Bidirectional WDM self-healing ring network composed of add fibre and drop fibre

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A bidirectional WDM self-healing ring network composed of add and drop fibres is reported. In this network, it is possible to relax the device requirement and realise self-healing without the need for protection switches in the transmission paths. In addition, the transmission capacity can be doubled in the operating state.

Introduction: Self-healing ring (SHR) networks have been studied for use in interoffice networks because they improve survivability and flexibility [1 – 3]. The WDM ring networks connect a central office (CO) and N remote nodes (RNs) with a working fibre. A protection fibre is required to ensure network survivability [1, 2]. These architectures are based on optical add/drop multiplexers and protection switches in the transmission paths. In this Letter, we demonstrate a bidirectional WDM SHR using an add fibre and drop fibre based on add multiplexers (AMs) and drop demultiplexers (DDs). Each RN consists of two 2 × 2 optical switches, an AM connected to the add fibre and a DD connected to the drop fibre. In this way, we can relax the device requirement for suppression of the relative intensity noise (RIN) in the bidirectional ring networks. The proposed network provides self-healing without the need for protection switches in the transmission paths.

Fig. 1 Remote node configurations

a) Add multiplexer
b) Drop demultiplexer
c) Add multiplexer and drop demultiplexer with two AWGs

Experiment: Schematic diagrams of the AM and the DD in the RN are shown in Figs. 1a and b, respectively. The AM and the DD are composed of two WDM filters and are connected to the add fibre and the drop fibre, respectively. Each WDM filter is able to add or drop one wavelength assigned to each RN. The 2 × 2 optical switch is used to exchange the paths of the bidirectional signals to ensure survival of the higher priority signal in the protection state.

To demonstrate the proposed network, we realised the RN using two 16 × 16 arrayed waveguide gratings (AWGs) instead of WDM filters, as shown in Fig. 1c. For example, λ1 signals launched into port 5 of each AWG exit through port 8 and are transmitted in both directions through the add fibre. In the other way, λ1 signals coming from both directions through the drop fibre are dropped into port 4 of each AWG. Since the AM and the DD composed of two AWGs are not isolated, the inchannel crosstalk between the added signals and the dropped signals degrades the system performance. Note that this crosstalk is not shown for the schemes in Figs. 1a and b.
Fig. 2 shows the experimental setup for the proposed bidirectional WDM SHR network. The fibre lengths between the nodes were 10, 25, and 15 km. The CO transmits two wavelength signals bidirectionally through the drop fibre. Two wavelength signals are modulated with different data by external modulators at 2.5Gbit/s (pattern length: 2^31 - 1). The transmission capacity of the proposed network can be doubled in the operating state.

![Diagram of WDM SHR network](image)

**Fig. 2** Experimental setup of WDM SHR network

Add/drop wavelengths were assigned as shown in Fig. 2. For example, \( \lambda_1 \) signals (wavelength: 1550.92 nm) transmitted bidirectionally at the CO were dropped at RN 1 by the DD. Similarly, \( \lambda_2 \) signals (wavelength: 1552.52 nm) were dropped at RN 2. New \( \lambda_1 \) and \( \lambda_2 \) signals were then added at RN 1 and RN 2, respectively. These added signals were transmitted bidirectionally through the add fibre. The receivers at the CO and the RNs received the optical signals. Bidirectional amplifiers with a gain of 11 dB are used at RN 2 to compensate for the loss of the AWGs.

When a transmission failure (e.g., due to a fibre-cut) occurs between RN 1 and RN 2, the CO transmits the higher priority \( \lambda_1 \) and the higher priority \( \lambda_2 \) signals using the optical switches in the counter-clockwise and clockwise directions, respectively. These higher priority signals were dropped at RN 1 and RN 2. Consequently, we can maintain survivability of the ring network for higher priority signals without the need for optical protection switches in the transmission paths.

![Output and dropped spectra at the remote nodes](image)

**Fig. 3** Measured output and dropped spectra at the remote nodes

- \( a \) Output spectra at point A in Fig. 2
- \( b \) Dropped spectra at drop port \( \odot \) of RN 2
- \( c \) Output spectra at point B in Fig. 2
- \( d \) Dropped spectra at drop port \( \odot \) of RN 2

Experimental results: Figs. 3a and c show the optical spectra of the signals transmitted bidirectionally through the add fibre at RN 1. The optical spectra shown in Figs. 3b and d were measured at both drop ports of the DD in RN 2. An interchannel crosstalk of less than –25 dB was obtained. The optical signal-to-noise ratio of the left-hand dropped signal (Fig. 3d, at drop port \( \odot \) of RN 2) is worse than that of the right-hand dropped signal (Fig. 3b, at drop port \( \odot \) of RN 2) because of the crosstalk induced by the amplified spontaneous emission (ASE) of the bidirectional amplifiers.

To evaluate the performance of the proposed network, we measured the bit error rate (BER) characteristics. The measured BER curves for the \( \lambda_1 \) signals and \( \lambda_2 \) signals are shown in Figs. 4a and b, respectively.

![Measured BERs against received optical power](image)

**Fig. 4** Measured BERs against received optical power

- \( a \) BER curve of \( \lambda_1 \) signal (wavelength: 1550.92 nm)
- \( b \) BER curve of \( \lambda_2 \) signal (wavelength: 1552.52 nm)
- • at port \( \odot \) of remote node (operating state)
- ○ at port \( \odot \) of remote node (operating state)
- △ at port \( \odot \) of central office (operating state)
- ◀ at port \( \odot \) of central office (operating state)
- ▽ at port \( \odot \) of remote node (protection state)
- + at port \( \odot \) of central office (protection state)
- X at port \( \odot \) of central office (protection state)

The maximum power penalties measured at RN 1 and RN 2 were 0.35 and 0.52 dB (at BER = 10^-9), respectively. The power penalties arise from the RN induced by the leakage of the added signal due to the crosstalk of the AWGs and optical reflections. The power penalty at RN 2 is larger than that at RN 1 since the bidirectional amplifiers located at RN 2 increase the optical reflection effects. For RN 2, the calculated penalty based on a measured crosstalk level of –28 dB was 0.5 dB, which is close to the experimental value of 0.52 dB [4]. Using add/drop WDM filters instead of AWGs, we can suppress the interchannel crosstalk between the added signals and the dropped signals.

We simulated the network failure by breaking the transmission fibre between RN 1 and RN 2. The measured BER curves at the CO, RN 1 and RN 2 show no power penalty, as shown in Figs. 4a and b.

When the isolation of the WDM filter is 10 dB (this may be the specification of a lower grade WDM filter) and the optical back reflection coefficient is –30 dB, the interchannel crosstalk induced by the RN is 50 dB below the signal power. The penalty due to the RN is then negligible, i.e., we can suppress the crosstalk successfully using low-isolation WDM filters. Thus the scalability of the proposed ring network is not limited by the RN induced by imperfect isolation of the WDM filters and optical back-reflections.

**Conclusion:** We have demonstrated a bidirectional WDM SHR network composed of an add fibre and drop fibre. The proposed ring network provides self-healing without the need for optical protection switches in the transmission paths. In addition, we can double the transmission capacity in the operating state. It is possible to realise a simple and cost-effective WDM SHR network since the requirement of the WDM filters is considerably relaxed.

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Transmission of 32 ETDM channels at 40 Gbit/s (1.28 Tbit/s capacity) over $3 \times 100$ km of TeraLight™ fibre


The transmission of 32 channels at 40 Gbit/s is demonstrated over $3 \times 100$ km of TeraLight™ fibre. The result was obtained with full ETDM terminal equipment and hybrid Raman/erbium amplifiers.

Introduction: One way of meeting the ever-growing demand for terabit/s capacities in WDM terrestrial transmission systems is to increase the channel rate from 10 to 40 Gbit/s. However, this is only beneficial in terms of total throughput if, at the same time, the spectral efficiency $\eta$ is increased by reducing the channel spacing to $< 200$ GHz [1], down to at least 100 GHz [2, 3]. In particular, the transmission of 80 channels spaced 100 GHz apart ($\eta = 0.4$ bit/s/Hz) was recently demonstrated over 3 $\times$ 100 km [2]. However, as at 10 Gbit/s, an electronic time-domain multiplexing (ETDM) approach is desirable to contain costs not only in the transmitter [2] but also in the receiver [1, 3].

In this Letter, we demonstrate the transmission of 32 channels at 40 Gbit/s to a high spectral efficiency of $\eta = 0.4$ bit/s/Hz with 100 GHz channel spacing, using full 40 Gbit/s ETDM receiver/equipment. A total capacity of 1.28 Tbit/s is demonstrated over $3 \times 100$ km of TeraLight™ fibre, using hybrid Raman/erbium amplifiers.

**Fig. 1 Experimental setup**

**Fig. 2 Spectrum at end of fibre span 1**

Resolution = 9.2 nm

- $\lambda$ Raman pumps off
- $\delta$ Raman pumps on

**Fig. 3 Dispersion maps for channels 1 and 32**

In the booster, in the line amplifiers and in the preamplifier, the amount of DCF was carefully optimized to guarantee the best achievable performance. The cumulated fibre dispersion for channels 1, 32 along the link is depicted in Fig. 3, showing nearly full in-line dispersion compensation. Variable channel-by-channel post-compensation was carried out at the receiver end by steps of 20 ps/nm, to match the theoretical requirement for the total cumulated dispersion of 5 ps/nm. The dispersion of the post-compensating fibre is shown in Fig. 4 as a function of wavelength. It varies from...