Technical Report

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TR 00-021

On Protecting Link Failure of Wavelength Routed Mesh Network

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March 24, 2000

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Abstract

The Dense Wavelength Division Multiplexing (DWDM) is the most cost-effective way to upgrade the optical links to the wavelength-routed optical network, while each link can carry a certain number of wavelengths. The mesh is recognized as the topology to serve the optical networks since it has higher reliability and requires lower spare bandwidth. To decide whether a wavelength-routed mesh network with W wavelengths can support a set of requests has been shown to be NP complete. To consider re-routing the requests on the single link failure makes the problem even harder. This paper proposes polynomial-time approximation algorithms for this problem. The performance ratio of the approximation is also being analyzed.

Keywords: Fault tolerant Approximation algorithms, WDM optical networks.

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1 Introduction

With the enormous increasing demands for the bandwidth, the backbone SONET network needs to be upgraded to all optical WDM network. The Wavelength-Division Multiplexing (WDM) can utilize the tremendous bandwidth of optical fiber by dividing the bandwidth into many non-overlapping wavelength channels. In a WDM network, each routing node could switch the input data based on their wavelength, which is referred as wavelength routing. Some routing nodes are attached to access stations where data from several end-users could be multiplexed on to a single WDM channel. Using Add and Drop Multiplexier, an access node source and sink the certain wavelength signals to the fiber. Although optical wavelength converter already exists in the lab, the real use of such device is many years away, which means that one wavelength cannot translated to a different wavelength without optical/Electronic (O/E) conversions. Consequently, the intermediate routing node should not convert the input wavelength to another output wavelength.

Dense Wavelength-Division Multiplexing (DWDM) is the technology used to gradually evolving the existing packet-routed SONET rings to the wavelength routed all optical meshes. While embedding the original SONET packet streams into one wavelength channel, the DWDM switch can increase the bandwidth capacity by introducing more than one wavelength channel. By connecting to the wavelength switches, the SONET rings topology can be upgraded to meshes.

Because the O/E and E/O overhead is so high comparing to the signal propagation and switching themselves, the conversion is normally prohibited in the intermediate nodes. This constraint requires us to allocate a common wavelength to the fiber links along one end-to-end connection from the source station to the destination. Such an all-optical path is referred to as a lightpath or a clear channel. The entire bandwidth available on this lightpath is allocated to the connection during its holding time during which the corresponding wavelength cannot be allocated to any other connection. When a connection is terminated, the associated lightpath is torn down and the wavelength is released on all of the links along the route. The routing and wavelength assignment (RWA) problem is defined as follows. Given a network topology, a set of end-to-end lightpath requests, determine a route and

wavelength(s) for the requests, using the minimum possible number of wavelengths. When designing and deploying the DWDM technology, we know that the number of the wavelengths is normally fixed while we are trying to maximize the utilization of the wavelengths. In this case, we have a similar problem of RWA, the maximal throughput problem (MTP). Instead of try to minimize the number of wavelength with fixed set of request, MTP problem try to maximize the number of requests in the given set of requests with fixed number of wavelength.

The optical networks are high-speed, high capacity systems that handle many types of user data services. These systems can transport vast amounts of information. A failure of a network component can lead to severe disruption in the network, so the fault recovery is the first order consideration when designing the WDM network. The failures can be categorized to link failures and node failures. The link failure lead to the failure of all the lightpaths that traverse that link, while the node failure disconnects any lightpaths through that node. Comparing the node failure, the link failure is more common. There are several ways to protect the link failure. One protection scheme is using multiple fibers to set up the physical back-up links. The other approach is to reserve spare bandwidth or wavelength when establishing lightpath.

The mesh topology has been considered more reliable than chain, ring and tree topologies for optical networks, while the RWA problem and the fault tolerant design for the mesh network are much more complicated than the ring and tree.

The remaining of the paper is organized as following. Section 3 introduces previous related results. In Section 3, we give a approximation algorithm and do the performance analysis. Section 4 concludes the paper with discussion of the contributions and the related problems.

2 Previous work

The RWA problem is same as the minimum path coloring problem (MPCP). The MPCP problem can be reduce to the well-known maximal disjoint path problem (MDPP). In [2], the author gives a sub-logarithmic bounds for MPCP. In [3], the authors show the reduction

of the MTP problem to MDPP problem and research the approximations for ring, tree, mesh and other general topologies. In this paper, we only consider the MTP problem.

We are trying to consider the fault recovery schemes while solving the MTP problem. The two existing approaches to address link failure survivability are link restoration and path restoration. In link restoration, each connection that goes through the failed link is rerouted between the two end nodes of the failed link. In path restoration, each connection that goes through the failed link is reconfigure to different route that excludes the failed link. [4] gives the reasons that the path restoration is preferable over link restoration. There are also two schemes to preserve the wavelength: (a) One-on-one protection, and (b) multiplexed-spare-capacity. One-on-one scheme reserves a backup lightpath for every lightpath that needs to be protected against link failures. The multiplexed-spare-capacity scheme shares the spare wavelength with a set of requests. This paper considers the path restoration approach with the multiplexed-spare-capacity scheme.

The design of a survivable optical network has been studied in papers [4] [6] [7] [5] [8]. In [6], the authors proposed physical protection schemes based on one-on-one protection. The work in [7] considers fault-tolerant design of optical ring networks. In [5], the authors propose an automatic proction switching (APS)scheme that protects optical mesh networks from link and node failures using multiple fibers. In, the authors propose analytical methods to estimate capacity utilization in optical networks that are resilient against single link failures. (Barry's paper in Infocomm)

3 Approximation Algorithm

Our problem is the modified MTP problem with the fault tolerant consideration of the single link failure. We call this problem FTMTP, which is defined as follows. For the mesh network, given a set of end-to-end lightpath requests and W wavelengths, find the maximal subset of the requests, and determine the route and wavelength assignment for the selected requests. If a request is selected and routed, a link disjoint spare path must also be preserved and routed.

Our algorithm based on Kleinberg's MDPP approximation algorithm [1] and Wan's

1. Algorithm for FTMTP
2. **for** $i = 1$ to W step 2 do
3. **begin**
4. Run Kleinberg's algorithm on R and output an independent subset Ai of Ri and the path set Pi
5. Assign wavelength i to requests in Ai
6. Calculate an disjoint path for each path in Pi and output to Pi'
7. Reserve wavelength $i + 1$ for Pi'
8. R=R - Ai;
9. if R==0 exit
10. **end.**

Figure 1: Algorithm 1.

greedy MTP algorithm [3]. Kleinberg and Tardos [1] give a constant-factor randomized approximation algorithm for the MDPP in a broader class of graphs called uniformly *densely embedded Euclidean graphs*, which includes two-dimensional mesh and many other planar graphs. Wan and Liu [3] reduce the MTP problem to the MDPP problem and propose a greedy algorithm to solve the MTP problem, which utilizes Kleinberg's approximation algorithm.

With the observation that if a sub set of the requests can be routed with disjoint path, this set of requests can share the backup wavelength, since we assume there is at most single failure occurs. Our algorithm utilizes Wan's algorithm, while reserve the spare wavelength for each maximal disjoint-path set (See Figure 1). In each iteration, we try to approximate the maximal disjoint-path problem to output an independent subset of requests. We then assign two wavelengths to this set of requests, one for normal traffic and the other for the spare. We assumed that the available number of wavelength is an even number, which is normally true in most wave systems.

Theorem 1 *The Algorithm 1 is a constant-factor approximation algorithm for the FTMTP*

problem in wavelength-routed optical mesh network.

Wan[3] shows that his greedy MTP algorithm is a constant-factor approximation algorithm. Our algorithm differs from Wan's algorithm only by preserving half the wavelengths for the spare lightpath. Therefore, the performance ratio of Algorithm 1 is one time worse than [3]'s algorithm, while it remains as a constant factor.

4 Conclusion

Optical networks based on WDM technology can potentially transfer Gbps to Tbps data on each fiber link in the network. However, the high bandwidths carried by links have the drawback that a link can potentially lead to the loss of a large amount of data.

This paper proposes a polynomial time constant-factor approximation algorithm for the FTMTP problem. However, half of the wavelengths is reserved for the spare light path, which means that the best bandwidth utilization is 50%. Some simulations [4] show that the bandwidth utilization could be as high as 70%. It is an open problem to find other approximation schemes that provide better bandwidth utilization.

This paper only deals with the pre-calculation of the restoration path and it assumes that the WDM network should have its optical layer to discover the fault conditions and to switch the failed lightpaths to the spared ones.

Aknowledgement

Authors wish to thank Peng-Jun Wan for his inspiring thought.

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