Cost Comparisons for Hierarchical and Single-layer Optical Path Networks Considering Waveband and Wavelength Path Protection

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Abstract: This paper, for the first time, investigates and clarifies the effectiveness of the waveband networks that adopt waveband level protection in a comparison with single layer optical path networks with optical path level protection. ©2008 Optical Society of America

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1. Introduction

Wavelength routing using ROADM.s (Reconfigurable Optical Add/Drop Multiplexers) has been recently introduced extensively to develop cost-effective metro networks. WXCs (Wavelength path Cross-Connects) are also widely applied to create testbed networks around the world. Internet traffic is, however, expected to explode in the near future spurred by the penetration of new broadband services including IP-TV and High Definition TV. This will result in a great increase in the number of wavelength paths processed at nodes. The hierarchical optical path networks [1-7] that utilize wavebands (aggregated wavelength paths) have been recognized as an important technology that will prevent the expected cost explosion stemming from optical switch scale increase in optical routing nodes [1-3]. The impact of introducing waveband paths strongly depends on the network design algorithm, which includes the routing and accommodation of wavelength paths within waveband paths, and then within fibers. Even for the single layer optical path networks, the Routing and Wavelength Assignment (RWA) problem is known to be NP complete [8]. In hierarchical optical path network design, we must resolve a harder problem in that we must consider waveband paths and wavelength paths simultaneously. It is, therefore, computationally impossible to obtain the optimal solution for practical scale networks. To resolve this, some heuristic algorithms for hierarchical optical path network design have recently been developed [4,5]. However, almost no design algorithms consider failure survivability, although it is a crucial requirement in developing reliable networks. In [6], the authors proposed a heuristic design algorithm for hierarchical optical path networks that considers protection at the wavelength path level, not the waveband path level. We have so far proposed a novel heuristic design algorithm that incorporates failure survivability with waveband protection [7]. The report merely showed that the algorithm is effective when compared to one that utilizes a simple end-to-end waveband assignment scheme. The effectiveness of the waveband networks that adopt waveband protection was left uncertain. This paper, for the first time, investigates and clarifies the effectiveness of the waveband networks with waveband level protection as compared with networks based on single layer optical paths and optical path level protection. In the following, we first discuss the possible advantages of waveband protection and the constraints raised by waveband protection. The developed algorithm is based on the observation that a pair of primary and backup waveband segments (a portion of a waveband) forms a loop to attain link and node disjoint protection for each segment. We then demonstrate results of numerical experiments that show the network resources required to implement waveband protection and they are compared with those needed for single layer networks. It is finally proved that the waveband networks with waveband protection offer significant cost effectiveness even when traffic is rather small.

2. Hierarchical optical path network design considering waveband protection

We assume the hierarchical optical cross-connect (HOXC) architecture shown in Fig. 1. This architecture enables us to introduce segmented waveband path protection, where each primary waveband path may split into several segments and a backup waveband path is defined for each segmented-path. Switching to backup paths in a case of failure is done only at the BXC (WaveBand Cross-Connect), which significantly reduces the operations needed compared with protection at the wavelength path level. In this paper, we avoid the use of costly wavelength/waveband converters. General objectives of waveband network design are to maximize cost reduction by cut-through of WXC as well as to improve the utilization of waveband paths. Our
This algorithm iterates the following procedures until all demands are satisfied:

1. **End-to-End Scheme**
   - This method establishes a waveband loop that accommodates wavelength paths whose source/destination nodes coincide with those of the loop. We can not aggregate wavelength paths originating from more than three source nodes on the source node loop (S-loop) because the waveband collision occurs on the loop (Fig. 2). The concatenation of waveband loops makes a waveband chain as shown in Fig. 3. The waveband of the intermediate loop aggregates wavelength paths whose source nodes are the two highlighted nodes on the source-loop (S-loop); whereas the destination nodes are the two highlighted nodes on the destination-loop (D-loop). We call a pair of source-loop and destination-loop the S-D loop pair. In this paper, we employ the following design algorithms for hierarchical optical path networks employing dedicated wavelength protection. The End-to-End scheme is a straightforward approach that establishes single waveband loops as depicted below, and will be referred to as the conventional method.

2. **Proposed Design Algorithm**
   - This method first establishes a waveband loop as in the End-to-End scheme for each pair of nodes which has enough wavelength path demands to fill up the capacity of a waveband. Next, for the remaining demands, it constructs waveband chains by locating the S-D loop pairs that have enough demands to fill the intermediate waveband paths. The pairs of the primary and backup waveband routes are computed by Suurballe's algorithm [9].

3. **Single-layer Design Algorithm**
   - This algorithm iterates the following procedures until all demands are accommodated in fibers. First, we evaluate shortest path hops for all demands. Next, for the remaining demands, it constructs waveband chains by locating the S-D loop pairs that have enough demands to fill the intermediate waveband paths. The pairs of the primary and backup waveband routes are computed by Suurballe's algorithm. Finally, the sparsely distributed remaining wavelength paths are accommodated in fibers. The details and effectiveness of the algorithm can not be presented here because of space limitation, and will be reported elsewhere.

**3. Numerical Experiments**

We tested a 9x9 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. The 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 density of traffic while changing the traffic distribution. The obtained network costs are the average of the 20 times for each traffic demand. For details of other parameters, refer to [7].

Fig. 4 shows the network costs of the proposed design algorithm and the End-to-End Scheme. They are
normalized by the costs of single-layer optical path networks calculated using the single-layer design algorithm explained before. The results demonstrate that hierarchical networks with waveband protection are more cost-effective than single layer networks with wavelength path protection for a wide range of traffic demands (where the number of wavelength paths is larger than 0.5). The results also show that the proposed algorithm achieves a 10-45% cost reduction compared to the conventional End-to-End scheme at all traffic demands. It is noted that in the lower traffic demand area, i.e. when the number of wavelength paths is less than 2, the proposed algorithm offers much lower costs than the conventional End-to-End Scheme.

Fig. 5 shows the network costs of hierarchical and single layer optical path networks with or without protection. For waveband network design without protection, we used the design algorithm proposed by Yagyu, et al. [5], which has been shown to be very efficient. It is revealed that reliable hierarchical networks with waveband protection can be realized with a marginal cost increase from single-layer networks without protection.

4. Conclusion
This paper investigated and clarified the effectiveness of the waveband networks that adopt waveband level protection comparing to the networks that are based on single layer optical paths and protection. It was proved that hierarchical optical path networks that adopt the waveband protection scheme are more cost effective than single-layer networks with optical path protection for a wide range of traffic demand. It is noted that the effectiveness of hierarchical optical path networks strongly relies on the proposed algorithm, which was demonstrated by a comparison with conventional end-to-end schemes. It was also revealed that reliable hierarchical networks with waveband protection can be realized with marginal cost increase from single layer networks without protection. This work has eliminated one of the key barriers preventing the full adoption of hierarchical optical path networks.

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5. Reference