Architecture and Performance of a Bidirectional OXC Based on Reversible Optical Switches with Reduced Complexity

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Abstract *By exploiting the symmetry of bidirectional wavelength-connections in WDM networks, we propose an N×N bidirectional OXC using one N/2×N/2 reversible optical switch to reduce the complexity of the OXCs. The feasibility is demonstrated at 10 Gb/s.*

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Introduction

As the wavelength-count and fiber-count increase rapidly in wavelength-division multiplexed (WDM) networks, high-port-count optical switch matrix is needed. Generally a large switch matrix can be built by smaller available constituent switches as exemplified by the well-known Benes and Clos architectures. WDM networks are wavelength routed and, generally, show bidirectional symmetry in end-to-end wavelength connections [1]. By exploiting this symmetry, the complexity of the switch matrix and optical cross-connect (OXC) can be reduced [1-4]. In this paper, such a bidirectional OXC is denoted as BOXC, while a conventional unidirectional OXC is referred to as UOXC.

A class of BOXCs based on tuneable fiber Bragg gratings, arrayed-waveguide gratings (AWGs), and three or multi-port optical circulators (OCs) were reported in [2-4]. However, the number of wavelengths that can be supported by them is rather limited, e.g., much less than 160. Simmons et al [1] reported another class of BOXC which achieved *N*×*N* cross-connects by using *N*/2×*N*/2 switches. However, the optical switches have to be bidirectional cross-connected, in which each mirror is designed to reflect two light beams, as opposed to a single light beam. As a result, the mirrors would be enlarged in area and collimators be doubled in number.

In this paper, we propose and demonstrate a novel BOXC by using reversible optical switches (ROSs) together with OCs. This architecture reduces the complexity and implementation cost as compared to other existing approaches, since it uses some conventional optical switches as ROSs. The feasibility and performance are evaluated experimentally for a prototype at 10 Gb/s.

Proposed BOXC Architecture

The reversibility in optics allows a light ray be reflected and traverse back exactly through the incoming path [5]. The optical mechanical switches [6] and Micro Electromechanical System (MEMS) [7] optical switches work on the basis of light ray principle, and are reversible in optical path. As a result, they would work bidirectionally, i.e., a pair of reverse lights goes in the same path. Therefore, they can be used to construct a BOXC.

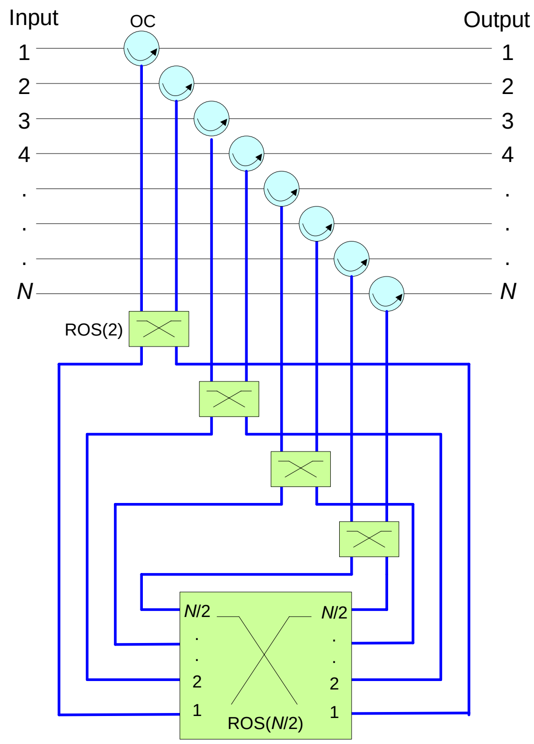

Fig.2 The architecture of proposed generic N×N BOXC architecture. OC: optical circulator; ROS: reversible optical switch.

Fig. 1 shows the proposed generic BOXC architecture. One *N*/2×*N*/2 and *N*/2 2×2 ROSs are used, which are labelled as ROS(*N*/2) and ROS(2), respectively, for simplicity in the following part. Totally *N* three-port OCs are equipped to pass *N* input and *N* output light paths separately. According to the principle discussed in [1], the proposed architecture in Fig.1 has the property of *N*×*N* cross-connects in re-arrangeably non-blocking manner.

Taking input #*i* to output #*j* for example, the cross-connect operation is described as follows. Input signal comes into the #*i* OC and is subsequently fed into the #*a* ROS(2), where *a*=integer[(*i*+1)/2]. Then, one of following two cases is encountered:

1) The #*a* ROS(2) in bar state passes the signal to the left port #*a* of ORC(*N*/2), which switches the signal to its right port #*b*, where *b*=integer[(*j*+1)/2]. Next, the signal is sent back to #*b* ROS(2), then to #*j* OC and finally to output #*j*, where the #*b* ROS(2) is in cross state if *j* is odd and in bar state if *j* is even.
2) The #*a* ROS(2) in cross state passes the signal to the right port #*a* of ORC(*N*/2), which switches the signal to its left port #*b*, where *b*=integer[(*j*+1)/2]. Next, the signal is sent back to #*b* ROS(2), then to #*j* OC and finally to output #*j*, where the #*b* ROS(2) is in bar state if *j* is odd and in cross state if *j* is even.

Conversely and symmetrically, input #*j* is simultaneously switched to output #*i* since both ROS(2) and ROS(*N*/2) transmit lights bidirectionally.

Our proposed BOXC achieves the same functionality as the one reported in [1]. However our architecture reduces the complexity and cost. More important, our architecture can be implemented using currently available optical switches without re-designing.

Prototype and Experiment

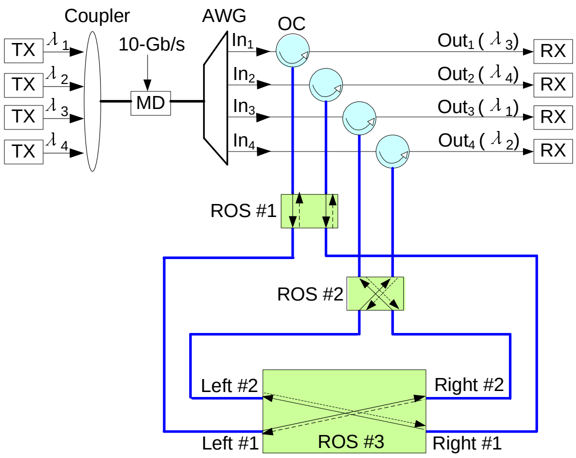

Fig.2. Experimental setup of the proposed BOXC prototype. OC: optical circulator; ROS: reversible optical switch. AWG: arrayed waveguide grating.

A prototype is set up to validate the feasibility, functionality and performance of the proposed BOXC. The experimental setup is shown in Fig.2, which is comprised of four three-port OCs, and three ROSs, which are conventional optical switches of mechanical technique [6]. Four wavelength channels from 1549.67 nm to 1552.07 nm with channel spacing of 100 GHz are combined by an optical coupler. The combined signals are modulated by a 10-Gb/s non return-to-zero (NRZ) signal with a pseudo random bit sequence (PRBS) word length of 2^{31}-1. The modulated signals are demultiplexed by an AWG into four individual signals before they are launched into the BOXC.

Two scenarios are comparatively studied in the experiment. One is that the four wavelength channels are switched in bidirectional pairs. For example, two pairs are set up in ROS #3 between the Left #1 and Right #2, and between Left #2 and Right #1, respectively, as shown in Fig.2. The other is in normal UOXC and four unidirectional cross connections are set up.

The measured bit error rates (BERs) and eye diagrams of the four channels are shown in Fig.3. It is clearly seen that all the wavelength channels exhibit clear eye openings. The average receiver sensitivities for the optical paths in both BOXC and UOXC at BER of 10^{-9} are about -18.5dBm. No error floor is observed. The experimental results have verified the feasibility of the proposed BOXC architecture and shown no power penalty.

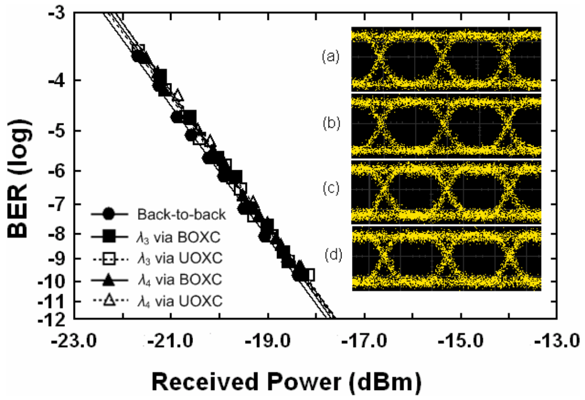

Fig.3. Measured BERs and eye diagrams. (a) λ3 via BOXC, (b) λ3 via UOXC (c) λ4 via BOXC and (d) λ4 via UOXC.

Conclusions

We have proposed a novel BOXC architecture with reduced complexity by using ROSs and OCs. Both analysis and experiment results have shown that conventional optical switches of mechanical and MEMS technique can be employed as ROSs due to the reversibility of optical paths. In comparison with the normal unidirectional OXC, the proposed BOXC achieves the same BER level and eye diagrams without power penalty.

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