Survivable Hierarchical Optical Path Networks Employing Waveband and Wavelength Path Protection

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Abstract: We propose a novel hierarchical optical path network design algorithm ensuring wavelength path protection. The effectiveness of the waveband networks that adopt waveband or wavelength path protection are elucidated compared to single layer optical networks.

OCIS codes: (060.4257) Networks, network survivability; (060.4261) Networks, protection and restoration;

1. Introduction

Internet traffic is expected to explode in the near future spurred by the penetration of broadband access including ADSL and FTTH and the introduction of new broadband services including high-/ultrahigh- definition TV and e-Science. This will result in a significant increase in optical cross-connect switch scale if optical paths are switched at the wavelength granularity [1]. The hierarchical optical path networks that utilize wavebands [1-4], each consists of multiple wavelength paths, have been recognized as an important technology to ease this concern. They will effectively suppress the expected optical cross-connect switch cost explosion. The impact of introducing waveband paths strongly depends on the network design algorithm, which determines not only the routing and waveband assignment but also the accommodation of wavelength paths within waveband paths. Hereafter, we focus on the hierarchical optical path network design with objective being to minimize required network resources subject to given fixed traffic demands. Even for the single layer optical path networks, the Routing and Wavelength Assignment (RWA) problem is known to be NP complete [5]. In the hierarchical optical path network design, the problem is much harder since we must consider both waveband paths and wavelength paths simultaneously (not only wavelength path collision, but also waveband collision must be resolved). It is computationally impossible to obtain optimal solutions for practical scale networks. Several heuristic algorithms have thus been developed (a review is shown in [1, 2]). We recently developed an efficient one that has been proven to significantly reduce network costs [6].

Network survivability is an important issue, however, few studies have addressed hierarchical optical path networks so far. To create survivable hierarchical optical path networks, two mechanisms for dedicated protection in the optical layer are identified. One is wavelength path protection, switching working wavelength paths to their backup paths; the other, waveband protection, switches wavebands. The latter minimizes protection processing overhead while the former will further reduce network resource requirements. The former scheme is especially effective when two types of optical path co-exist; one requires optical path protection and the other does not. The services that utilize electrical layer protection/restoration, such as Label Switched Path (LSP) fast rerouting, will only need non-protected optical paths (will not need optical layer protection). The waveband protection automatically reserves working and backup resources simultaneously. As a first step, we have already developed a novel network design algorithm that employs waveband protection, and demonstrated its cost effectiveness [7, 8]. The algorithm achieves almost 50% cost reduction compared to single layer optical path networks with wavelength path protection for large scale networks.

In this paper, we newly propose an efficient network design algorithm for hierarchical optical path networks that employ wavelength path protection. The proposed algorithm aggregates wavelength paths by considering ‘closeness’ among paths; closeness is related to the accommodation efficiency of wavebands. Numerical results confirm that the proposed algorithm offers much lower cost than conventional single layer optical path networks with wavelength path protection. The results also demonstrate that wavelength path protection achieves lower cost than waveband protection only with relatively small traffic demands due to the enhanced utilization efficiency of wavebands. This work, in addition to our previous works [7, 8], allows us to create cost effective and robust hierarchical optical path networks while meeting different optical path layer protection requirements.

2. Designing Reliable Hierarchical Optical Path Networks

We assume here the Hierarchical Optical Cross-Connect (HOXC) architecture shown in Fig. 1. We avoid the use of costly wavelength/waveband converters. The characteristics of the two protection mechanisms are summarized below.

(A) Waveband Protection

Conducted in the waveband layer and processed at BXC. The backup process minimizes required switching operations because of the large granularity used in recovery processes. Another advantage is that the network design problem is relatively simple.

(B) Wavelength Protection

Switching is performed in the wavelength layer, that is, with wavelength granularity. Higher waveband utilization efficiency is expected due to its finer switching granularity.

General objectives of hierarchical network design are to maximize waveband routing to strengthen

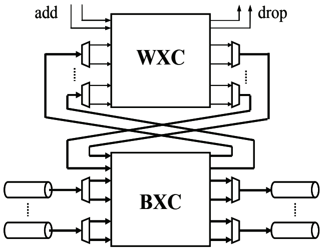

Fig.1 Hierarchical optical cross-connect

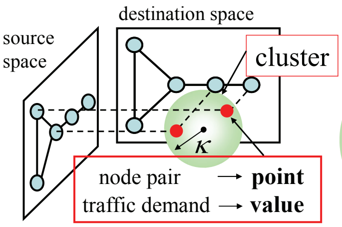

Fig. 2. s-d Cartesian Product Space

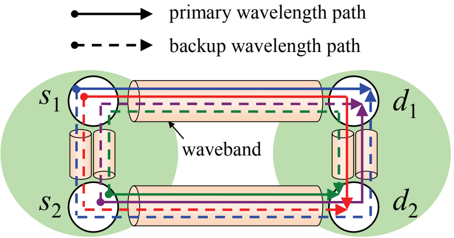

Fig. 3. Simple Loop with Wavelength Protection

cut-through WXC operation and to improve the utilization of each waveband path. We have so far proposed an efficient network design algorithm that achieves these objectives together with waveband protection. The algorithm adopts segmented waveband protection and was developed based on the observation that the pair of primary and backup waveband paths of each segment forms a loop; for the details, please see [7, 8].

3. Proposed Hierarchical Optical Path Network Design Algorithm Employing Wavelength Protection

The outline of our proposed algorithm is as follows. To achieve the two objectives mentioned above, it is necessary to identify a group of demands whose source/destination nodes are closely located. This concept has been shown to yield an efficient hierarchical network design algorithm that does not consider survivability [6]. Based on our previous work [6], we adopt an s-d (source-destination) Cartesian Product Space where nearby traffic demands are classified as clusters of points (Fig. 2). The proposed algorithm iteratively searches for a cluster in the space that stands for nearby wavelength path demands. Then it establishes wavebands that accommodate the corresponding wavelength paths, while ensuring survivability with wavelength protection. After that, the remaining sparsely distributed traffic demands are accommodated by using the vacant capacity of existing waveband paths. Details are presented below.

Design Algorithm Procedures

Step 0. Initial Setup

Suppose that the network topology is equivalent to a 2-connected graph $G=(V,E)$, which assures that a pair of node and link disjoint paths can be found between any two nodes in the network [9].

Let a set of pairs of nodes $B_\kappa(s,d) := \{(s',d') \in V \times V \mid \mathrm{hop}(s',s)+\mathrm{hop}(s,d)+\mathrm{hop}(d,d') \le \kappa\}$

where $s,d \in V$ and $\mathrm{hop}(x,y)$ stands for the minimum hop count between node x and y. This set forms a cluster in the s-d Cartesian Product Space. Determine a threshold $X_{wb}(1 \le X_{wb} \le W)$ for establishing new waveband paths in step2, where W is the maximum number of wavelength in wavebands.

Step 1. Search for Node Pairs Satisfying the Threshold

In descending order of $\mathrm{hop}(s_1,d_1)$, search for (s_1,d_1) and $(s_2,d_2) \in B_\kappa(s_1,d_1)$ such that $X_{wb} \le \sum_{i,j\in\{1,2\}} \mathrm{dem}(s_i,d_j)$ where $\mathrm{dem}(x,y)$ represents required wavelength path demands from x to y.

If exists, go to Step. 2. Otherwise, go to Step. 3.

Step 2. Establish Waveband Paths and Primary and Backup Wavelength Paths

If $\mathrm{dem}(s_1,d_1) \ge X_{wb}$, establish two direct disjoint waveband paths connecting s_1 and d_1 by using Suurballe's algorithm [10]. Otherwise, after routing by Dual Hub Routing Algorithm [10, 11] for the selected node pairs $\{(s_1,d_1),(s_2,d_2)\}$, establish waveband paths that form a simple loop as shown in Fig. 3. Accommodate up to W wavelength path demands to each waveband. Go back to Step. 1.

Step 3. Accommodation of Remaining Wavelength Paths

Define a multi-layered graph where each layer is related to a different wavelength. At each layer, add additional links that represent free wavelength channels in existing wavebands. Smaller weight is assigned to these links to encourage the use of existing waveband paths. Next, select some shortest routes as candidates for a working path based on depth first search. Next, remove the edges that share the candidate of the working path from a multi-layered graph with Shared Risk Link Group (SRLG). Finally, apply Dijkstra's algorithm [10] to the multi-layered graph with SRLG to locate the backup path. If placement of working and backup paths fails, find the disjoint shortest paths using Suurballe's algorithm on the graph without additional links. Repeat this procedure until all remaining wavelength paths are accommodated.

4. Numerical Experiments

We assume an NxN (N=5, 7) polygrid network without wavelength conversion. Traffic demands, represented as the average number of wavelength paths between each node pair, were randomly distributed. Each fiber was set to accommodate 64 wavelengths, or 8 wavebands, i.e. each waveband accommodates 8 wavelengths. The network cost was evaluated by a linear function of the number of ports and that of fibers (For detail, see [6]). The cost function also includes a constant that represents control systems and other overheads. For each algorithm, we repeated the network design simulation 20 times for each traffic density while changing the random traffic distribution. The obtained network costs are the average of the 20 runs for each traffic demand. The parameters of the proposed algorithm were selected so as to minimize network costs; $\kappa \in \{1,2,3\}$, $X_{wb} \in \{1,2,\ldots,8\}$. For comparison, we employ the End-to-End scheme that accommodates all wavelength paths in

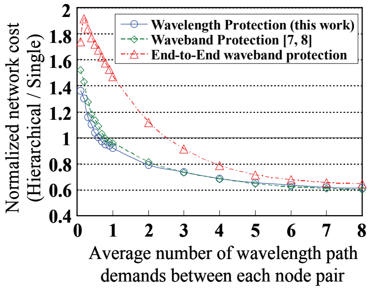

Fig.4. Normalized network costs by single-layer network

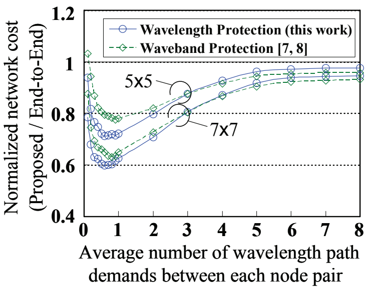

Fig. 5. Normalized network costs by End-to-End scheme

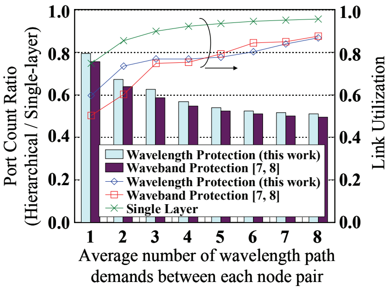

Fig. 6. Port count ratio and Link utilization

waveband paths that directly connect the source and destination nodes of wavelength paths, and a single layer design algorithm based on Suurballe's algorithm to find the shortest disjoint pair of working and backup paths.

Figure 4 shows the network costs so obtained, normalized by the costs of single layer optical path networks simulated by each algorithm for the 7x7 polygrid network. Similar to the previous study, which did not consider protection, the hierarchical networks that employ protection are more cost-effective than single layer networks over a wide range of traffic demands. Among them, the proposed wavelength path protection gives the lowest cost over a wide range. Please note that the wavelength path protection scheme provides node and link disjointness of working and protection wavelength paths from source and destination nodes; whereas, the waveband protection scheme [7, 8] only achieves disjointness with regard each segment of wavebands.

Figure 5 compares the ratios of network costs achieved by the previous algorithm employing waveband protection and the newly proposed algorithm with wavelength protection relative to the costs of the End-to-End waveband protection scheme. It demonstrates that the proposed method with wavelength protection is more cost effective when average traffic demand is not so large. The results also show that the proposed algorithm achieves up to 40% cost reduction compared to the conventional End-to-End waveband protection scheme. Near the traffic demands favorable for waveband, i.e. when the average number of wavelength paths is about 8 (waveband bandwidth), the proposed method with wavelength protection has slightly worse performance than that with waveband protection. This is because wavelength protection assures full disjointness while waveband protection only assures the disjointness within each segment.

Figure 6 shows the ratios of the cross-connect port count which are displayed by bar charts, and link utilization which is displayed by line graphs for the 7x7 network. The single layer networks achieve the best link utilization; hierarchical networks, on the other hand, can greatly reduce port count, by up to 50%. Node cost usually dominates network cost, and so its reduction leads to a substantial total network cost reduction. Our proposed algorithms with waveband protection and that with wavelength path protection achieve high link utilization. It is verified that hierarchical optical path networks are very effective in creating reliable and cost-effective optical networks. The protection scheme will be selected according to the service requirements. If some services do not require optical level protection, only working paths will be established for the services and wavelength path protection will be adopted for the other services, which will reduce total network resource requirements.

5. Conclusion

This paper investigated and clarified the effectiveness of the hierarchical optical path networks that offer waveband or wavelength path protection, in a comparison to conventional single layer optical path networks with protection. It was proved that survivable hierarchical optical path networks are more cost effective than single layer networks with optical path protection for a wide range of traffic demands, regardless of which protection scheme is adopted, waveband or wavelength path. Which protection scheme should be used will be determined by the requirements imposed by the optical layer protection set for accommodated services. This work has resolved one of the key issues preventing the full development of hierarchical optical path networks.

Acknowledgment

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6. Reference

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