Low Loss and Cost-Effective Hierarchical Optical Path Cross-Connect Switch Architecture based on WSS/WBSS

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Abstract: We propose a novel hierarchical optical cross-connect node architecture that consists of WSSs/WBSSs (waveband selective switch). The proposed architecture reduces the number of WSSs/WBSSs by effectively utilizing star couplers. The large power loss of the couplers is efficiently offset by the novel waveband drop function.

Keywords: hierarchical optical cross-connect, waveband, micro-electro mechanical system, wavelength selective switch, waveband selective switch

1. Introduction

Due to the rapid traffic expansion [1], the single-layer optical path network using reconfigurable optical add-drop multiplexers (ROADMs) has been extensively introduced in Japan and North America. To cope with the traffic expansion expected with the introduction of future broadband services such as IP-TV/VoD that utilize ultra-high definition TV (60-72 Gbps/ch), hierarchical optical path network technologies that utilize waveband paths (groups of multiple wavelength paths) have been developed [2, 3]. Different switch technologies can be adopted to realize the hierarchical optical cross-connects (HOXCs): planar lightwave circuit switch, 2-D and 3-D micro-electro mechanical systems (MEMS) [4] and LC (liquid crystal) switch. Among them, the 3-D MEMS/LC based wavelength selective switch (WSS) is widely utilized in present ROADMs. The WSS/WBSS can route any combination of incoming wavelength/waveband signals to any output ports. MEMS-based WSSs have advantages such as low optical insertion loss and crosstalk. However, the reliability of the mirror and manufacturing yield can be an issue. In order to resolve this problem, we have proposed a MEMS-based HOXC architecture that can greatly reduce the necessary number of mirrors [5]. In this paper, we propose a novel HOXC architecture that realizes further switch scale reduction by effectively applying star couplers. By separating the drop operation of waveband paths, the proposed HOXC not only reduces the number of WBSSs necessary but also suppresses the power loss of wavelength paths. The broadcast & select function for optical multicast is also realized.

2. HOXC based on WSS/WBSS

Figure 1 illustrates the ratio of the total number of optical cross-connect switch ports necessary for a hierarchical optical path network to that for the comparable conventional single-layer optical path network. Over the wide area wherein the ratio is less than 1, the hierarchical optical path network can reduce the total number of ports [2]. The estimation is based on an ideal case, however, it has been proven that nearly full performance is achieved when an efficient network design algorithm [6] is used.

In the MEMS-based WSS, a mirror is assigned to each wavelength. WBSS can be achieved in the same manner by replacing a group of mirrors, for wavelengths that form a waveband, by a large mirror (if the focal length of the lens is the same). WBSS switches the waveband; all wavelengths in a waveband are switched simultaneously by the same mirror. Recently, one chip WBSS using PLC (planar lightwave circuit) has also been successfully developed [7]. One advantage of the WSS/WBSS-based HOXC architecture is its modular growth capability. Expanding the node scale requires only the addition of necessary WSS/WBSS and hence incremental cost-effective expansion is possible. When we use MEMS-based WSS/WBSS the failure probability and cost of an HOXC heavily depend on the number of the mirrors. Minimizing the number of mirrors (or number of WSS/WBSS) is, therefore, a crucial requirement for MEMS-based node architectures.

3. Proposed HOXC architecture

Let L be the number of wavelength paths per fiber, K the node degree, i.e. the number of incoming/outgoing fibers to/from a node, M that of wavebands per fiber, and N that of wavelength paths per waveband (i.e. $L=M\times N$). Suppose that y and z are upper bounds for the ratio of added/dropped paths at each waveband index and each

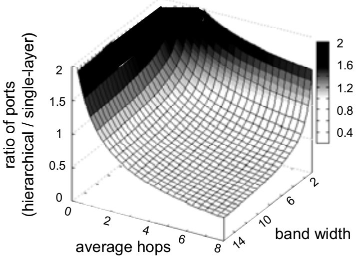

Fig. 1: Ratio of required optical ports between hierarchical and single-layer networks

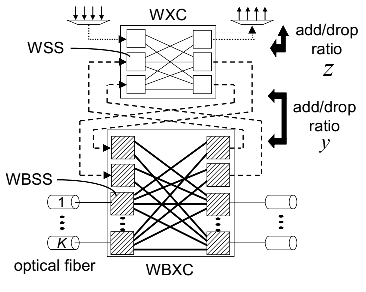

Fig. 2: HOXC architecture that utilizes MEMS-based WSS/WBSS [5]

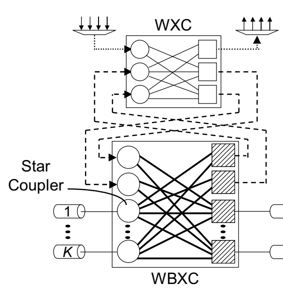

Fig. 3: Prototype HOXC architecture

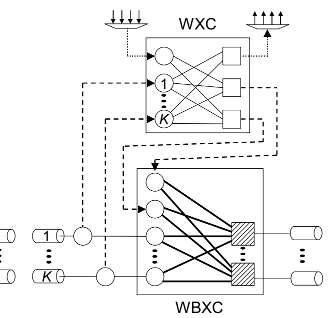

Fig. 4: Proposed HOXC architecture

wavelength index, respectively (See Fig. 2). In this paper, node complexity increases with ratios y and z [5].

3.1 Prototype HOXC node architecture

The numbers of WSSs and WBSSs in Fig. 2 can be straightforwardly halved by replacing the devices on the left (right) hand side with star couplers of the same degree (Fig. 3). In addition to the original routing capability, the broadcast & select function can be realized with the star couplers. Hereafter, we refer to the architecture in Fig. 3 as the "prototype HOXC architecture". As shown later, the power loss of optical paths is relatively large.

3.2 Proposed HOXC node architecture

If we assume an ideal coupler (no excess loss) with uniform power distribution across the output ports, power loss by the coupler at WBXC of the prototype HOXC is given by $10\log K \le 10\log(K+\lceil yK \rceil) \le 10\log K + 3$ dB ($\cong 10\log K + 1.76$ dB if y = 0.5). The total pass through loss at each HOXC is the sum of the above value and WBSS loss. We realized further reduction of WBSS and loss suppression by separating the waveband drop function and the add/routing function at WBXC (See Fig. 4 for detail). This strategy enables us to remove WBSSs for drop operations, and to cut through WBXC at the destination node. On the other hand, total loss at an intermediate node slightly increases (ex. 3 - 1.76 = 1.24 dB if y = 0.5), however, the gain by WBXC cut through is larger than the loss increase in almost all cases. The numbers of WBSSs and WSSs necessary for optical cross-connects are summarized in Table 1. The single-layer OXC is derived by simply replacing WSSs, on one side of OXC, in the same manner as the prototype HOXC. The number of WSS devices, which mostly determines the total hardware scale (as shown in Fig. 5), is minimized in the prototype and proposed architectures. The proposed architecture can also reduce the number of WBSS compared to the prototype one.

4. Numerical results

We evaluated the numbers of devices and mirrors necessary and estimated HOXC power loss. We set L = 64, K = 6, M = 8 and N = 8. The ratio z in HOXC was set at 1 so that any wavelength path that enters/leaves into/from the WXC can be added/dropped.

Figure 5 shows the numbers of mirrors required for each optical cross-connect. Proposed HOXC requires 25% fewer mirrors than the single-layer optical cross-connect when their add/drop ratios are 0.5. Figure 6 shows the number of WBSSs needed to implement the proposed HOXC. It confirms that the proposed HOXC architecture is realized by 67% of WBSSs in prototype HOXC when add/drop ratio is 0.5.

Figures 7 (a) and (b) show the transmission loss differences against the original HOXC architecture in Fig. 2 at y = 0.5. The evaluation assumes WSS power loss of 6 dB [4], WBSS loss of 6 dB and star coupler loss of 10log$A$ + 1 dB (A is the number of output ports in star coupler, and 1 dB is excess loss). Since intermediate grooming of optical paths on the route improves the efficiency of the hierarchical optical path network, the loss in the direct connection case (end-to-end waveband) and that on once intermediate grooming case (two consecutive wavebands are traversed for a wavelength path) are evaluated. Proposed HOXC suppresses the loss, especially when intermediate grooming is done.

Table 1. Comparison of cross-connects in terms of the numbers of WSSs and WBSSs

(Note: the # of WSS mostly determines the total hardware scale)

	Single-layer	Prototype (Fig. 3)	Proposed (Fig. 4)
# of WSSs	$K+\lceil yK \rceil$	$2\lceil yK \rceil$	$2\lceil yK \rceil$
# of WBSSs		$K+\lceil yK \rceil$	K

5. Conclusion

We proposed a novel HOXC node architecture based on 3-D MEMS systems and verified that the numbers of mirrors and WBSSs, which determines reliability and cost, can be reduced by making the best use of star couplers. The possible loss increment becomes smaller with the proposed architecture and will not be significant in most cases. The expected overall cost reduction attained with a proposed architecture will resolve one of the issues preventing the wider application of optical cross-connect systems.

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References

[1] http://www.jpix.ad.jp/jp/techncal/traffic.html

[2] K.Sato et al., "Prospects and Challenges of Multi-Layer Optical Networks," IEICE TRANS. Commun., vol. E90-B, no.8, pp.1890-1902, 2007.

[3] L.Noirie et al., "Multi-granularity Optical Networks," Proc. ECOC, vol. 3, pp.269-270, 2000.

[4] J.C.Tsai et al., "A High Port-Count Wavelength-Selective Switch Using a Large Scan-Angle, High Fill-Factor, Two-Axis MEMS Scanner Array," IEEE Photonics Technology Letters, vol.18, no.13, 2006.

[5] S.Mitsui et al., "Hierarchical Optical Path Cross-Connect Node Architecture Using WSS/WBSS," Proc. Photonics in Switching, S-04-1, 2008.

[6] I.Yagyu et al., "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.

[7] K. Ishii et al., "Monolithically Integrated Waveband Selective Switch Using Cyclic AWGs," ECOC 2008, Mo.4.C.5, 2008.

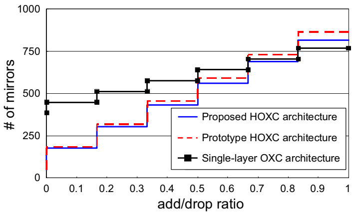


Fig. 5: comparison of # of mirrors between single-layer OXC and HOXC

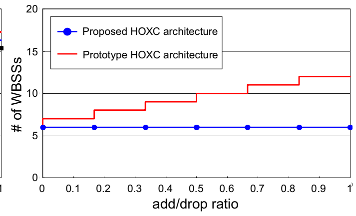
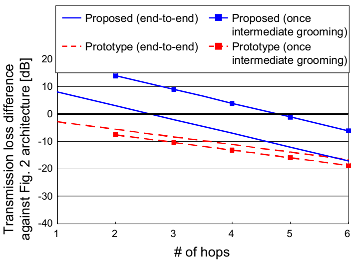
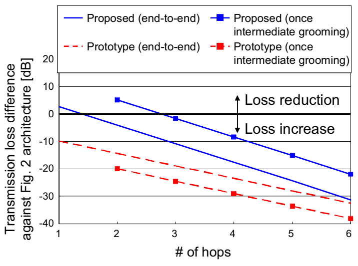


Fig. 6: comparison of # of WBSSs between prototype and proposed HOXC



(a) K = 4



(b) K = 6

Fig. 7: transmission loss differences against the original HOXC architecture (Fig. 2)