A Group Protection Architecture (GPA) for Traffic Restoration in Multi-wavelength Passive Optical Networks

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Abstract: We propose and experimentally demonstrate a novel network architecture and wavelength assignment scheme for multiwavelength passive optical networks with protection capability. Fiber failure can be protected and the bidirectional traffic can be restored promptly.

Introduction

Multi-wavelength passive optical networks (WDM-PON) [1-3] are emerging to deliver broadband interactive services in last mile applications. Thus, a reliable access network architecture is highly desirable. However, little work has been done to offer protection capability in conventional passive optical networks. Recently, we have proposed a WDM-PON network architecture [4] to provide protection against fiber link failure between the remote node (RN) and the optical network unit (ONU), thus the optical line terminal (OLT) is transparent to such fiber failure. In this paper, we propose and investigate an improved network architecture, not only provides the bi-directional fiber link protection, but also employs a novel wavelength assignment scheme to reduce the amount of required network resources.

Network topology and wavelength assignment

Fig. 1: Proposed network architecture with 8 ONUs.

Fig. 2: Proposed wavelength assignment plan. The dotted lines show an example of the transmission peaks of the AWG at the RN.

Fig. 1 shows our proposed network architecture with N ONUs. Eight ONUs are considered here as an example to facilitate our illustration. The RN comprises one 1x2 3-dB fiber coupler and an 2xN array-waveguide grating (AWG) to route the wavelength channels to the ONUs. The OLT is connected to the two input ports of the AWG at the RN via the 1x2 3-dB fiber coupler. Two adjacent ONUs are assigned to a group and each of them is connected to a specified AWG output port as shown in Fig. 1. Such fiber connection pattern is designed according to a proposed wavelength assignment plan, as shown in Fig. 2, which will be described later in this section. In each group, a single piece of fiber is used to connect the two ONUs to provide an alternative path. Whenever there is a possible fiber cut between an ONU and the RN, it can still route its upstream and downstream traffic to/from the OLT via its neighbouring ONU in the same group, thus traffic restoration is achieved. As a result, an ONU can protect its adjacent ONU in the same group from being isolated due to fiber cut, although each of them can still serve their respective connected subscribers in both normal and protection modes. Mutual 1:1 protection is therefore achieved.

To support such protection scheme, a novel wavelength assignment plan, as shown in Fig. 2, is proposed to allocate the downstream (in wavebands A & C) and the upstream (in wavebands, B & D) wavelengths for each group of ONUs. At the RN, the spectral transmission peaks of the two AWG input ports have to be spaced by half of the free-spectral range (FSR) of the AWG, so that each downstream data wavelength will be duplicated and directed to two distinct AWG output ports. With the wrap-around spectral periodicity property of the AWG, each AWG output port will be supporting two downstream wavelengths as well as two upstream wavelengths, as illustrated in Fig. 1. It is shown that there are N/2 pairs of AWG output ports, each of which supports an identical set of downstream and upstream wavelengths. Thus, each of them will be connected to a pair of ONUs in a group and form the fiber connection pattern, as shown in Fig. 1.

Optical Network Units (ONUs)

Fig. 3(a) illustrates the internal structure of the ONUs under normal operation mode. The downstream wavelengths, A, and C, are carried on the fiber link connected to ONU \textsuperscript{1}, and the same composite signal is also delivered to ONU \textsuperscript{i}, where the superscript denotes the ONU number and i denotes the group number. Its destined downstream wavelength, A, will be filtered out by the Red/Blue (R/B) filter and so is C, in ONU \textsuperscript{i}. On the other hand, the upstream wavelengths, B, and D, will follow exactly the same path as A (respectively C) except that they travel in the opposite direction. After passing through the R/B filter, a WDM coupler is used to separate the
Transmission performance required transmitted power. the components' insertion losses and to achieve the inserted in front of the AWG in order to compensate each passband. On the OLT side, EDFAs were implemented. The data rate for both the upstream and the downstream wavelengths of the ONU was 2.5-Gb/s. A 16×16 AWG with 100-GHz channel spacing and an FSR of 12.8 nm was used for the RN. At the ONU, each Red/Blue filter had a bandwidth of about 18 nm in each passband. On the OLT side, EDFAs were inserted in front of the AWG in order to compensate the components' insertion losses and to achieve the required transmitted power.

Transmission performance: We have measured the bit-error-rate (BER) performance using 2.5-Gb/s 2^{23}-1 PRBS data for both the upstream and the downstream traffic; and the measurement results were depicted in Fig. 4. In normal operation, both the upstream and the downstream traffic wavelengths travelled through a transmission distance of 20 km between the OLT and the ONU. Then, the fiber link between the RN and the ONU was intentionally disconnected to simulate the fiber cut scenario. The single piece of fiber connecting the two ONUs was 2 km. In all cases the measured receiver sensitivities at 2.5-Gb/s varied from -31.5 dBm to -32.6 dBm. The small (<1 dB) induced power penalty was mainly due to chromatic dispersion.

Switching/Restoration Time: We have also measured the switching time or the restoration time in case of the simulated fiber cut between the ONU and the RN. The optical power of the downstream signals from the RN and from the ONU were monitored and the result was shown in inset of Fig. 4. The lower waveform showed the downstream signal from the RN to the ONU, while the upper was the re-routed downstream signal via the ONU. The switching time was measured to be about 9 ms and this corresponded to the network traffic restoration time. Fast restoration time was achieved since only one switch has to be reconfigured, as illustrated in Fig. 3.

Protection switching and Restoration
In case of fiber cut at the fiber link between the RN and the ONU, for example, both the optical switches inside the ONU would be reconfigured, as shown in Fig. 3(b). Both the upstream and the downstream wavelengths of the ONU would be rerouted to the ONU via the single fiber connecting between them. Conversely, ONU protects ONU in a similar way. With this protection mechanism, a fast restoration of the broken connections can be achieved, with minimal effect on the existing traffic. The OLT is transparent to such fiber failure.

Experimental Demonstration
We have experimentally investigated the transmission performance and protection switching of our proposed network. The experimental setup is similar to Fig. 1 and a pair of ONUs, as shown in Fig. 3, was implemented. The data rate for both the upstream and the downstream channels is 2.5-Gb/s. A 16×16 AWG with 100-GHz channel spacing and an FSR of 12.8 nm was used for the RN. At the ONU, each Red/Blue filter had a bandwidth of about 18 nm in each passband. On the OLT side, EDFAs were inserted in front of the AWG in order to compensate the components' insertion losses and to achieve the required transmitted power.

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