Cost-Effective Design of GMPLS Networks with Sparse Multi-granularity Optical Cross-Connect

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Abstract. In this paper, we propose the efficient placement of MG-OXC (multi-granularity optical cross-connect) nodes in GMPLS networks to reduce all the network cost. When only a limited number of nodes are allowed to have the capability of waveband switching, it is shown that selection based on max-traffic performs better than Random and Nodal-degree schemes. Performance of the sparse placement of max-traffic scheme can be achieved very close to that of all placement of MG-OXC.

1 Introduction

Generalized Multi-Protocol Label Switching (GMPLS) is being developed in the Internet Engineering Task Force (IETF) [1]. In GMPLS with ordinary-OXC networks, pass-through traffic dominates over add-drop traffic in large-scale networks. Since many lightpaths conveying path-through traffic might have the same route, the size of the optical switch matrix would be largely reduced if they were dealt with as a single channel. Fig.1 shows the node architecture for networks employing MG-OXC where the direct waveband add/drop ports in waveband crossconnect (WBXC) are added to the ordinary-OXC architecture described in [2]. The switching units of FXC, WBXC, and WXC are fiber, waveband, wavelength, respectively. Note that wavelength con-version is allowed only at the wavelength crossconnect because of the significant technical difficulty of waveband conversion. In all previous research on waveband switching in optical networks, it is assumed hat every network node has waveband switching capability, which may not be practical or cost-effective in a nationwide optical

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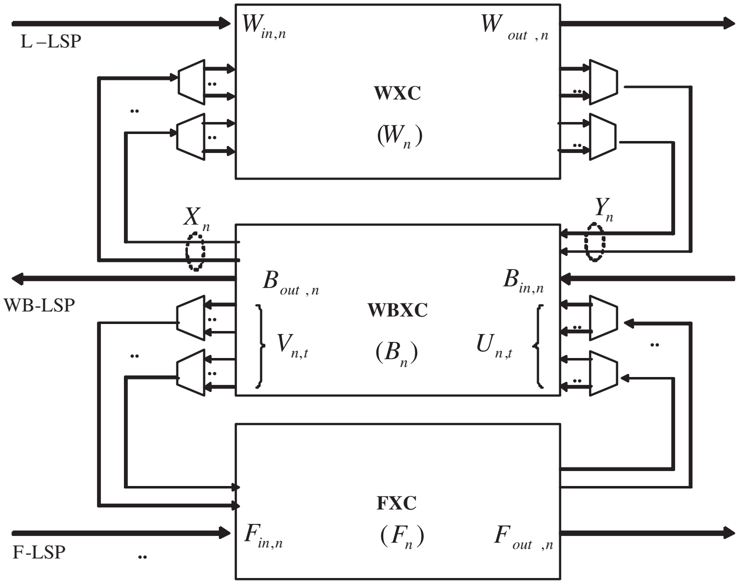

Fig. 1. The proposed architecture of MG-OXC [2]

backbone network [3,4]. In this paper, we propose a selection method for sparse MG-OXC nodes in GMPLS networks. We also propose a heuristic design procedure as a practical method to general large scale networks (not presented in this paper because of space limitation). By applying the proposed design method to ARPA network, the benefits of the sparse MG-OXC placement are discussed with respect to the traffic load.

2 Design of GMPLS Networks with Sparse MG-OXC Nodes

The characteristics of three different cost functions for selecting MG-OXC nodes, namely nodal-degree selection, maximum flow selection, and random selection. Note that some ideas on these node selection schemes are borrowed sparse-wavelength-converter-placement studies [5].

Nodal-Degree Selection: In this scheme, the first M nodes which have the maxi-mum nodal degree are picked to be MG-OXC nodes. If several nodes have same nodal degree and only some of them can be chosen, random selection is used to break any ties.

Max-Traffic Selection: For a given node ν , the total amount of traffic which may pass-through the node is computed, assuming that each traffic request is routed physical network topology using a k-shortest path routing algorithm. The M nodes which have maximum amount of pass-through traffic flow can be selected as MG-OXC nodes. Instead of routing the traffic requests between a node pair (s, d)using a single shortest path route, it may be also possible to compute alternate paths between (s, d) and bifurcate the traffic among these K alternative paths.

Random Selection: In this scheme, M nodes are randomly selected to be MG-OXC nodes.

One can also design other schemes to select the MG-OXC nodes. To minimize the size of MG-OXC with the minimum number of wavelengths and to select the MG-OXC with maximum traffic, the heuristic design method explained below consists of three stages: routing, selecting the MG-OXC nodes, and waveband assignment in MG-OXC node

2.1 Routing of Lightpaths

To maximize the number of complete waveband paths, it is clear that the light-paths with the same destination should have the same route. Therefore, we make all light-paths in the network satisfy the optimality principle. That is, if node y is on the optimal path from node x to node z, then the optimal path from node y to node z follows the same route on that part from x to z. As an optimal path, we use *k-shortest path* because the size of the MG-OXC is proportional to the number of hops of a path. Based on optimality principle, we can construct auxiliary graphs for each destination node. However, several auxiliary graphs may be found for one destination node be-cause multiple shortest paths may exist. In order to choose an auxiliary graphs leading to minimum number of wavelengths, we use least loaded routing. This procedure is summarized as follows:

1. Find the *k-shortest* paths for each lightpath request.
2. List all lightpath requests in descending order of minimum hop path length.
3. Decide the route of each lightpath request on the list.
4. If a lightpath request has several shortest paths, select a path with the least link loading on the route.

2.2 Selecting the MG-OXC with Max-Traffic

After selecting the route of each lightpath, we determine which waveband each light-path would be grouped into. To achieve a large reduction gain of the size of MG-OXC, it is clear that the lights path with many common links should be grouped into a wave-band. We use the following simple lightpath grouping rules.

1. Classify each lightpath into classes according to the destination node, and list all lightpaths in each class in descending order of the number of hops.
2. Select a lightpath on the top of the list in a class and find $W_B - 1$ lightpaths which have the most common links to form a waveband group. Then assign a waveband number to the group of lightpaths and remove them from the list. Reapply this procedure to the remaining lightpsths in the class.
3. Repeat step 2. for the other classes.

4. Once the wavebands and the routes for all lightpaths are determined, calculate the size of MG-OXC and list all MG-OXC in descending order of maximum size of MG-OXC.
5. Select the MG-OXC nodes, M on the list of MG-OXC.

2.3 Wavelength Assignment in a Waveband of MG-OXC Node

Each lightpath in a waveband path should have a wavelength for all links of its route because the wavelength conversion is not allowed in WBXC. We propose following new wavelength assignment rule for the lightpaths in a waveband of MG-OXC nodes.

1. Select a group of MG-OXC nodes, which has the Max-Traffic, and do the following.
2. Choose a node which has the Max-Traffic. If several candidates exist, select the waveband path is the longest.
3. If w is set as the lowest wavelength in each waveband path on the list, lightpaths in this waveband path may have one of the wavelengths from w to $w+W_B-1$. Then solve the following binary linear programming, where W_B is wavelength granularity:

$$\text{Maximize} \qquad \sum_{p=1}^{W_B} \sum_{k=w}^{W_B+k} \alpha_{p,k}\beta_{p,k} \tag{1}$$

$$\text{Subject to} \qquad \sum_{k=w}^{W_B+k} \alpha_{p,k}\beta_{p,k} \leq 1, \qquad \forall p = 1,\ldots,W_B \tag{2}$$

$$\sum_{p=1}^{W_B} \alpha_{p,k}\beta_{p,k} \leq 1, \qquad \forall k = w,\ldots,W_B+w \tag{3}$$

   where $\beta_{p,k}$ is a binary variable that becomes 1 when pth lightpath in a complete waveband path is assigned wavelength k, and $\alpha_{p,k}$ is binary constant that becomes 1 when wavelength k is available for pth lightpath in a complete waveband path. The value of objective function is equal to W_B if every lightpath in a complete waveband path is successfully assigned a wavelength. If not, increase w by W_B and solve again the above binary linear programming until the objective value is equal to W_B as shown Fig.2.
4. If any MG-OXC nodes in the group are not assigned the waveband, then go to step 2). Otherwise, go to step 5.
5. If all MG-OXC nodes are assigned the waveband, this algorithm finishes. Otherwise, go to step 1.

The above problem formulation is quite tractable because the number of constraints and the number of variables are $2W_B$ and W_B^2 , respectively, and independent of network size.

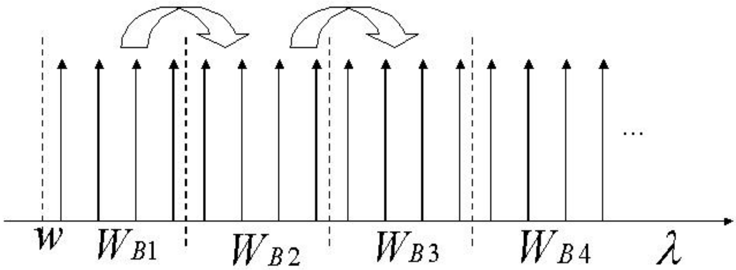

Fig. 2. An example of wavelength assignment in a complete waveband. W_{B1} and W_{B2} are not selected if every lightpath in a complete waveband path is failed when wavelengths are assigned to every lightpath in wavelength granularity W_B . However, W_{B3} is selected because every lightpath in a complete waveband path is successfully assigned a wavelength

3 Numerical Results of Heuristic Design

We calculate six parameters of MG-OXC networks that Mwxc, Mwbxc, SumMax, Twxc, Twbxc, and SumTotal are the maximum WXC size, the maximum WBXC size, the sum of Mwxc and Mwbxc, the sum of WXC sizes in all nodes, the sum of WBXC sizes in all nodes, and the total sum of Twxc and Twbxc, respectively. The ARPA network with N=20 and L=30 was chosen as a test network [2]. Fig.3 shows the example of MG-OXC selection when $W_B = 8, M = 14$. In this case, node 10 has largest waveband number, node 19 has has least waveband number. Fig.4 shows the number of port of MG-OXC with respect to the various wavelength granularity values. For uniform demand pattern of $D_p = 2$, we can achieve a maximum reduction gain of more than 50% for SumTotal at $W_B = 6$ (SumTotal of MG-OXC and ordinary OXC are 4492 and 8676 ports, respectively). Therefore, it can be concluded that an optimal wavelength granularity value leading to maximum reduction gain may exist. However such an optimal wavelength granularity value may depend on network topology, traffic demand, and traffic pattern. Nonetheless, the reduction of MG-OXC size can be still be expected with non-optimal wavelength granularity values. Another advantage is that the maximum size of WXC and WBXC in MG-OXC network is less than half of the maximum size of ordinary OXC (that is 619 ports). On the contrary, disadvan-tage of MG-OXC is the increase in number of required wavelength at overall wave-length granularity values. Also, the number of port in MG-OXC is saturated to any values as the increase of wavelength granularity values. From Fig.4, we can see the relation of waveband and traffic demand per node. In less traffic load, smaller waveband needs less number of ports. However, in more traffic load, more wavelength granularity needs less number of ports. In Fig.5, we observe that the Max-Traffic selection can achieve much better performance than Random and Nodal-Degree selection. This validates the importance of problem of MG-OXC placement. When there are five MG-OXCs, Nodal-Degree and Max-traffic selection result in the same placement scheme, which have better

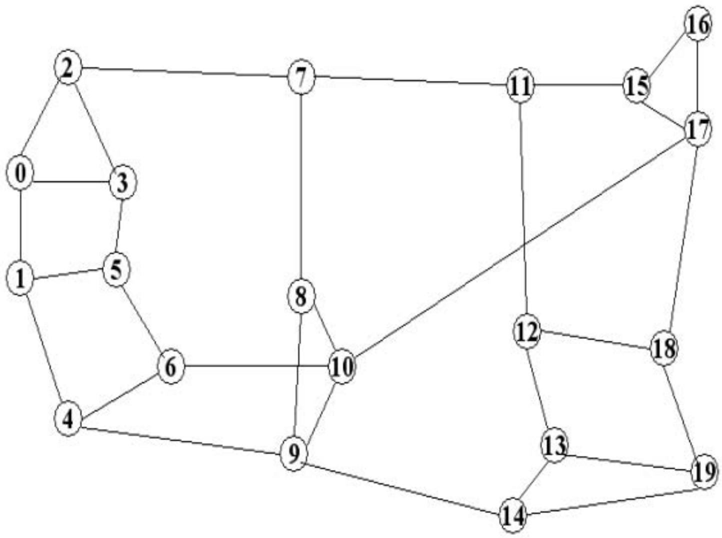

Fig. 3. An Example of MG-OXC placement when $W_B = 8, M = 14$

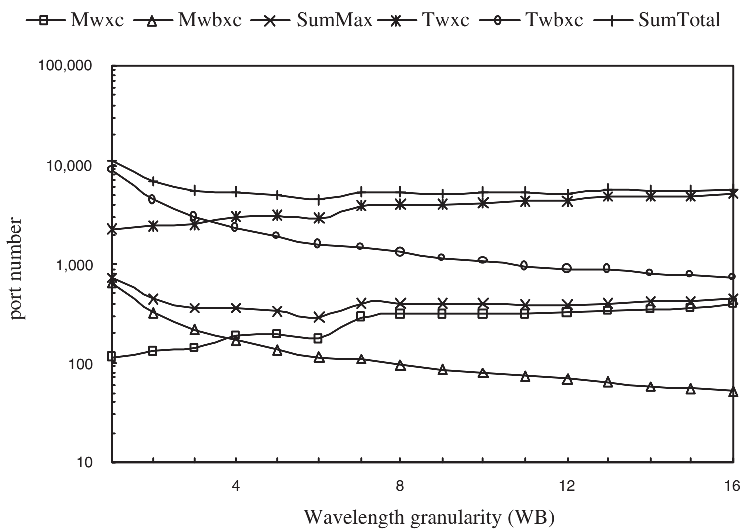

Fig. 4. The effect of wavelength granularity for uniform demand pattern of $D_p = 2$

performance than Random. When there are ten MG-OXCs, we observe that with the number of waveband switching increased, the blocking probability is increased because of wave-length shortage. From the above simulation analysis, we conclude that sparse MG-OXC placement improves blocking probability performance significantly in mesh networks if the MG-OXCs are placed appro-

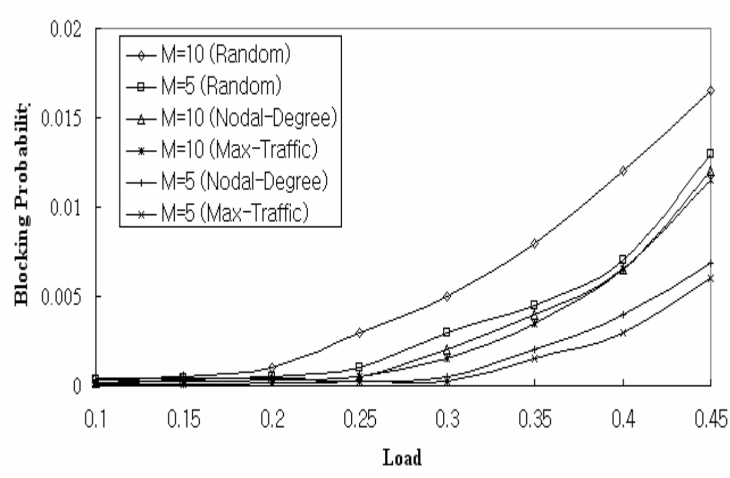

Fig. 5. Blocking probability vs. traffic load in the 20-node ARPA network

priately. The proposed Max-traffic selection for MG-OXC can achieve better performance than Random and Nodal-Degree selection.

4 Conclusion

In this paper, we propose cost-effective design of multi-granularity optical cross-connect (MG-OXC) which significantly reduces the number of used ports and hence the cost of GMPLS network. The proposed selection method of MG-OXC is that the nodes with maximum of traffic flow are chosen. Performance analysis shows that the proposed design method of MG-OXC is more cost-effective than that of Random and Nodal-degree.

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