Novel Hierarchical Optical Cross-Connect Architecture Utilizing Dedicated Add/Drop Switches that Effectively Offer Colorless and Directionless Capability

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Abstract: Hierarchical optical cross-connect architectures based on dedicated add/drop switches for terminating traffic is proposed. The architecture can significantly reduce switch scale for implementing colorless/directionless/contentionless capabilities.
OCIS codes: (060.4510) Optical communications; (060.6718) Switching, circuit;

1. Introduction

The continual increase in traffic volume drives the introduction of optical network technologies due to their cost effectiveness and low power consumption [1]. In the current optical cross-connect (OXC) systems, optical paths are switched at wavelength path granularity, which is called as single layer optical path network. To cope with further traffic expansion caused by video-centric broadband services such as ultrahigh definition TV and 3D-TV, the hierarchical optical path network has been receiving attention [1–4]. The hierarchical OXC (HOXC) introduces the waveband path (a bundle of multiple wavelength paths) as a higher-order optical path. The HOXC consists of waveband cross-connect (WBXC) and wavelength cross-connect (WXC) [1–4]. It has been verified that a hierarchical optical path network with waveband routing can greatly reduce the total number of optical switch ports, and thus decrease the switch scale needed [2–4]. The reduction in switch size strongly depends on the waveband add/drop ratio [3], i.e. the ratio of the number of added/dropped waveband paths to that of all outgoing/incoming waveband paths. However, further switch size reduction is desirable and it will be most effectively attained by the scale reduction of the WXC part, which is the dominant part of the current HOXC. We have already proposed an HOXC architecture that separately handles two categories of add/drop wavebands; originating/terminating and grooming [5]. The architecture can reduce the total switch size since added/dropped wavelength paths from/to the electrical layer do not pass through the WXC part.

An OXC with colorless and directionless (C/D) capability is the key to creating flexible optical networks [6,7]. However, the switch scale necessary for implementing the C/D function is very large, so costs are high. For example, to handle 8 optical fibers, each carrying 96 wavelength channels, the OXC needs a huge 768 x 768 switch, which is obviously impractical. It is therefore natural to limit the maximum number of wavelength paths originating or terminating at the OXC.

In this study, we propose novel matrix switch based hierarchical optical node architectures for the purpose of reducing C/D switch scale. By applying a dedicated add/drop interface, the proposed node architecture not only decreases the scale of WXC part but also controls the originating/terminating ratio independently, which can minimize C/D switch scale. The configuration of the C/D switch itself is not discussed herein. Several technologies for creating the C/D switch are known, for example optical or electrical space switches or ODU cross-connects if sub-λ granularity is necessary. Starting from our previous work, which introduced a node architecture with dedicated add/drop functionality, this paper, for the first time, offers a strategy to reduce C/D switch scale. A quantitative analysis shows that the proposed node architecture can substantially reduce total switch scale.

2. Preliminaries

2.1. Conventional switch architectures for single-layer OXC and HOXC

Figures 1 and 2 depict conventional switch (SW) architectures for single-layer OXC and HOXC, respectively. Let K be the number of input/output fibers and L the number of wavelength paths per fiber. The originating/terminating ratio is denoted as z. Conventional single-layer OXC has L $(1+z)K \times (1+z)K$ matrix SWs for each group of optical paths with the same wavelength, see Fig. 1 [3]. This architecture imposes a limit on the number of added/dropped wavelength paths within each wavelength path group. For the HOXC, let M be the number of waveband paths per fiber, N the number of wavelength paths per waveband, and y the grooming ratio. Conventional HOXC has M $K \times K$ matrix SWs for each waveband group, and N $(y+z)KM \times (y+z)KM$ matrix SWs for each i-th wavelength path in incoming wavebands. In addition, this HOXC uses $2K$ matrix SWs specially designed for waveband add/drop operations and colorless multi/demultiplexers (MUXs/DEMUXs) that can be commonly used by any wavebands to achieve colorless waveband add/drop operation. For more details of this configuration, refer to [4]. In the node architecture proposed in this paper, we assume the HOXC architecture shown in Fig. 2, except for add/drop functions from/to the electrical layer, since it is one of the most advanced matrix-switch based architectures [4].

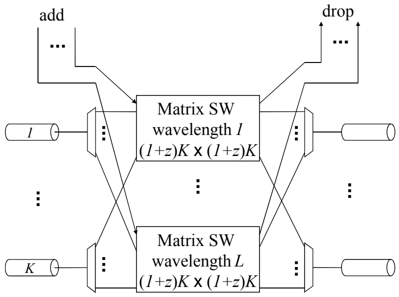


Fig.1. Conventional single-layer OXC

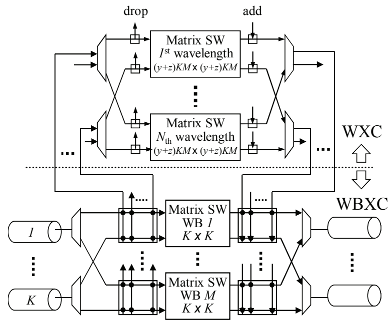


Fig. 2. Conventional HOXC architecture

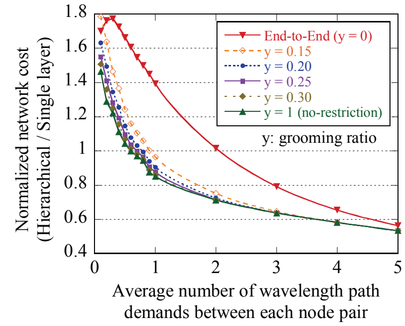


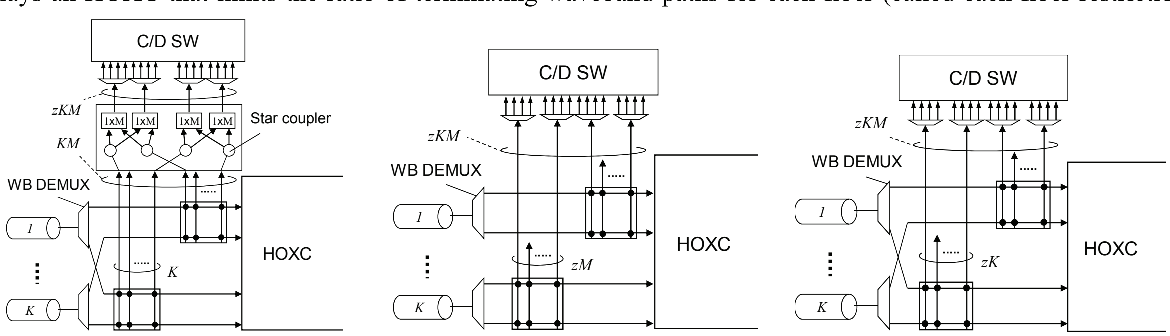
Fig. 3. Normalized network cost for 9x9 network

2.2. Basic concept of node architecture with dedicated add/drop switch for termination

The basic concept of the proposed HOXC architecture is splitting add/drop functions into those for originating/terminating waveband paths and those for grooming waveband paths. Their ratios are called originating/terminating ratio and grooming ratio, respectively [5]. This concept can be straightforwardly applied to conventional single-layer OXCs (replace HOXC with single-layer OXC in Fig. 4), however, we focus here on the HOXC. The important point is to allocate small SWs dedicated to specific functions. It is noted that we can control only the grooming ratio because the originating/terminating ratio (or number of paths) is determined by demands from the upper layer. We have proposed a network design algorithm with grooming ratio restriction that is applicable to our proposed HOXC architecture [5]. As shown in Fig. 3, our proposed HOXC architecture and design algorithm can achieve significant reductions in switch scale and hence network cost, compared to the single layer optical path network. Even when the grooming ratio is restricted to 0.2, the proposed algorithm provides almost the same network costs as that with no restriction for all traffic demand areas. This means that the HOXC offers about 50% switch scale reduction in the cross-connect part [5]. Please note that carriers do not need to know the optimal value of the grooming ratio. What carriers should do is to declare the amount of originating or terminating traffic at nodes and node degree. With the values, the network design algorithm automatically determines necessary switch hardware scale to accommodate the demands with consideration of the grooming ratio restriction.

3. Proposed HOXC architectures considering three kinds of originating/terminating ratios

Discussion is focused in this paper on just the drop side of the node, that is, the drop side SW for termination. The same SW architecture can be applied to the add side SW for origination paths by reversing the optical signal direction. We propose three HOXC architectures that impose different drop restrictions. Separation of drop SW part can be realized by matrix SWs that have through ports, as are used in conventional HOXC nodes [4]. In the proposed HOXC architectures, a cyclic AWG is utilized as the waveband DEMUX in front of the C/D SW. Figure 4(a) shows an HOXC that restricts the terminating ratio, the number of drop waveband paths to total incoming waveband paths, (this ratio is unrelated to fiber or waveband index). We call this total restriction. Figure 4(b) displays an HOXC that limits the ratio of terminating waveband paths for each fiber (called each fiber restriction).



(a) total restriction (b) each fiber restriction (c) each waveband restriction

Fig. 4. Proposed HOXC architectures with add/drop ratio restriction on originating/terminating paths (only drop part is illustrated).

Table 1. Comparison of proposed HOXC architectures

Kinds of restriction	Figure	SW element	# of SC	# of cross-points
Total	Fig. 4-(a)	$K \times K$	KM	$2K^2M+2zKM(M-1)+2yK^2M^2+K^2M+(yKM)^2N$
Each fiber	Fig. 4-(b)	$M \times zM$	-	$2zKM^2+2yK^2M^2+K^2M+(yKM)^2N$
Each waveband	Fig. 4-(c)	$K \times zK$	-	$2zK^2M+2yK^2M^2+K^2M+(yKM)^2N$

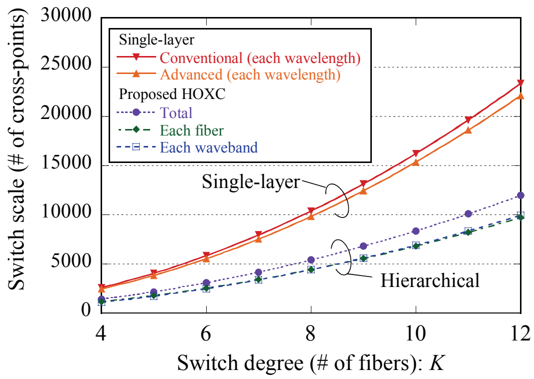


Fig. 5. Switch scale evaluation for switch degree, *K*.

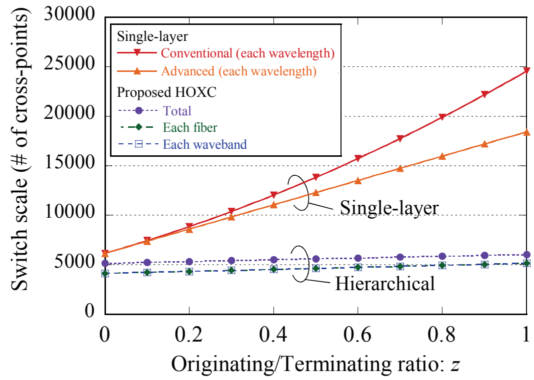


Fig. 6. Switch scale evaluation for add/drop ratio, *z*.

Figure 4(c) shows an HOXC that restricts the number of terminating waveband paths by each waveband index (called each waveband restriction). Table 1 summarizes required SW elements, the number of star couplers, and number of switch cross-points.

4. Switch scale evaluations and comparison of HOXC vs. single-layer OXC

The SW scale is evaluated by counting the number of cross-points including the drop side SW for termination as well as the add side SW for origination and the cross-connect part represented as HOXC. All the SWs except for C/D SWs are compared because the required C/D SW scales are the same as that of a single-layer OXC with the same add/drop ratio. For comparison, we consider two single-layer OXCs. One is that shown in Fig. 1, and the other is a single-layer OXC, called the advanced single-layer OXC, that adopts separate add/drop SWs for origination and termination. The advanced single-layer OXC employs matrix switches with through ports as in the proposed HOXC, but they operate at wavelength path granularity. These single-layer OXCs offer each wavelength restriction as regards originating/terminating wavelength paths. In this evaluation, the following parameters are used, M=8, N=12, thus L=96, y=0.2. As mentioned above, the reason for choosing grooming ratio y=0.2 is that the efficient algorithm [5] yields almost the same performance as when no grooming restriction is imposed.

Figure 5 demonstrates the evaluated SW scales with regard to switch degree K, where z is set at 0.3. The proposed HOXC architectures greatly reduce SW size compared to conventional and advanced single-layer OXCs regardless of restriction type. The proposed HOXCs with each waveband restriction and each fiber restriction offer almost the same SW scale. Figure 6 demonstrates the SW scale variation in terms of z when K=8. It is clarified that the proposed HOXC architectures substantially reduce SW size compared to the single-layer OXCs regardless of restriction type. The result also shows that the proposed HOXC variants have almost constant size as the originating/terminating ratio z increases. It should be noted that the SW scale evaluations in this paper do not include the C/D SW part (common to all switches). The scale of C/D SW increases in proportion to the square of the originating/terminating ratio.

5. Conclusion

This paper proposed novel optical node architectures that can control the number of added/dropped optical signals. The architecture separately implements, at WBXC, the add/drop functions for originating/terminating operations and those for grooming operations. Numerical evaluations revealed that the proposed HOXC architecture can significantly reduce total switch scale. Moreover, thanks to the dedicated implementation of each add/drop function, colorless and directionless capabilities can be realized efficiently. The substantial degree of switch scale reduction available with novel HOXC architectures presented here will extend technology choices; reliable PLC technology, for example, can be applied to create flexible OXC nodes with colorless/directionless capability. The hardware implementation of an 8x8 HOXC, each fiber of which carries 80 λ's, will be presented elsewhere soon [8].

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6. References

[1] K. Sato, and H. Hasegawa, *OSA/IEEE J. Opt. Commun. Net.*, vol. 1, no. 2, A81, Jul. 2009.
[2] I. Yagyu, H. Hasegawa, and K. Sato, *IEEE J. Sel. Areas Commun.*, vol. 26, no. 6, Part Supp., pp. 22-31, Aug. 2008.
[3] S. Kakehashi, H. Hasegawa, and K. Sato, *IEICE Trans. Commun.*, vol. E91-B, no. 10, pp. 3174-3184, Oct. 2008.
[4] R. Hirako, H. Hasegawa, and K. Sato, in *Proc. Photonics in Switching*, Fr-II2-2, Sept. 2009.
[5] Y. Yamada, H. Hasegawa, and K. Sato, in *Proc. ECOC*, Th.10.F.1, Sept. 2010.
[6] S. Woodward, M. Feuer, P. Palacharla, X. Wang, I. Kim, and D. Bihon, in *Proc. OFC/NOFOEC*, PDPC8, Mar. 2010.
[7] R. Jensen, A. Lord, and N. Parsons, in *Proc. ECOC*, Mo.2.D.2, Sept. 2010.
[8] R. Hirako, K. Ishii, H. Hasegawa, K. Sato, H. Takahashi, and M. Okuno, submitted to elsewhere.