A Novel Centrally Controlled Protection Architecture for Bidirectional WDM Passive Optical Network
Zhaoxin Wang, Xiaofeng Sun, Chinlon Lin, Chun-Kit Chan, and Lian-Kuan Chen
Department of Information Engineering, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong SAR.
Tel: +852-2609-8385, Fax: +852-2603-5032, Email: zxwang3@ie.cuhk.edu.hk

Abstract A novel centrally controlled protection scheme for AWG based bidirectional WDM-PON is proposed and experimentally demonstrated. Compared with previous distributed structures, required network resources are greatly reduced.

Introduction
Wavelength division multiplexing passive optical network (WDM-PON) [1-2] is a promising access technology to deliver high capacity data to the subscribers. In order to avoid enormous loss in data and business due to fiber cut, providing protection and restoration function to the network will become an important issue in the design for WDM-PON. Some former work [3-4] utilizing the periodic and cyclic property of AWG has been reported. However, in both of these structures, the protection equipments (i.e. switches) are distributed in each Optical Network Unit (ONU), which makes the ONU design complicated. In this paper, a novel network architecture based on centrally controlled protection scheme is proposed and demonstrated. It only needs one set of protection equipment located at the Optical Line Terminal (OLT) end, not only simplifying the ONU design, but also significantly reducing the amount of required network resources.

Network structure and wavelength assignment
Our proposed structure with N=2\(^n\) ONUs is shown in Fig.1. Without loss of generality, 8 ONUs are considered here as an example to facilitate the illustration.

At the OLT end, two isolators with opposite directions and a 2x2 switch are inserted before the two feeder fibers. In normal operation, the switch is set to bar state to make sure that feeder fiber I and II are used for downstream and upstream traffic respectively. At the Remote Node (RN) end, feeder fibers I and II are connected to the two AWG input ports respectively and the spectral transmission peaks of the two ports are spaced by half of the free-spectral range (FSR) of the AWG. Two adjacent ONUs are assigned to a group and each of them is connected to a specified AWG output port through a distribution fiber, as shown in Fig.1. Such fiber connection pattern is attributed to a proposed wavelength assignment plan, as shown in Fig.2, which is the same as in [4]. The wavebands A and B in blue band are allocated for down- and up-stream of ONU\(_1\), respectively, while the wavebands C and D in red band are for down- and up-stream of ONU\(_2\), respectively. The details of each ONU group are illustrated in Fig.3. In each ONU, a Red/Blue (R/B) filter (the definitions of Red/Blue band are described in Fig.2) is connected to its distribution fiber. A coupler in ONU\(_1\) and an interconnecting fiber between the two ONUs will combine both of the blue band outputs together for the traffic of ONU\(_1\). A wavelength coupler is applied to separate the up- and down-stream traffic. The design of ONU\(_2\) is similar to ONU\(_1\) except that the two red band outputs are combined.
Protection operation principles
In the normal operation mode, the switch is set to bar state. So, fibers I and II in the feeder section are used for down- and up-stream path respectively. Due to the periodic property of AWG and our wavelength assignment plan, all of the downstream traffic will reach the leftmost four distribution fibers, which are connected to ONU\(^1\). Then, the R/B filter in ONU\(^1\) will divert the signals to the receivers in both of the ONUs in this group. The upstream signal will be divided by the coupler and transmit in two different paths to the OLT. However, the optical isolator located at the OLT end will block one path of the signal. Thus, only the signals passing through the leftmost four distribution fibers are transported to the OLT. From the above analysis, it is obvious that only half of the distribution fibers are used in normal operation while the other half are considered as backup. Here, we name them as ‘working fiber’ and ‘protection fiber’ respectively. In case of any working fiber failure, the OLT will detect the loss of some upstream signals. So, it will change the optical switch to cross state. Thus, fiber I is now for the upstream path while fiber II is for the downstream path. In this case, all of the bidirectional data wavelengths are switched from the working fibers to the respective protection fibers, as shown in Fig. 3 (b), and thus a fast traffic restoration can be achieved.

Experimental results
The experimental setup is similar to Fig. 1 and a pair of ONUs, as shown in Fig. 3, were implemented. The data rate for both the upstream and the downstream channels was 2.5-Gb/s. A 16×16 AWG with 100-GHz channel spacing and an FSR of 12.8nm was used for the RN. At the ONUs, each Red/Blue filter had a bandwidth of about 18 nm in each passband. Each of the interconnecting fiber connecting between the two ONUs in the same group was 2 km long. At the OLT side, EDFAs were inserted in front of the AWG to compensate the insertion losses. In normal operation, both the upstream and the down-stream wavelengths travelled through a transmission distance of 20 km standard SMF between the OLT and the ONU. Then, the fiber link between the RN and the ONU\(^1\) was intentionally disconnected to simulate the fiber cut scenario. Utilizing the 2.5-Gb/s 2\(^{23.1}\) PRBS data, the bit-error-rate (BER) performance of ONU\(^1\) for both the upstream and the downstream traffic was measured, with the results depicted in Fig. 4. In all cases the measured receiver sensitivities at 2.5-Gb/s varied from -24.5 dBm to -26.0 dBm. The additional 1.5-dB power penalty was induced mainly by the chromatic dispersion of fiber as well as the possible reflection among the connectors. We have also measured the switching time or the restoration time in case of the simulated fiber cut between the ONU\(^1\) and the RN. The optical power of the upstream signals from the ONU\(^1\) was monitored at the OLT end and the result was shown in the inset of Fig. 4. The switching time was measured to be about 9 ms.

Discussion
In this proposed scheme, the number of protection switch required is significantly reduced from N sets [4] to only one. Thus, the structure of the ONU is much simplified; albeit it requires a pair of fibers connecting two ONUs in the same group. Nevertheless, the OLT can always keep track of the network status information, thus facilitates the network management. However, if there exists any simultaneous fiber cuts in a working fiber as well as a protection fiber, the traffic restoration mechanism may not be performed properly.

Conclusion
We have proposed a novel centrally controlled protection scheme for bidirectional WDM-PON. Fast automatic protection and traffic restoration against fiber failure and the transmission characteristics of the 2.5-Gb/s signal over the WDM-PON have been experimentally demonstrated and characterized. The proposed network architecture simplifies the ONU design and thus reduces the network cost. This work was partially supported by a research grant from Hong Kong Research Grants Council (Project No. CUHK4216/03E)

References