Available online at www.sciencedirect.com
ScienceDirect
Computer Communications 29 (2006) 3197–3213
computer communications
www.elsevier.com/locate/comcom

A heuristic algorithm for shared segment protection in mesh WDM networks with limited backup path/segments length

Hongbin Luo *, Hongfang Yu, Lemin Li

Key Lab of Broadband Optical Transmission and Communication Networks University of Electronic Science and Technology of China, Chengdu 610054, China

Received 25 May 2005; received in revised form 19 April 2006; accepted 27 April 2006
Available online 24 May 2006

Abstract

This paper investigates the problem of dynamic survivable lightpath provisioning against single-link failure in optical mesh networks employing wavelength-division multiplexing (WDM). We focus on the special problem of provisioning lightpath requests according to their differentiated protection-switching time, since lightpath may have different protection-switching time requirements. We assume that the protection-switching time requirements of connections can be transformed to the hop limits of backup path/segments by using techniques proposed in the literature such as [Y. Luo, N. Ansari, Survivable GMPLS networks with QoS guarantees, IEE Proc. Commun., vol. 152, (4) (2005) 427–431]. We propose a heuristic algorithm, namely Suurballe-based Heuristic Algorithm using Least number of segments for SSP with hop Limit (SHALL), to efficiently solve this problem. We inspect the effects of hop limit on various performance matrices and compare the SHALL approach with three other well-known protection approaches, namely shared path protection (SPP), shared link based protection (LBP) and cascaded diverse routing (CDR). Numerical results demonstrate that the SHALL approach outperforms its counterparts in blocking probability and protection-switching time with mirror decrease of spare capacity efficiency.

Keywords: Wavelength division multiplexing (WDM); Quality-of-Service (QoS); Survivability; Routing algorithms; Shared segment protection; Protection-switching time

1. Introduction

Wavelength-routed wavelength division multiplexing (WDM) networks have been considered to be a promising network infrastructure for future backbone transport networks. In such networks, each fiber link offers huge bandwidth capacity to carry user traffic. A single network failure may cause a large amount of data loss in the network, which would largely degrade network performance and even disrupt network services. Thus network survivability is of great importance in such networks. To guarantee network services, the network must incorporate effective protection and restoration capabilities to survive different kinds of network failures (e.g., a fiber cut or a node fault). Although the higher layers (e.g., IP, ATM and SONET) may provide their own protection and restoration mechanisms, it is still attractive to provide protection and restoration capabilities at the optical layer because of a number of advantages, such as fast service recovery, efficient resource utilization, and protocol transparency.

Survivability is the ability of the network to withstand equipment and link failures. The main goals of survivable network design are to be able to perform rapid restoration at as small a cost as possible (i.e., using minimum resources). Node equipment failures are typically handled using redundant equipment within the node (including redundant switches). On the other hand, link failures, which are by far the most common failures in optical networks, occur due to backbone accidents. In this paper, we restrict ourselves to the case of link failures.

At the same time, there is an increasing importance for service providers to provide guaranteed service in recent

* Corresponding author. Tel.: +86 28 83201113; fax: +86 28 832001113.
E-mail addresses: luohb@uestc.edu.cn (H. Luo), yuhf@uestc.edu.cn (H. Yu), lml@uestc.edu.cn (L. Li).

0140-3664/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.comcom.2006.04.017

years. This entails that survivable routing schemes should not only be both capacity- and computational-efficient, but also minimize the possible restoration time for a specific connection, such that the maximum benefits can be gained in the operation of carrier networks [15].

Segment shared protection (SSP) [1–14] is one of the best approaches to meet the above design requirements, where a working path is divided into a set of possible overlapping active segments (AS), and provide protection for some or all of the links along each AS using a backup segment (BS), which is link/node-disjoint with the AS. Comparing with its counterpart-shared path protection (SPP) [15–21], SSP has been reported to achieve a better throughput by maximizing the extent of spare capacity resource sharing.

In this paper, we investigate the problem of how to efficiently derive backup segments with limited hop length for a given working path in a dynamic network environment, where connection requests arrive dynamically one after another. In the following, we present the art of state of SSP and motivate our study.

1.1. Literature review

Much work on SSP has been conducted in optical WDM networks. In [1] and [4], two similar dynamic algorithms are proposed for each link to switchover from its immediate upstream neighbor node and to merge back to the original path at the immediate downstream node and any of the downstream nodes, respectively. However, both of the studies do not impose any limitation on the length of the backup paths, and may not be able to guarantee the restoration time when a failure occurs. It is notable that the lengthy backup paths can degrade overall performance even if they share spare capacity with the other backup paths [3]. In [14], an algorithm is developed to find the working path first followed by its backup path segments. This study is characterized by the fact that the backup bandwidth sharing is not considered until the physical routes of the backup segments are defined, which may impair the total performance. The study in [5] provides an algorithm for computing QoS paths with restoration, which is characterized by considering multiple-link metrics in searching the working and protection segments. This study does not consider resource sharing and has adopted exhaustive searching for those backup segments for the working path. The study in [6] proposes an integer linear program ILP for performing SSP according to the working path given in advance. The algorithm is characterized by the fact that it has to inspect all the possible allocations for self-healing loops along the working path and iteratively try all the possible number of self-healing loops. The studies in [7,8] take a very similar approach to that in [6]. The algorithm finds a backup path segment for each link along the working path given in advance, in which a ''backtrack'' by hops is allowed, where can be an arbitrary positive integer or infinity. In [9], a novel approach is proposed for segment protection that makes use of a modified graph for facilitating the searching of the backup segments. This study, however, does not consider spare resource sharing, and may not be able to take advantages of the effort of segmenting the primary path. In [10], a simulation-based study is conducted to investigate the performance of path, sub-path, and link restoration. The same as that in [9], the study does not consider resource sharing, and does not clearly define the adopted survivable routing approach. It is notable that all of the above schemes deal with segment protection by having not considered the backup segment length constraint, or even attempt to deal with it. In [11], a framework known as short leap shared protection (SLSP) is proposed, which implements SSP by pre-assigning a series of switching/merging node pairs along a given working path. In [6] and [11], a dynamic survivable routing algorithm called cascaded diverse routing (CDR) is proposed. To improve the flexibility and performance in finding the link-disjoint working and protection path-pair in each self-healing loop, k-shortest paths ranking between switching and merging nodes of each self-healing loop is performed. CDR is reported to outperform the path shared protection solutions. However, due to the fact that the location of switching/merging nodes for each working path are predefined instead of dynamically computed, there exist opportunities for further improvement. In [12], a scheme is devised to partition the network into multiple sub-networks such that the protection is performed within each sub-network domain. Although better computation efficiency can be achieved, the scheme may fall short of being less dynamic to the traffic distribution variation. At last, an ILP is formulated in [13] to solve the working and protection path segments for a connection request in a single step. Although the optimal solution (least-cost) with the best resource sharing can be derived, the resultant huge computation complexity in solving the ILP avoids the approach from any practical application.

1.2. Motivation

As quality-of-service (QoS) getting more and more important, some lightpath requests may have differentiated protection-switching-time (PST) requirements. For example, lightpaths carrying voice traffic may require 50 ms PST while lightpaths carrying data traffic may have a wide range of PST requirements [24]. It is notable that, in shared protection, the PST required to restore a connection upon a link failure is mainly determined by the hop length of the backup path/segment. This is because, in order to restore a connection, one has to configure the cross-connects along the backup path/segment, which often consume a time greatly longer than the failure notification time [24]. Thus, we in this paper assume that the PST requirements of connections can be transformed to hop limits of backup path/segments by using techniques proposed in the literature such as [23]. Note that, although we focus on limiting the hop length of backup path/segments, the SHALL approach proposed in this paper can be easily extended to the case that the total hop length