

# Impact of Waveband Capacity on Protected Hierarchical Optical Path Networks

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**Abstract:** This paper investigates the impact of waveband capacity on the cost of hierarchical optical path networks with waveband and wavelength path protection. Numerical experiments demonstrate the importance of waveband capacity optimization.

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## 1. Introduction

The penetration of broadband access including ADSL and FTTH is continually raising Internet traffic levels. Further traffic expansion will occur in the near future spurred by the introduction of new broadband services such as high-/ultrahigh- definition TV and e-Science. This will result in a significant increase in the number of wavelength paths processed at each node, which enlarge the scale and complexity of optical switches [1]. The hierarchical optical path networks that utilize wavebands, each consisting of multiple wavelength paths, have been investigated as an important technology to resolve this problem [1-4]. Waveband routing has been shown to reduce the total switch size and, as a result, the cost of optical cross connects [1, 2]. The effect of introducing waveband paths, however, strongly depends on the network design algorithm.

Network survivability is another important requirement to be satisfied for practical use. We recently developed two heuristic network design algorithms that can create reliable hierarchical optical path networks. One adopts dedicated protection in the waveband path layer [5], and the other utilizes dedicated protection in the wavelength path layer [6]. Both algorithms efficiently solve the routing and waveband/wavelength assignment problem that is computationally more intensive than the corresponding problems in single layer optical path networks, which are known to be NP complete [7]. The algorithms attain significant improvements, about 5-40% cost reduction, over the simple End-to-End scheme that accommodates all wavelength paths to waveband paths that directly connect source and destination nodes of wavelength paths. They also achieve almost 40% cost reduction compared to single layer optical path networks with wavelength path protection [6]. However, the effectiveness of those algorithms varies with the waveband capacity, the number of wavelength paths per waveband, which is one of the important network parameters. Since network costs heavily depend on this network parameters, we need to investigate the impact of its values in detail. This paper investigates how waveband capacity impacts network cost. Some different network design algorithms are considered and numerical evaluations are presented. We demonstrate that the waveband capacity should be large if we are to attain a certain level of cost reduction.

## 2. Network Model and Protection Mechanisms for Hierarchical Optical Path Network

We assume the Hierarchical Optical Cross-Connect (HOXC) architecture which consists of wavelength cross-connects and waveband cross-connects that do not use costly wavelength/waveband converters. To create survivable hierarchical optical path networks, two mechanisms for dedicated protection in the optical layer are identified. The characteristics of the two protection mechanisms are summarized below.

### (A) Waveband Protection

Switching operation is conducted in the waveband layer and processed at the WaveBand Cross-Connect. This mechanism minimizes required switching operations and signaling related overhead because of the coarse granularity used in recovery. Another advantage is that the network design problem is relatively simple. Besides, we can introduce the segmented waveband path protection scheme [6]. In this scheme, each primary waveband path may be split into several segments and a link and node disjoint backup waveband path is defined for each segmented path.

### (B) Wavelength Path Protection

Switching is performed in the wavelength layer, that is, with wavelength granularity. The wavelength path protection scheme will reduce network resource requirements more because its finer switching granularity offers higher waveband utilization efficiency. This scheme is especially effective when there are different requirements for optical layer protection; i.e. when two types of optical paths 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 not need optical layer protection. The waveband protection scheme automatically reserves working and backup resources simultaneously.

The objective of network design subject to a fixed traffic demand is to minimize network resource requirements as well as to provide the survivability demanded. We have so far proposed efficient network design algorithms that achieve these objectives simultaneously for both protection mechanisms. Numerical experiments in [6] reveal that the two algorithms attain up to 40% cost reduction over conventional single layer networks for

a  $7 \times 7$  regular mesh network and a fixed waveband capacity (8 wavelengths per waveband). These results are not shown here due to the space limits.

### 3. Numerical Results

We employ a COST266 pan-European network in the numerical evaluation [8]. Traffic demands are randomly distributed and represented as the average number of wavelength paths between each node pair. Each fiber is set to accommodate 64 wavelengths, and waveband capacity is denoted as  $W$ . For comparison, we employ a single layer design algorithm based on Suurballe's algorithm to find the shortest disjoint pair of working and backup paths [9]. The network cost is evaluated by a linear function of the number of cross-connect switch ports and that of fibers. 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 the patterns of traffic distribution were randomly changed. The obtained network costs are the average of the 20 results, and normalized by those of single layer optical path networks.

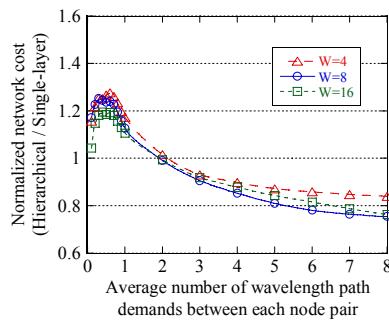


Fig. 1. Wavelength path protection algorithm

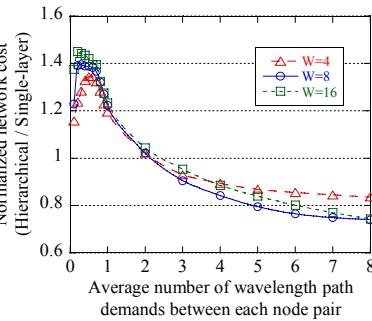


Fig. 2. Waveband protection algorithm

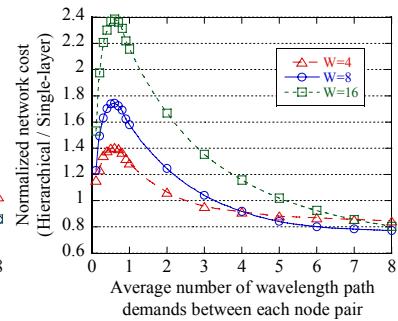


Fig. 3. End-to-End algorithm

Figures 1, 2 and 3 show the ratios of total network costs with different values of waveband capacity ( $W = 4, 8, 16$ ), obtained by applying the wavelength path protection algorithm, the waveband protection algorithm and the End-to-End algorithm, respectively. Both of the proposed algorithms (Fig. 1 and Fig. 2) reduce the cost differences among different waveband capacities, especially in the small demand area. This is due to their efficient path accommodation capability. Note that the wavelength path protection algorithm achieves the best performance in this area, because it attains higher link utilization than the waveband protection algorithm. In Figs. 1 and 2, the small waveband capacity ( $W = 4$ ) reduces network cost only slightly when traffic demand is large, because fewer ports can be eliminated. When the demand is larger than 3,  $W = 8$  achieves the minimum cost ratio since it achieves a large port count reduction and the smaller link cost than with  $W = 16$ . These results demonstrate that the waveband capacity does impact network costs for all design algorithms, however, the characteristics depend on the algorithm. When we use very efficient design algorithms as shown in Figs. 1 and 2, the impact is apparent where the traffic demands are large. On the other hand, when the algorithm is less effective (Fig. 3), the impact is enhanced at the small traffic region.

### 4. Conclusion

This paper investigated the network costs when the waveband capacity, one of the important network parameters, is changed. Numerical experiments revealed that the waveband capacity has a significant impact on network costs when the traffic demand is large if efficient design algorithms are utilized. It is important to determine the best waveband capacity for minimizing the total network cost.

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