

Hierarchical Optical Path Network Design Algorithm that can Best Utilize WSS/WBSS based Cross-connects

Hai-Chau LE, Hiroshi HASEGAWA, Ken-ichi SATO

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

Abstract: In order to reduce cross-connect switch scale by utilizing the WSS/WBSS based hierarchical cross-connect switch architecture, we propose a novel network design algorithm that satisfies a restriction on add/drop ratio for each waveband. The effectiveness of the proposed algorithm is proven by numerical experiments.

Keywords: Wavelength/Waveband selective switch, Hierarchical optical cross-connects, Waveband, Routing and wavelength/waveband assignment

1. Introduction

The advances in WDM techniques and related optical technologies enable ROADM-based single layer optical path networks to cope with the increased traffic demands driven by broadband access services such as xDSLs and FTTH. Further traffic growth is expected due to the penetration of high-speed broadband services including IP-TV and High/Super-High Definition TV. This will result in an explosive increase in the optical switch size at cross-connect node. To meet the traffic increase, hierarchical optical path networks [1] that employ hierarchical optical cross-connects (HOXCs) with waveband switching have been developed. In order to reduce the switch scale of cross-connect systems, restricting the waveband add/drop ratio is essential [2,3]. We have already proposed a network design algorithm that considers a restriction on the "colorless" waveband add/drop ratio, which is defined as the ratio of the number of added/dropped waveband paths to the total number of outgoing/incoming waveband paths. The "colorless" indicates that the restriction ratio is defined with regard to the total number of add/drop wavebands without consideration of waveband indices [4]. This restriction is very effective in reducing the optical switch scale of matrix-switch based HOXCs [2], but it is not effective for reducing that of WSS/WBSS (wavelength selective switches/waveband selective switches) based HOXCs. Rather, the restriction increases the total hardware scale compared to that of single layer OXC. The switch scale of a WSS/WBSS based HOXC can be reduced only when the restriction is on each waveband index as was proven in [3]. This type of restriction, on each waveband, is more severe, and makes network utilization inefficient. In this paper, we propose a new design algorithm for hierarchical optical path networks considering the waveband add/drop ratio constraint on each waveband. The proposed method is based on our previously developed design strategy [4,5] that grooms wavelength paths with neighbouring source and destination nodes. The algorithm combines the grooming technique with a waveband routing strategy and considers the add/drop ratio constraint on each waveband. The efficiency of the proposed algorithm is

verified by numerical experiments.

2. WSS/WBSS based HOXC architecture [3]

WSS based ROADMs are widely deployed in the world. We consider the WSS/WBSS based HOXC architecture as shown in Figure 1 where the HOXC consists of a WSS-based OXC (WXC) and a WBSS-based waveband cross-connect (WBXC). Main advantage of the WSS/WBSS-based HOXC architecture is its modular growth capability; expanding the node scale requires only the addition of WSSs/WBSSs and hence incremental cost-effective expansion is possible. The larger the maximum waveband add/drop ratio is, the greater number of required WSS modules is, and therefore, the add/drop ratio limitation is essential to effectively reduce hardware.

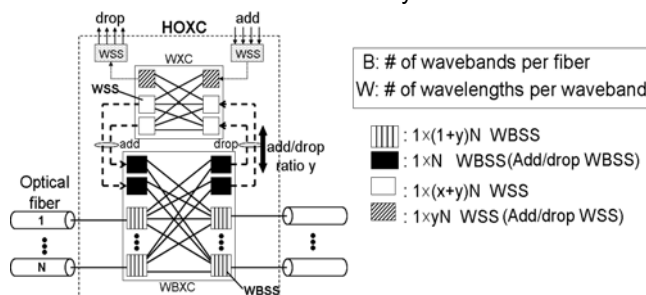


Figure 1 : WSS/WBSS based HOXC architecture

Let y be the upper bound for the ratio of added/dropped waveband paths to/from WBXC of the HOXC on each waveband index; yN wavebands can be dropped from N incoming wavebands of the same waveband index. In terms of the number of MEMS mirrors in WSS/WBSS, the HOXC is more effective than the single layer OXC if y is less than a specific value y_{max} as shown in Figure 2 [3]. In backbone networks, the add/drop wavelength path ratio typically ranges from 0.2 to 0.4 for various network conditions, however, note that the ratio is on total wavelengths, not each wavelength index. So, the above restriction ratio, y , imposes harder restrictions on network design. In the next section, our newly developed routing and waveband/wavelength assignment algorithm that considers the limitation on y is presented.

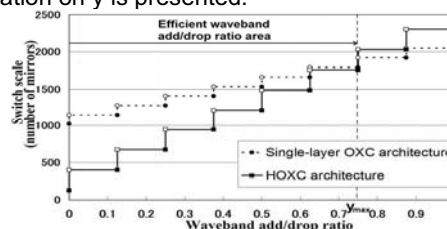


Figure 2 : Comparison of switch size between HOXC and OXC

3. Waveband add/drop ratio constrained design algorithm

Conventional design algorithms focus on minimizing the network cost function, which approximates cost as a linear function of optical port count and number of fibers required [5,6,7]. Our network design algorithm not only minimizes the total network cost but also simultaneously satisfies the given waveband add/drop ratio constraint on each waveband index in order to effectively reduce switch sizes in HOXC nodes. The proposed method iteratively grooms wavelength paths into a waveband, and then routes, and assigns the waveband path with consideration of the waveband add/drop ratio restriction on each waveband index by using a virtual multi-layer waveband/wavelength graph of the network (see Figure 3). The proposed algorithm is summarized as follows:

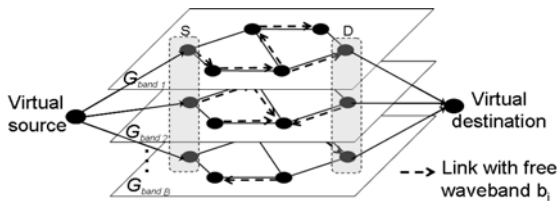


Figure 3 : Virtual multi-layer waveband graph of the network

<Network design with a restriction on each waveband add/drop ratio>

Parameters:

X_{wb} : Waveband construction threshold for establishing a new waveband path ($X_{wb} \in (0,1)$).

K: Number of path candidates found by the K-shortest path algorithm.

y_0 : Upper-bound of the waveband add/drop ratio on each waveband index.

Step 1: Wavelength grooming:

For wavelength path demands, in descending order of hop count between source and destination nodes, search for a set of neighbouring source nodes $\{s_j\}$ and a set of neighbouring destination nodes $\{d_j\}$ that satisfy $\sum(\text{traffic demand between } (s_j, d_j)) \geq X_{wb} W$. Choose a pair of nodes $(s, d) \in \{s_j\} \times \{d_j\}$ where wavelength paths are accommodated into a waveband connecting the nodes. If such a set does not exist, go to Step 3. Otherwise, go to Step 2.

Step 2- Routing and waveband assignment:

Define a multi-layer waveband graph G_{band} of the network where each layer $G_{band i}$ is related to a different waveband index $i (i=1..B)$. Virtual source/destination nodes are defined and respectively connected to the original s and d on all layers. Find K-shortest paths (r_1, \dots, r_K) from s to d .

For each route candidate r_k from s to d , calculate a preference function that is the square root of sum of squared deviations of waveband add/drop ratio from y_0 at each node along the route, denoted by σ_k . Choose the route candidate which maximizes the preference function σ_k . If several such paths are available, select one randomly. Go back to Step 1.

Step 3- Refinement:

Accommodate all remaining wavelength paths by using a multi-layer wavelength graph G_{WL} of the network and applying the shortest path algorithm. Finally, some spare waveband ports can be added to the appropriate nodes in order to satisfy the given restriction.

4. Network cost evaluation

We assume the following parameters in numerical experiments of the proposed network design algorithm: pan-European network topology (COST266) consisting of 26 nodes and 51 links with randomly distributed traffic demand, 8 wavelengths per waveband ($W=8$) and the capacity of fiber is 64 wavelengths ($B \times W=64$). We also set $K=4$ and $y_0 \in \{0.3, 0.5, 0.7, 0.9, 1\}$. Figure 4 illustrates the network cost normalized by that calculated for the corresponding single-layer optical network. The network cost depends on y_0 , and the cost reduction strengthens with traffic between node pairs since small traffic demands limit the room for port count reduction. Figure 4 also shows that increasing y_0 above 0.5 slightly helps in reducing the normalized network cost, and the proposed algorithm can attain up to 20% cost reduction when the average traffic demand is around 8 and y_0 is 0.5.

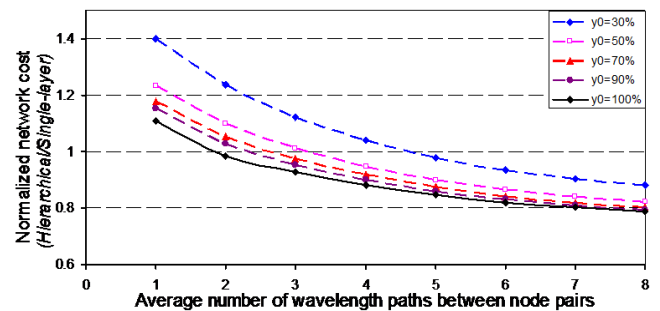


Figure 4 : Cost reduction in COST266 network

5. Conclusion

We have developed a network design algorithm that applies a restriction on the waveband add/drop ratio to each waveband for the hierarchical optical path networks. Numerical experiments verified that the proposed algorithm attains substantial network cost reduction while satisfying the constraint on each waveband add/drop ratio. The restriction can be met with the WSS/WBSS based hierarchical optical path cross-connect architecture that can best utilize existing technologies.

Acknowledgment

This work was partly supported by NICT of Japan.

References

- [1] K. Sato et al., "Prospects and Challenges of Multi-Layer Optical Networks," IEICE TRANS. Commun., vol. E90-B, no.8, pp.1890-1902, August 2007.
- [2] S. Kakehashi et al., "Optical Cross-connect Switch Architectures for Hierarchical Optical Path Networks", in Proc. SPIE OpticsEast 2006, vol. 6388, pp. 638809-1 - 638809-9, Oct. 2006.
- [3] S. Mitsui et al., "Hierarchical Optical Path Cross-connect Node Architectures using WSS/WBSS", in Proc. Photonics in Switching 2008, S-04-1, Japan, 2008.
- [4] H.C. Le et al., "Hierarchical Optical Path Network Design Algorithm Considering Waveband Add/Drop Ratio Constraint", in Proc. COIN2008, SB-64, Japan, 2008.
- [5] I. Yagyu et al., "An Efficient Hierarchical Optical Path Network Design Algorithm based on a Traffic Demand Expression in a Cartesian Product Space," in Proc. ECOC, pp.113-114, 2006.
- [6] P.-H. Ho et al., "A Scalable Design of Multigranularity Optical Cross-connects for the Next Generation Optical Internet", IEEE JSAC, vol. 21, pp. 1133 -1142, Sep. 2003.
- [7] X. Cao et al., "A Study of Waveband Switching with Multilayer Multigranular Optical Cross-connects", IEEE JSAC, vol. 20, pp.1081-1094, Sep. 2003.