Hierarchical Optical Path Cross-Connect Node Architecture Using WSS/WBSS

Shin-ichi Mitsui Hiroshi Hasegawa Ken-ichi Sato

Department of Electrical Engineering and Computer Science, Nagoya University
Furo-cho, Chikusa-ku, Nagoya, 464-8603 Japan

Abstract: We propose a new hierarchical optical cross-connect node architecture that utilizes 3D MEMS-based WSS and WBSS (Waveband Selective Switch). We evaluate the total number of MEMS mirrors necessary to implement the node, a key parameter in determining node reliability and cost. It is demonstrated that the proposed hierarchical architecture requires a lot less mirrors than conventional single-layer WSS based node architectures.

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

1. Introduction

Owing to the rapid traffic expansion [1], and provisioning for Ethernet base virtual private network services, reconfigurable optical add-drop multiplexers (ROADMs) have been extensively introduced in Japan and North America. To cope with the traffic expansion envisaged with the penetration of IP TV and high/super-high definition TV, hierarchical optical path networks that utilize wavebands, which consist of multiple wavelength paths, have been investigated [2, 3]. Figure 1 demonstrates the switch port reduction that is attained by introducing wavebands [2]. The vertical axis represents the ratio of the number of the total optical switch ports necessary for single layer and for hierarchical optical path networks. The hierarchical optical path network is effective if the ratio is less than 1, and the area is shown to be very wide. The estimation is based on an ideal case and so there is some gap with regard to practical network design, however, it has been proven that nearly full performance is achieved when an efficient network design algorithm [4] is used. Another work [5] demonstrates that scale reduction of 2-D matrix SW for optical cross-connect (OXC) is possible by introducing the hierarchical structure and by specifying the ratio of add/drop traffic (optical paths) to/from electrical systems at each node. This is because the scale of wavelength cross-connect (WXC) part dominates that of the hierarchical optical cross-connects (HOXCs) as explained later.

Different switch technologies can be adopted to realize HOXC: planar lightwave circuit switch, 2-D and 3-D micro-electro mechanical system (MEMS), and liquid crystal switch. Among them, the 3-D MEMS based wavelength selective switch (WSS) is widely utilized in present ROADMs. The WSS/WBSS can route any combinations of incoming wavelength/waveband signals to output ports. The 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, particularly given a large output port number and large number of optical paths per fiber. This is because it uses mechanical actuators with high voltage drivers and as the number of output ports increases, the number of steps in mirror movement increases [6]. To resolve this deficiency, we propose a new HOXC node architecture that is composed of MEMS-based WSS/WBSS. The architecture minimizes the number of mirrors, which leads to lower node cost and higher reliability. Quantitative evaluations of the number of mirrors needed for HOXC and single-layer OXC architectures are given; the restriction of add/drop optical path ratio is considered. We show that the number of mirrors can be halved from that of single-layer OXC, which will lead to a substantial node cost reduction.

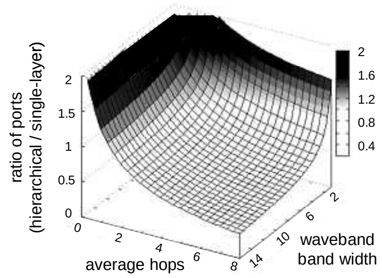


Fig. 1: Ratio of required optical ports between hierarchical and single-layer networks

2. WSS and WBSS

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 (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. The number of steps in mirror movement corresponds to "# of output ports". Hereafter, we call it "mirror step".

The MEMS-based OXC can be realized by assigning a WSS to each input/output fiber, whereas the HOXC is realized as stacked WSS-based OXCs and WBSS-based waveband cross-connects (WBXCs) (see Fig. 3) [5]. One advantage of the WSS/WBSS-based HOXC architecture is modular growth capability. Expanding the node scale requires only the addition of WSS/WBSS and hence incremental cost-effective expansion is possible. However, since the mirrors are mechanical, failure probability of a HOXC heavily depends on the number of its mirrors. Hereafter, we discuss the reduction in the number of mirrors attained by introducing the hierarchical architecture.

3. Node architecture

Considering practical applicability, we place a restriction on add/drop ratio in order to reduce switch scale (See Fig. 2) [5]. Let M be the number of wavelength paths per fiber, N that of fibers, K that of wavebands per fiber, and L that of wavelength paths per waveband (M=L×K). Let x be an upper bound of the ratio of the maximum number of added/dropped wavelength paths to that of all incoming/outgoing wavelength paths for a single-layer OXC.

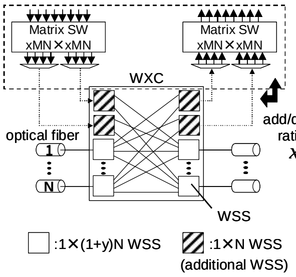


Fig. 2: Single-layer OXC node architecture

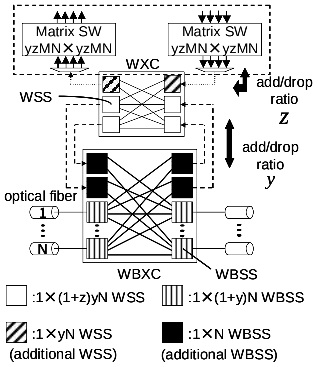


Fig. 3: HOXC node architecture

Similarly, let y and z be upper bounds for the ratios of added/dropped waveband and wavelength paths for a HOXC, respectively.

3.1 Single-layer OXC node architecture

Since WSS can not process multiple same wavelength paths, the minimum number of WSSs required for add/drop operation in a single-layer OXC is the maximum number of added/dropped paths to which the same wavelength is assigned. Hence the number of mirror steps is the sum of the number of the same incoming/outgoing wavelengths and that of the same added/dropped wavelengths. Thus as the number of the same added/dropped wavelengths increases, the number of WSS and the complexity of each WSS increase.

Dropped wavelength paths at each node are demultiplexed and directed to an electrical routing system. In order to assign any receiving port of the electrical system to each wavelength path without fiber manipulation by hand (this is referred to directionless), a matrix switch, upper side in Fig. 2, needs to be introduced. Another matrix switch is also needed to attain similar flexibility for sending. A capability that any wavelengths can be added from or dropped to the electrical system is called colorless add/drop capability; it is attained by tunable LDs and colorless receivers at the electrical system.

3.2 HOXC node architecture

MEMS-based HOXC consists of WXCs and WBXCs (See Fig. 3). The architecture of the former is essentially same as that of the single-layer OXC. The architecture of the latter is realized by replacing each WSS in the single-layer OXC by a WBSS. The complexities of the WSS and the WBSS increase as the ratios y and z increase. The HOXC architecture illustrated in Fig. 3 also offers directionless capability due to its matrix switches.

4. Comparisons of switch scale between single-layer OXC and HOXC architectures

In this section we present comparisons between the single-layer OXC and the HOXC in terms of the number of mirrors and the number of mirror steps in WSS/WBSS at different add/drop ratios. We employed parameters M = 64, N = 8, K = 8, and L = 8. The ratio z in HOXC is set to 1 so that any wavelength path that enters/leaves to/from WXC can be added/dropped. In this case, matrix switch sizes in Figs. 2 and 3 are the same, and the directionless capability is not always required, and hence, we compare only WSS and WBSS parts hereafter. Figure 4 (a) provides a comparison in terms of the numbers of mirrors between the single layer OXC and the HOXC. By adopting the HOXC architecture, the number of mirrors can be reduced by 48% to 21% over an area where the add/drop ratio is between 0.2 and 0.5 (typical values for general networks).

Figures 4 (b) and (c) illustrate distributions of the number of mirror steps of MEMS in OXC and HOXC, respectively. It is shown that not only the number of mirrors but also the number of mirror steps in each WSS/WBSS change as add/drop ratio changes. Fig. 4 (c) also shows that in HOXC, the WXC part is dominant and almost all switches have fewer mirror steps than those in the single-layer OXC. It is demonstrated that HOXC can be developed with relatively simple WSSs and WBSSs.

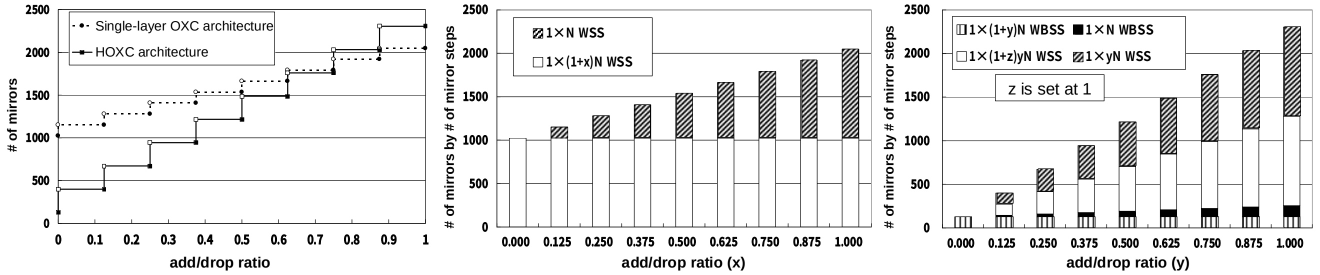
5. Conclusion

We proposed a HOXC node architecture based on MEMS switches and evaluated the number of mirrors needed, an important parameter in determining system reliability and cost. The number of mirrors in HOXC can be significantly reduced compared to the single-layer OXC.

Acknowledgement: This work is partially supported by NICT.

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] 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.
[5] S. Kakehashi et al., "Optical Cross-Connect Switch Architecture for Hierarchical Optical Path Networks," Proc. SPIE Optics East, vol.6388, pp.6388091-6388099, 2006.
[6] P. Wall et al., “WSS Switching Engine Technologies,” Proc. OFC/NFOEC, OWC1, 2008.



(a) comparison of # of mirrors between single-layer OXC and HOXC

(b) # of mirrors by # of mirror steps in single-layer OXC

(c) # of mirrors by # of mirror steps in HOXC

Fig. 4: Evaluations of switch scale for single-layer OXC and HOXC architecture