A NOVEL OPTICAL CROSS-CONNECT WITH BUILT-IN OPTICAL-PATH SUPERVISORY SCHEME FOR ALL-OPTICAL NETWORKS

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Abstract: We propose and demonstrate an optical cross-connect with built-in optical-path supervision for all-optical wavelength routing networks, which does not tap off any power at the data wavelengths for monitoring.

Introduction

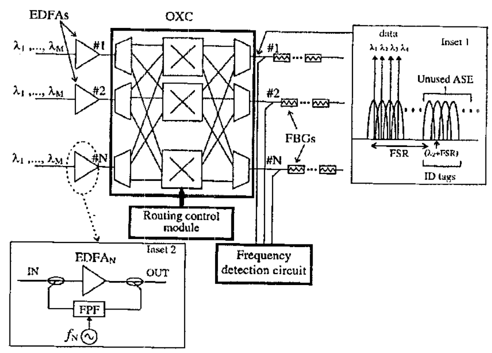
The optical cross-connect (OXC) [1] is one of the most critical enabling technologies that, together with other network elements, offer scalability, high throughput, and multi-access capability in all-optical wavelength routing networks. Through the OXCs, wavelength channels from various sources are routed to their respective destinations in accordance to the prescribed switch settings registered in a routing control module residing at these devices. The network configuration management will reconfigure these settings prior to each data transmission. In an OXC, any partial or complete failure, or malfunction in the optical switches will route streams of data to completely wrong destinations and lead to data loss. It is therefore of immense interest to develop an OXC that can detect any routing failure at the earliest possible stage.

Previously proposed optical path management schemes based on a pilot tone [1] and a supervisory channel [2] are intrusive in nature, sacrificing data transparency and privacy. In this paper, we propose a novel OXC with built-in optical path supervision for all-optical networks. The OXCs considered here are the types without wavelength conversions. The basic principle of operation is to assign each input fiber of the OXC with a unique identification (ID), which will be detected and processed immediately at each output port without tapping off any power at the data wavelengths. Thus any failure or incorrect physical connection at the switches can be detected at once by comparing the as-detected physical connection and the switch-setting information stored in the routing control module. The detected failure will be reported to the central office at once, facilitating fault identification, and alerting the network configuration management such that network downtime and data loss can be kept at a minimum.

Optical Path Supervision in Proposed OXC

Fig. 1 shows the proposed optical cross-connect with built-in optical-path supervisory scheme for an NxN OXC, which can be formed by a total of $2N$ (N incoming and N outgoing) 1xM arrayed waveguide gratings (AWG) interconnected by M banks of NxN optical space switches, assuming that there are M data wavelengths (λ_1, ..., λ_M) carried on each input fiber. Identical wavelength channels but from different input fibers will be routed by the same NxN optical switches to various output fibers in accordance to the routing assignment kept in the routing control module. We assume that there is an Erbium-doped fiber amplifier (EDFA) at each input port of the OXC for gain equalization and loss compensation. The free spectral range (FSR_{AWG}) of the AWG is chosen to be less than one-half of the usable gain spectrum of the EDFA. Because of the periodicity property of the AWG, there exists both routed wavelength channels and filtered amplified spontaneous emission (ASE) located at one FSR_{AWG} from the corresponding routed wavelength channels at the output ports (see Fig. 1, inset 1).

Fig. 1: Architecture of proposed OXC with optical-path supervision



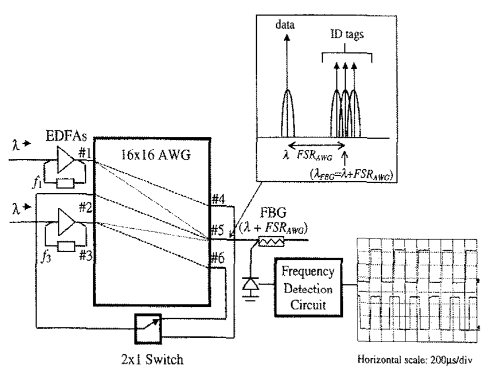
A unique and distinct ID will be introduced to each input fiber. To generate the ID tag for the i-th input port ($i=1,...,N$), a small portion of the ASE is looped back to the input of EDFA$_i$ through a scanning Fabry-Perot filter (FPF) modulated at a distinct sinusoidal frequency f_i (~kHz) (see Fig. 1 inset 2). The loopback configuration generates lasing action and the amplifier gain is clamped. The selected scanning spectral range of the FPF should span at least one FSR_{AWG} over a portion of the EDFA spectrum which is unoccupied by the data channels. Accordingly, for a wavelength channel at λ_k being routed by the OXC from the i-th input fiber to the j-th output fiber, there appears an ID tag on the j-th output fiber, located at one FSR_{AWG} from λ_k, (e.g. $\lambda_{ID\text{-}k}=\lambda_k+FSR_{AWG}$; $k=1,...,M$), and represented by periodic pulses that correspond to the power fluctuation at $\lambda_{ID\text{-}k}$ with an frequency of f_i. Such pulses at $\lambda_{ID\text{-}k}$ is due to the periodic scanning lasing at the i-th input port. Thus, there will be M ID tags on each output fiber, each signifying the input fiber in which the corresponding data channel is routed from. Note that the IDs for different wavelength channels will not be mixed up because no two data channels of identical wavelengths will be routed to the same output port.

On each output fiber, fiber Bragg gratings (FBG) with center wavelengths at $\lambda_{FBG\text{-}k}=\lambda_{ID\text{-}k}$ (for $k=1,...,M$) are used to drop the ID tags through circulators. The ID tags can be either demultiplexed, or scanned by an FPF before being detected by photodiodes. A frequency detection circuit is then used to recover the frequency of the detected pulses at each ID tag. By comparing the as-detected physical connection with the prescribed switch settings stored in the routing control module, any failure or error in routing can immediately be detected. Finally, a broadband rejection filter is to be placed after all the FBGs on each output fiber to eliminate the IDs, and new IDs will be generated at the input ports in the next OXC.

Experimental Results

Fig. 2 shows our experimental setup. In our experiment, a thermally stabilized 16x16 AWG with a channel spacing of 100 GHz, an FSR_{AWG} of 12.8 nm and a 3-dB full-width of 0.4 nm in a loopback configuration is used to simulate the OXC. Two similar EDFAs ($EDFA_1$ and $EDFA_3$) are placed at the input ports 1 and 3 of the AWG, respectively. Output ports 4 and 6, which correspond to the routing of two different data channels but of identical wavelength at λ=1546.7 nm from input ports 1 and 3, are looped back to input port 2 through a 2x1 optical switch (insertion loss = 0.3 dB). The resultant configuration can route the data channel λ, from either input port 1 or 3 to output port 5, depending on the state of the 2x1 optical switch. This configuration also generates three neighboring IDs at output port 5, two originating from one input EDFA and one from the other, which allows us to study the worst-case scenario of the neighboring ID tags.An FBG with a center wavelength of $\lambda_{FBG}=\lambda_{ID}$=1559.5 nm (one FSR_{AWG} away from λ), a power reflectivity of 54 dB and a 3-dB full-width of 1 nm, is placed at the output port 5 for reflecting the power at λ_{ID} (ID).

Fig. 2: Experimental Setup. The inset shows the detected and recovered channel ID at output #5 when the 2x1 switch input is connected to output fiber #4 (upper trace, f_1=2.5 kHz, and #6 (lower trace, f_3=3 kHz).

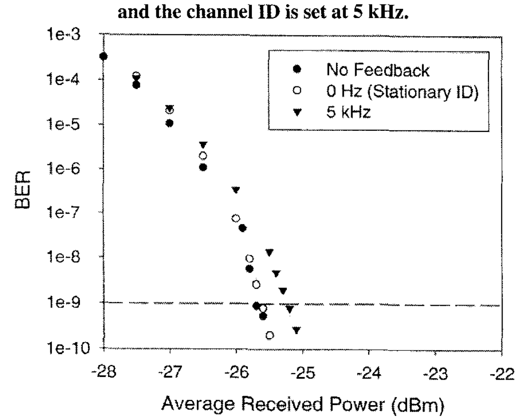


To generate the channel ID, a small portion from each of the amplifiers' outputs (through a 95:5 coupler) is fed back to its input (through a 50:50 coupler). A tunable FPF of finesse 100 with a 3-dB bandwidth of 0.7 nm is placed in between the couplers at each input fiber 1 and 3. By applying a sinusoidal voltage of 0.4 V (peak-to-peak) at 2.5 kHz to the FPF at input port 1 and an identical voltage at 3 kHz to the FPF at input port 3, we thus obtain the IDs for the input ports 1 and 3, respectively.

A simple detection circuit is implemented after the photodiode and is used to recover the fluctuation frequency of the power reflected from the FBG, which is the ID for the data channel. Inset in Fig. 2 shows the recovered waveforms of the detected ID when the 2x1 switch is in two different states. The frequency of the pulse pattern changes from 2.5 kHz to 3 kHz when the 2x1 switch's input is changed from output port 4 to 6, and vice versa. This shows our scheme can effectively detect the routing status at the OXC.

BER measurements were also performed for the data channel at λ, externally modulated by a 1-Gb/s 2^{15}-1 PRBS NRZ data stream, for a channel ID frequency of 5 kHz. The results are displayed in Fig. 3, showing that there is only 0.5 dB power penalty arising from the scanning FPF.

Fig. 3: BER performance of the data channel with and without the proposed supervisory scheme. The data channel is externally modulated by a 1-Gb/s 2^{15}-1 NRZ PRBS and the channel ID is set at 5 kHz.



Summary

We have proposed and demonstrated the principle of operation for an optical cross-connect with built-in optical-path supervisory for all-optical wavelength routing networks. Any error in optical-path routing due to failure in the cross-connect can be detected without tapping off the power at the data wavelengths, and no dedicated monitoring light source is required.

References

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