A Novel Supervisory Scheme for OXC Based on Different Time-Delay Recognition

Chien-Chung Lee, Ta-Chun Kao, Hung-Chang Chien, and Sien Chi

***Abstract*—A novel supervising technique, based on different time-delay recognition scheme, for monitoring the switch fabric of optical cross-connects is proposed. This method features fast detection, high reliability, fault location, and actual routing information. The supervising of 4×4 switch fabric with a detecting time of less than 300 ns was achieved. It is also verified experimentally that the degradation of the system performance caused by this supervising approach is negligible.**

***Index Terms*—Optical cross-connect (OXC), supervising.**

I. INTRODUCTION

OPTICAL cross-connects (OXCs) are the essential network elements in all-optical wavelength-division-multiplexing (WDM) networks. In these networks, each OXC, controlled by network configuration management, is reconfigurable for optical paths between source nodes and destination nodes. WDM signal transmission depends strongly on routing status and the performance of OXCs, so the failure of optical path connections at some OXCs will lead to unexpected communication loss. Thus, the need to provide more reliable surveillance technique for each OXC is becoming all the more necessary. Recently, several methods have been reported such as the use of pilot-tones as channel IDs to detect the routing error [1], [2] or the employment of an arrayed waveguide grating to monitor the optical path and crosstalk [3]–[5]. However, none of them can provide fast monitoring to meet the requirement for OXC with packet switching functionality in future networks. Moreover, most of them verify the cross connections of optical signals based on the information registered in the cross-connect map instead of by checking the actual inputs–outputs and the connection configuration of the switch fabrics. Therefore, this letter proposes and demonstrates the feasibility of a novel supervising technique, based on different time-delay recognition scheme, to monitor the operations of the switch fabric at OXCs. The accuracy of optical-path fault location and data transparency are also experimentally verified.

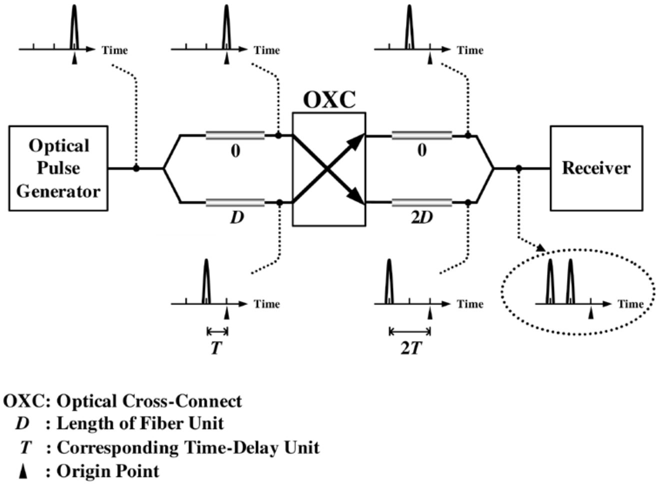

Fig. 1. Principle of operation for the proposed supervisory scheme based on different time-delay recognition.

II. OPERATION PRINCIPLE

Fig. 1 depicts the operation principle of the proposed supervisory scheme. A 2×2 OXC with two connection configuration, cross and bar, is discussed. The fiber lengths for different time delays arranged at the input and output ports are $(0, D)$ and $(0, 2D)$, respectively. D denotes the fiber length unit and T is the corresponding one bit period of the monitoring signal. In Fig. 1, the monitoring signals with 0 and T time delays will be injected into the OXC, routed to different destinations, and imposed by $2T$ and 0 time delay units at the output ports. Then, the monitoring signals with delays of T and $2T$ are combined and converted into a serial pulse stream at the receiver. Therefore, the stream pattern at the receiver provides evidence that the OXC must be in the cross state without any switch fault or line fault, and a unique mapping exists from the switch connection configurations to the stream patterns.

The design of the fiber delay arrays at the monitoring-signal generator and receiver requires a unique pattern for each possible switch connection configuration. Thus, the design rule for an $N \times N$ OXC $(N \geq 2)$ can be expressed as

$$I_n - I_{n-1} = mD, \tag{1}$$

$$O_n - O_{n-1} = \begin{cases} 2mD, & \text{for } N = 2 \\ I_{\max}, & \text{for } N > 2 \end{cases} \tag{2}$$

where $I_{1\sim n}$ and $O_{1\sim n} (n \in 2 : N)$ represent the lengths of the input and output delay arrays, m is an positive integer, mD represents the common difference, and $I_1 = O_1 = 0$ is assumed.

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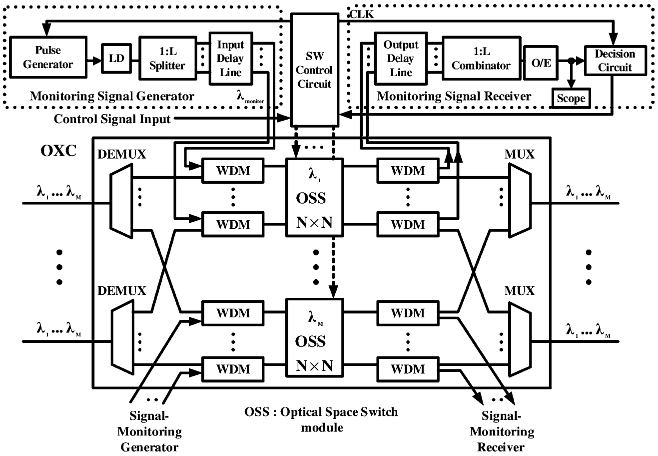

Fig. 2. Proposed systematic architecture for supervising switch fabric in OXC.

III. PROPOSED ARCHITECTURE

Fig. 2 shows the proposed structure for monitoring the switch fabric of an $N \times N$ OXC with M banks of $N \times N$ optical space switches (OSS). Each input channel has M data wavelengths. The monitoring signals with the wavelength $\lambda_{\mathrm{monitor}}$ are injected into each OSS through WDM couplers, and are shared over all OSSs. After they have passed through the switch module, the monitoring signals are retrieved by WDM couplers and sent to the monitoring-signal receiver. The monitoring signals are converted into a serial data stream. After the decision circuit process, the switch module status is transmitted to the switch control circuit. The monitoring-signal generator comprises an optical pulse generator, and a $1 : L$ $(L = M * N)$ fiber delay array. The optical pulse generator consists of a pulse generator and a laser to provide adequate optical monitoring signals. The $1 : L$ fiber delay array contains a $1 : L$ splitter and L-corresponding fiber delay lines. Thus, the monitoring-signal generator provides L optical pulse-streams with different time delays. These optical pulse streams, accompanied by the data stream in the individual system, pass through the switch module and are routed to different output ports. At the monitoring-signal receiver, the retrieved monitoring signals will be imposed by another corresponding fiber delay array, combined by an $L : 1$ combiner, and are then converted into a serial pulse stream. Table I shows the expected received pulse streams for a 4×4 wide-sense nonblocking structure with all possible switch connection configurations as an example. The notation "$x - y$" in the column of connection configuration denotes the cross-connection from input port x to output port y. Therefore, this table may be applied to verify the switching status at an OXC and identify the possible switching error.

IV. EXPERIMENTAL SETUPS AND RESULTS

Fig. 3(a) exhibits the experimental setup for monitoring packet switching ((switching time $<=$ 300 ns) and circuit switching (switching time in the millisecond range). In order to simulate the fast packet switching, a 2×2 1550 nm acoustooptic (AO) switch with a 100-ns rise time is selected, while the slow circuit switching is achieved by a 2×2 mechanical switch. A similar 1×1 AO switch at the output Port 4 is used to simulate switching failure. The monitoring signal from the monitoring-signal generator has the following parameters: a $\lambda_{\mathrm{monitor}}$ of 1510 nm, a pulse period of 300 ns, a bit period of 6.4 ns (155 Mb/s), a fiber length unit of 1.29 m, a bit length of 48 in the pulse stream (32 for monitoring and 16 for guarding), and a time delay of [0, 2, 4, 6] and [0, 6, 12, 18] units for input and output delay line arrays, respectively.

TABLE I
OUTPUT OF SERIAL PULSE STREAM FOR DIFFERENT CONNECTIONS OF THE SWITCH MODULE

Case	Connection configuration	4 "1" bit positions of the serial pulse stream
1	1-1, 2-2, 3-3, 4-4	0, 8, 16, 24
2	1-1, 2-2, 4-3, 3-4	0, 8, 18, 22
3	1-1, 3-2, 4-3, 2-4	0, 10, 18, 20
4	1-1, 3-2, 2-3, 4-4	0, 10, 14, 24
5	1-1, 4-2, 2-3, 3-4	0, 12, 14, 22
6	1-1, 4-2, 3-3, 2-4	0, 12, 16, 20
7	2-1, 3-2, 4-3, 1-4	2, 10, 18, 18
8	2-1, 3-2, 1-3, 4-4	2, 10, 12, 24
9	2-1, 4-2, 1-3, 3-4	2, 12, 12, 22
10	2-1, 4-2, 3-3, 1-4	2, 12, 16, 18
11	2-1, 1-2, 3-3, 4-4	2, 6, 16, 24
12	2-1, 1-2, 4-3, 3-4	2, 6, 18, 22
13	3-1, 4-2, 1-3, 2-4	4, 12, 12, 20
14	3-1, 4-2, 2-3, 1-4	4, 12, 14, 18
15	3-1, 1-2, 2-3, 4-4	4, 6, 14, 24
16	3-1, 1-2, 4-3, 2-4	4, 6, 18, 20
17	3-1, 2-2, 4-3, 1-4	4, 8, 18, 18
18	3-1, 2-2, 1-3, 4-4	4, 8, 12, 24
19	4-1, 1-2, 2-3, 3-4	6, 6, 14, 22
20	4-1, 1-2, 3-3, 2-4	6, 6, 16, 20
21	4-1, 2-2, 3-3, 1-4	6, 8, 16, 18
22	4-1, 2-2, 1-3, 3-4	6, 8, 12, 22
23	4-1, 3-2, 1-3, 2-4	6, 10, 12, 20
24	4-1, 3-2, 2-3, 1-4	6, 10, 14, 18

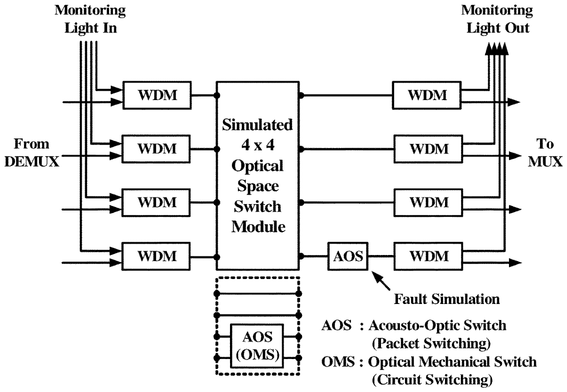

Fig. 3. Experimental setup of the simulated switch fabric connection for both packet and circuit switching.

Fig. 4(a) shows the experimental packet switching results for Case 1 and Case 6 in Table I. When the AO switch is ON (Case 6), the serial data stream becomes [1000 0000 0000 1000 1000 1000 0000 0000] and the corresponding hexadecimal representation is [80 08 88 00]. The results indicate that the detecting time can be less than 300 ns, and the switch statuses are detected correctly. Additionally, the uneven magnitude of the generated pulse stream, resulting from the different insertion losses of the AO switch, does not affect the accuracy of the supervision. Fig. 4(b) presents the measurement results of the cir-

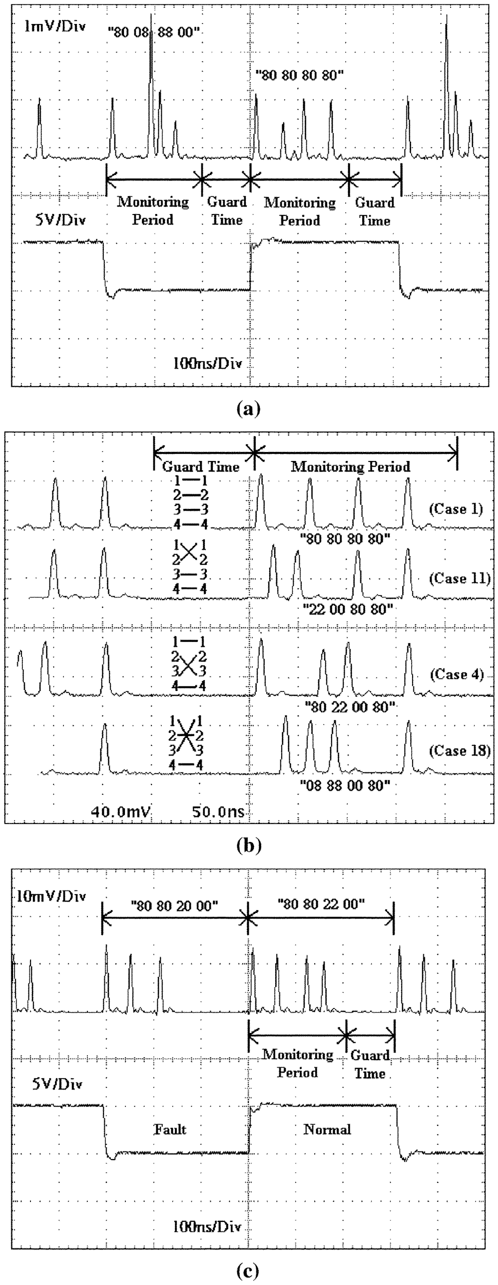

Fig. 4. Signal waveforms at the monitoring signal receiver for (a) packet switching structure when AOS is turning ON and OFF, (b) circuit switching structure at different connecting configurations, and (c) circuit switching structure to simulate the switch status of normal and fault condition

cuit switching structure at different connection configurations. The traces in order from top to bottom refer to Cases 1, 11, 4, and 18 in Table I, respectively. The detected waveforms of the pulse streams are totally consistent with the cross-connection configuration of the switch module. Fig. 4(c), simulating Case 2 in Table I, displays the detected stream pattern when the switch fails at the fourth output port. The results clearly show that when AO is OFF, only three "1" bits remain, and the fault can be easily located. Fig. 5(a) presents the experimental setup for evaluating the bit-error-rate (BER) performance at 10 Gb/s when the monitoring signal was added and removed, and the measured results are shown in Fig. 5(b). The results indicate that the BER degradation caused by the monitoring signal is negligible. For a full OXC, the required pattern length in the monitoring period is $(I_{\max} + O_{\max}/D = N(N-1)m$ bits, and the detecting time is $N(N-1)mT$. Hence, in order to achieve the scalability of this proposed scheme, a monitoring signal with a high bit rate, and many short fiber length units are required and simply available, while the scalability in the conventional cases [1]–[5] could not easily be realized since the associated supervisory cost will increase dramatically with the number of active components for channel identifying. Moreover, the proposed monitoring scheme can not only guarantee a nanosecond-range detecting time, which is not provided in the traditional cases [1]–[5], but also simultaneously supervise the actual optical-path connection for all channels.

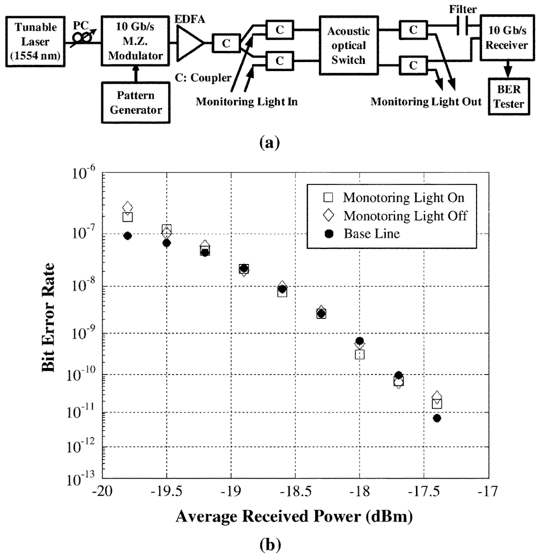

Fig. 5. Experimental setup for verifying the BER degradation (a), and (b) the measured results when the monitoring signal is added and removed.

V. CONCLUSION

A novel supervising technique, based on the recognition of different time delays, to supervise the switch fabric of OXC has been proposed and analyzed. The supervising of a 4 × 4 switch fabric with a detection time of less than 300-ns was successfully realized. Moreover, the actual routing status can be precisely detected with negligible BER degradation.

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