Wavelength-matching scheme for wavelength grating routers in all-optical transport networks

C.-K. Chan, F. Tong and L.-K. Chen

The authors propose and demonstrate a new wavelength-matching scheme for wavelength grating routers in all-optical transport networks. The wavelength assignment of the data channels and the transmission peaks of the wavelength grating routers can be matched automatically and continuously. The scheme uses the unutilised ASE spectra of the EDFA as the source and a temperature-compensated fibre Bragg grating as the matching indicator. It is also insensitive to dynamic ASE power variations arising from channel add-drop.

Introduction: A wavelength grating router (WGR) is one of the most critical network elements in all-optical transport networks, performing the functions of channel routing, add-drop, and demultiplexing. To achieve optimal operation of a WGR, it becomes essential that its transmission peaks should always match with the wavelength assignment of the data channels. However, depending on the material from which the WGR is fabricated, the spectral response can be greatly influenced by the ambient temperature fluctuations or device ageing, causing a wavelength mismatch between the data wavelengths and the WGR. This not only leads to substantial attenuation of the transmitting signals, but also introduces severe crosstalk to the neighbouring channels, thus greatly impairing the performance of the entire system. A wavelength-matching scheme must be implemented to ensure optimal network operation.

Wavelength matching by tuning the source wavelength [1] is inapplicable to wavelength routing networks while dithering of the reference signal [2] induces a system penalty and requires complicated circuitry. The scheme proposed in [3] is feasible but requires an additional stable laser source and uses up to two dedicated WGR output ports for monitoring. In this Letter, we propose and demonstrate a novel and effective wavelength-matching scheme for WGRs. The scheme makes use of a temperature-compensated fibre Bragg grating (TC-FBG) and the amplified spontaneous emission (ASE) from an erbium-doped fibre amplifier (EDFA) as the monitoring source. This scheme is also insensitive to dynamic ASE power variations arising from channel add-drop.

Fig. 1 Proposed wavelength-matching scheme for WGR

Proposed scheme: Fig. 1 shows the proposed wavelength-matching scheme for an \( N \times N \) WGR, which can be formed by an \( N \times N \) arrayed waveguide grating (AWG) [4]. Although a static WGR is shown in the diagram, the principle of operation can also be applied to a dynamic WGR in which the demultiplexed channels have to pass through banks of \( k \times k \) switches, \( k \) being the number of wavelength channels in each input fibre.

An EDFA is placed at each input port so as to compensate and equalise the power among various channels [5] caused by the near-end effect of the add-drop nodes. We assume that the free spectral range (FSR) of the WGR is less than the usable bandwidth of the ASE spectrum of the EDFA and that the unused portion of the ASE can be employed as the monitoring source. As a result, at each output port, in addition to the transmitted wavelength channels, there are multiple filtered ASE peaks, each originating from different input EDFAs in accordance with the characteristics of the AWG.
For our wavelength-matching scheme, only two adjacent filtered ASE peaks at one of the WGR’s outputs are needed. A temperature-compensated fibre Bragg grating (TC-FBG) with its centre wavelength matched at the midpoint (crossover wavelength) between the two adjacent filtered ASE peaks is placed at one output port (inset of Fig. 1). A TC-FBG is adopted since it has a very small temperature-induced shift at the centre wavelength ($\pm 4 \times 10^{-4}$ Å/$^\circ$C) [6], about several orders of magnitude better than that of the usual SiO$_2$-based WGR device ($\pm 0.15$ Å/$^\circ$C), although a high performance AWG with a wavelength-dependent wavelength drift of $5.9 \times 10^{-4}$ Å/$^\circ$C was reported recently [7]. The TC-FBG reflects the filtered ASE power at that crossover wavelength back to the two corresponding input ports. The two reflected signals are then tapped off by circulators, filtered by FP filters and detected by photodiodes as shown.

![Fig. 2 Experimental results](image)

**Fig. 2 Experimental results**

Difference signal before and after feedback loop is closed. Inset: BER performance of 1 Gbit/s 2$^5$-1 PRBS NRZ data stream with and without proposed scheme. Also shows two transmitted ASE spectra (one FSR away from data wavelengths) before FBG on WGR's output port no. 12. FBG is centred at mid-point between peak wavelengths of these two spectra. ▲ without scheme ○ with scheme

![Fig. 3 Numerical result](image)

**Fig. 3 Numerical result**

Difference signal against attenuation of input ASE power of one input EDFA (input ASE power of other EDFA is kept constant) for temperature shifts of $\Delta T = 0$, $-5$ and $-10^\circ$C, with or without compensation for ASE dynamics. ▲, △, ● with compensation ○, □ without compensation

To compensate the dynamic variations in input ASE power, the two reflected signals are normalised with their respective input ASE powers. The difference of the normalised signals is monitored carefully. Any change in the difference signal will trigger a servo-control circuitry, which controls the current source of a thermo-electric cooler attached to the WGR. The sign and magnitude of the difference signal will lead to either heating or cooling of the WGR until a predefined level of the difference signal is reached. In this way, automatic wavelength matching is achieved. Such a scheme also supports in-service monitoring and will not degrade the performance of the data channels.

**Experiments and results:** In our experiment, a 16 × 16 AWG with a channel spacing of 100GHz, a 3 dB full-width of 0.4 nm, and a temperature coefficient of 0.012 nm/$^\circ$C are used to simulate the WGR. Two optical amplifiers with similar gain outputs are placed in front of input port no. 11 and input port no. 12 of the WGR. Modulated data at $\lambda = 1586.2$ nm is also fed into input port no. 11. An FBG with a centre reflection wavelength of $\lambda_{ref} = 1559.525$ nm and a 3 dB full-width of 1 nm is placed at output port no. 12 of the WGR, where the two adjacent filtered ASE peaks considered are located at $\lambda_{a} = 1559.144$ nm and $\lambda_{b} = 1559.906$ nm (Fig. 2 inset) when the WGR’s temperature is set at 11.5$^\circ$C. By activating the control-servo circuitry, the peak transmission of the WGR gradually shifts from the initial wavelength, which corresponds to the initial temperature of 21.8$^\circ$C, to our desired wavelength assignment, corresponding to 11.5$^\circ$C, within 4 min. Over many hours of testing, the difference signal remains constant within $\pm 0.01$ dB, which corresponds to a wavelength deviation of $<\pm 0.001$ nm (Fig. 2). Bit error rate measurements are also performed using 1 Gbit/s 2$^5$-1 PRBS NRZ data with the circuitry on, and no performance degradation is observed (Fig. 2 inset). The effect of dynamic variations in the ASE power of the EDFA on the stability of the difference signal is also analysed numerically. The input power of one EDFA is varied by >10 dB while the other is kept constant for three mismatch conditions ($\Delta T = 0$ matched), $-5$, $-10^\circ$C. The results are shown in Fig. 3, revealing that our scheme, which has dynamic power compensation, is insensitive to any dynamic power variation in the EDFA’s ASE.

**Summary:** We have proposed and demonstrated a simple and effective wavelength-matching scheme for WGR in all-optical transport networks. No dedicated laser source is required for reference. The scheme supports in-service monitoring and will not degrade the performance of the data channels.

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3 TONG, F., HO, K.P., SCHRENS, T., HALL, W.E., GRAND, G., and MOTTER, F.: '1 Gbit/s 2$^5$-1 PRBS NRZ data with the circuitry on, and no performance degradation is observed (Fig. 2 inset). The effect of dynamic variations in the ASE power of the EDFA on the stability of the difference signal is also analysed numerically. The input power of one EDFA is varied by >10 dB while the other is kept constant for three mismatch conditions ($\Delta T = 0$ matched), $-5$, $-10^\circ$C. The results are shown in Fig. 3, revealing that our scheme, which has dynamic power compensation, is insensitive to any dynamic power variation in the EDFA’s ASE.

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