Dual-Homing Protection in WDM Mesh Networks [1]

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Abstract: This paper studies optical-layer protection design in a WDM mesh network given that a dual-homing infrastructure is implemented at the IP layer. The problem is formulated as an integer linear program and solved using CPLEX.

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1 Introduction

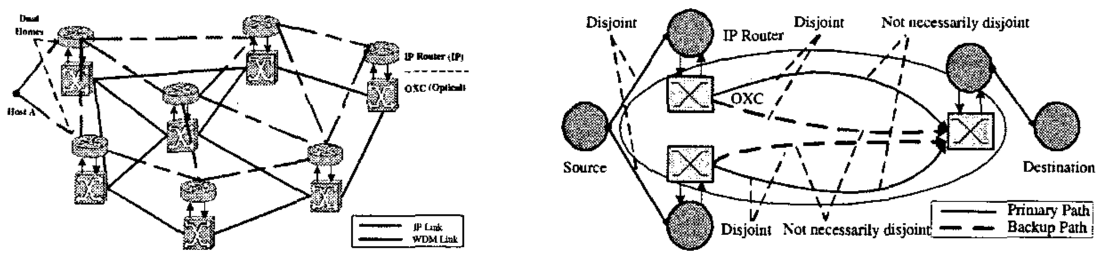

Fig. 1. (a) IP-over-WDM Network Architecture. (b) Dual-Homing Protection Architecture.

An important issue in IP-over-WDM networks is survivability. Survivability is the capability of the network to function in the event of node or link failures. *Dual homing* is generally used to enhance the survivability of the access network. In dual homing, a host in the access network can be connected to two IP routers, which in turn are connected to underlying edge optical cross connects (OXCs) of the core network. Fig. 1(a) illustrates the principle of dual-homing. The main objective of dual homing is to protect end users against access point failures caused by system malfunction, scheduled outage, or an access link failure. Dual homing architecture design has been widely studied in self-healing ring networks [1-2].

The survivability in WDM networks is implemented using *protection* and *restoration* techniques. Protection is a static mechanism to protect against failure, where the resource for both the primary and the backup lightpaths are reserved prior to the data communication. Restoration on the other hand, is a dynamic mechanism where the backup lightpath is not set up until the failure occurs. Survivability using these techniques is usually provided to handle single link failures in the core network. Existing literature on protection and restoration in WDM networks can be found in [3-4]. There have been several efforts for providing survivability for a dual-homed IP network over an WDM networks [5-6]. In most of these works, the authors consider providing survivability separately at the IP layer and as well as the WDM layer. In [5], the authors discuss how to support dual-homing in passive optical networks; while [6] studies survivability in IP over WDM networks and provides different protection types (unprotected, protected, and dual homing) for each IP link in order to keep the networks connected in the event of link failure. The focus of this paper is to provide an integrated solution for providing survivability in an IP-over-WDM mesh networks.

In this paper, we integrate dual homing and protection, using dual-homing to protect against a single access node failure, and protection to handle a single link failure in the optical core. We consider the problem of providing protection in the core network, given the dual homing architecture. We assume that the failures in the access network and the core network are independent, which means that the failure of the access node and the failure of the link or node in the core network can occur simultaneously. By considering the dual-homed IP-over-WDM architecture (Fig. 1(b)), we observe that, at any given time, each host transmits data to the destination only through one of the dual homes. Based on this observation, we see that only one of the primary paths will be utilized at any given time. Also, this leads to fewer restriction on the disjointness property between the two primary (bold lines) and two backup paths (dotted lines). We observe that by providing an integrated solution, we can obtain significant cost benefits as compared to handling survivability separately at each of the layers (IP and WDM).

The rest of the paper is organized as follows. The detailed problem description is presented in Section 2. An integer linear programming (ILP) model is given in Section 3. In Section 4, we evaluate the performance of the ILP model.

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Finally, the conclusion is presented in Section 5.

2 Problem Description

A WDM network can be modeled as a directed graph $G =< V, E >$, where V is the set of OXCs and E is the set of WDM links. Let the wavelength cost of a WDM link $e \in E$ be $c(e)$. Let the maximum number of wavelengths in each link be W. Let R be the requests in G, and let each request $r_k = \{\{s_1^k, s_2^k\}, d^k\}$, where s_1^k and s_2^k are two OXCs connected to the dual homed edge routers of host k, and d^k is the destination OXC that in turn is connected to an IP router which connects to the destination host. Let the primary lightpath from s_1^k to d^k be denoted by $p_a^1(k)$ and the backup lightpath from s_1^k to d^k be denoted by $p_b^1(k)$. Similarly, the primary lightpath from s_2^k to d^k is denoted by $p_a^2(k)$ and the backup lightpath from s_2^k to d^k is denoted by $p_b^2(k)$. Let L^k be all the links used in the primary lightpaths and backup lightpaths for request r_k. L^k is defined as $p_a^1(k) \cup p_b^1(k) \cup p_a^2(k) \cup p_b^2(k)$.

In this paper, we study how to route $p_a^1(k)$, $p_b^1(k)$, $p_a^2(k)$, and $p_b^2(k)$ for all requests in R simultaneously, which is called *static dual-homing protection*. The relationship between the primary lightpaths and backup lightpaths is described in Fig. 1(b). We assume that full-wavelength conversion capability is available at each OXC in the core network and that the wavelength conversion cost is not significant. We only consider the wavelength cost. Therefore, our objective in static dual-homing protection is to find L^k for each request r_k in R, such that the total cost C is minimum, where:

$$C = \sum_{r_k \in R} \cdot \sum_{e \in L^k} c(e). \tag{1}$$

3 Static Dual-Homing Protection

We develop an integer linear programming (ILP) formulation for the static dual-homing protection problem. We have the following notation: $x_a^n(k,e)$ is 1 if path $p_a^n(k)$ uses link e, 0 otherwise, when $n = 1,2$ and $x_b^n(k,e)$ is 1 if path $p_b^n(k)$ uses link e, 0 otherwise, when $n = 1,2$. y_e^k is 1 if any path for request r_k uses link e, 0 otherwise, and y_e is total number of wavelengths used in link e. $In(v)$ is set of links that end at node v and $Out(v)$ is set of links that start from node v. The objective is to minimize:

$$\sum_{e \in E} y_e c(e) \tag{2}$$

subject to:

$$\sum_{e \in Out(s_n^k)} x_a^n(k,e) = 1 \qquad \forall k, n = 1,2 \tag{3}$$

$$\sum_{e \in Out(s_n^k)} x_b^n(k,e) = 1 \qquad \forall k, n = 1,2 \tag{4}$$

$$\sum_{e \in In(d^k)} x_a^n(k,e) = 1 \qquad \forall k, n = 1,2 \tag{5}$$

$$\sum_{e \in In(d^k)} x_b^n(k,e) = 1 \qquad \forall k, n = 1,2 \tag{6}$$

$$\sum_{e \in In(v)} x_a^n(k,e) = \sum_{e \in Out(v)} x_a^n(k,e) \quad \forall k, v,\ v \neq s_n^k, n = 1,2 \tag{7}$$

$$\sum_{e \in In(v)} x_b^n(k,e) = \sum_{e \in Out(v)} x_b^n(k,e) \quad \forall k, v,\ v \neq s_n^k, n = 1,2 \tag{8}$$

$$x_a^n(k,e) + x_b^n(k,e) \leq 1 \quad \forall k, e, n = 1,2 \tag{9}$$

$$y_e^k \geq \frac{1}{4}\sum_{n=1}^{2}(x_a^n(k,e) + x_b^n(k,e)) \qquad \forall k, e \tag{10}$$

$$y_e = \sum_k y_e^k \qquad \forall e \tag{11}$$

$$y_e \leq W \qquad \forall e \tag{12}$$

$$y_e^k \in \{0,1\} \qquad \forall k, e \tag{13}$$

$$x_a^n(k,e) \in \{0,1\} \quad \forall k, e, n = 1,2 \tag{14}$$

$$x_b^n(k,e) \in \{0,1\} \quad \forall k, e, n = 1,2 \tag{15}$$

Constraints (3) - (8) are the network flow conservation constraints. Constraint (9) forces $p_a^1(k)$ and $p_b^1(k)$ to be disjoint, and also forces $p_a^2(k)$ and $p_b^2(k)$ to be disjoint. Constraint (10) indicates that no more than one wavelength is reserved in any link e for a request r_k. Constraints (11) and (12) indicate the maximum requests a link can support.

4 Simulation Results

In this section, we analyze the performance of static dual-homing protection. We compare the dual homing protection (DHP) model with three other models that offer lower degrees of survivability: single homing without protection (SH), single homing with protection (SHP), and dual homing without protection (DH). In SH, each host is connected to a single access node, and the path from the access node to the destination over the optical core is unprotected. SHP is similar to SH except that the path over the optical core is protected. In DH, each host is connected to two access nodes, but there is no protection in the optical core. The above three models can be described by slightly revising the previously developed ILP model. We can modify the flow conservation constraints at the accessing and destination nodes to indicate whether a path $(p_a^1, p_a^2, p_b^1, p_b^2)$ is needed in a specific model. For a given instance of the problem in terms of network topology and a set of connections, we attempt to provide the four different services and calculate the cost for each service. All problems are solved by CPLEX.

In the first experiment, we evaluate the cost as a function of the number of connections. We set the number of nodes in the network, $V = 50$, the maximum outgoing degree of a node, $D = 20$, the number of wavelengths on every link, $W = 32$. Let the number of connection requests be $K = 8, 16, 24$, and 32. For each K, we randomly generate 50 instances, calculate the cost for each type of service, and report the average cost.

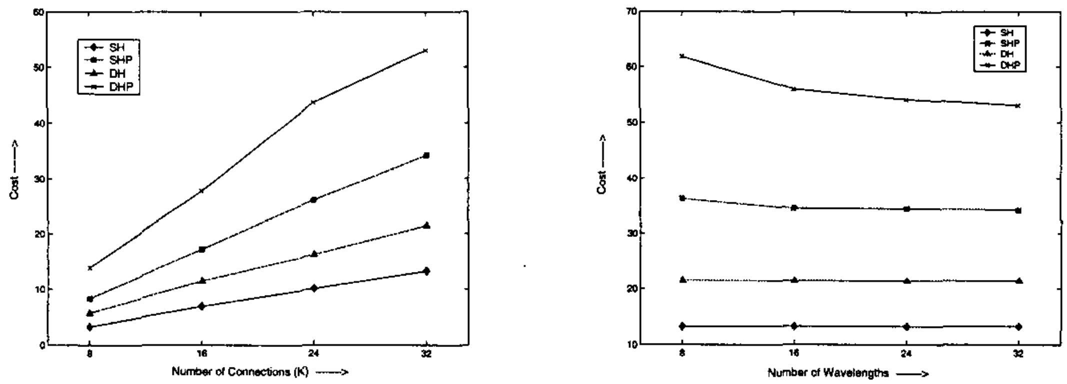

Fig. 2. (a) Cost for different services versus number of connection requests, and (b) Cost for different services versus various number of wavelengths.

Fig. 2(a) plots the average cost versus the number of connection requests. Not surprisingly, we observe that the cost increases with the number of connection requests for each type of service. DHP has the highest cost, followed by SHP, DH, and SH. An interesting observation is that the ratio of the costs between any two types of services does not vary too much. We also observe that SHP has a higher cost than DH. Both SHP and DH require two paths for each connection. However, the two paths in SHP are disjoint for the purpose of link protection, while the two paths in DH can be shared to reduce cost. This implies that protecting link failures (protection) is more expensive than protecting access node failures (dual-homing).

In the second experiment, we study how the number of wavelengths affects the cost. In a WDM network, each link has a limited number of wavelengths, each of which can be assigned to an individual connection request. Hence, there is a limit on the number of connections that can share a common link. Accordingly, when there are fewer wavelengths available on every link, some connection requests have to choose longer paths and thus will have a higher cost.

Fig. 2(b) illustrate such results, wherein we set the number of nodes, $V = 50$, the maximum outgoing degree of a node, $D = 20$, the number of randomly generated connection requests, $K = 32$. The number of available wavelengths on each link is varied from 8 to 32. From Fig. 2(b), we see that the number of wavelengths has little impact on the cost of SH and DH, since there are relatively fewer links required for these two schemes. On the other hand, the cost of DHP increases when there are fewer wavelengths per link. This verifies our previous argument that fewer wavelengths will force some connections to choose longer paths with higher costs.

5 Conclusion

We investigate the protection issue in IP-over-WDM networks when a dual homing architecture is implemented in the access network. Our goal is to provide survivability for such an infrastructure subject to two independent failures, one failure from the access network and one failure from the core network. The problem is formulated into an integer linear programming model and solved by CPLEX.

References

1. C. Lee and S. Koh, "A Design of the Minimum Cost Ring-Chain Network with Dual-homing Survivability: A Tabu Search Approach," *Computers Operations Research*, **24**, 883-897, (1997).
2. M. Willebeek-LeMair and P. Shahabuddin, "Approximating Dependability Measures of Computer Networks: An FDDI Case Study," *IEEE-ACM ToN*, **5**, 311-327, (1997).
3. E. Modiano and A. Narula, "Survivable Lightpath Routing: A New Approach to the Design of WDM-Based Networks," *IEEE JSAC*, **20**, 800-809, (2002).
4. D. Zhou and S. Subramaniam, "Survivability in Optical Networks," *IEEE Network* , **14**, 16-23, (2000).
5. A. Phillips et al., "Redundancy Strategies for a High Splitting Optically Amplified Passive Optical Network," *IEEE J Lightwave Tech.*, **19**, 137-149,(2001).
6. G. Sasaki and C. Su, "The Interface between IP and WDM and its Effect on the Cost of Survivability," *IEEE Comm. Mag.*, **41**, 74-79, (2003).