Demonstration of Compact Hierarchical Optical Path Cross-Connect Utilizing Wavelength/Waveband Selective Switches

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Abstract: We demonstrate a compact wavelength/waveband selective switch based hierarchical optical cross-connect (HOXC) system for the first time. Its performance confirms that the HOXC will be applied to create cost-effective metro-core and metro-edge ring interconnections.

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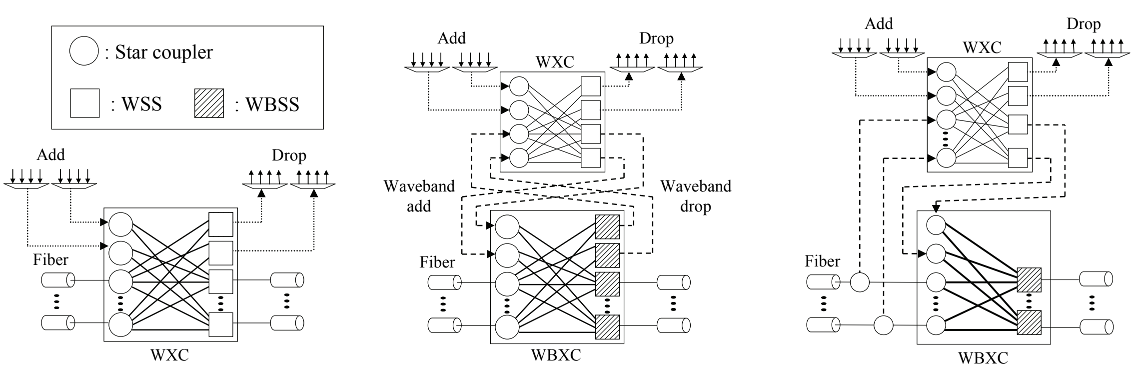
1. Introduction

Single-layer optical path networks utilizing reconfigurable optical add-drop multiplexers (ROADMs) have been widely adopted in Japan and North America to accommodate the rapidly increasing amount of traffic. In the near future, further traffic expansion is expected due to the introduction of new broadband services such as IP-TV/VoD with ultra-high definition TV quality (60-72 Gbps/ch). In order to resolve this problem, hierarchical optical path networks that utilize waveband paths, which consists of multiple wavelength paths, have been investigated [1, 2]. An efficient network design algorithm [3] was developed to verify substantial network cost reduction achieved by using the architecture. The total number of optical ports of the hierarchical optical cross-connects (HOXCs) was reduced by up to 45% at 9×9 regular mesh network compared to that for single-layer OXC. We have investigated various HOXC architectures that are based on selective switches (i.e. wavelength selective switch (WSS) and waveband selective switch (WBSS)) [4] and matrix switches [5]. It has been proved the switch scale, the number of mirrors for example used in MEMS-type selective switch based HOXC and that of cross points in matrix switch based HOXC, can be significantly reduced. However, high degree WSSs/WBSSs and large matrix switches are still costly devices and therefore reducing of the number of such devices is crucially important. We have recently proposed a HOXC architecture that can effectively reduce the required number of WSSs/WBSSs and the transmission loss [4]. The point of the proposed HOXC compared to the conventional architecture is that waveband drop function is separated from waveband routing function. This separation minimizes the number of WBSSs and significantly reduces the transmission loss of signal drop operation at the expense of slight loss increment in pass through operation. Selective switches are replaced with star couplers to the degree possible to lower the cost. The proposed HOXC architecture realizes not only the minimization of the switch scale but also the suppression of the transmission loss. The star coupler loss increases as the node degree increase, and so the proposed architecture will be very attractive particularly when it is applied to a relatively small degree node (e.g. ring interconnections). For such a node, the required WBSS scale is small, and consequently, it enables WBSS to be fabricated on one-chip using planar lightwave circuit (PLC) technologies [6]. In combination with the WSS/WBSS reduction attained by adopting the HOXC architecture and using one-chip WBSSs, we can create very compact and cost-effective optical cross-connects. In this paper, we developed a HOXC prototype utilizing PLC based one-chip WBSSs and LCoS



(a) Single-layer OXC (b) Conventional HOXC [4] (c) Proposed HOXC [4]

Fig. 1: Selective switch based single-layer/hierarchical cross-connect architecture

Table 1. Switch scale comparison between different optical cross-connect architecture

	# of WSSs	# of WBSSs	MEMS mirrors (reduction ratio)
Single-layer OXC (Fig. 1 (a))	10		640
Conventional HOXC (Fig. 1 (b))	4	10	336 (48%)
Proposed HOXC (Fig. 1 (c))	4	8	320 (50%)

(Note: The total hardware scale is mostly determined by # of WSSs)

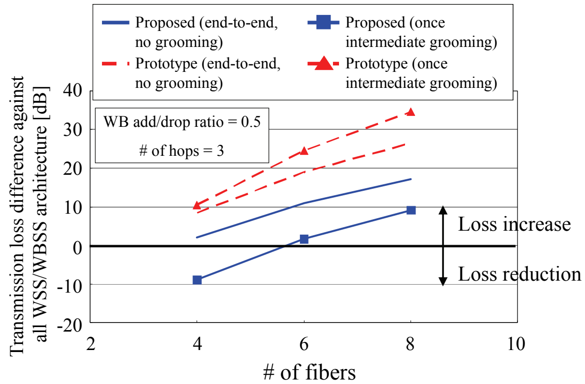


Fig. 2: Relative transmission loss to all WSS/WBSS HOXC architecture

based WSSs. The power penalty (BER=10^{-9}) was less than 0.2 dB after traversing 5 nodes including one grooming node. This development verifies the applicability of selective switch based HOXC.

2. Compact HOXC architecture with WSS/WBSS

First we briefly explain the compact HOXC architecture [4] and its advantages. Figure 1 (a) depicts the conventional single-layer OXC consisting of star couplers on the input side and WSSs on the output side. In addition to the original routing capability, this architecture provides the broadcast-&-select function that can be used for optical multicasting for video distribution. Hierarchical optical cross-connect system can also be constructed using WSSs and WBSSs in the same manner as shown in Fig. 1 (b). In order to reduce further the switch scale, we have proposed separating waveband drop function from WBXC (See Fig. 1 (c)), which minimizes the number of WBSSs. Table 1 summarizes the number of WSSs/WBSSs and MEMS-system mirrors required for all WSS/WBSS, which are metrics for the switch scale of each optical cross-connect. Here, the number of fibers is 8, the number of wavelength paths per fiber is 64, the number of waveband paths per fiber is 8, and add/drop ratio is 0.25 (this value is sufficient for ring interconnection application). By introducing hierarchical structure, the number of WSSs is reduced by 60% at the cost of 10 WBSSs that use much less mirrors than WSS. The number of component MEMS mirrors, which substantially determines the total hardware scale and device reliability, can be reduced by approximately 50% compared to single-layer OXC. Additionally, the proposed HOXC architecture in which the waveband drop operation is independently implemented by star couplers placed before WBXC can minimize the number of WBSSs. Figure 2 shows the relative transmission loss to a HOXC where star couplers in Fig. 1 (b) are replaced by WSSs/WBSSs when the waveband add/drop ratio at each node is 0.5 and the number of hops is 3 (the average the number of hops for a 5x5 polygrid network with uniform traffic distribution). Although the reference HOXC exhibits low loss characteristics due to the full use of selective switches, the proposed HOXC reduces the gap to the reference HOXC compared to the conventional HOXC. Note that there is a region where the relative loss for 3-hop transmission can be negative, despite of using lossy couplers. Intermediate groomings are needed in practical situations since it improves the utilization ratio of wavebands especially when traffic demand between each node pair is smaller than the waveband capacity [3]. It is therefore important to minimize the transmission loss with at least once intermediate grooming from the viewpoint of practical operations. Due to the use of star couplers, the relative loss of the proposed and conventional HOXC will become worse if the number of fibers and the add/drop ratio increase. However, the advantages of the proposed HOXC over the conventional one in terms of cost and transmission loss considering intermediate groomings will still be valid. Please note that the above discussion on the hardware reduction is true when WBSS is more simply achieved than WSS. For example, when the same WSS is used as WBSS since WBSS function can be achieved by WSS, no hardware scale reduction will be achieved due to the redundant WSS function.

3. Experiments

Figure 3 illustrates the developed prototype HOXC system architecture, which consists of 9 1x2 couplers, 5 1x4 couplers, 2 LCoS based WSSs and 4 PLC based WBSSs [6]. The WBXC part is equipped in a small box (5x12.5x21.5 cm^3) as shown in Fig. 3; this is made possible by utilizing a monolithically integrated one-chip WBSS (3.4x6.4 cm^2), similarly as preliminary fabricated 5x5 WBXC module [7]. We evaluated the transmission characteristics for two typical conditions shown in Fig. 4: (a) optical path direct connection between source and destination node pairs (end-to-end waveband), and (b) once intermediate grooming case. BER and power penalty

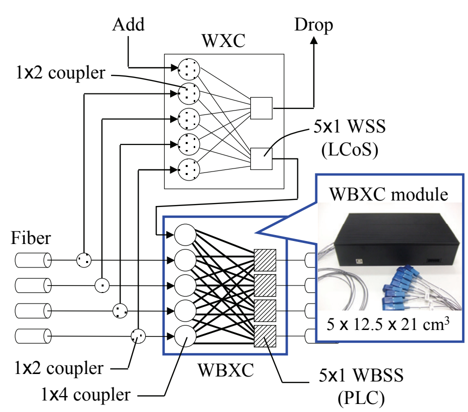
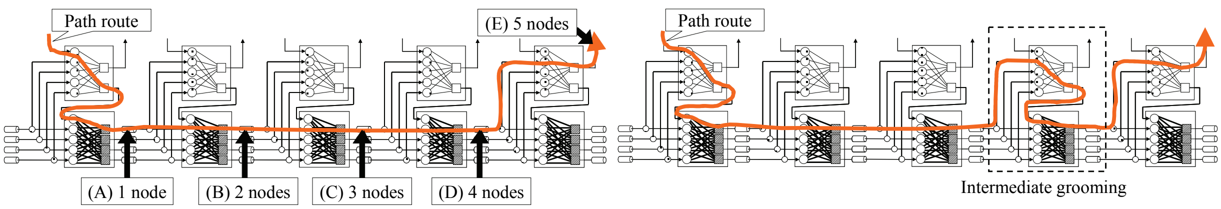


Fig. 3: Developed prototype HOXC architecture



(a) End-to-End connection   (b) With once intermediate grooming

Fig. 4: Transmission testbed

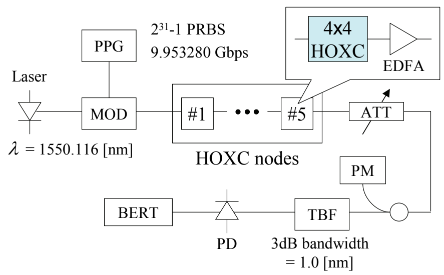


Fig. 5: Experimental setup for BER evaluation

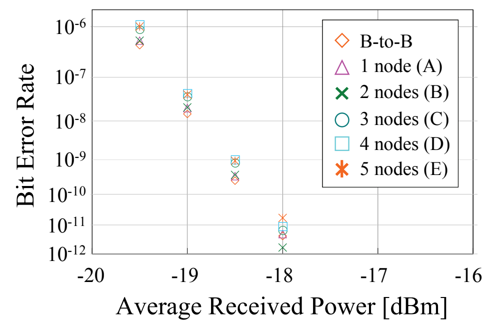
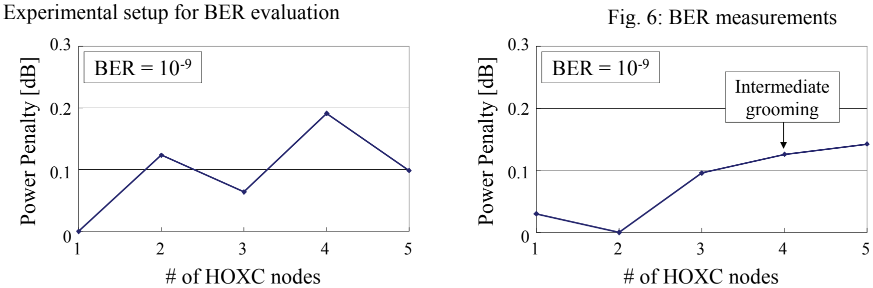


Fig. 6: BER measurements



(a): End-to-End connection   (b) With once intermediate grooming

Fig. 7: Power penalty at bit error rate of 10^{-9}

are evaluated for each measurement point from (A) to (E) in Fig. 4. The experimental setup used for BER evaluation is illustrated in Fig. 5. Figure 6 shows the evaluated BER. Figures 7 (a) and (b) plot the power penalty at BER of 10^{-9} versus HOXC hops. With and without intermediate grooming, power penalties are less than 0.2 dB after traversing 5 nodes. Please note that if the HOXC is applied to ring interconnections, 3-4 two-fiber ROADM ring concatenation (for this, 2-3 HOXC transmissions at maximum) will be the maximum since the maximum number of node for the transparent optical transmission is practically limited.

4. Conclusions

We have developed, for the first time, a very compact HOXC prototype that utilizes two WSSs and one box WBXC (4 one-chip WBSSs and 5 couplers are included). Transmission experiments confirmed the technical feasibility of the prototype system, and the advantages of our proposed HOXC architecture are successfully verified. This HOXC will be suitable especially for developing ROADM ring interconnections in cost-sensitive metro-edge and metro-access areas.

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5. References

[1] K. Sato and H. Hasegawa, “Prospects and challenges of multi-layer optical networks,” *IEICE TRANS. Commun.*, vol. E90-B, no.8, pp.1890-1902, 2007.
[2] L. Noirie , C. Blaizot, and E. Dotaro, "Multi-granularity optical networks," *Proc. ECOC*, vol. 3, pp.269-270, 2000.
[3] I. Yagyu, H. Hasegawa, and K. Sato, "An efficient hierarchical optical path network design algorithm based on a traffic demand expression in a cartesian product space," *Proc. ECOC*, pp.113-114, 2006.
[4] S. Mitsui, H. Hasegawa, and K. Sato, "Low loss and cost-effective hierarchical optical path cross-connect switch architecture based on WSS/WBSS," *Proc. Photonics in Switching*, FrII2-3, 2009.
[5] R. Hirako, K. Ishii, H. Hasegawa, K. Sato, and O. Moriwaki, "Hierarchical optical cross-connect architecture that implements colorless waveband add/drop ratio restriction utilizing a novel wavelength multi/demultiplexers," *Proc. Photonics in Switching*, FrII2-2, 2009.
[6] K. Ishii, H. Hasegawa, K. Sato, S. Kamei, H. Takahashi, and M. Okuno, “Monolithically integrated waveband selective switch using cyclic AWGs,” *Proc. ECOC*, Mo.4.C.5, 2008.
[7] K. Ishii, H. Hasegawa, K. Sato, M. Okuno, S. Kamei, and H. Takahashi, “An ultra-compact waveband cross-connect switch module to create cost-effective multi-degree reconfigurable optical node,” *Proc. ECOC*, paper 4.2.2, 2009.