

Design of Tunnel-based Protection Schemes in Multigranularity Optical Cross-connect Networks

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Abstract—As the technology advances to increase the number of wavelengths in fiber links, multigranularity optical cross-connects (MG-OXC) have emerged as a solution to reduce the manufacturing cost of the traditional optical cross-connects (OXC). In this paper, we aim to provide an efficient fault-recovery protection scheme for the lightpaths in the MG-OXC networks. A segment-based protection scheme, called Tunnel Based Segment Protection (TSP) is proposed to recover the communications interrupted by a fiber cut. TSP first allocates all the tunnels off-line according to the historical traffic matrix and then starts to serve the incoming requests. When allocating a tunnel, a backup tunnel is always allocated as well. Consequently, a lightpath is naturally divided into segments according to the switching types along the path. Therefore, after a working path is found for a connection request, only a shared backup path for those segments in the corresponding wavelength-switching layers need to be found. In addition, TSP utilizes wavelength-switching ports efficiently since working and backup tunnels can share the same wavelength-switching ports at two ends of the tunnel. Simulation results show that the network performance is improved comparing to adapt a straightforward path protection scheme for MG-OXC networks.

Keywords- Fault-recovery, protection, optical cross-connect (OXC), multigranularity optical cross-connect (MG-OXC), tunnel

I. INTRODUCTION

Wavelength-division multiplexing (WDM) optical networks are widely accepted as the solution for supporting the growing demands of bandwidth. Recently, hierarchical optical cross-connects, or multi-granularity Optical Cross-connects (MG-OXC) [1]-[3] are even gaining more and more research attention due to their attractiveness in saving the network cost. The principal idea of MG-OXC networks is to bundle a group of consecutive wavelength channels together and switch them as a single unit on their common sub-path so that the required ports of intermediate cross-connects along the route can be reduced. The bundled channels form the so-called waveband or fiber tunnels in which lightpaths can not be wavelength-switched except at the ends of the tunnels. In this paper, we aim to provide an efficient fault-recovery protection scheme for the lightpaths in the MG-OXC networks.

Basically, protection schemes can be classified into path protection, link protection, and the compromise of the previous

two, segment protection. The protection schemes can be further categorized into shared protection and dedicated protection. In dedicated protection, different backup paths do not share any link in the same wavelength plane. To share the backup resources, the constraint is that two backup paths cannot share wavelengths on the links if their corresponding working paths have common links. Obviously, shared protection utilizes bandwidth more efficiently than dedicated protection. Nevertheless, it is at the expense of recovery time because in shared protection, cross-connects can not be pre-configured to save the reconfiguration time [4].

The protection problem in MG-OXC networks has only been considered in [5]. The authors propose a graph-based heuristic that tries to minimize the total number of switch ports in the network, given a set of static connection requests. Our study differs from [5] because we assume that the network resource is already given and the node architecture is the multi-layer MG-OXC proposed in [1] instead of the single-layer MG-OXC. The problem is described as follows. Given the network resources and a historical traffic matrix that the future requests will follow, provide a shared protection scheme that minimizes the blocking probability of future requests under the constraint so that for each request, both working path and backup path must be found to guarantee 100% survivability.

II. PROTECTION SCHEMES IN MG-OXC NETWORKS

The MG-OXC architecture [1] is shown in Fig. 1. In the MG-OXC network, a directional link consists of $F = F_1 + F_2 + F_3$ fibers, where F_1 , F_2 and F_3 fibers are assigned as fiber-, waveband-, and wavelength-switched fibers, respectively. In a waveband- or fiber-switched fiber, all the wavelengths in a waveband or a fiber have to be switched together. Depending on the size of the grouped wavelengths, the tunnel-like passage formed by the grouped wavelengths, which is switched as a single unit, is termed as a waveband tunnel or a fiber tunnel.

Intuitively, the protection problem in MG-OXC networks can be divided into two phases: 1) off-line tunnel allocation and 2) finding link-disjoint lightpaths for each incoming request. A straightforward solution is to allocate tunnels off-line without protection consideration and then find two link-disjoint lightpaths from source to destination for each

This work is supported by National Science Council, Taiwan under Grant Nos. NSC 92-2213-E-009-068 and NSC 91-2218-E-009-016.

incoming request. We call this scheme Tunnel Based Path Protection (TPP). Although TPP provides a protection solution for the networks with MG-OXC, the lack of protection consideration in the first phase complicates the finding of link-disjoint lightpaths since two tunnels sharing any common link can not be utilized by a working path and its backup path. Therefore, we propose another scheme called Tunnel Based Segment Protection (TSP). In TSP, a working tunnel is always allocated followed by the allocation of a backup tunnel. Consequently, MG-OXC network protection problem can be formed into one kind of segment protection problem.

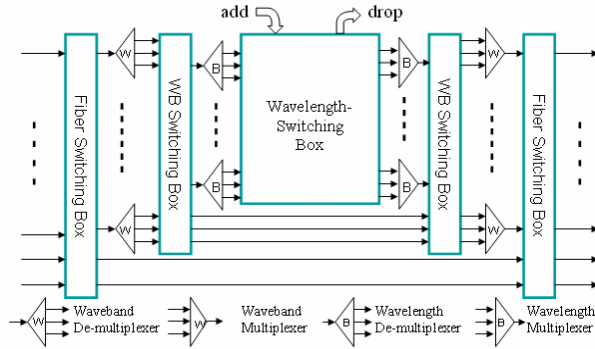


Fig. 1. Architecture of the MG-OXC

A. Tunnel Based Path Protection (TPP)

It should be noted that while allocating tunnels, we only take tunnels that comply with length constraint into account [1]. The length constraint forces all tunnels to have equal length to simplify tunnel allocation. If the value of the length constraint is set too small, the wavelength-switching ports can be used up easily. On the other hand, if it is set too large, the routing flexibility would be decreased since most of the lightpath requests are shorter than the tunnels. In our study we set the tunnel length constraint to the average hop distance.

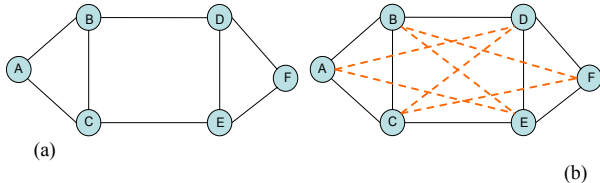


Fig. 2. (a) The original network topology with average hop distance equal to two. (b) The corresponding auxiliary graph.

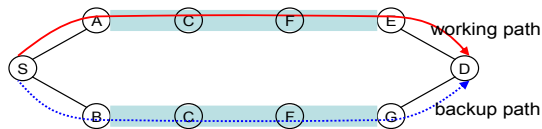


Fig. 3. An example of TPP.

We first transform the physical network topology into an auxiliary graph by adding edges, which we term as potential tunnel edges, between nodes whose shortest hop length follows the length constraint. Fig. 2 demonstrates the construction of the auxiliary graph. After the auxiliary graph is constructed, the historical traffic matrix is temporarily routed on the auxiliary graph with the assumption that the load between each node pair will be equally distributed on all its

shortest paths. After finish the routing of all traffics, the total load, or weight, on each potential tunnel edge by this time is just the estimated load between the nodes incident to that edge, and the larger the value the higher priority it gets to be allocated as a tunnel. We then pick up the potential edge with the largest weight, allocate a tunnel for it and decrease its weight for a fixed amount of value. This process is repeated until all the weight of the potential edges are less than or equal to zero. Details of this process can be found in [3].

After the tunnels are allocated on the network, we can start to serve the incoming requests. For each request, both working path and protection path should be found or the request should be blocked. For example, in Fig. 3, two link-disjoint paths are found for request (S, D).

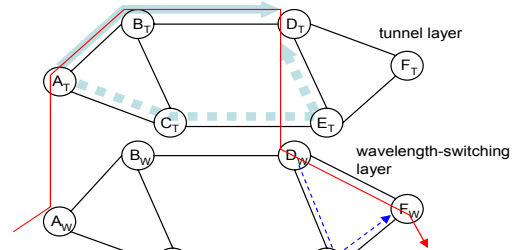


Fig. 4. A layered view for the concept of TSP.

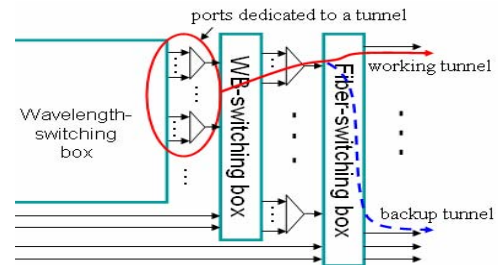


Fig. 5. MG-OXC only reconfigures the fiber-switching box to switch the traffic in working tunnel to protection tunnel

B. Tunnel Based Segment Protection (TSP)

TSP operates similarly to TPP except that whenever allocating a tunnel for a node pair, a backup tunnel should also be allocated. Consequently, a working path for a request can be segmented according to the switching types along its route. Since the segments in the tunnel layer are already protected by their backup tunnels, only those segments in the wavelength-switching layer need to be further protected. Fig. 4 gives a layered view of this concept. A working path from node A to node F (A-B-D-F), shown as the red solid line, is divided into A-B-D and D-E, where segment A-B-D is protected in the tunnel-switching layer by backup tunnel A-C-E-D and segment D-E is protected in the wavelength-switching layer by backup lightpath D-E-F.

We deduce that TSP provides better performance than TPP (in terms of blocking probability) for two reasons. The first comes from the intrinsic superiority of resource sharing efficiency in segment protection than in path protection. Second, a backup tunnel in TSP can use the same wavelength-switching ports, which is the critical resource in MG-OXC

networks, with its working tunnel. Once a link failure occurs and results in breakdown of a working tunnel, we only have to reconfigure the fiber- or waveband-switching boxes on the backup path while leaving the wavelength-switching ports at the two ends of the tunnel unchanged. Fig. 5 shows the port sharing on the ingress side of a working fiber tunnel and its backup tunnel. In contrast to TSP, there is no sharing of wavelength-switching ports between tunnels in TPP, thus a lightpath request may require more wavelength-switching ports.

III. SIMULATION RESULTS

We evaluate the performance of TPP and TSP via simulation using a 16-node topology. We assume that each directional link has five fibers. Each fiber contains forty wavelengths which are evenly divided into four wavebands. Each node is assumed to have enough wavelength conversion capability, but there is no waveband conversion. (F1)F(F2)B(F3)L stands for the experiment with $F1$ fibers for fiber-switching, $F2$ fibers for waveband-switching, and $F3$ fibers for wavelength-switching in each directional link. The traffic is assumed to be uniformly distributed. Each request is randomly generated among all node pairs and once satisfied, it remains on the network until simulation ends.

Fig. 6 shows the simulation results. Blocking probability increases as $F1$ and $F2$ increase. The results show that TSP outperforms TPP in all switching type combinations. We also observe that the fewer fibers dedicated to the wavelength-switching layer, thus less wavelength switching ports, the larger the difference of blocking probability between TSP and TPP. For example, in 1F1B3L, TSP is 43% better than TPP in terms of blocking probability when there are 1200 requests. In 1F2B2L, TSP is 48% better than TPP when there are 900 requests. Furthermore, in 2F2B1L, TSP is 91% better than TPP when there are 350 requests. This indicates that wavelength-switching ports are critical resource in the MG-OXC networks. Fig. 7 demonstrates this point more clearly. It shows that the less of the traffic is blocked with the more wavelength-switching ports. The wavelength-switching ports influence the performance of the networks significantly, thus it makes sense to derive an algorithm that can save ports. TSP can save ports by letting a pair of working and protection tunnel use the same ports, thus it will have better performance.

IV. CONCLUSION

In this paper, we investigate the protection schemes for the single link failure in the MG-OXC networks. Path protection based scheme TPP provide a straightforward resolution. However, the absence of taking protection requirement into consideration when allocating tunnels propels us to provide another scheme, TSP, to improve the performance of TPP. In TSP, a backup tunnel is always allocated with a working tunnel. Hence, the working path of a lightpath request can be naturally segmented according to the switching types along its route, with each segment protected in its corresponding layer. In addition to the intrinsic superiority of resource sharing in segment protection than in path protection, TSP also utilizes less wavelength-switching ports for a lightpath request. Simulations are conducted to compare the performance of TPP

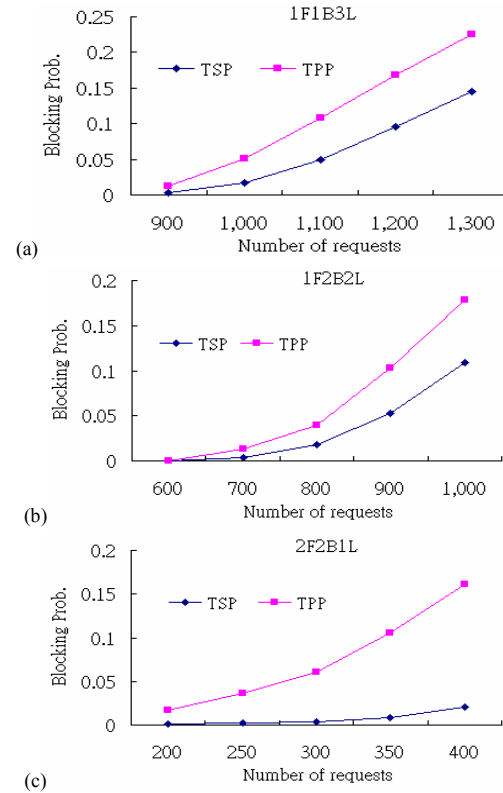


Fig. 6. Comparison of TSP and TPP under different combination of switching types. (a)1F1B3L. (b)1F2B2L. (c)2F2B1L.

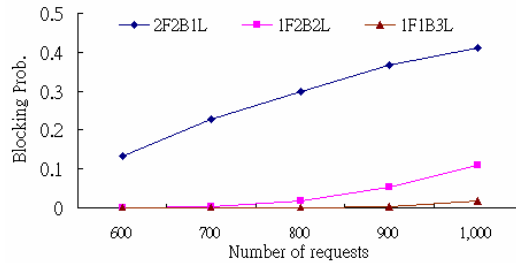


Fig. 7. Traffic load vs. blocking probability in different switching combinations in TSP.

and TSP. The results show that TSP outperforms TPP in terms of blocking probability, due to the better sharing efficiency of TSP in link capacity and wavelength-switching ports.

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