Hierarchical Optical Cross-Connect Architecture that Implements Colorless Waveband Add/Drop Ratio Restriction Utilizing a Novel Wavelength Multi/Demultiplexers

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Abstract: We propose a novel compact hierarchical optical cross-connect architecture that implements the colorless waveband add/drop ratio restriction, and a novel MUX/DMUX that can be used by different wavebands. We show that the proposed cross-connect architecture can reduce switch scale significantly compared to conventional one. The function of the newly proposed MUX/DMUX is verified in an experimental system.

Keywords: hierarchical optical cross-connect, waveband, arrayed waveguide grating, add/drop ratio restriction

1. Introduction

Broadband access is being rapidly adopted throughout the world and, as a result, traffic is continually increasing. To cope with the further traffic expansion due to the introduction of future broadband services such as IP-TV/VoD, which uses ultra- high definition TV (60-72 Gbps/ch, uncompressed), hierarchical optical path networks that utilize waveband paths, groups of multiple wavelength paths, have been investigated [1, 2]. The hierarchical optical cross-connects (HOXCs) consist of waveband cross-connects (WBXCs) and wavelength path cross-connects (WXCs). It was shown that node switch scale can significantly be reduced when the waveband add/drop ratio at WBXC, the ratio of number of added/dropped waveband paths to that of incoming/outgoing total waveband paths, is restricted [3, 4] (for example, the switch scale can be reduced to about 1/2, when the add/drop restriction ratio is 0.25). The add/drop ratio restriction can be done in two ways; colorless waveband add/drop ratio restriction and add/drop ratio restriction on each waveband. The former restriction covers all waveband paths coming to (outgoing from) the node while the latter is on each waveband. Wavelength/waveband selective switch (WSS/WBSS) based HOXC architecture can exploit only the latter constraint while matrix switch based architecture can accommodate both constraints and hence offers much more flexible routing capability (see Table 1). In regard to network design, the constraint can increase network cost, however, a recent work [5] elucidates that the colorless waveband add/drop ratio restriction hardly increase network cost when a new effective design algorithm is utilized.

Considering the switch scale reduction possible with HOXC and to maximize the flexibility in routing, we develop a novel matrix-switch-based HOXC architecture that implements the colorless waveband add/drop ratio restriction. This is attained when each MUX/DMUX in WXC, connected to WBXC, can process any waveband (namely the colorless MUX/DMUX in terms of waveband). We newly develop a novel AWG based MUX/DMUX that can be used by any waveband. Numerical evaluations demonstrate that our proposed HOXC can reduce node switch scale significantly compared not only to the single layer OXC but also the conventional HOXC that offers the same restriction. We also verify the performance of the proposed MUX/DMUX in an experimental system.

Table 1 HOXC architecture with add/drop ratio restriction

OXC type	Add/drop restriction	
	Each waveband	Colorless waveband
WSS/WBSS based OXC	S. Mitsui et al., 2008 [3]	Hardware increase
Matrix SW based OXC	S. Kakehashi et al., 2008 [4]	This work

2. Proposed HOXC architecture

Let K be the number of incoming/outgoing fibers, M the number of waveband paths per fiber, N the number of wavelength paths per waveband. Suppose that x is given as the upper bound of ratio of added/dropped wavelength paths to all incoming/outgoing wavelength paths (wavelength add/drop ratio) for a single layer OXC. Similarly, let y and z be the upper bounds for colorless waveband add/drop ratio and wavelength add/drop ratio for WBXC and WXC of HOXC, respectively. Hereafter we assume that $x=y$ and $z=1$ since they maximize switch scale reduction in HOXC [4].

The point of our strategy to reduce switch scale is to divide a common purpose large switch into small dedicated-purpose switches as much as possible. If, for example, a 16x16 switch can be divided into four 4x4 switches dedicated to the different functions, the switch scale (total number of cross-points) can be reduced by 75%. Thus, effective functional separation needs to be developed.

Fig. 1 shows the proposed HOXC architecture. The major differences from conventional HOXC [4] shown in Fig. 2 are; 1) WXC consists of N smaller matrix switches where i-th switch is shared by i-th wavelength paths in incoming wavebands, 2) a novel MUX/DMUX that can be used by all wavebands is introduced to achieve colorless waveband add/drop capability, 3) the proposed WBXC replaces add/drop function at WBXC and two matrix switches between WBXC/WXC necessary for colorless operation in conventional HOXC (see Fig. 2) by two separate matrix switches.

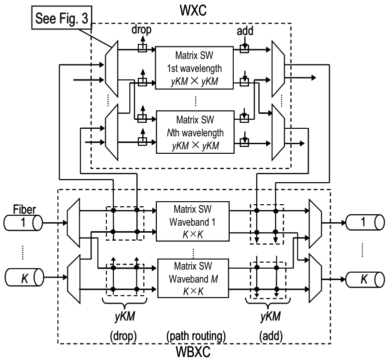

Fig. 1 Proposed HOXC architecture

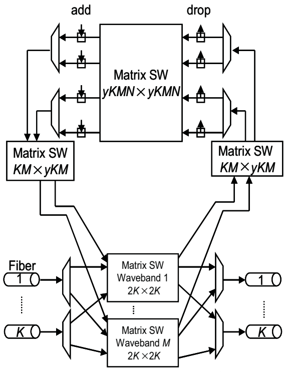

Fig. 2 Conventional HOXC architecture [4]

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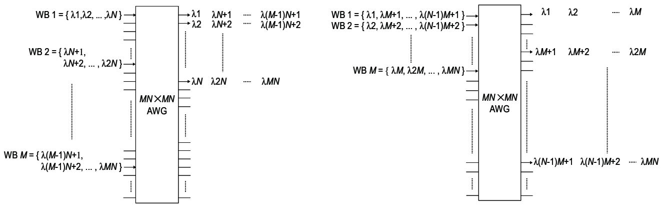
3. Proposed MUX/DMUX

Regarding item 2), we must develop a new device that can demultiplex *N* component wavelength paths of a waveband path among *N* fixed output ports regardless of the waveband index. We realize this with an AWG-based MUX/DMUX. Figures 3(a) and (b) show, respectively, the proposed devices applicable to continuous and interleaved waveband arrangements [2]. Note that each can be used for different waveband paths: wavebands input to each corresponding input port of the device are demultiplexed into the same fixed set of output ports. A single input waveband signal is delivered to the MUX/DMUX by WBXC drop switch. For continuous waveband arrangement, a cyclic AWG whose FSR coincides with waveband bandwidth can be used, however, a cyclic AWG yields loss variations of the output ports (loss near the FSR edges tends to be large), which does not occur with the proposed device.

4. Switch Scale Evaluations

In this section, we compare switch scales of single layer optical cross-connects and the HOXC. Assumed parameters are, *M*=8, *N*=8, and *x*=*y*=0.375. Table 2 compares switch scales of the different architectures; switch scale is evaluated by the number of element cross-point switches. Fig. 4 provides switch scale variations in terms of the degree of OXC, i.e. the number of incoming/outgoing fibers. Conventional HOXC can significantly reduce switch scale compared to a conventional single OXC. It is demonstrated that the proposed HOXC further reduces the switch scale from conventional HOXC.



(a) Continuous WB Arrangement (b) Interleaved WB Arrangement

Fig. 3 Proposed AWG based MUX/DMUX

5. Evaluation of the proposed MUX/DMUX

We constructed an experimental system with proposed MUX/DMUX by utilizing uniform-loss and cyclic frequency (ULCF [6]) 32x32 AWGs; 32 100-GHz spaced channels (192.1+0.1x*n* THz; *n*=0~31) on an ITU-T grid. The device can be used by different four WBs, each of which consists of 8 channels. Figures 5(a) and (c) show the spectra of the 1st and 2nd waveband that should be input to the AWG from input ports #1 or #2, respectively. The corresponding output spectrum at #1 output port are shown in Figs. 5(b) and (d), respectively. It is verified that the 1st wavelength path of each waveband is demultiplexed to the same output port #1.

6. Conclusion

We proposed an HOXC architecture that implements the colorless waveband add/drop ratio restriction, and also an efficient MUX/DMUX architecture. We verified the compactness of the proposed HOXC and the functionality of the proposed MUX/DMUX in an experimental system.

7. Acknowledgment

This work is partly supported by CREST, JST.

8. References

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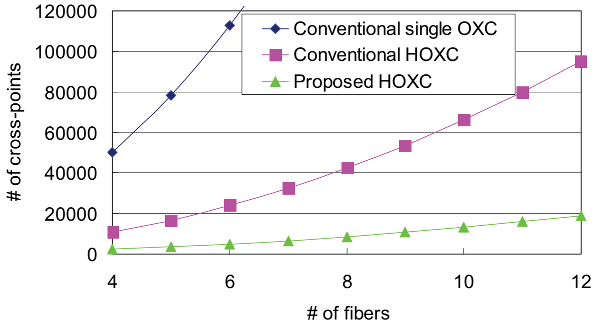
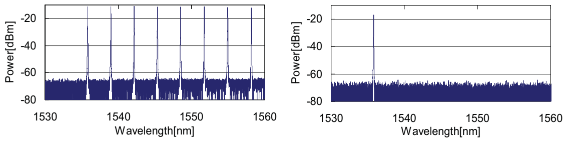
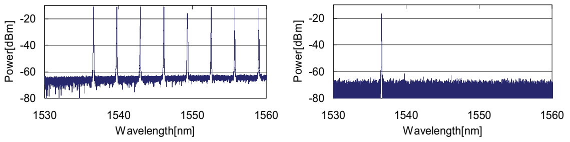


Fig. 4 Switch scale evaluation



(a) 1st waveband **(b) Output at port #1**



(c) 2nd waveband **(d) Output at port #1**

Fig. 5 Input and output spectra at AWG

Table 2 Comparison of Single layer and Hierarchical OXCs

XC type	Add/drop ratio restriction	WBXC structure	WXC structure	# of cross-points
Conventional single OXC [4]	Wavelength, Colorless	————	Single matrix SW	$K^2MN + 2xK^2M^2N^2$
Conventional HOXC [4]	Waveband, Colorless	Independent SW is assigned to each waveband		$K^2(4M + 2yM^2 + y^2M^2N^2) + 2yKMN$
Proposed HOXC			Independent SW is assigned to *i*-th wavelength in wavebands	$K^2(M + 2yM^2 + y^2M^2N) + 2yKMN$