A Broadcast and Select WDM-PON and its Protection
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Abstract A broadcast and select WDM-PON is proposed and experimentally demonstrated for both dedicated and broadcast services. Group protection concept is used to increase the network reliability at relatively low cost.

Introduction
Wavelength division multiplexing passive optical network (WDM-PON) is an attractive method to deliver high bandwidth services to the premises. In the conventional WDM-PON [1], a WDM MUX/DMUX is placed at the Remote Node (RN) to route each wavelength to a certain optical network unit (ONU), to realize a virtual point-to-point connectivity between Optical Line Terminal (OLT) and ONU. In this paper, A WDM-PON architecture based on the concept of broadcast and select [2] is proposed. Compared with the traditional WDM-PON, although it will induce a relatively larger loss at the RN, the advantages are numerous: first, the flexibility can be greatly enhanced; second, since the network architecture between the OLT and RN is compatible with the current PON, it paves a smooth way to evolve from current PON to future high capacity WDM-PON; third, the broadcast service can be easily incorporated; last, since the signal in each distribution fiber contains the information for all ONUs, the two adjacent ONUs can be grouped together to protect each other from distribution fiber cut. Considering the distance between two adjacent ONUs is usually much shorter than the length of distribution fiber when the number of ONU is relatively large, the group protection method [3] is potentially low cost when compared with the conventional method [4] of duplicating fiber links to provide redundancy. In this paper, we propose and experimentally demonstrate a simple architecture with protection functions using low cost CWDM technology. Both dedicated and broadcast traffic are supported.

Network Architecture and Operating Principles
Fig. 1 shows the proposed network architecture with N ONUs (here, N=8 for simplicity). At the OLT side, it consists of a CWDM MUX/DMUX, N pairs of CWDM transceivers with each of them corresponding to a certain ONU for dedicated bidirectional service and one extra transmitter for broadcast service. The CWDM standard defines 18 wavelengths. Except for the 1390nm wavelength located at the water peak of standard fiber, there are 17 wavelengths available. In our experiment, the 1550nm will be used for the broadcast service. The other 16 wavelengths can be assigned for dedicated bidirectional (up- and downstream) service freely, thus supporting 8 ONUs. At the RN, a 2×N splitter is used to broadcast the signals to each ONU. From the OLT to the RN, there is one backup fiber link to protect the working feeder fiber. At the ONU side, two adjacent ONUs are assigned to one group with a pair of interconnecting fibers.

Fig. 1: Proposed network architecture with N ONUs

Fig. 2: Structure of an ONU group
The details of each ONU group with the interconnecting fiber are shown in Fig. 2. In the ONU_1i, there are two band filters to divide the traffic into two categories (dedicated and broadcast) and then combine them together again. The 3-port thin film filter (TFF) with 1550nm center wavelength can be used as the band filter. In the dedicated path, two 3-port TFFs with different center wavelengths are cascaded to act as a unidirectional OADM: one wavelength is dropped as the downstream traffic for ONU_1i and the other wavelength is added as the upstream traffic for ONU_2i. The two wavelengths can be chosen freely except for the broadcast wavelength. For other wavelengths, they can pass through ONU_1i without restraint from both directions. Through the interconnecting fiber, these wavelengths can provide the protected traffic for ONU_2i. In the broadcast path, a 50/50 coupler is used to drop half of the broadcast signals for ONU_1i's broadcast receiver. The other half broadcast signals can pass through ONU_1i and be sent to ONU_2i via the interconnecting fiber to provide protected signals for ONU_2i. A 1×2 switch is also incorporated in ONU_1i. The structure of ONU_2i is similar to ONU_1i except that its dedicated wavelengths are different from ONU_1i. There are two
interconnecting fibers between the two ONUs. However, they can be encapsulated into one cable, thus reducing the deployment cost. Under normal operation, each ONU will communicate with the OLT via its own distribution fiber. In case of a fiber cut at the fiber link connecting to ONU\textsubscript{i}, the control circuit can find this failure and change the switch state to connect the ONU\textsubscript{i} with the interconnecting fiber. Thus, the ONU\textsubscript{i} can still obtain its signals from the distribution fiber connecting to ONU\textsubscript{j}.

**Experimental Results**

The experimental setup is similar to Fig. 1. Only the distribution fiber protection was demonstrated. A 1×16 splitter constructed from two stages of 1×4 splitters with the total insertion loss 12.5dB was used at the RN to simulate a PON serving 16 ONUs. The transmission distance between OLT and ONU was 20km. Only one group of ONUs, as shown in Fig.2, was established. Five CWDM standard wavelengths were used. Among them, the 1550nm served as the broadcast wavelength. 1530nm and 1610nm were used as the up- and down-stream traffic for ONU\textsubscript{i}, respectively and 1490nm and 1570nm were used as the up- and down-stream traffic for ONU\textsubscript{j}, respectively. The interconnecting fiber length was 1km. The transceivers serving the ONU\textsubscript{i} were directly modulated with 1.25Gbit/s PRBS data to simulate the Gigabit Ethernet while the others were unmodulated. The output powers of these commercial transceivers are from 0dBm to 2dBm. To simulate the fiber cut, the ONU\textsubscript{i}'s distribution fiber was intentionally disconnected. The control circuit would detect this failure and change the switch state to realize the protection. Using this setup, we measured the BER performance of various traffics (dedicated up- and down-stream; broadcast) for ONU\textsubscript{i} in both normal mode and protection mode, with the results shown in Fig. 3 and Fig. 4. In all cases, the measured receiver sensitivities (at BER=10^{-9}) were around -28dBm and the power penalty with respect to back-to-back measurement is almost negligible. There were 8-10dB system margin for dedicated traffic depending on the output power of transceiver. The system margins for the broadcast traffic were 6.3dB (normal mode) and 2.7dB (protection mode) respectively. This is because the broadcast traffic uses the couplers to drop signals, thus inducing larger loss. The switching time (3 ms) was also measured, as shown in the inset of Fig. 4, corresponding to the restoration time.

**Discussions**

When only the CWDM standard wavelengths are used, our scheme can only support 8 ONUs. To support 16 ONUs, a hybrid C/DWDM scheme is necessary. For instance, 16 DWDM wavelengths around the 1550nm range can be assigned for the dedicated downstream traffics, while 16 CWDM wavelengths can be used for dedicated upstream traffics. In this case, the broadcast wavelength might need to be shifted from 1550nm to other wavelength window, such as 1310nm. In the future, when the DWDM components become an economical option, this structure can even support 32 ONUs. For example, 64 DWDM wavelengths in the C+L bands are used for dedicated services and 1310nm is allocated for broadcast service. They can be easily divided with the 1.3μm/1.5μm band filters. Considering the additional over 3dB loss induced by 1×32 splitter compared with the 1×16 splitter, APD receivers might be needed to guarantee enough system margins.

**Conclusions**

We have proposed and demonstrated a broadcast and select WDM-PON, which can support both dedicated and broadcast traffic. By connecting two adjacent ONUs in one group, fast automatic protection against fiber failure can be achieved. It provides the possibility for smooth and graceful upgrade from current PON to WDM-PON as the broadband services demand increases in the future. This project was partially supported by Hong Kong RGC Project No. CUHK4216/03E.

**References**