Hierarchical Optical Path Network Design Algorithm Considering Waveband Add/Drop Ratio Constraint

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Abstract—**We investigate the relation between waveband add/drop ratio and switch size for hierarchical optical path cross-connects. We then propose a design algorithm for hierarchical optical path networks that considers restrictions on the waveband add/drop ratio. Its performance is evaluated by numerical experiments.**

Index Terms—**Waveband, Hierarchical optical path network, Waveband add/drop ratio, Network design algorithm**

I. INTRODUCTION

THE advances in WDM techniques and related optical technologies permit a single layer optical path network using optical cross-connects (OXCs) to realize enormous bandwidth transport capability. This is capable of satisfying traffic demands driven by broadband access such as xDSLs and FTTH which are being adopted throughout the world. Further Internet traffic expansion is expected due to the penetration of high-speed broadband services including IPTV and High-Definition TV. The traffic growth will result in an explosive demand in the switch size of OXCs and ROADMs. To avoid explosions in the cost and complexity of the switches, hierarchical optical path networks that employ hierarchical optical cross-connects (HOXCs) using waveband switching have been developed [1]-[3]. It has been verified that hierarchical optical path networks can reduce the total number of optical ports needed, a parameter that determines HOXC switch size [3]-[5]. Ref. [2] provided a detailed analysis of HOXC switch size. It showed that total switch size strongly depends on the waveband add/drop ratio which is defined as the number of waveband paths incoming/outgoing from/to wavelength cross-connect (WXC) to the number of all incoming/outgoing waveband paths at a waveband cross-connect (BXC) (see Fig. 1). From the hardware realization point of view, it is desirable to determine the upper-bound of the ratio since through ports and add/drop ports require different optical interfaces [2]. Maximum flexibility in terms of the ratio (i.e. no bound) triggers non-optimized switch

Fig. 1. HOXC architecture

architectures. The conventional network design algorithms do not consider the ratio and, as a result, the waveband add/drop ratio at each node is determined only after the design is completed.

In this paper, we propose a new design algorithm, as an extension of our previously proposed algorithm [3], for hierarchical optical path networks subject to waveband add/drop ratio restriction at every node. To attain our proposal, we introduce a preference function that is the sum of the square of the deviation from the restriction at every node along the selected route. The proposed algorithm first selects several wavelength paths that can be carried efficiently by a waveband path, and then assigns to the waveband path the pair of waveband and route with the largest preference. After optimization, for nodes that cannot satisfy the specified restriction, additional spare through ports are added so that the restriction can be met (of course this increases node cost). Numerical experiments verify that our proposed algorithm can achieve almost the same cost as that without considering the restriction when the restriction is not so tight. By using the proposed algorithm, the effect of the restriction on total network cost has been clarified.

II. HIERARCHICAL OPTICAL PATH NETWORK

Given the hierarchical optical path network, we assume the HOXC without costly wavelength conversion shown in Fig.1. The HOXC consists of BXC part and WXC part [2]. The former consists of BXC and waveband multiplexer/demultiplexer for routing higher-order waveband paths, and the latter consists of WXC and wavelength multiplexer/demultiplexer for routing lower-order wavelength paths.

Here, let B and W be the number of wavebands in a fiber and the number of wavelengths in a waveband, respectively. Let y denote the waveband add/drop ratio of the HOXC. Suppose that all fibers are fully occupied by wavelength paths and all wavelength paths are accommodated by direct wavebands (source and destination of the wavelength paths and the waveband paths coincide). Comparing the port number of the HOXC and that of an OXC accommodating the same number of both input/output fibers and add/drop wavelengths, the HOXC port number is less than that of OXC if $y \leq \frac{W-1}{W+1} = y_{max}$ (the proof is not given here because of the space limit). This means that in order to ensure that HOXC is more cost-effective than OXC, the waveband add/drop ratio must be less than the specific value y_{max}.

The waveband add/drop ratio y is obviously related to the switch sizes of BXC and WXC. Therefore, y should be upper-
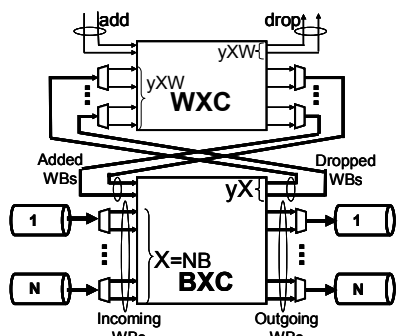
bounded by some threshold that is smaller than y_{max} so that the same node architecture can be employed throughput the hierarchical optical path network while decreasing the total port count of the network.

III. NETWORK DESIGN ALGORITHM CONSIDERING WAVEBAND ADD/DROP RATIO RESTRICTION

Based on the observation made in Sec.II that the waveband add/drop ratio y should be upper-bounded, we develop a network design algorithm that minimizes the total network cost while satisfying the restrictions on waveband add/drop ratio. The procedure of the proposed network design algorithm is summarized as follows:

Step 0-Selection of parameters

Select proper values for the following parameters.

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

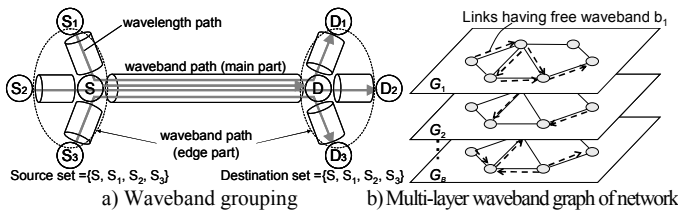K: Number of path candidates found by K-shortest path algorithm.

a) Waveband grouping   b) Multi-layer waveband graph of network

Fig. 2. Waveband grouping and multi-layer waveband graph of network

y_0 : Upper bound of waveband add/drop ratio.

Step 1- Waveband grouping

In descending order of hop count between source and destination node, search for a set of neighboring source nodes $\{s_i\}$ and a set of neighboring destination nodes $\{d_i\}$ that satisfy $\sum "\text{traffic demand between}(s_i, d_i)" \geq X_{wb}W$. Choose the source and destination $(s,d) \in \{s_i\} \times \{d_i\}$ of the main waveband path connecting the two sets.

If such a set does not exist, go to Step 3. Otherwise, go to Step 2.

Step 2- Waveband routing

Define a multi-layer waveband graph of the network where each layer is related to a different waveband. Network graph with respect to waveband i (i=1..B) can be represented by layer G_i of the multi-layer waveband graph (see Fig. 2b). Based on this graph, apply the K-shortest path algorithm to each layer and find the K-shortest paths $(r_1,…, r_K)$ from s to d among the KB path candidates.

For each candidate r_k from s to d, calculate the square root of sum of squared deviations of add/drop ratio from y_0 at each node along the route, denoted by σ_k ; $\sigma_k = \sqrt{\sum_{n \in N(r_k)}(\max\{y_n - y_0, 0\})^2}$ where $N(r_k)$ is all nodes of candidate r_k.

Choose the path with the largest σ_k among the candidates. If multiple paths are available, choose one randomly.

Step 3- Refinement

Step 3.1- Accommodate all remaining wavelength paths by creating a multi-layer wavelength graph of the network and applying the shortest path algorithm (Dijkstra) to route each remaining wavelength path. After all wavelength paths are accommodated, go to Step 3.2.

Step 3.2- Add spare waveband ports to nodes whose ratios are greater than y_0 so that their ratios satisfy the restriction.

IV. NUMERICAL RESULTS

We employed the following parameters for the numerical experiments: a 7×7 polygrid network, random traffic demand with uniform distribution, 8 wavelengths per waveband (W=8) and fiber capacity is 64 wavelengths (8 wavebands per fiber; B=8). We also set K=2; $y_0 \in \{0.1, 0.2, …, 1\}$ and $X_{wb} \in \{1/W, 2/W, …, W/W\}$; one of the thresholds that minimizes total network cost is then selected. The total network cost is evaluated by a linear function of the numbers of ports and fibers for simplicity (see [6]).

Figure 3 shows the normalized network cost achieved by the proposed algorithm. This result shows that the proposed algorithm can offer up to 40% less cost compared to single
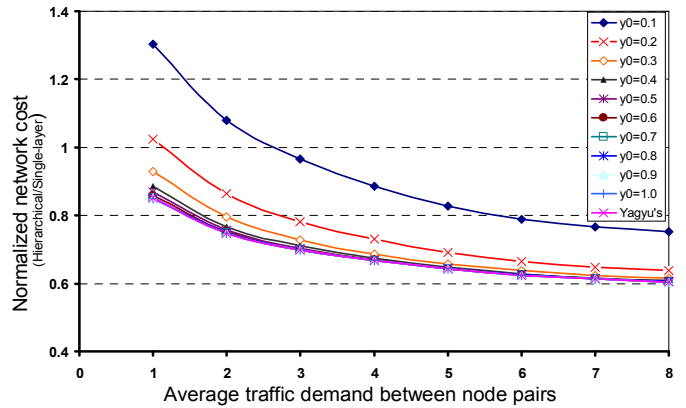

Fig. 3. Normalized network cost by proposed algorithm

layer networks while satisfying the waveband add/drop ratio constraint at all nodes. Increasing y_0 to greater than 0.4 does not obviously help in reducing the normalized network cost: with such y_0 values, the normalized network cost is almost same as that obtained by the previously developed algorithm without waveband add/drop ratio restriction [3].

V. CONCLUSION

We have proposed a hierarchical optical path network design algorithm that can incorporate restrictions on waveband add/drop ratio. Simulation results have proved its effectiveness.

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