A Survivable WDM Passive Optical Network with Colorless Optical Network Units

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Abstract
We propose and experimentally demonstrate a survivable network architecture for WDM-PONs with colorless ONUs. Fiber failure can be protected and the bi-directional traffic can be restored promptly.

1 Introduction
Wavelength division multiplexed passive optical network (WDM-PON) is a very promising approach for next-generation broadband access. In such network, colorless (wavelength-independent) optical network units (ONUs) are desirable to reduce the costs of operation, administration, and maintenance (OA&M) functions [1]. Recently, a WDM-PON architecture using centralized light sources (CLS) at the central office (CO) has emerged as an attractive solution for colorless ONU implementation [2]-[3]. To assure network reliability, protection and restoration functionalities are highly desirable. In [4], a wavelength-shifted protection scheme was reported for a carrier distributed WDM-PON. However, it duplicated a set of transmitters, receivers, which largely increased both the network complexity and the cost.

In this paper, we propose a survivable architecture to protect the fiber link between the CO and remote node (RN) in aCLS WDM-PON. The protection switching is performed at the CO, and the ONU is kept simple and colorless.

2 Network topology and wavelength assignment
Fig. 1 illustrates our proposed WDM-PON architecture with N ONUs. Without loss of generality, 8 ONUs are considered as an example. WDM broadband light sources (BLS), supplying un-modulated optical carriers in the C-band are centralized at the CO, and they are to be modulated at the ONUs for the upstream traffic, thus no wavelength-specific transmitter is incorporated at the subscriber side. The downstream channels are assigned with L-band wavelengths. Both the L-band downstream wavelengths and the C-band BLS wavelengths are combined by the L/C combiner, followed by a 1×2 optical switch, which connects to the RN via a pair of working and protection fiber feeders. Under normal operation, the switch is connected to the working feeder fiber. The RN consists of two identical 2×N AWGs, one for the downstream wavelengths and the other for the upstream wavelengths. The AWG dedicated for the upstream traffic at the RN connects to the receivers at the CO via another pair of working and protection feeder fibers. The spectral transmission peaks of the two AWG input ports are spaced by half of the free-spectral range (FSR) of the AWG. Wavelength assignment plan for upstream and downstream wavelengths is shown in Fig. 2.
There are two fibers connecting RN and each ONU. One distribution fiber delivers a downstream signal and an optical carrier to each ONU, while the modulated upstream signal is delivered back to RN through the other fiber. Since there is no light source in the ONU, the colorless ONU can support any wavelength channel.

3 Protection operation principles
Under normal operation, the switch is connected to the working fiber I. Both the downstream wavelength $\lambda_i$ ($i = 1, 2, \ldots, N$) and upstream carrier $\lambda_{i+N}$ are transmitted via working fiber I to ONU$_i$ ($i = 1, 2, \ldots, N$). At each ONU, downstream wavelength $\lambda_i$ was received by a photodetector (PD), while the optical carrier $\lambda_{i+N}$ is modulated by upstream signal and sent back to the CO via working fiber II. In this case, only the working fibers are used, and there is no traffic running on the protection fibers.

In case of any cut in the working feeder fiber, the CO will detect the power loss of upstream signals. So, the data control circuit will change the status of the downstream signals. The downstream signal destined for ONU$_i$ ($i = 1, \ldots, N/2$) is changed to another wavelength $\lambda_{i+N/2}$, while the downstream signal destined for ONU$_j$ ($j = N/2+1, \ldots, N$) is changed to wavelength $\lambda_{j-N/2}$. At the same time, the decision circuit will trigger the optical switch to connect to the protection fiber I. Thus, both the downstream wavelength $\lambda_i$ ($i = 1, 2, \ldots, N$) and upstream carriers $\lambda_{i+N}$ are transmitted via the protection fiber I to the RN. With the wrap-around spectral periodicity property of the AWG, the downstream wavelength $\lambda_j$ ($j = 1, \ldots, N/2$) and the upstream carrier $\lambda_{i+N}$ are routed and sent to ONU$_{j+N/2}$, while the downstream wavelength $\lambda_j$ ($j = N/2+1, \ldots, N$) and the upstream carrier $\lambda_{j+N}$ are routed and sent to ONU$_{j-N/2}$. At the ONU, the dedicated downstream signals are received, while the upstream carriers are modulated and sent back to CO via the protection fiber II. As the colorless ONU in such carrier distributed WDM-PONs can handle any wavelength, there is no protection equipment needed in any ONU.

4 Experimental Results
We have experimentally investigated the transmission performance and the protection switching of our proposed network. ONU 1 with working downstream and upstream wavelengths of 1546.52 nm and 1581.36 nm, respectively; and protection downstream and upstream wavelengths of 1549.72 nm and 1584.73 nm, respectively, was demonstrated. The data rate for both the upstream and the downstream channels was 2.5 Gb/s. The standard single mode fiber (SMF) link between the CO and the RN was 8-km long. Two 16×16 AWG with 100 GHz channel spacing and an FSR of 12.8 nm were used in the RN. At the CO side, EDFAs were inserted in front of the AWG in order to compensate for the insertion loss. We have measured the bit-error-rate (BER) performance using 2.5 Gb/s 2³²-1 PRBS data for both the upstream and the downstream traffic under normal and protection modes, respectively. Avalanche photo diode (APD) receiver was used in our experiment. From the results depicted in Fig. 3, nearly no power penalty was observed for both normal and protection operations. We have also measured the switching time in case of the simulated fiber cut. The fiber link between the CO and the RN was intentionally disconnected to simulate the fiber cut scenario, with the result shown in the inset of Fig. 3. The switching time was measured to be about 5 ms.

5 Summary
We have proposed a simple protection architecture for optical carrier distributed WDN-PONs, which can achieve fast protection and traffic restoration against feeder fiber failure successfully. The ONUs are colorless. The bi-directional transmission of the 2.5 Gb/s signal over the WDM-PON have been experimentally demonstrated and characterized. In the proposed protection scheme, only one set of transceivers are needed at the CO, and all monitoring and protection equipment is consolidated at the CO. However, data switching between downstream signals is necessary when any feeder fiber failure occurs. This project was partially supported by a research grant from Hong Kong RGC (CUHK4216/03E).

References
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