WDM Network Design with Waveband and Wavelength Multiplexing Scheme

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Abstract: A network design method employing a two-stage multiplexing scheme which exploits the merits of wavelength granularity is presented for wavelength division multiplexing mesh networks. The effects of wavelength granularity and average demand on the crossconnect requirements and wavelength requirements are discussed.

I. Introduction

Recently, the concept of wavelength granularity has been proposed so as to simplify OXC [1-4]. Several lightpaths are grouped into a waveband, and the lightpaths in a waveband are routed together as a single channel. Because the granularity of waveband is coarser than that of wavelength, its cross-connect requirements can be less than the case of using only wavelength crossconnect.

We refer to these networks using two-stage multiplexing scheme as hierarchical crossconnect (HXC) networks and the networks using single-stage multiplexing scheme as wavelength crossconnect (WXC) networks, respectively. In this paper, we propose a design method for HXC networks, and evaluate its performance in terms of the reduction gain of crossconnect size.

II. Waveband Formation in HXC Networks

Fig. 1 shows the node architecture for the networks using multi-stage multiplexing where the direct waveband drop ports in waveband crossconnect are added to the basic node architecture described in [1, 3].

As waveband formation scheme, there may be three waveband formation schemes;

1. Grouping the lightpaths with the same source-destination pair
2. Grouping the lightpaths with the only same destination
3. Grouping the lightpaths with common intermediate links

The first scheme seems to be a natural choice, but the efficiency can be lowered because the demands of all nodes are not always the same with the wavelength granularity, that is, the number of wavelength channels in a waveband.

In the third scheme, the routing of lightpaths is free. However, when we wish to transfer the lightpaths in a waveband to another waveband, it is only possible with wavelength crossconnect. This may result in the unexpected increase of wavelength crossconnect size. In the second scheme, when the lightpaths with the same destination are once grouped into a waveband, they do not need to be reconnected in a wavelength level. It results in substantial reduction of wavelength crossconnect size.

We therefore choose the second scheme. We refer to the waveband paths consisting of the lightpaths with the same destination as the packed waveband paths. The other waveband paths are referred as the unpacked waveband paths.

III. Design of HXC Networks

Optimal design for HXC networks can be presented by integer linear programming, but has a very complex form and cannot be applicable to large networks. In this section, we present a heuristic design method.

A. Routing

To maximize the number of packed waveband paths, the lightpaths with the same destination should have the same route as possible. Hence, we make all lightpaths in the network satisfy the optimality principle. And then, we can construct auxiliary graphs for each destination node. However, several auxiliary graphs may be found for one destination node because several optimal paths may exist.

In order to choose an auxiliary graph leading to the minimum crossconnect requirements and the minimum wavelength requirements, we use the minimum hop path routing; from the shortest logical connections, find the minimum hop paths. If several paths are found, select a path having the least link loading among the paths from the next hop nodes of the source node to the destination node.

B. Lightpath grouping

In this phase, we determine which waveband the lightpaths should be grouped into. We use the following simple rule; for the lightpaths with the same destination, find the lightpaths sharing the most common links each other. If the number of the found lightpaths reaches the wavelength granularity, assign a waveband number to the lightpath.

After determining the wavebands, we can calculate the size of optical switch matrices at WXC and WBXC.
C. Wavelength assignment

Each lightpath in packed wavelength paths should have a wavelength for all links of its route because the wavelength conversion is not allowed in WBXC. Therefore, we should first assign wavelengths to lightpaths in packed wavelength paths and then to lightpaths in unpacked wavelength paths.

1. Sum the number of hops of lightpaths in each packed wavelength path and list them in descending order.
2. For the first packed wavelength path on the list, set \( W \) the lowest wavelength given in the network. Next, solve the following integer linear programming.

**Objective function**

\[
\text{max } \sum_{p=1}^{n} \sum_{k=w}^{W} \sigma_{p,k} \delta_{p,k} 
\]

subject to

\[
\sum_{k=w}^{W} \sigma_{p,k} \delta_{p,k} \leq 1 \quad \forall p = 1, \ldots, W_p \tag{2}
\]

\[
\sum_{p=1}^{n} \sigma_{p,k} \delta_{p,k} \leq 1 \quad \forall k = w, \ldots, W + w \tag{3}
\]

where \( \delta_{p,k} \) is a variable that becomes 1 when \( p \) th lightpath in a packed wavelength path selects wavelength \( k \). \( \sigma_{p,k} \) is a binary constant that is 1 if wavelength \( k \) is available. The value of objective function is equal to \( W_p \) if all lightpaths in a packed wavelength path are successfully assigned wavelengths. If not, increase \( W \) by \( W_p \) and solve again the above integer programming until the objective value is equal to \( W_p \).

3. Repeat the wavelength assignment procedure of step 2 until all lightpaths are assigned wavelengths.

IV. Numerical Results

For the comparison, the following four ratios of HXC networks to WXC networks are defined.

- \( T_s \): Ratio of optical switch matrix requirements
- \( U_s \): Ratio of unit switch requirements
- \( M_s \): Ratio of maximum optical switch matrix
- \( W_s \): Ratio of wavelength requirements

ARPA network was chosen as a test network. Fig. 3 shows the effects of wavelength granularity for the previously defined ratios. For the uniform demand pattern with \( D = 2 \), we can achieve the maximum reduction for \( T_s \) at \( W_s = 4 \), and even larger reduction for \( U_s \). Another advantage can be expected such that the maximum sizes of WXC and WBXC can be reduced, each of which is less than half of the maximum size of WXC in a usual WXC network. Fig. 4 shows the variation of the ratios with respect to the several uniform demands \( D \) of logical connections. These values on the curves in Fig. 4 are acquired at the optimal wavelength granularity. It is found that the greater reduction effects of cross-connect requirements can be obtained with the larger demands of logical connections.

Fig. 3. Effects of wavelength granularity. \( W_s \) represents the wavelength granularity.

Fig. 4. Effects of the demand of a logical connection under uniform demand pattern. \( D \) represents the demand of a logical connection.

V. Conclusions

In this paper, we presented a heuristic design method for HXC networks employing a two-stage multiplexing scheme of wavelength and wavelength, which consisted of three phases: the minimum hop path routing combined with optimality principle, lightpath grouping, and wavelength assignment.

It has been shown that the introduction of wavelength leads to a very large reduction of crossconnect requirements for large networks and high logical connection demands. This result was verified by applying the proposed scheme to the ARPA network.

References


