Ultra-fast Out-of-band 1+1 Protection Using a WDM Backup Channel and a Tunable Receiver

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ABSTRACT

1+1 protection is usually used to implement fast failure recovery and provide high reliability to data connections. A typical scheme of 1+1 protection employs a primary working lightpath and a dedicated diversely-routed backup ligthpath to carry the same data, in which the same wavelengths are always used for the two lightpath, thus putting edge-disjoint restrictions on the wavelength routing. Because current standard requires <50-ms protection-switching time, a mechanical switches with several millisecond switching time can be used before the receiver for channel switching. However, with the transmission speed of single wavelength channel increasing to tens of Gb/s, a faster switching time is highly desired to reduce the amount of data loss. In this paper, we propose an out-of-band 1+1 protection scheme, which employs two different wavelengths for primary working lightpath and protection backup path, respectively. At the destination node, a fast tunable heterodyne-detection receiver is used to select the desired wavelength lightpath. The proposed fast tunable receiver significantly reduces the protection switching time between the two paths. To investigate the performance of the proposed protection scheme, a fast channel selection experiment is performed. Two optical wavelength channels were modulated simultaneously by a Mach-Zehnder (MZ) external modulator with data rate 1.25Gb/s. The tunable heterodyne receiver switches between the working lightpath and protection lightpath to demonstrate the capability of 1+1 protection. A <0.8-ns switching time is obtained which demonstrates the potential of hitless protection switching, if the switching occurs at the transition of two neighboring ’1’s.

Keywords: 1+1 protection, automatic protection switching, ultra-fast tunable receiver, out-of-band protection, optical networks.

1. INTRODUCTION

With the development of optical transmission system towards higher data rates, the capacity that one wavelength channel can carry has increased to tens or even hundreds of Gigabits per second. Accordingly, the network failure,

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e.g. link cut, node or other equipment malfunction, would lead to severe data loss and service interruption. Conventionally, 1+1 protection is used to implement fast failure recovery, which consists of a primary working lightpath and a dedicated diversely-routed backup ligthpath to carry the same data for protection. In the case the primary working lightpath fails the service quickly switches to the protection lightpath at the receiver. 1+1 protection usually employs the same wavelengths for the working and protection lightpath, which puts restrictions on the wavelength routing and requires edge-disjoint between the two lightpaths [1-3]. In addition, current standard requires <50-ms protection-switching time so that mechanical switches with several millisecond switching time is often used before the receiver for channel switching. However, as the transmission speed of single wavelength channel increases, a faster switching time is highly desired to reduce the amount of data loss, especially for those with high quality of service (QoS) requirement, and error-free or hitless optical switching is anticipated. Recently, coherent receivers employing fast-switching local lasers have become candidates for tunable channel-access receivers due to their good performance in wavelength selectivity. In this case, the channel-switching time depends on the local lasers which potentially can achieve nanosecond scale switching.

In this paper, we propose an out-of-band 1+1 protection scheme, which employs two wavelengths for primary working lightpath and protection backup path, respectively. After passing through different intermediate nodes the working signal and the protection signal are simultaneously routed into the receiver, where a heterodyne-detection receiver is used to select the desired wavelength lightpath by switching the local lasers of the receiver accordingly. This approach relaxes the routing limitation of the two paths and allows them passing the same edges of the networks, which is sometimes necessary especially in mesh networks. In addition, the proposed fast tunable receiver significantly reduces the time of the protection switching between the two paths. Of course, to reduce the time in the switching initiation, a light-weight switching protocol should be employed. Here we focus on the switching time of the tunable receiver.

In order to investigate the performance of the proposed protection scheme, we performed a fast channel selection experiment. Two continuous wave optical channels (1563.808-nm working channel and 1554.473-nm protection channel) were modulated simultaneously by a Mach-Zehnder (MZ) external modulator with data rate 1.25Gb/s. The heterodyne receiver employs a typical envelope-detection system for intermediate frequency detection and a fast switched local oscillator which are controlled by two MZ switches for channel selection. B-to-B performance of the two channels is measured. A transient process analysis is illustrated to help understanding the fast protection switching capability of the receiver. A <0.8-ns switching time is observed which is fast enough to obtain a hitless protection switching [4], if the switching occurs at the transition of two neighboring '1's. Recently, coherent receivers employing fast-switching local lasers have become candidates for tunable channel-access receivers due to their good performance in wavelength selectivity [5]. In this case, the channel-switching time depends on the local lasers which potentially can achieve nanosecond scale [5, 6].

PROTECTION SCHEME

Traditional 1+1 protection scheme employs a primary working lightpath and a backup ligthpath to carry the same data for protection. The two paths usually use the same wavelength for simplifying the design of the transmission systems. Fig. 1a illustrates the traditional implementation scheme in a mesh networks. At the head node, same data stream from the data source are transmitted into primary path and protection path by the working line terminal and

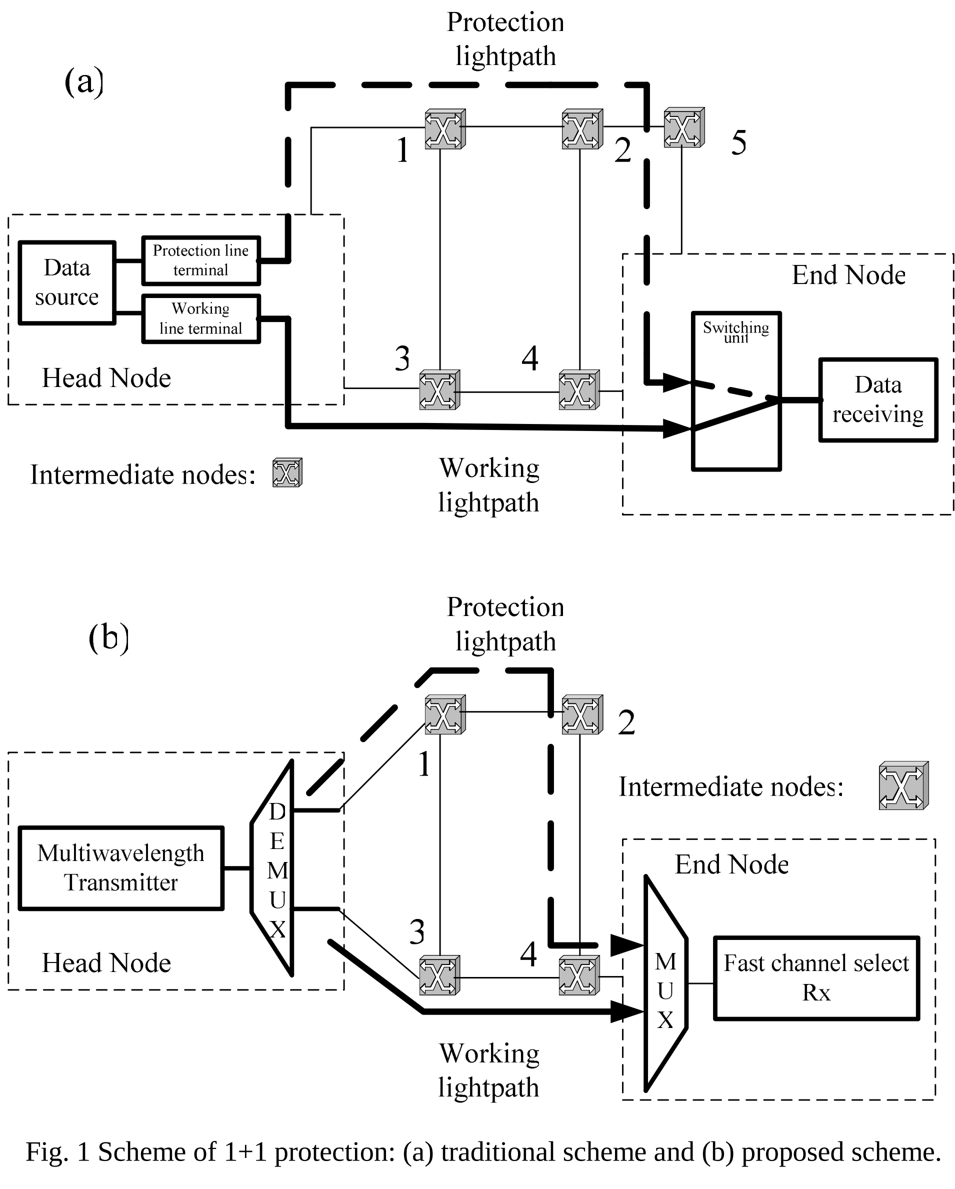

Fig. 1 Scheme of 1+1 protection: (a) traditional scheme and (b) proposed scheme.

protection line terminal respectively. The two paths can carry the information in same wavelength because the protection path and working path are always edge-disjoint or space division in most applications, for example, in metro bidirectional ring networks with two or four fibres. The two paths will pass space division routes to reach the destination node. A switching unit are used to select the data from desired path at the end node, which can be fast optical switch or electronic selection system. The former method introduces excess optical insertion loss and the latter one increases the cost of the system. In the other side, fast increased transmission speed of single channel requires a faster switching time to reduce the amount of data loss and provide high QoS service, in which error-free or hitless optical switching is expected.

The proposed 1+1 protection scheme is shown in Fig. 1b. The head node employs a multi-wavelength transmitter to send the data to protection lightpath (dashed arrow line) and the working lightpath (solid arrow line) using two wavelengths. After passing through different intermediate nodes the working signal and the protection signal are simultaneously routed into a tunable receiver, which is capable of switching to the desired channel by tuning the local oscillator. This is so called out-of-band protection as the working path and the protection path use different wavelengths. Here, for clarity, only the parts of the transceivers in the head and end nodes are plotted to show the operation principle in the figure. In practice, the difference in the propagation delay between the two paths needs to be taken into account to recover the data. This proposed approach relaxes the limitation in routing of the two paths and allows them passing the same edges of the networks, which is in some cases necessary especially in mesh networks. In addition, the proposed fast tunable receiver significantly reduces the time of the protection switching between the two paths.

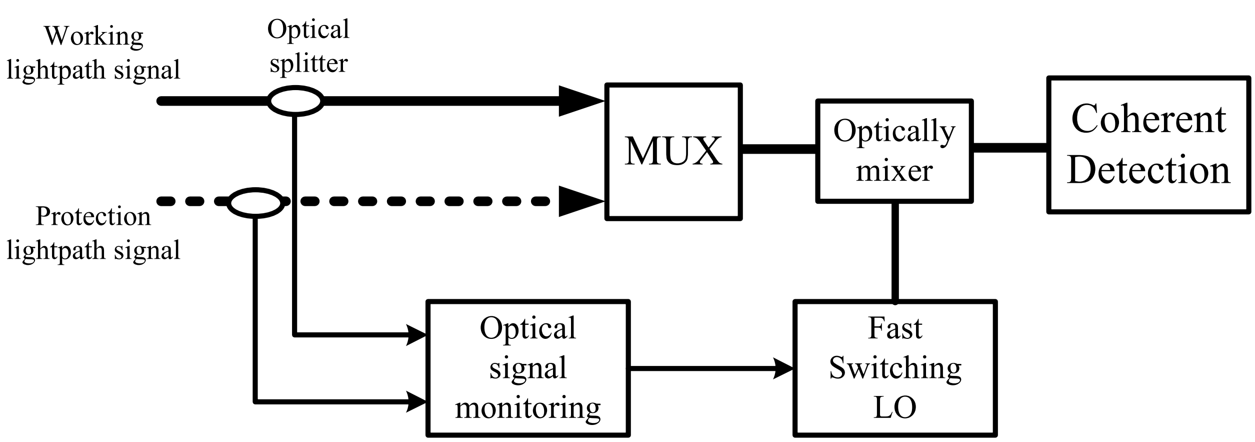

Fig. 2 Block diagram of protection switching in receiving end by using fast tunable heterodyne receiver.

EXPERIMENT AND RESULTS

The end node keeps detecting any failure occurring in working path by monitoring the optical signal. Once a failure is detected a protection switching protocol immediately initiates a switching process to receive data from the protection channel. Fig.2 provides the block diagram of protection switching in receiving end implemented by using the fast tunable heterodyne receiver, where an optical power monitoring module is used to detect the signal power of working path and protection path, and output fast trigger signals in the case of signal loss in the lightpaths to incur switching action of the LO source of the coherent receiver from working channel to protection channel. To reduce the time in the switching initiation, a light-weight protocol, and a fast electrical monitoring and trigger circuit should be employed. Here we focus on the switching time of the tunable receiver and the time of monitoring and triggering can be reduced through design of high-speed circuit.

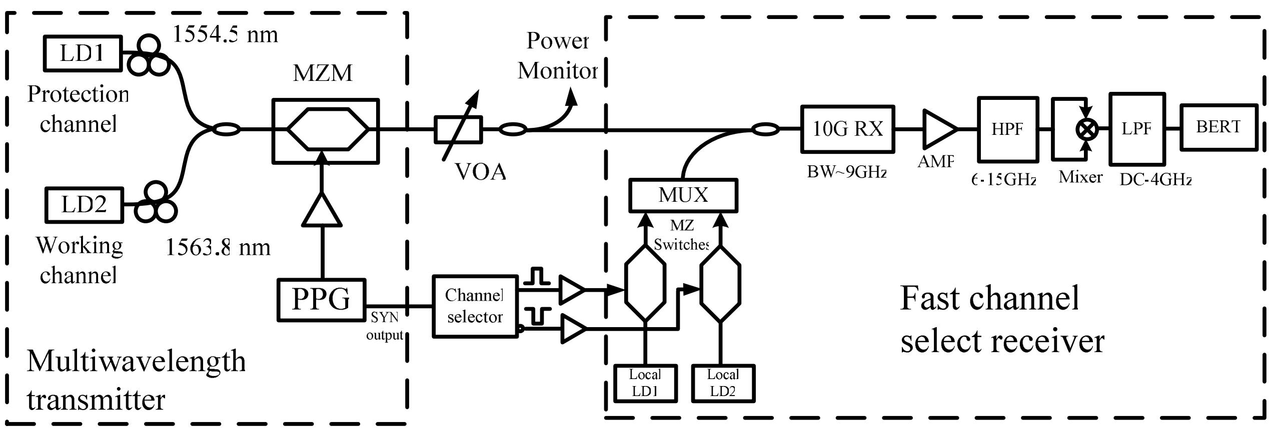

Fig. 3 Experimental setup.

In order to investigate the performance of the proposed protection scheme, we performed a fast channel selection experiment as shown in Fig. 3. The lights from two continuous wave (CW) DFB lasers are combined by a 3-dB coupler after passing through the polarization controllers as the working channel (1563.808-nm) and protection channel (1554.473-nm) carriers, respectively. Then a Mach-Zehnder (MZ) modulator is used for external data modulation, which is driven by a 1.25-Gb/s non-return-to-zero (NRZ) data stream. To facilitate bit-error-rate (BER) measurement, two wavelength channels are transmitted in the same fibre to keep them in phase. A variable optical attenuator is used to change the input signal optical power of the channel selection receiver. The heterodyne receiver employs a typical envelope-detection system for intermediate frequency detection, and fast-switched local lasers which are controlled by two MZ switches for channel selection. The multiplexing output of the switching local lasers is adjusted to ~-2dBm. The intermediate frequencies (IFs) of both channels are set to the same value of ~8.4 GHz. The B-to-B BER performances of two channels are tested with 1.25-Gb/s NRZ PRBS of length 2^{31}-1 as shown in Fig. 4. The sensitivities of -22.0 dBm and -22.7 dBm are obtained for the protection channel and the working channel respectively. The difference could be mainly attributed to the laser instability issue. An eye diagram is provided as an inset in the figure. In the experiment little pattern dependence was observed.

To demonstrate the switching process, complementary electric switching control signals are obtained from the frame output of the pulse pattern generator (PPG) to drive two MZ optical switches so that the resulted rise and fall times of the switching optical are less than 600 ps. For synchronization purpose, the bit pattern length is set to 128. Under the control of this signal, the local laser source switches between two channels periodically and the corresponding signal can be selected. The demodulated signal is then sent to sampling oscilloscope and BERT for analysis.

Fig, 5 shows the measured waveform of switching transient process between two channels. The optically mixed signal (Fig. 5a) indicates that the switching occurs at a ‘1’ bit. Its demodulated electrical waveform is shown in Fig.5b that gives a clear view of the switching time, which is less than one bit period of 0.8 ns. The switching time is fast enough that it enables error-free protection switching operation.

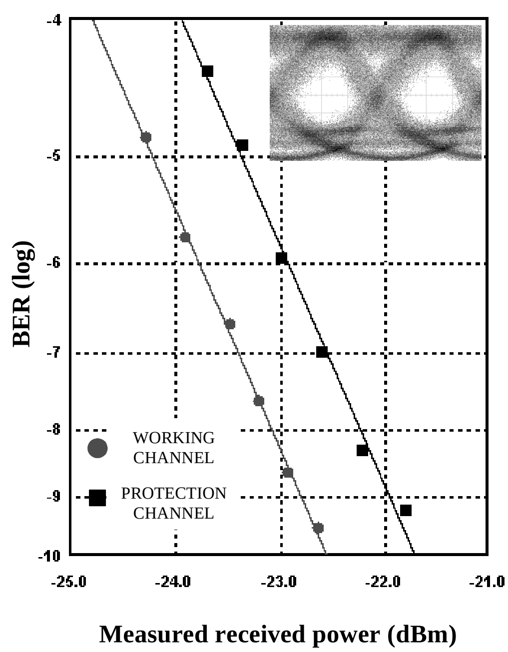

Fig. 4 B-to-B performance of two channels.

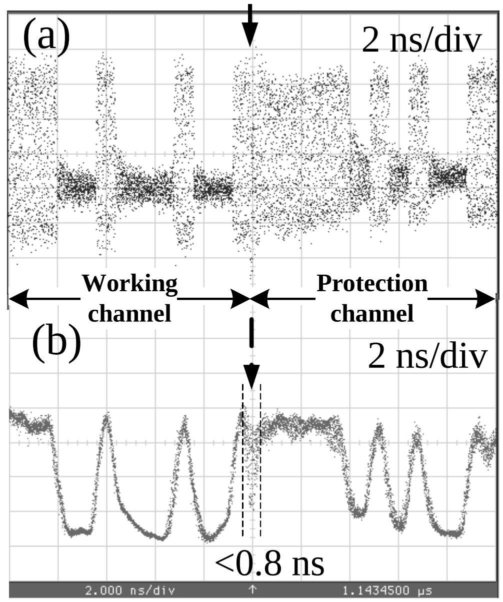

Fig. 5 The switching between two channels, (a) Optically-mixed signal and (b) demodulated electrical signal.

CONCLUSION

We propose and experimentally demonstrate a new out-of-band 1+1 protection scheme. The protection channel uses a different wavelength to provide flexibility in wavelength routing. Furthermore, a fast switching heterodyne receiver is employed to greatly reduce the time of channel switching. In the experiment, a <0.8-ns switching time is observed which is fast enough to obtain a hitless protection switching, if the switching occurs at the transition of two neighboring '1's.

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REFERENCES

1. David S. Levy, Kevin Solomon, Steven K. Korotky, "Loss-Less Bridging in 1 + 1 Optical Protection Using a Modified Transmitter and Receiver," IEEE Photonics Technology Letters, Vol. 15, No. 3, March 2003, pp.485-487.

2. SONET Dual-fed unidirectional path switched ring (UPSR), Bellcore Standard BR-GR-1400-CORE, 1999.

3. Transmission and Multiplexing; Synchronous Digital Hierarchy; Network Protection Schemes; Types and Characteristics, European Telecommun. Standards Inst. TS101 009 v1.1.1, 1997.

4. Kapil Shrikhande, Yoshiaki Ikoma, Akira Nakamura, Kyeong Soo Kim, Kazuyoshi Horie, Leonid G. Kazovky, "Hitless Wavelength Add-Drop Using a Novel Signaling Protocol Combined with Hitless Switching Techniques," in Proc. Optical Fiber Communications Conf. (OFC) 2002, 2002, Paper ThGG91.

5. Lothar Möller, Matthias Kauer, Andrew Adamiecki, Jeff Sinsky, Larry Buhl, "Multicast Optical Switch Fabric With Ultrafast Channel Access Based on Heterodyne Receivers," IEEE Photonics Technology Letters, Vol. 16, No. 1, January 2004, pp. 272-274.

6. F. Tong, C.-S. Li, G. Berkowitz, "A 32-Channel Tunable Receiver Module for Wavelength-Division Multiple-Access Networks," IEEE Photonics Technology Letters, Vol. 9, No. 11, November 1997, pp. 1523-1525.