A novel star-ring protection architecture scheme for WDM passive optical access networks

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Abstract: We propose and demonstrate a star-ring network architecture and wavelength assignment scheme for multi-wavelength passive optical networks with full path protection capability. Bi-directional traffic can be restored promptly for single/multiple link failure scenarios.

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OCIS codes: (060.2330) Fiber optics Communications, (060.4250) Networks

1. Introduction
Broadband networking technologies such as multi-wavelength passive optical networks (WDM-PONs) [1] have been extensively studied throughout the past decade for last mile applications. Thus, a reliable access network architecture is highly desirable. However, little work has been done to offer the protection capability in the optical access networks. Recently, we have proposed a WDM-PON network architecture [2] to provide protection against fiber link failure between the remote node (RN) and the optical network units (ONUs), thus the optical line terminal (OLT) is transparent to such fiber failure. In this paper, we propose and investigate a new network architecture, called star-ring protection architecture (SRPA), so as to integrate and extend the capability to protect against link failure between the RN and the ONUs, as well as that between the RN and the OLT simultaneously. The design and the protection strategies under various failure scenarios will be discussed.

2. Network Topology of SRPA and Wavelength Assignment

![Network Topology of SRPA and Wavelength Assignment](image)

Fig. 1(a) shows our proposed star-ring protection architecture for WDM-PONs. At the OLT, the downstream signals are multiplexed through a 1×N AWG, duplicated by a coupler and transmitted to the RN on feeder fibers F1 and F2, respectively. At the RN, the fibers F1 and F2 are connected to input ports 1 and 2 of 2×N AWG, respectively, and those AWG input ports correspond to two adjacent passband channels. The value of N is chosen to be an even number. And ONU(i) (for i=1,..N) is connected to the ith output port of the AWG at the RN by a piece of optical fiber, denoted as Li. A piece of protection fiber, denoted as Pi(i+1), is connected between the ONU(i) and the ONU(i+1), except that the PN,1 will be connecting ONU(N) and ONU(1), to close the ring. The resultant network topology can be visualized as a three-dimensional star-ring structure as shown in the Fig. 1(a). Fig.1(b) illustrates the wavelength assignment plan, which is on ITU wavelength grid. The downstream and upstream wavelength channels are interleaved with each other for the ONUs. For each ONU, the up- and downstream wavelengths, of which one is in blue band while the other is in red band, are separated from each other by one free-spectral range (FSR) of the AWG.

ONUs with odd indices are assigned with downstream wavelengths in blue band and upstream wavelengths in red band, whereas ONUs with even indices are assigned with downstream wavelengths in red band and upstream wavelengths in blue band, as illustrated in the table of Fig. 1(b).

*Note: D – Downstream wavelength; U – Upstream wavelength
*The downstream wavelength for each ONU is marked with the dot box.
3. Structure of ONU and Protection Mechanism against Fiber Link Failures

Fig. 2(a) illustrates the structure of ONUs under normal operation. The downstream wavelengths \( \lambda_i \) (for \( i \) is odd) and \( \lambda_{i+N} \) (for \( i \) is even), destined for the ONU(i)’s are carried via fiber \( F_1 \), AWG and fiber \( L_i \). Due to the presence of the additional fiber feeder \( F_2 \) and the channel-shifting input-output property of the AWG, the same WDM downstream wavelengths from all the ONUs will be routed back to the OLT via the fiber feeder \( F_2 \), as illustrated in Fig. 3(b).

There are two types of fiber failures: Type I (link failure(s) between ONU and RN) and Type II (feeder fiber failure between OLT and RN). Fig. 2(b) illustrates the ONUs configuration under single Type I failure between the RN and the ONU(2), for instance. A drastic drop in power at the monitoring unit (M) of ONU(2) will be detected. Thus, the optical switch inside ONU(2) will be automatically reconfigured to the lower port, as illustrated in Fig. 2(b). Both the up-/downstream wavelengths of the isolated ONU(2) will be routed to/from the ONU(1) via the protection fiber between them. Thus, with the channel-shifting property of the AWG at the RN, they can still be routed to the OLT via the feeder fiber \( F_2 \), as shown in Fig. 2(b). With this protection mechanism, a fast restoration of fiber failure can be achieved, without any disturbance on the existing traffic and other ONUs. If there exists multiple Type I link failures, the SRPA can still be able to protect and restore the affected traffic using the above mentioned mechanism, provided that such multiple Type I link failures do not occur at two adjacent ONUs. On the other hand, for Type II fiber feeder failure, for example, the fiber feeder \( F_1 \) is broken between the RN and the OLT, the protection mechanism is similar to that in Type I except that the monitoring units in all ONUs will trigger the respective optical switches simultaneously. The wavelength channels for each ONU will be routed via its adjacent ONU and all wavelengths from all the ONUs will be routed back to the OLT via the fiber feeder \( F_2 \), as illustrated in Fig. 3(b).
4. Experimental Demonstration

The transmission performance and the protection switching of our proposed network were experimentally investigated, using the setup similar to Fig. 2. Two ONUs have been implemented to demonstrate the operation principle. 2.5-Gb/s directly modulated DFB laser diodes were used at the OLT and the ONUs. A 16×16 AWG, with 100-GHz channel spacing and a free-spectral range (FSR) of 12.8nm, was used at the RN. It was also connected to the 1×16 AWG, as the channel multiplexer, at the OLT via a pair of 22-km standard single-mode fibers (SMF), as the fiber feeders. The Red/Blue filters used at the ONUs had 18-nm passband at both red and blue bands. A piece of 4-km protection fiber was used to connect the two ONUs. Each ONU was incorporated with one 1×2 optical switch to re-route the wavelength under the protection mode. Under this configuration, the optical power of the downstream and upstream signals from the OLT to the ONU(2) was monitored. Both single Type I and Type II fiber link failures were simulated by intentionally 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. 4. 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.

5. Summary

We have proposed a novel star-ring protection architecture (SRPA) for WDM-PONs. By incorporating simple optical switches and filters into the ONUs, and by connecting ONUs in the proposed star-ring structure, full protection capability can be achieved. Thus the isolated ONUs can still communicate with the OLT in case of any fiber cut in the PON with minimum disturbance to its neighborhood. This project was partially supported by a research grant from the Hong Kong Research Grants Council (Project No. CUHK4216/03E).

6. References