Chapter 9
Robust Design and Management of Optical Networks: Incorporating Availability-Awareness

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ABSTRACT
High capacity advantage of optical networks also introduces the risk of huge data loss in case of a service interruption, even if the outage lasts a short time. Therefore, survivable and reliable design and management of optical networks is urgent. However, deployment of efficient survivability policies does not always guarantee the continuity of the service. Long failure restoration delays, multiple failures, and lack of protection resources may lead to service unavailability. Hence, connection availability arises as a design constraint, and it is defined as the probability of a connection being in the operating state at any time. Availability-constrained optical network design and availability-constrained connection provisioning are two important problems to guarantee robustness of connections in a survivable network.

INTRODUCTION
As a result of the increasing bandwidth demand of the Internet applications, optical networking seems to be a strong candidate for the long haul communication. This great advantage of optical networks also introduces the risk of huge data loss in case of a service interruption even though the outage lasts short. Therefore survivable and reliable design and management of optical networks is urgent (Mouftah and Ho, 2003). Various survivability schemes have been proposed to avoid data loss in case of a failure.
Survivability schemes can basically be grouped in three main categories, i.e., ring protection, span protection and path protection. These survivability policies introduce the trade-off between restoration delay and resource redundancy which have also been widely studied in the literature. Existing survivability policies are derived from these categories, and these policies usually attempt to find a compromise for this trade-off. For instance, segment protection is a hybrid of span protection and path protection where failure detection delay is close to that of link protection, and backup redundancy is close to path protection (Krishna et al., 2000). Similarly, as another hybrid survivability scheme, pre-configured cycle (p-cycle) protection provides path/link protection-like backup resource consumption and ring protection-like restoration efficiency (Stamatelakis and Grover, 2000).

Figure 1 illustrates the survivability schemes that fall in the scope of this chapter. Figure 1.a illustrates the Dedicated Path Protection (DPP) scheme for two connections simply assuming that node failures are negligible. The connection from N1 to N7 uses the working path passing through the nodes, N1-N3-N5-N7 on the wavelength channel $\lambda_1$, while the connection from N2 to N7 has the working path passing through the nodes, N2-N4-N6-N7 on the wavelength channel $\lambda_2$. The former connection uses the backup path N1-N4-N6-N7 on the wavelength channel $\lambda_1$, while the latter uses the backup path N2-N1-N4-N5-N7 on the wavelength channel $\lambda_2$. Thus, on the common link N1-N4, backup channels of the connection from N1 to N7 are not shared with the connection from N2 to N7.

Figure 1.b illustrates a Shared Backup Path Protection (SBPP) scenario for two connections. The connection from N1 to N7 switches to its backup path following the route N1-N4-N6-N7 on wavelength $\lambda_2$ in case of a failure on its working path. The connection from N2 to N7 switches to its backup path following the route N2-N1-N4-N5-N7 on wavelength channel $\lambda_2$. Thus, the two connections share the backup channel $\lambda_2$ on the link N1-N4 which will lead to unavailability of either of the connections in case of such a dual failure. Ramamurthy et al. presented a comprehensive discussion on the advantages and disadvantages of DPP and SBPP (Ramamurthy et al., 2003).

Figure 1.c illustrates a segment protection scenario which was presented by Krishna et al. (Krishna et al., 2000). Primary path of the connection follows the path formed by the links between the following nodes: Source-N1-N2-N3-N4-N5-N6-N7-Destination, and it is protected by three overlapping backup segments. In the illustrated scenario, the link between the nodes N3 and N4 fails. Following the failure, the connection does not immediately switch to the backup resources but it forwards the traffic on a short segment of the working path from Source to N2. At node N2, the connection switches to the backup segment starting at N2 and ending at N6. At node N6, the connection switches to the working path again and routes the traffic to the Destination node. In order to keep it simple, shared segment protection is not illustrated in the figure however, shared segment protection stands for the overlapping segment protection type where the backup resources on the backup segments are being shared by the connections.

Figure 1.d illustrates a Pre-configured Protection Cycle (P-Cycle). In the figure, the bold lines denote the on-cycle links which form the main protection ring while the dashed lines represent the straddling links which can be protected by either half of the protection cycle in case of a failure. Thus, a p-cycle protects the links on the protection ring and further protects the off-cycle links whose both ends lie on the cycle. P-cycles offer mesh-like spare capacity and ring-like restoration time efficiency as stated by Stamatelakis and Grover (Stamatelakis and Grover, 2000).

Deployment of efficient survivability policies does not guarantee the continuity of the service. Therefore connection availability arises as a design constraint, and it is defined as the probability of
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