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A new cross-protection dual-WDM-PON architecture with carrier-reuse colorless ONUs

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ABSTRACT

This paper proposes a new cross-protection colorless dual-WDM-PON architecture. The proposed protection scheme can provide 1 + 1 downstream protection and 1:1 upstream protection against both feeder fiber and distribution fiber failures by using the fiber links and AWGs of the neighboring WDM-PON. Wavelength is reused for the down- and up-stream transmissions in dual-WDM-PONs where gain-saturated reflective semi-conductor optical amplifiers (RSOAs) are employed as colorless transmitters in ONUs. The number of extra protection fibers is minimized and wavelength is much more efficiently utilized compared with other protection schemes. The feasibility and operation of the proposed dual-WDM-PON architecture are experimentally verified with 1.25 Gb/s for upstream and 2.5 Gb/s for downstream over 20 km single mode fiber transmission in both working and protection modes.

1. Introduction

Wavelength division multiplexed passive optical network (WDM-PON) is broadly viewed as a promising solution for future broadband access networks, since it offers almost unlimited bandwidth, protocol transparency, excellent security, simple management and easy upgradeability [1–4]. With the rapid increase of WDM-PON transmission capacity, any possible failure of either feeder fibers (FFs) or distribution fibers (DFs) will disrupt the services, leading to a large amount of data loss. Thus protection against FF or DF failures is imperative for network operators to enhance the network reliability.

So far, several protection schemes against fiber failures for WDM-PONs have been proposed [5–10]. The basic idea is to switch the affected data to an alternate protection path upon detection of fiber fault. These schemes can be classified into three categories: duplication protection [5,6], group protection [7,8] and ring protection [9,10]. In the duplication protection approach, both working FF and DF are duplicated for protection and connected to an $N \times N$ arrayed waveguide grating (AWG) [5] or two $1 \times N$ AWGs [6] located at the remote mode (RN). This scheme is relatively simple, but requires a large number of protection fibers (the same as the number of working fibers), which is costly. In the group or ring protection approach, an extra interconnection fiber (IF) serves as an alternate path between optical network units (ONUs), while ONUs are either adjacently connected to form a group [7,8] or connected in sequence to form a ring [9,10] to offer a backup protection path. These schemes can greatly reduce the number of protection DFs, but the FF is still duplicated. To improve fiber utilization and save extra fibers, a dual-PON-based protection architecture was proposed in [11,12], where the protection resources were provided across two PONs and no extra FF is required. In case of the FF failure, the disrupted signal can be recovered using the fiber links of the neighboring PON. However, in [11], the DFs were still duplicated and the number of extra DFs is relatively large. The authors in [12] used group protection scheme to avoid the DF duplication, but a half of the power of the downstream backup signals would go back to the OLT along a sub-ring by using the ONU structure designed in [12]. The sub-ring structure in [12] not only degrades the downstream performances due to the backscattering noise, but also results in lower wavelength utilization and the need of active lasers in ONUs, because two different wavelengths are used for the down- and up-stream transmissions in each ONU.

In this paper, we propose a new cross-protection dual-PON-based architecture with carrier-reuse colorless ONUs. Our proposed protection scheme can provide 1 + 1 downstream protection and 1:1 upstream protection against both FF and DF failures by using the fiber links and AWGs of the neighboring WDM-PON. Only two different wavebands are utilized in dual-WDM-PONs where gain-saturated reflective semi-conductor optical amplifiers (RSOAs) are used as colorless transmitters in ONUs. The number of extra protection fibers is minimized and the wavelength is much more efficiently utilized compared with other protection schemes [5–12]. The feasibility and operation of the proposed scheme are experimentally verified with 1.25 Gb/s for upstream and 2.5 Gb/s for downstream over 20 km transmission in both working and protection modes.

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2. Architecture and operation principle

Fig. 1 shows the proposed cross-protection dual-WDM-PON which consists of two WDM-PONs each with N colorless ONUs. As shown in Fig. 1, the 1st WDM-PON operates in the C-band and the 2nd WDM-PON in the L-band. In both WDM-PONs, the downstream wavelengths are reused for upstream transmission based on gain-saturated RSOAs to efficiently utilize wavelength resource. As shown in Fig. 1, in each WDM-PON, N transceivers are connected to an AWG which multiplexes the downstream signals and de-multiplexes the upstream signals. A circulator is used to separate down- and up-stream signals in each transceiver. The C- and L-bands are separated by n ($n \geq 1$) free spectral ranges (FSRs) of the AWGs as shown in Fig. 2. In the OLT located at central office (CO), the two waveband signals are combined by a coarse WDM and then power-split into the FF-1 and FF-2 by a 1×2 optical coupler (OC). An optical amplifier is used for each waveband to compensate the downstream power loss and to improve the power budget. The remote node (RN) consists of two periodical AWGs with the same FSR and links to each ONU via one DF. Each ONU in the C-band is connected with an ONU in the L-band via an interconnection fiber (IF); these two ONUs have a wavelength spacing of n FSRs of the AWG used. They form a group to protect each other. Inside each ONU, 10% of the downstream signal is tapped by a monitoring and control circuit (MCC). The MCC consists of a photo detector (PD) and a control circuit. The PD is used to monitor the optical power of downstream signals, and the control circuit is responsible for controlling the connection state of a local 1×2 optical switch (SW) according to the absence or presence of the power detected by the PD. Upon detection of fiber failure (loss of optical signal), the MCC generates an electrical signal to control the connection state (cross or bar) of the SW. Two coarse WDMs were used to separate and combine the C- and L-bands. Following the SW, a 1×2 OC is used to split the optical power into two parts: one part is fed to a downstream receiver (RX); the other is amplified and re-modulated with upstream signal via a gain-saturated RSOA.

In the working mode, the 1st port of the SW is connected to the 3rd port of the SW in each ONU, and the down- and up-stream signals traverse the respective DF path from/to OLT. In case of any working DF failure (e.g., DF-1) as shown in Fig. 3, the corresponding MCC will detect the loss of optical signal and subsequently will reconfigure the SW in ONU-1 to the port 3-2 connection. Thus, the disrupted down- and up-stream signals in C-band are recovered through FF-2, AWG4, DF-($N+1$) and ONU-($N+1$) and IF-1 path. If FF-1 fails, the SW's connection states of the N ONUs in the C-band are changed and the bidirectional signals are transmitted through the neighboring PON in the L-band and the corresponding IFs. Thus, the architecture provides $1+1$ downstream protection and 1:1 upstream protection against the failures of both FF and DF.

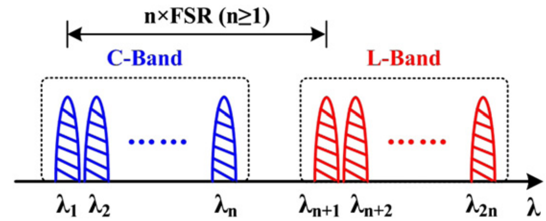

Fig. 2. Waveband allocation plan.

3. Experiment results and discussions

To verify the operation of the proposed cross-protection scheme, we performed an experiment as shown in Fig. 4. In the OLT, a continuous wave (CW) light from a laser diode at 1545.5 nm is modulated via a Mach–Zehnder modulator (MZM), which was biased at the transmission null point and driven by a 2.5 Gb/s data with a pseudo-random bit sequence (PRBS) with length of 2^{31}-1 to generate downstream non-return-to-zero (NRZ) signal with an extinction ratio (ER) of around 5. Note that since the downstream carrier is reused and re-modulated with upstream data, the downstream signal should have a low extinction ratio (ER) (e.g., up to 5 dB) so that the interference from the downstream signal to the upstream signal is minimized and the error-free upstream transmission can be achieved [13]. The downstream signal is amplified by an optical amplifier and then passes through an optical circulator and a band-pass filter (BPF) before it reaches an optical coupler (OC). The BPF emulates a $1 \times N$ AWG at the OLT and has an insertion loss of 3.5 dB. Two 1×16 AWGs located in the RN have 100-GHz channel spacing and a FSR of 31-nm. The FF and DF are single mode fibers (SMFs) with lengths of 15 km and 5 km, respectively. The IF is 2-km SMF. At the ONU, two coarse WDMs were used to separate and combine the C- and L-bands. The 2×2 optomechanical switch used in our experiment has a switching speed of milliseconds, 1-dB insertion loss and −70-dB crosstalk. One part of the downstream signal was detected by an avalanche photodiode (APD) receiver; the other was amplified and re-modulated by 1.25 Gb/s 2^{31}-1 PRBS upstream data via a gain-saturated RSOA. The un-cooled RSOA is packaged in a TO-can. The optical gain of the device was 23.5 dB when it was biased at 60 mA via a Bias-T circuit and the optical power of the injected light was −15 dBm. At these conditions, the RSOA got saturated (e.g., its optical gain decreases by 3 dB from the maximum value) with the

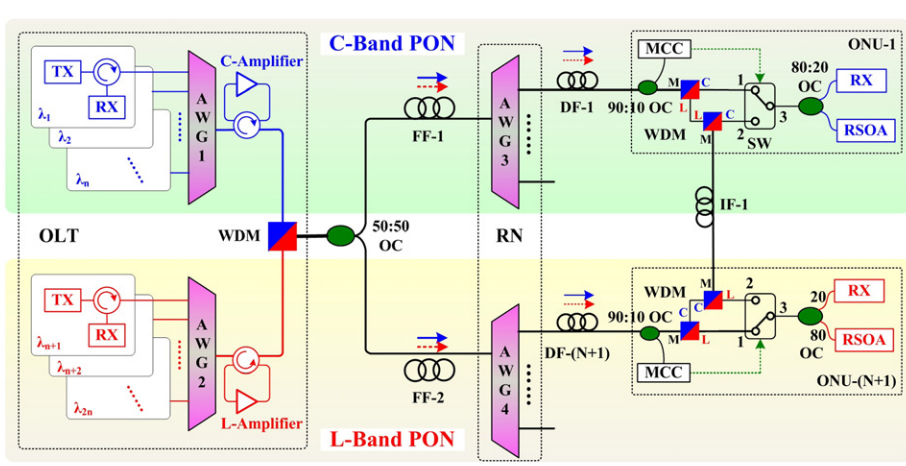

Fig. 1. Schematic diagram of the proposed cross-protection colorless dual-WDM-PON architecture.