Evaluations on Physical and Optical Path Level Hierarchical Networks to Implement Optical Fast Circuit Switching

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Abstract: We propose an efficient network architecture to implement optical fast circuit switching. To effectively manage dynamic path operations, we introduce a hierarchical structure consisting of physical network level and optical path level. Numerical experiments show that the proposed hierarchical network greatly reduces the necessary number of switch ports.

1 Introduction

The rapid penetration of broadband access is driving an explosive increase in backbone traffic all over the world. In order to cope with this large increase in traffic demand, ROADM-based photonic networks, in which optical signals are routed without O/E and E/O conversion, are being introduced. In the next stage, new generation services such as Ultra High Definition TV (raw bit rate of 72 Gbps) and optical VPNs which require not only huge bandwidth but also dynamic path operation capability, will emerge. Hence we must develop an efficient network architecture that is suitable for transporting less-bursty but quality-demanding high bit rate real or near real-time services. Optical fast circuit switching (OCS) technology will play a key role [1, 2]. Since OCS needs to dynamically operate a large number of optical paths (path and circuit is used interchangeably in this paper), a sophisticated architecture is necessary to reduce the operation, administration and maintenance (OA&M) costs. On the other hand, for the static optical path network design problem, where fixed optical paths are established for a given traffic demand, it has been demonstrated that switching at the waveband granularity level, groups of wavelength paths, can significantly reduce network cost [3]. However, the hierarchical optical path structure that consists of wavelength/waveband paths has not been considered for developing dynamic optical path networks so far.

In this paper, we propose a novel hierarchical network-architecture for OCS and discuss its impact on network facilities and path operation cost. The proposed network also adopts a physically hierarchical network architecture that consists of several local networks in a lower layer and a higher layer transit network connecting the local networks. In the higher layer network, waveband paths are adaptively established/removed to provide virtual mesh connectivity between local networks so as to efficiently carry wavelength paths that traverse multiple local networks. Numerical experiments revealed that the proposed hierarchical network architecture achieves the reduction of network resources as well as the number of path operations.

2 Hierarchical Network Architecture for Efficient Optical Fast Circuit Switching

2.1 Network Architecture

In this paper, we propose the network architecture shown in Fig.1. This architecture is hierarchical in two aspects; one is in topology and the other is in path granularity. The topological hierarchy means that the network consists of several local networks in the lower layer and the local networks are connected using a higher layer transit network. Each local network has a special node named the center node and two local networks are connected via their center nodes. The hierarchy in optical path granularity means that a wavelength path and a waveband path are used; the waveband is utilized here in the higher layer transit network. Since the transit network carries a large number of optical paths connecting nodes in different local networks, the introduction of larger switching granularity significantly reduces cost. The waveband path connections between central node pairs logically provide a direct optical path mesh connection between all central nodes, and therefore, they simplify connection/disconnection operation of optical wavelength paths. No wavelength/waveband conversions are utilized in this network except for wavelength conversion at the local center nodes for transit paths that connect two local networks. The wavelength conversion emphasizes the independent operation capability between higher/lower layer physical networks and simplifies their OA&M.

2.2 Dynamic Hierarchical Path Operation

We assume that wavelength paths are established /released dynamically in response to connection requests. If source and destination nodes of a given connection request belong to the same segment, a wavelength path is established in the local network if available. If they belong to different segments, we first establish a wavelength path between the source(/destination) node and the center node in each segment. Next, we try to set a wavelength path in the higher layer that connects the center nodes. If there

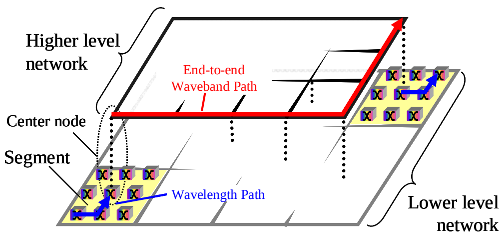

Fig. 1 Hierarchical network model

exists a waveband path with spare capacity that directly connects the two center nodes, the wavelength path is accommodated within the waveband path. Otherwise, a direct waveband path routed on one of the shortest paths is newly established. Wavelength path connections are released when they become unnecessary. If some waveband paths become empty after the path removal, they are also deleted.

3 Numerical Experiment

We assumed the following parameters in evaluating the efficiency of the proposed hierarchical network.

- Physical network topology: NxN polygrid network (N=6, 9, 12, 15) equally divided into 3x3 square local segment networks.
- Capacity of waveband, W, is set at 10 or 20 wavelengths per waveband, and each fiber accommodates 100 wavelengths paths (i.e. 100/W wavebands per fiber).
- Traffic demand: uniformly distributed among node pairs and generated between each node pair following a Poisson distribution with D [erl] (D=1, 2, 3, 4, 5). The connection holding time follows a negative exponential distribution whose average is the unit time length.

The number of fibers on each link of hierarchical/single-layer networks is pre-determined through a static network design [4] for a uniform traffic pattern where the traffic volume between each node pair, D, is changed. Figure 2 compares the required network resources, optical switch port and fiber counts, given by the initial design for different values of D, which are normalized by those required for conventional networks, i.e. single layer networks in terms of both physical and optical path level. It is shown that, at all traffic volumes, the proposed hierarchical network needs approximately 30% more fiber. This is mainly because some connections require longer end-to-end paths to be accommodated within the physically hierarchy. On the other hand, the proposed network can reduce the number of costly optical switch ports by almost 60%. Using the networks designed above, we evaluated network performance against dynamic operation of wavelength/waveband paths. At each average traffic volume, traffic demand patterns were changed on the above conditions and blocking probability was measured as shown in Fig. 3 for the single-layer and proposed hierarchical networks. Figure 3 demonstrates that almost equivalent blocking probabilities are achieved by the proposed and single-layer networks. Next, we compared the facility/operation costs of these networks where network scales were changed. Please note that as shown in Fig. 3, the blocking probability was set to be constant, 0.01, in all cases. The red/blue lines in Fig. 4 show network costs determined from Fig. 2 by using the cost values in [3]. The green line in Fig. 4 stands for the average number of nodes whose optical switches are involved in path set-up/release operation on each connection set-up/release request. The results demonstrate that the degree of performance improvement attained by the proposed architecture is enhanced as the network scale expands and the traffic volume increases.

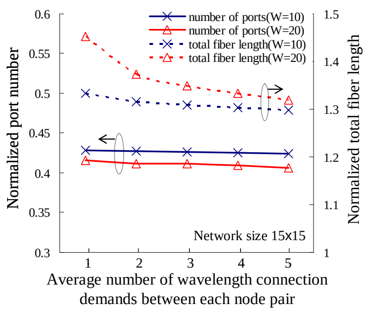

Fig. 2 Comparison of port number and total fiber length

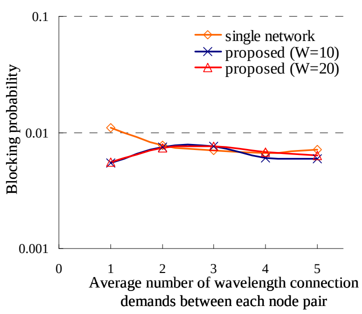

Fig. 3 Blocking probability

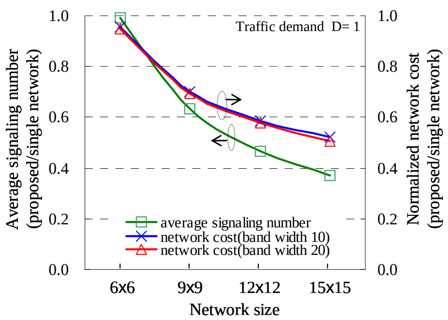

Fig. 4 Cost comparison with single network

4 Conclusion

We proposed a hierarchical network architecture in terms of both physical and optical path level to develop a fast efficient optical circuit switching network for the future. The effectiveness of the proposed architecture was confirmed through numerical evaluations.

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