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Cost-effective Edge-side Single LD-drive Protection with Reflection Blocking for Single Star/Passive Double Star Link Switchable Point-to-Multipoint Full-duplex Fiber Transmission

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Abstract *We propose full-single λ operation under normal conditions and an ONU-side Fresnel antireflection for bypass and backup path switchable point-to-multipoint systems. The 4ONU optical coherent system provides full-duplex fiber transmission without power penalty using wavelength conversion and shared link switching for primary link failure. ©2022 The Authors*

Introduction

The 4th generation (4G) mobile communication system is a single-star (SS) physical topology with a dedicated parallel link that connects optical transmitters/receivers between centralized and distributed stations [1,2]. The cell range of the 5th generation (5G) mobile communication system is narrower than 4G system, and the number of radio base stations per space is higher. Previously, the optical access network (OAN) was popularized for conventional fiber-to-the-home [3,4]. Another candidate for this network is a passive double star (PDS) physical topology with a shared cost-effective single link [5,6]. The PDS topology economically consolidates traffic from multiple radio base stations into a single optical fiber [7-10].

Flexible concepts, such as various optical fiber connections around the edge node with an optical gateway on the aggregation side, have also been proposed [11-13]. The recently reported disaster-tolerant switchable point-to-multipoint (P-to-MP) optical communication system uses a dedicated fiber link characterized by low loss as the primary link and an economical shared fiber link as the secondary link [14]. Like the passive optical network (PON) protection discussed in the ITU standardization, the P-to-MP configuration effectively uses the output terminal of the 2×2 optical coupler in the remote node [15-17]. Path-pair sharing protection methods that can be reconnected in a catastrophe where the primary and secondary links fail at the same time are also reported [18]. However, the link shared by the half-divided optical node units (ONUs) and the link shared by all ONUs are used as the dedicated primary link and shared secondary link, respectively, in the conventional switchable point-to-multipoint, system. Since the development of configuration protected wavelength division multiplexing (WDM) coherent PON systems, regular operation without link failures requires multiple operating light sources on the central station side.

This research proposes a unique link switchable P-to-MP system consisting of a dedicated link for each ONU and a shared link that combines all ONUs as primary and secondary links, respectively. The proposed configuration can operate the entire system with a single wavelength under normal conditions. Therefore, the OPEX of the entire system can be reduced by consolidating the operating light sources on the optical line terminal (OLT) side into one unit. Furthermore, the reflection block configuration on the ONU side uses an optical switch that enables the transmission of the same wavelength during both uplink and downlink. This configuration can also consolidate the light sources on the ONU side into one unit and reduce the CAPEX of the entire system. An experiment with a 4 ONU × 100 Gb/s/way bidirectional transmission system was conducted and the feasibility of a coherent OAN configuration that can switch between dedicated and shared links using anti-reflection methods associated with single link failure was confirmed.

No upstream/downstream same-wavelength single-core full-duplex transmission link failure has been reported when the signal and local light sources on the ONU side are consolidated into one unit using the reflection block function.

Configuration of an SS/PDS Link Switchable P-to-MP System with Reflection Blocking

Figure 1 shows the wavelength allocation and switch connection of a dedicated and shared link switchable P-to-MP system with a reflection block function and four ONUs with no primary and secondary link failure. The 2 × 2 optical coupler in each ONU enables simultaneous output of the optical transmitter upstream to the primary and secondary links. It selectively inputs the optical receiver downlink to the primary or secondary link.

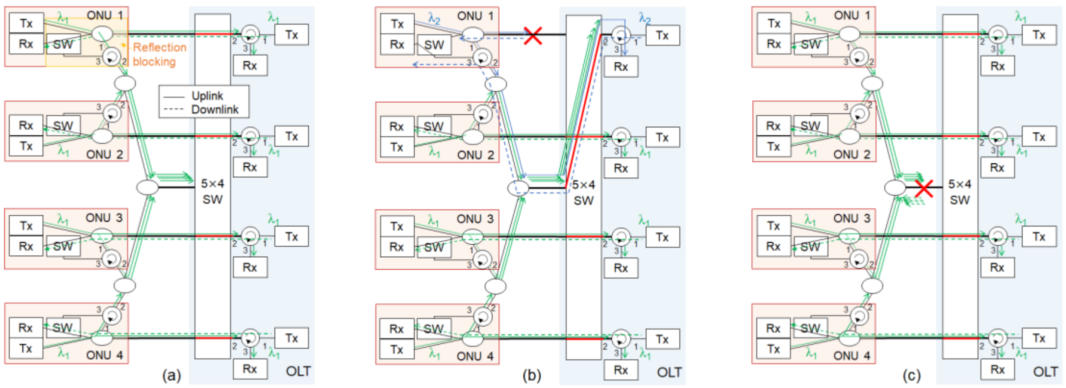

Fig. 1: SS/PDS link switchable P-to-MP architecture with edge-side single LD protection: (a) no failure case, (b) primary failure case, (c) secondary failure case.

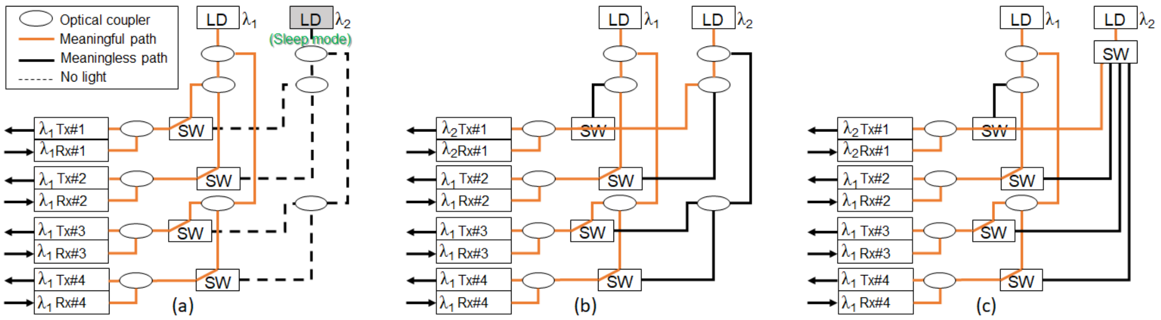

Fig. 2: OLT-side LD commonization setup: (a) no failure and secondary link failure cases, (b) primary link failure case with sub-LD light broadening, (c) primary link failure case with sub-LD light switching.

In addition, the 1 × 2 optical switch placed in the ONU and the optical circulator set in the secondary link allow the input of the optical receiver downlink to be selected from either the primary or secondary link. On the OLT side, transmitter/receiver pairs are placed according to the number of ONUs. A transmitter/receiver pair can be connected to the optical switch in a form with a lower loss than that of an optical coupler by switching up and down with an optical circulator. In an OLT with (N+1)×N optical switches, four main links and one sublink can access any optical transmitter/receiver pairs in the OLT. If another ONU is sleeping and one of the transceivers fails in the OLT, the transceiver access feature allows a connection to another optical transceiver. In the non-link failure situation illustrated in Fig. 1 (a), the entire system is operated only with λ_1, and the optical switch is connected such that all ONUs use the primary link. The primary link disconnection for ONU 1, as illustrated in Fig. 1 (b), converts both the upstream and downstream wavelengths of ONU 1 to λ_2. By switching the 1 × 2 optical switch on the ONU side to the secondary link side, the reflected signal from the primary link side was blocked by the optical switch. The ONU, in which the dedicated link corresponding to the primary link is broken, uses the secondary link and connects to the corresponding optical transmitter/receiver pair by switching another 1 × 2 optical switch. In case of secondary link failure illustrated in Fig. 1 (c), the reflected signal can be block from the secondary link by connecting the optical switch in the ONU to the primary link. The wavelength allocation of each ONU and the optical switch connection on the OLT side are the same as those for no-link failure.

Figure 2 shows the arrangement of the laser diode (LD), optical fiber wiring, and switch connection in the OLT for each situation. Figure 2 (a) shows the condition of LD sharing for no link and secondary link failure, where the ONU can be operated with a single LD output. Figures 2 (b) and (c) correspond to light source sharing when the primary link fails and can operate with two LD outputs. The configuration shown in Fig. 2 (b) is the same as that shown in Fig. 2 (a). It is a relatively inexpensive configuration that uses only an optical coupler without arranging an optical switch on the optical output side of λ_2. Figure 2 (c) shows a configuration in which sufficient power budget can be obtained with high transmission power downlink and a high local oscillator (LO) input uplink by selecting an optical switch without distributing the optical output of λ_2. The configuration shown in Fig. 2 (c) is suitable for transmitting a secondary link that has significant loss compared with the primary link. The laser diode (LD) output in sleep mode can be connected to any transmitter/receiver pair via an optical switch to deal with any primary link failure.

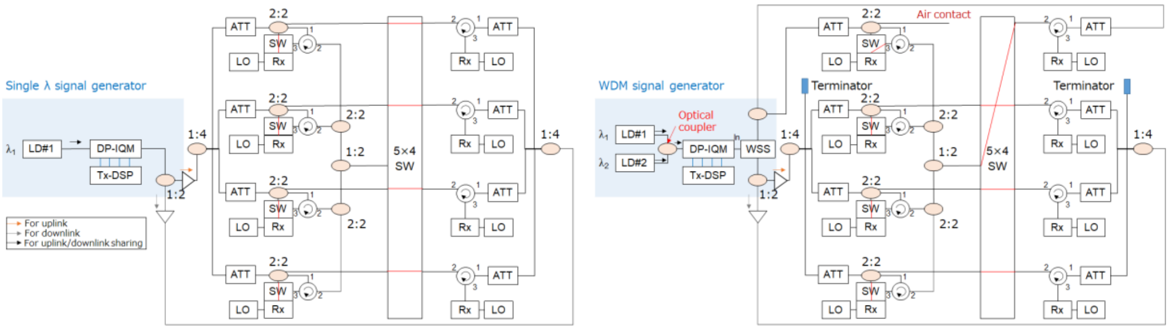

Fig. 3: Experimental setup: (a) no failure and secondary link failure cases, (b) primary link failure case.

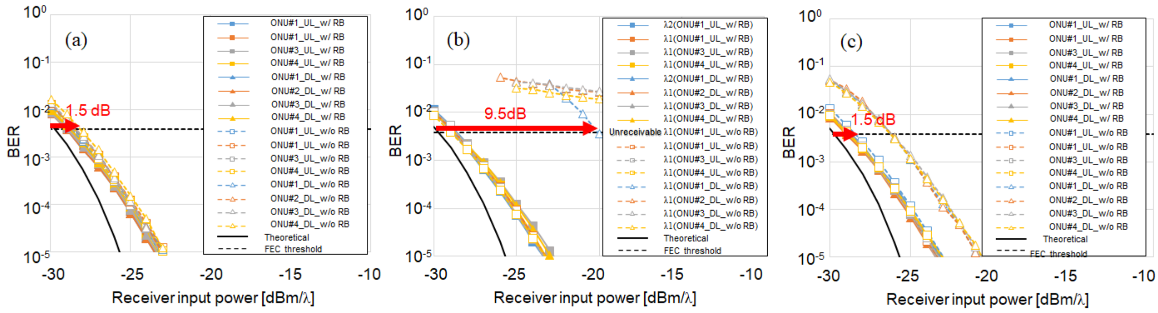

Fig. 4: Experimental BERs: (a) no failure case, (b) primary link failure case, (c) secondary link failure case.

Experimental Setup and Results

Figs 3 shows an experimental single-core bidirectional transmission system consisting of a dedicated/shared link switchable P-to-MP with a reflection block configuration. This setup simulates nonlink, primary link, and secondary link failures. Figure 3 (a) shows the system configuration for cases of no link failure and secondary link failure. An optical coupler combines the output from the LD array. A dual-polarized (DP)-quadrature phase-shift keying (QPSK) signal is collectively modulated based on the 4-lane electrical signal output from the Tx-side digital signal processor (DSP) by the DP-in-phase and quadrature modulator (IQM). The DP-QPSK signal is divided into two parts by an optical coupler and amplified into 4ONU by an optical amplifier. Then, an uplink 4ONU signal is generated by a 1 × 4 optical coupler. An optical amplifier amplifies the uplink signal that is then divided into four ONU signals using a 1 × 4 optical coupler. The uplink signal of each ONU is adjusted by the optical attenuator, transmitted separately to the main link and secondary link by the 2 × 2 optical coupler, and then input to the 5 ×4 optical switch on the OLT side. Like the uplink signal procedure, the downlink DP-QPSK signal of each ONU is selected via a 5×4 optical switch from the OLT side and then coherently detected and demodulated by the optical receiver of each ONU. Figure 3 (b) shows the system configuration in case of primary link failure. As shown in Fig. 3 (a), the WDM-DP-QPSK signal is divided by the wavelength through a wavelength-selective switch (WSS). The 1 × 4 optical coupler generates the uplink and downlink signals after the optical amplifier. Route selection by the optical switch is switched to the connection, as indicated by the red line.

Figs 4 shows the measurement bit error ratio (BER) of the ONU and OLT signals of the uplink and downlink, with and without link failure. Moreover, the BER characteristics with and without the reflection block when the link fails are compared. To use a hard-decision forward error correction (FEC) code with a redundancy of 7 %, an error correction limit of FEC limit = 3.8×10^{-3} is assumed. If primary link failure occurs on the downlink without a reflection block, an error floor will occur owing to solid interference of sharing the same wavelength after switching 5×4 optical switch, and the FEC limit will not be reached. In addition, in the event of a primary link failure on the downlink without reflective blocks, the power penalty exceeds 9.5 dB owing to relatively strong back reflections. Even if a downlink with a reflection block has a primary and secondary link failure, the power penalty is less than 1.5 dB because of the effect of slight backward reflection owing to the same wavelength at all times.

Conclusions

An SS/PDS link-switchable P-to-MP system with edge-side single LD protection with reflection blocking was proposed in a single-link failure scenario. We have experimentally confirmed that the converted path can be reconnected using reflection blocking without being affected by the back reflection of the end face during switching or full-duplex transmission after allocation.

References

[1] F. Saliou, P. Chanclou, L. A. Neto, G. Simon, J. Potet, M. Gay, L. Bramerie, and H. Debregeas, "Optical access network interfaces for 5G and beyond," *Journal of Optical Communications and Networking*, vol. 13, no. 8, pp. D32-D42, Aug. 2021.
DOI: 10.1364/JOCN.425039

[2] I. Alimi, A. Teixeira, and P. Monteiro, "Toward an efficient C-RAN optical fronthaul for the future networks: A tutorial on technologies, requirements, challenges, and solutions," IEEE Communications Surveys & Tutorials, vol. 20, no. 1, pp. 708-769, Firstquarter 2018.
DOI: 10.1109/COMST.2017.2773462

[3] M. Presi, M. Artiglia, F. Bottoni, M. Rannello, I. V-Cano, J. Tabares, J-C. Velasquez, S. Gasemi, V. Polo, G. Y. Chu, J. Prat, G. Azcarate, R. Pous, C. Vila, H. Debregeas, G. V-llosera, A. Rafel, and E. Ciaramella, "Field-trial of a high-budget, filterless, λ-to-the-user, UDWDM-PON enabled by an innovative class of low-cost coherent transceivers," *IEEE Journal of Lightwave Technology*, vol. 35, no. 23, pp. 5250-5259, 2017.
DOI: 10.1109/JLT.2017.2748597

[4] S. Yoshima, M. Nogami, S. Shirai, N. Suzuki, M. Noda, H. Ichibangase, and J. Nakagawa, "A 10.3 Gbit/s LAN-PHY based burst-mode transmitter with a fast 6 ns turn-on/off time for 10 Gbps-based PON systems," *Proc. Optical Fiber Communication Conference (OFC)*, OWL.4, San Diego, USA, Feb. 2008.
DOI: 10.1109/OFC.2008.4528731

[5] L. A. Neto, J. Maes, P. L-Edefors, J. Nakagawa, K. Onohara, and S. J. Trowbridge, "Considerations on the use of digital signal processing in future optical access networkis," *IEEE Journal of Lightwave Technology*, vol. 38, no. 3, pp. 598-607, Feb. 2020.
DOI: 10.1109/JLT.2019.2946687

[6] J. S. Wey and J. Zhang, "Passive optical networks for 5G transport: technology and standards," *IEEE Journal of Lightwave Technology*, vol. 37, no. 12, pp. 2830-2837, June. 2019.
DOI: 10.1109/JLT.2018.2856828

[7] N. Suzuki, S. Yoshima, H. Miura, and K. Motoshima, "Demonstration of 100-Gb/s/λ-based coherent WDM-PON system using new AGC EDFA based upstream preamplifier and optically superimposed AMCC function," *IEEE Journal of Lightwave Technology*, vol. 35, no. 8, pp. 1415-1421, Apr. 2017.
DOI: 10.1109/JLT.2016.2646344

[8] P. Parolari, A. Gatto, C. Neumeyr, and P. Boffi, "Flexible transmitters based on directly modulated VCSELs for next-generation 50G passive optical networks," *Journal of Optical Communications and Networking*, vol. 12, no. 10, pp. D78-D85, Oct. 2020.
DOI: 10.1364/JOCN.391872

[9] A. Pizzinat, P. Chanclou, F. Saliou, and T. Diallo, "Things you should know about fronthaul," *IEEE Journal of Lightwave Technology*, vol. 33, no. 5, pp. 1077-1083, Mar. 2014.
DOI: 10.1109/JLT.2014.2382872

[10] R. Borkowski, M. Straub, Y. Ou, Y. Lefevre, Z. L. Jelic, W. Lanneer, N. Kaneda, A. Mahadevan, V. Huckstadt, D. V. Veen, V. Houtsma, W. Coomans, R. Bonk, and J. Maes, "FLCS-PON - A 100 Gbit/s flexible passive optical network: Concepts and field trial," *IEEE Journal of Lightwave Technology*, vol. 39, no. 16, pp. 5314-5324, Aug. 2021.
DOI: 10.1109/JLT.2021.3102383

[11] J. Kani, S. Kaneko, K. Hara, and T. Yoshida, "Optical access network evolution for future super-broadband services and 6G mobile networks," *Proc. The 47th European Conference on Optical Communications (ECOC)*, Th2F.1, Bordeaux, Sept. 2021.
DOI: 10.1109/ECOC52684.2021.9606132

[12] Y. Senoo, S. Kaneko, T. Kanai, N. Shibata, J. Kani, and T. Yoshida, "Demonstration of in-service protocol-independent end-to-end optical path control and restoration in all-photonics network," *Proc. Optical Fiber Communication Conference (OFC)*, W3G.4, San Diego, USA, Mar. 2022. DOI: 10.1364/OFC.2022.W3G.4

[13] R. Bonk, P. Vorreau, D. Hillerkuss, W. Freude, G. Zarris, D. Simeonidou, F. Parmigiani, P. Petropoulos, R. Weerasuriya, S. Ibrahim, A. D. Ellis, D. Klonidis, I. Tomkos, and J. Leuthold, "An all-optical grooming switch for interconnecting access and metro ring networks," *Journal of Optical Communications and Networking*, vol. 3, no. 3, pp. 206-214, Mar. 2011.
DOI: 10.1364/JOCN.3.000206

[14] T. Kodama, T. Goto, and R. Matsumoto, "Wavelength collision-free and low-loss full-duplex transmission over switchable full-coupling or half-split coherent WDM-PON system with shared protection," *Proc. Optical Fiber Communication Conference (OFC)*, Th5I.3, Online, USA, June. 2021. DOI: 10.1364/OFC.2021.Th5I.3

[15] ITU-T G Suppl. 51, "Passive optical network protection considerations," June 2017 [Online].

[16] T. Nishitani, Y. Hirano, M. Noda, and K. Motoshima, "Protection systems for optical access networks," *IEEE/OSA Journal of Lightwave Technology*, vol. 35, no. 6, pp. 1197-1203, Mar. 2017.
DOI: 10.1109/JLT.2016.2644665

[17] N. Parkin and A. Rafel, "Novel low cost PON protection via harvested power," *Proc. Optical Fiber Communication Conference (OFC)*, Th2A.35, Mar. 2020. DOI: 10.1364/OFC.2020.Th2A.35

[18] T. Kodama, T. Nakagawa, and R. Matsumoto, "Any-Double-link failure tolerant bypass/backup switchable WDM-PON employing path-pair shared protection and bidirectional wavelength pre-assignment," *Proc. Optical Fiber Communication Conference (OFC)*, W3G.5, San Diego, USA, Mar. 2022. DOI: 10.1364/OFC.2022.W3G.5