Light Path Protection for IP/DWDM Networks

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Abstract -- This paper presents a new algorithm that dynamically allocate restorable bandwidth guaranteed paths in IP over DWDM network. This paper tackles the bandwidth efficiency by considering sharing of the bandwidth on the backup lightpaths. The amount of sharing that can be achieved is related to the information available to the algorithm. Three information scenarios are considered here: complete information scenario, partial information scenario and no information scenario. Simulation results show that the developed algorithm with a partial information scenario which uses only aggregated and not per-path information performs very well compared with the complete information scenario.

I. INTRODUCTION

Currently, most IP transport architectures are based on SONET/SDH, encapsulating IP packets(or ATM cells carrying IP packets) in SONET/SDH frames. However, this "full stack" approach reduces efficiency and poses increased management/operation costs. Therefore, designing a single, ubiquitous WDM access layer with tight IP interworking can significantly reduce the intermediate layering requirements. In order to provision a full range of network functionality, the optical layer must subsume some key functions which currently reside in different network layers. These include channel routing, channel monitoring, and fault detection and recovery capabilities. [1]. Recent years, a lot of work has been done on extending Multiprotocol Label Switching (MPLS) as a control plane that can be used not mealy with routers, but also with SONET equipment and optical devices like OXCs [2,3]. The control planes in the IP and optical networks can be loosely or tightly coupled. At one hand, the optical network primarily offers high bandwidth connectivity in the form of lightpaths. Standard signaling across the UNI is used to invoke the services. IP routers at the edge of the optical networks must necessarily establish such paths before communication at the IP layer can begin. On the other hand, the IP and optical networks are treated together as a single integrated network that is managed and traffic engineered in a unified manner. There is no distinction between UNI, NNI and any other router-to-router interface. It is assumed this control plane is MPLS-based, IP routers and OXCs can have a peer relation on the control plane.

The network survivability issue has long been of primary concern in transport networks. SONET/SDH networks mainly provide dedicated-resource protection, such as self-healing ring and automatic protection switching (APS), which relies on fixed (redundant) backup resources and a rigid electronic framing/synchronization format, and provides mainly point-to-point or ring based protection.

Similar protection and restoration mechanisms can be carried out on IP/WDM networks to provide survivability [4]. In the path protection scheme, the source and destination nodes of each connection statically reserve backup paths on an end-to-end basis during call setup. There is dedicated path protection, in which payload data is transmitted simultaneously over two disjoint paths, and a selector is used at the receiving node to choose the best signal. And there is also shared-path protection, at the time of call setup for a primary path, a link-disjoint backup path and wavelength are also reserved. However, the backup wavelength reserved on the links of the backup path may be shared with other backup paths.

In the path restoration scheme, the source and destination nodes of each connection traversing the failed link participate in a distributed algorithm to dynamically discover a backup route and wavelength on an end-to-end basis. If no new route is discovered for a broken connection, that connection is blocked.

The distinction between protection and restoration is centered on the different time scales in which they operate. Protection requires preallocated resources, while restoration relies on dynamic resource establishment.

WDM layer survivability cannot protect against failures at higher layers. It cannot handle all types of faults, can not be able to detect all types of faults, and only protect traffic in units of wavelength. So, multilayer survivability incorporates survivability mechanisms at multiple layers, and two escalation or interworking strategies can be used. One is bottom-up strategy, where recovery starts at the layer closest to the failure, and escalates upward upon expiration of a holdoff timer. This timer allows the lower layers time to recover form a fault before triggering recovery mechanisms at a higher layer, it ensuresquick activation of the recovery process. Another is top-down strategy, where recovery always starts at the uppermost layer and escalates downward. Holdoff timers are not necessary in this strategy, but a disadvantage is the potentially large number of traffic streams that must be restored at the higher layers.

II. RELATED WORK

Bandwidth sharing routing algorithm for providing protection in the traditional MPLS network has been developed in [5] and [7]. Bandwidth efficiency and the amount of information dissemination are two main concerns of the bandwidth sharing routing algorithm. A suitably developed algorithm in [5] can achieve good bandwidth utilization according to sharing backup bandwidth with only aggregated and not per-path information.

There exist some differences about sharing backup bandwidth between traditional MPLS network and IP/DWDM network. Firstly, routing in the traditional MPLS network only involves one layer of network, ie. IP layer, whereas routing in the IP/DWDM network considers two layers of network, the DWDM layer and the IP layer [9]. Secondly, the optical network has special properties that are different from the traditional MPLS network. Path selecting in the optical network is the problem of *routing and wavelength assignment* (RWA) [8], not simply shortest path problem [6]. Lightpath is the unit of end to end transmission in the optical network, and it forms the virtual connection between edge routers in the IP network. So the backup bandwidth that can be shared is reserved on lightpath instead of on each link as stated in [5].

So the new architecture of IP/DWDM network motivates us to extend the algorithm in [5] to provide protection against single fiber cut in the IP/DWDM network and optimize using network resources with feasible information dissemination as well.

III. SHARED PROTECTION PATH

Consider an IP/DWDM network, the optical layer is a mesh of *n* nodes (OXC), which do not perform opto-electronic-optic conversion, and *m* fiber links, and each fiber link contains *W* wavelengths. At the IP layer, ie., virtual network layer, there are *n'* nodes. The nodes at IP layer are edge routers, and each of them is connected to one OXC in the optical layer.

We assume the IP requests with bandwidth requirement arrive one by one dynamically at the ingress edge router. The goal of the algorithm is allocating a bandwidth guaranteed primary connection (ie. Lightpath) and backup connection for each request. The backup connection reserves the amount of bandwidth necessary to protect the traffic of the request on the primary connection against single fiber cut in the optical network. At the optical layer, the lightpaths of the primary virtual connection and backup virtual connection should be link-disjoint. When trying to process an IP request with protection requirement at ingress edge router, if either of the primary or backup connection cannot be allocated, the request is rejected.

Suppose current request arriving at the edge router requires *b* units of bandwidth, the primary connection for the request has to reserve *b* units of bandwidth for transmitting the packets. However, the backup virtual connection does not necessarily have to reserve *b* units of bandwidth. This is because the potential sharing of the bandwidth of the backup lightpath.

The information of each existing connection at the IP layer can be defined as follows. The capacity of the connection is the capacity of the corresponding lightpath. For each existing connection p, let G_p denote the amount of bandwidth reserved for backup purpose, R_p be the amount of residual bandwidth, which is the difference between the capacity of the connection and bandwidth already consumed, whether for primary transmission or backup.

A. No Information Model

In no information scenario, we only know residual bandwidth R_p for each existing connection *p*. So we cannot share the backup bandwidth in this information model. When a request (*s, d, b*) arrives, where s and d are ingress and egress routers, and b is bandwidth requirement. We first find out if there exists primary connection between edge router *s* and *d*. If there is, we reserve *b* units of bandwidth on the connection for transmitting the packets. If there is not, we dynamically establish a lightpath between the ingress edge router and egress edge router as the primary connection. Then we find out if there exists backup connection. If there is, we reserve *b* units of bandwidth on the connection to backup the traffic on the primary connection. Otherwise, we have to dynamically establish a link-disjoint lightpath as backup connection.

B. Complete Information Model

We have the complete connection information for all the requests currently in progress in complete information model. With the information, we can fully utilize the network resources by sharing the bandwidth of backup lightpaths. Then the problem is how to get the extra bandwidth needed to be reserved on backup connection.

Let A_{ij} denote the set of IP requests whose primary connections use fiber link (i, j). Let B_p represent the set of IP requests that use existing connection *p* as backup connection. Let ϕ_{ij}^{p} represent the set of IP requests that use existing connection *p* as backup connection, and their primary connection use fiber link (i, j). We have

$$\phi_{ij}^{p} = A_{ij} \cap B_p .$$

Let b_k denote the k-th request's bandwidth demand in set ϕ_{ij}^{p}, then the sum of all the bandwidths demands in set ϕ_{ij}^{p}

is $\delta_{ij}^{p} = \sum_{k\in\phi_{ij}^{p}} b_k$. So, if the lightpath of the primary connection for the current request that has bandwidth demand *b* uses link (i, j) in the route, the bandwidth necessary to be reserved on backup connection p for protecting the traffic on link (i, j) is,

$$\theta_{ij}^{p} = \begin{cases} 0, & \delta_{ij}^{p} + b \le G_p \\ \delta_{ij}^{p} + b - G_p, & \delta_{ij}^{p} + b > G_p \;\&\; R_p \ge \delta_{ij}^{p} + b - G_p \end{cases}$$

If we use a link-disjoint primary connection which is denoted as PRM for current request, the bandwidth necessary to be reserved on backup connection *p* is the maximum θ_{ij}^{p} for each link (i, j) of the route of PRM, that is $\max_{ij\in PRM}\{\theta_{ij}^{p}\}$.

C. Partial Information Model

Partial information model is the primary focus of this paper. In this model, the available information for each existing connection *p* is the residual bandwidth R_p, and backup bandwidth G_p.

We have following notations to define the fiber link state information in the optical network. Each fiber in the optical network has *W* wavelengths, which are numbered as 0, 1, … , *W*-1. Let A_{ij}^{w} denote the set of IP requests whose primary connections use fiber (i, j) and wavelength w. Then the total amount of bandwidth reserved on fiber link (i, j) and wavelength w for primary purpose is $f_{ij}^{w} = \sum_{k\in A_{ij}^{w}} b_k$. For each fiber link (i, j), the available information to the algorithm in partial information model is the aggregate bandwidth f_{ij}^{w} ($w = 0, 1, \ldots, W-1$). The main difference of the routing algorithm in partial information model from the one in complete information model is how to get the extra bandwidth needed to be reserved on backup connection *p* for the current request with limited information.

In order to achieve bandwidth sharing of backup lightpath with only partial information, we add a constraint when allocating connections for IP request. The constraint is that each virtual connection p can only backup the traffic on at most one wavelength for each link fiber (i, j). If we use $\phi_{ij}^{w,p}$ to denote the set of requests that use p as backup connection and their primary connection traverse link (i, j) and occupy wavelength w on link (i, j), the constraint is expressed as,

$$\phi_{ij}^{w_1,p} \cap \phi_{ij}^{w_2,p} = \phi \qquad (w_1 \ne w_2).$$

With this constraint, if we use primary connection PRM which occupies wavelength *w* and backup connection BAK for current request with *b* units of bandwidth demand, BAK can only protect the traffic on wavelength w for each fiber of the route of PRM. That is, for each fiber (i, j) of the route of PRM, we have $\phi_{ij}^{BAK} = \phi_{ij}^{w,BAK}$ and $\delta_{ij}^{BAK} = \delta_{ij}^{w,BAK}$, where $\delta_{ij}^{w,BAK} = \sum_{k\in\phi_{ij}^{w,BAK}} b_k$.

Note that $f_{ij}^{w} \ge \delta_{ij}^{w,p}$, because the traffic of wavelength *w* on fiber link (i, j) may be protected by the connections other than *p*. So we have $f_{ij}^{w} \ge \delta_{ij}^{p}$, if *w* is wavelength of the primary connection and *p* is the backup connection. Thus we can use f_{ij}^{w} to get the extra bandwidth $\theta_{ij}^{p}{}'$ needed to be reserved on backup connection *p* to protect the traffic on fiber (i, j), which is expressed as follows:

$$\theta_{ij}^{p}{}' = \begin{cases} 0, & f_{ij}^{w} + b \le G_p \\ f_{ij}^{w} + b - G_p, & f_{ij}^{w} + b > G_p \;\&\; R_p \ge f_{ij}^{w} + b - G_p \end{cases}$$

So we can reserve $\max_{ij\in PRM}\{\theta_{ij}^{p}{}'\}$ bandwidth on backup connection p if we use PRM as the primary connection of the current request.

The algorithm for allocating connections for each request is as follows. Each edge router stores all the existing connections starting from it in LSP table. Each primary connection is linked with a backup connection. When requests come in, the edge router tries to find a pair of existing primary connection and backup connection at first. If edge router cannot find a pair of connections, it tries to find a primary connection *p*, then scans through the LSP table to find a suitable backup connection. If no existing connections can satisfy the current request, the edge router will launch the RWA process to find a new primary connection, and scan through LSP table to find a suitable backup connection. If there is no available backup connection, the edge router will call RWA again to find a new backup connection. The suitable backup connection means the extra bandwidth necessary to be reserved on it is minimum.

The routing algorithm in this information model can be executed in polynomial time, since it only involves searching in table and finding shortest path in the network.

IV. SIMULATION RESULTS

This section compares the performance of the algorithms in the three different information scenarios. We test the performance in the mesh-based network topology shown in Figure 1. The optical network consists of 15 optical switches and 21 physical links. Each adjacent node pair is connected by a physical link that consists of bi-directional working fibers. We assume there is only one fiber in one direction, and each fiber contains 4 wavelengths. In the IP layer, there are ten edge routers, which are connected with OXCs. In our simulation, we set the capacity of the lightpath as 100. We assume that the bandwidth requirement of the requests is evenly generated between 1 and 10.

We set 70% of the requests go from edge router 1 to edge router 2, and 30% are evenly distributed among all pairs of edge routers in the IP network. There are totally 150 requests loaded to the network. Figure 2 shows the number of dropped requests for 10 random experiments. From the figure, we can see that partial and complete information models dropped fewer requests than the algorithm in no information model. This is because there are plenty of disjoint paths between edge router 1 and 2, and the backup lightpath can be shared by many requests. And the performance of the algorithm in partial information model is almost as good as that in complete information.

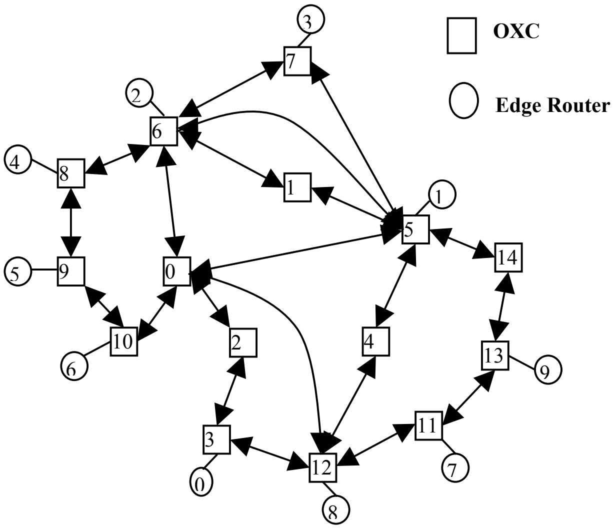

Figure 1 Testing IP/DWDM

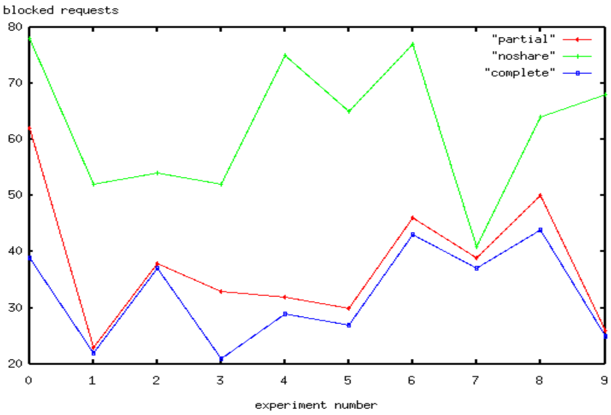

Figure 2 Number of rejected requests for 10 random experiments in 15-node DWDM network (70% traffic is from edge router 1 to edge router 2, 30% random)

V. CONCLUSION

This paper has introduced the survivability problem at IP/DWDM network. We consider providing protection to the connections in IP/DWDM network, and meanwhile, we attempt to optimize the usage of network resources through sharing backup bandwidth. Three information models are defined, and we presented a simple bandwidth sharing algorithm for sharing the bandwidth of backup lightpaths at IP/DWDM network under partial information model to achieve good performance as well as little information dissemination in the network. We implemented the algorithms of the three scenarios and compared their performance. The simulation results show that when the network has plenty of disjoint paths between edge routers our algorithm has almost the same good performance as the algorithm in complete information model.

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