transmitters at the OLT. Fig. 1(a) and Fig. 1(b) illustrate the flow of the downstream and the upstream wavelengths under normal operation.

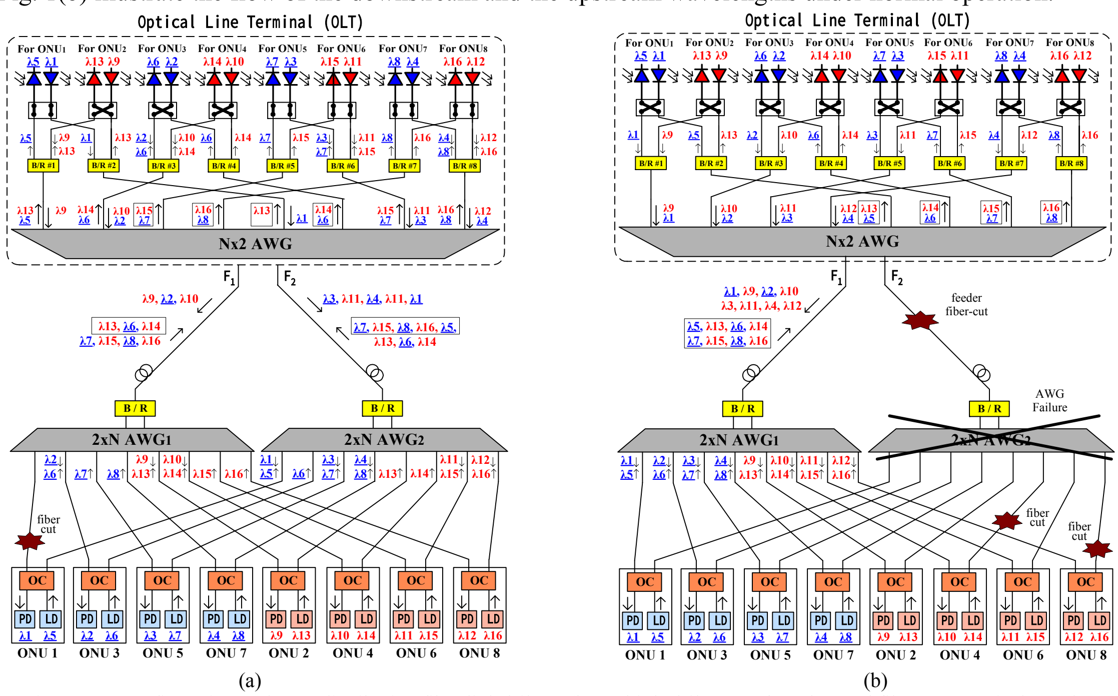
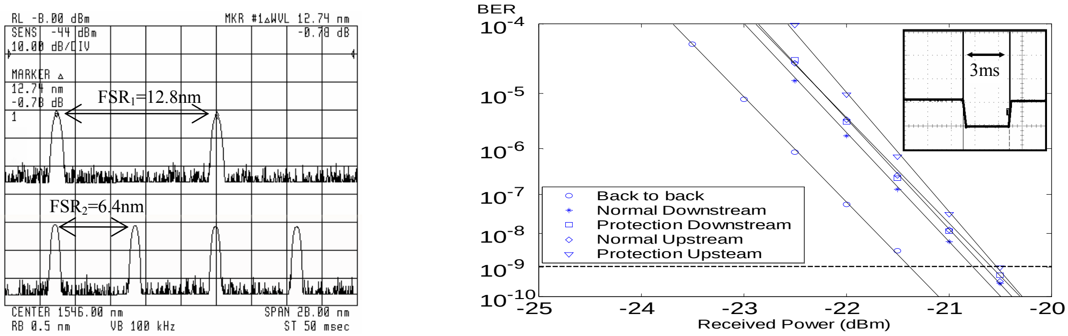


Fig 2. OLT configuration under (a) distribution fiber link failure; (b) multiple failures. B/R: Blue Red filter; OC: optical coupler.

In case of any fiber cut, the OLT will detect the loss of some upstream signals. Such conditions will trigger all the 2×2 optical switches associated with the transceivers designated for the affected ONUs at the OLT to toggle their switching states automatically. As a result, all the blocked downstream wavelengths can be routed to the affected ONUs through the other AWG at the RN along the other available path; while all the respective upstream receivers at the OLT can still receive a copy of the upstream wavelengths. Fig. 2(a) illustrates the flow of the downstream and the upstream wavelengths when the fiber between RN and ONU_1 is broken, as an example. Under this condition, the downstream wavelength for ONU_1 (λ_1) could not reach ONU_1 via the AWG_1. Thus the protection switching at the OLT re-routes λ_1 to go along the AWG_2 and reach the downstream receiver at ONU_1. At the same time, the upstream wavelength λ_5 from ONU_1 would reach the respective upstream receiver at the OLT via a different path, as illustrated in Fig. 2(a). In the same way, feeder fiber failure and AWG failure at the RN can be also protected. Traffic can be restored under multiple failures provided that at least one path is available between the OLT and each ONU, as illustrated in Fig. 2(b). With this proposed protection mechanism, a fast restoration of fiber failures and AWG failure at the RN can be achieved and all protection switching operations are performed at the OLT only.

4. Experimental Demonstration

The transmission performance and the protection switching of our proposed network were experimentally investigated, using the setup similar to Fig. 1. ONU_1 has been implemented to demonstrate the operation principle. 2.5-Gb/s directly modulated DFB laser diodes were used at the OLT and ONUs. A 16×16 AWG, with 100-GHz channel spacing and a FSR_1 of 12.8nm, was used at the OLT. It was also connected to two 1×16 AWGs, with 50-GHz channel spacing and a FSR_2 of 6.4nm, at the RN via a pair of 22-km standard single-mode fibers (SMF), as the feeder fibers. The optical spectrums of the AWGs in the OLT and RN were shown in the Fig. 3(a). The Blue/Red filters used at the OLT and RN had 18-nm passband at both red and blue bands. Each transceiver at the OLT was incorporated with one 2×2 optical switch to re-route the wavelength under the protection mode. Under this configuration, the optical power of the upstream signals from the ONU_1 to the OLT was monitored. Fiber link failures were simulated by disconnect the fiber connections. The bit-error-rate (BER) performance under both the normal and the protection path were measured and was depicted in Fig. 3(b). In all cases, the measured receiver sensitivities at BER=10-9 were very close to each other. The small induced power penalty (< 0.5dB) compared to the back-to-back measurement was due to chromatic dispersion of the directly modulated wavelength channels.



(a) (b)

Fig. 3 (a) The optical spectra of the AWGs at the OLT (upper) and RN (lower); (b) BER measurement of the downstream wavelengths for both the normal and the protection modes. Inset shows the switching time measurement under the protection mode.

The switching time or the restoration time in case of the simulated fiber cut was also monitored. The result was shown in the inset of Fig. 3(b). The waveform showed the signal measured at the monitoring unit in OLT. The switching time was measured to be about 3 ms and this corresponded to the network traffic restoration time achieved.

5. Summary

We have proposed and experimentally investigated a survivable WDM-PON. By incorporating simple optical switches and filters into the OLT, and by duplicating the AWG in the RN, full protection against feeder and distribution fiber link failures as well as the AWG failure in the RN can be achieved simultaneously. With the proposed alternate-path switching scheme, the protection switching is performed at the OLT only. This project was partially supported by a research grant from the Hong Kong Research Grants Council (Project No. CUHK4216/03E).

6. References

[1] ITU-T Recommendation G.983.1, *Broadband optical access systems based on Passive Optical Networks (PON)*, 1998.
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