Chapter XXVII
Optical Network Survivability

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INTRODUCTION

The telecommunications world is evolving dramatically toward challenging scenarios where the fast and efficient transportation of information is becoming a key element in today's society. Wavelength division multiplexing (WDM) technology has the potential to satisfy the ever-increasing bandwidth needs of the network users on a sustained basis (Mukherjee, 2000).

Network operators must provide uninterrupted service to their customers, that is, network survivability must be guaranteed. This means that networks must be able to handle link or fiber cuts as well as equipment failures, fact that influences the design and operation of networks (Gerstel & Ramaswami, 2000). When using WDM, survivability becomes even more important because of the huge amount of traffic carried by a single fiber. A single fiber failure, even for few seconds, can be catastrophic (Maier, Pattavina, Patre, & Martinelli, 2002). This issue is actually very important since the optical WDM technology is now being deployed in the field. Network survivability is not just an academic subject. In real networks, failures happen quite frequently (fiber cuts, for example, are very common in terrestrial networks since they share other utility transport conduits such as gas or water pipes and electrical cables, and are considered the least reliable component (Gerstel et al., 2000; Maier et al., 2002). The prevention of service interruption, or the reduction of the service loss when failures occur, must now be an integral part of the network design and operations strategy or otherwise severe service losses can happen.

BACKGROUND

For an easier implementation of optical transport network (OTN) functions, the optical layer has been divided into three sublayers according to the recommendation G.872 of the International Telecommunication Union-Telecommunication Standardization Sector (ITU-T) component (ITU-

T Recommendation G. 872, 1999; Gerstel et al., 2000; Maier et al., 2002):

- **Optical channel (OCh):** The managed entity is the lightpath. It takes care of all the end-to-end networking functions such as routing and wavelength assignment, connectivity check, and failure management. Its functions are done at the end-to-end lightpath terminations.
- **Optical multiplex section (OMS):** The managed entity is the multiplex of all the wavelength channels, that is, provides functionality for networking of an aggregate optical signal with multiple wavelengths. Basically, it performs WDM multiplex monitoring. Its functions are done at the link terminations.
- **Optical transmission section (OTS):** The managed entity is the multiplex of all the wavelength channels, as in the OMS, but it manages and supervises optical transmissions devices, such as amplifiers and repeaters, inserted in links. Therefore, it provides functionality for transmitting aggregate optical signals.

Network protection and restoration can be performed by the OCh or OMS sublayers. Schemes at the OCh sublayer protect individual lightpaths while schemes at the OMS sublayer protect all wavelength channels in a link as a group (Gerstel et al., 2000; Mohan & Murthy, 2000).

Besides the link failures, node and channel failures can also occur in a WDM network. A node failure is due to equipment failure at network nodes while a channel failure is due to the failure of transmitting and/or receiving equipment operating at some wavelength. The probability of such failures is much smaller, when compared to link failures, due to the built-in redundancy of most equipment. Besides being more common, link failures have a very high impact on service loss due to the simultaneous failure of several wavelength channels. Therefore, focus will be given to link failures. For more details on node failures, see Wang, Cheng, and Mukherjee (2003).

In non-WDM systems, the protected entity is the link. In WDM systems, due to the availability of multiple wavelength channels in a fiber, the survivability schemes can be more flexible. Either the link (fiber) or the lightpath (wavelength) can be the protected entity at the optical layer. This basically has to do with the sublayer of the WDM layer in which a given survivability mechanism operates. Since more multiplexing/demultiplexing and per-channel switching equipment is necessary for OCh protection, one could think that OCh protection is more expensive than OMS protection. However, this is not true if not all wavelength channels need protection. In this case, OCh protection utilizes capacity more efficiently than OMS protection and a benefit exists on the number of fibers necessary to provide protection. Since future networks tend to be flexible, providing lightpaths automatically as necessary with a variety of protection levels, and as equipment cost decreases, OCh protection seems to be the choice. For these reasons the focus will be on OCh protection. For more references on OMS protection see Maier et al. (2002).

LIGHTPATH SURVIVABILITY TECHNIQUES

The lightpath survivability techniques used in WDM networks can be broadly classified into protection and restoration (the terms proactive and reactive have also been used) (Mohan, Murthy & Somani, 2001; Sridharan, Salapaka, & Somani, 2002). Protection refers to the fact that recovery from network failures is based on preplanned schemes and uses dedicated resources. These resources are reserved for recovery from failures at either connection setup or network design time,