Chapter 2
Literature Survey

2.1 Introduction

This book contributes algorithms and schemes in the area of wavelength division multiplexing (WDM) based optical networks. In this context, this chapter provides a comprehensive survey on various works done in the field of routing and wavelength assignment, recovery techniques for handling faults in WDM based optical networks. This survey will provide a strong foundation to appreciate the different schemes developed throughout this book. The rest of this chapter is organized as follows. Section 2.2 discusses about the lightpath establishment problems in optical networks. Section 2.3 presents major routing problems for both static and dynamic traffic environment. In this section we also discuss about the pros and cons of different routing algorithms. Section 2.4 discusses and compares various algorithms for static and dynamic wavelength assignment approaches. Traffic grooming mechanism and its pros and cons are presented in Sect. 2.5. Section 2.6 focuses on different recovery methods and their working principle in optical networks. Further, in this section we discuss about the classification of recovery techniques. Finally, Sect. 2.7 concludes this chapter.

2.2 Lightpath Establishment

WDM based optical network has been rapidly gaining growing acceptance due to its ability to handle the ever-increasing traffic demands of network users. In a wavelength-routed WDM based optical network, end users communicate with each other via all-optical WDM channels, which are referred to as lightpaths. A lightpath is used to support a connection in a wavelength-routed WDM based network, and it may span multiple fiber links. It has been observed from the literature survey that mainly two different types of traffic assumptions [1–5] namely, (i) static traffic and (ii) dynamic traffic have been considered for routing and wavelength assignment (RWA) purpose, which are discussed below.

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- In case of static traffic assumption [1, 6], information about the connections are known in advance. The traffic demand may be specified in terms of source-destination pairs. These pairs are chosen based on an estimation of long-term traffic requirements between the node pairs. The objective is to find out end-to-end routes and assign wavelengths for all the traffic demand, while minimizing the number of wavelengths used.
- In case of dynamic traffic assumption [4–6], the arrival and departure of connections in the network take place one by one in a random manner. The lightpaths once established remain active for a finite amount of time before departing. The dynamic traffic demand models several situations in transport networks. Sometimes, it may become necessary to tear down some of the existing lightpaths and establish some new lightpaths in response to changing traffic patterns or network component failures.

The amount of call blocking using static traffic is higher than that of using dynamic traffic. Therefore, dynamic traffic is more preferable in optical networks to minimize call blocking and to maximize the network throughput. In the following subsections, we briefly discuss about lightpath establishment using both static and dynamic traffic.

2.2.1 Static Lightpath Establishment

The establishment of lightpath using static traffic assumption is known as static lightpath establishment (SLE) problem. Here, attempt is made to minimize the number of wavelengths required to setup a given set of lightpaths. In the literature, a number of studies [7–11] have investigated the SLE problem to establish a static set of lightpaths in optical networks. In this direction, R. Ramaswami et al. [10] formulated static RWA problem as an NP-hard problem. I. Chlamtac et al. [12] proved that the SLE problem is an NP-complete problem by formulating SLE problem as polynomial time reducible to n-graph-colorability problem. Therefore, many researchers have attempted to propose efficient heuristic algorithms [12, 13] for solving static RWA problems. Although the computational complexity of the SLE problem is found to be smaller than that of dynamic lightpath establishment problem, number of blocked connections in SLE is more compared to dynamic lightpath establishment. SLE problem is often decoupled into two subproblems, namely, (i) routing and (ii) wavelength assignment for making the problem more tractable.

2.2.2 Dynamic Lightpath Establishment

The establishment of lightpath under dynamic traffic assumption is known as dynamic lightpath establishment (DLE) problem. In dynamic provisioning, a lightpath is established in real-time without predetermined routes and the knowledge of future

lightpath provisioning events. Here, attempt is made to choose a route and a wavelength which maximizes the probability of setting up a given connection, while minimizing the number of blocked connections. In DLE, lightpaths are established dynamically on the basis of link-state information and as a result a virtual topology[1] is formed. The established connections are no longer required after a certain amount of time and then these lightpaths are taken down dynamically. Using this criterion, on-demand lightpath establishment has been implemented in order to enable service providers to fulfill customer demands quickly and economically. It had been revealed from the literature that DLE problem is an NP-hard problem [14]. Therefore, efficient heuristic approaches are the possible ways to tacle this difficult problem. In this direction, G. Shen et al. [15] and R. Ramamurthy et al. [16] proposed heuristic algorithms for establishing dynamic lightpaths in optical networks. Similar to SLE, DLE problem can also be decoupled into two subproblems, namely, (i) routing and (ii) wavelength assignment, which are discussed in Sects. 2.3 and 2.4, respectively.

2.3 Routing

Approaches for solving routing subproblem (also called routing algorithm) in optical networks can be categorized into four types, namely, (i) fixed routing [17], (ii) fixed alternate routing [18], (iii) adaptive routing [19–21], and (iv) least congested routing [22]. These routing approaches have mainly considered to find out the suitable end-to-end routes between source-destination pairs. Among these algorithms, fixed routing is considered to be the simplest among all, whereas adaptive routing provides the best performance in terms of call blocking. Fixed alternate routing offers a trade-off between time complexity and call blocking. Briefly discussion on these algorithms are presented in the following subsections.

2.3.1 Fixed Routing

In fixed routing (FR), a single fixed end-to-end route is pre-computed for each source-destination pair using some shortest path algorithms, such as Dijkstras algorithm [23]. When a connection request arrives in the network, this algorithm attempts to establish a lightpath along the predetermined fixed route. It checks whether a required wavelength is available on each link of the predetermine end-to-end route or not. If no wavelength is found available, the connection request is blocked. In the situation when more than one required wavelength is available, a wavelength selection mechanism is used to select the best wavelength.

[1] The set of lightpaths established over a physical topology forms a virtual topology. The higher layer in a transport network uses the virtual topology on the optical path layer for message transmission.

2.3.2 Fixed Alternate Routing

Fixed alternate routing (FAR) is an updated version of the FR algorithm. In FAR, each node in the network maintains a routing table (that contains an ordered list of a number of fixed end-to-end routes) for all other nodes. These routes are computed off-line. When a connection request with a given source-destination pair arrives, the source node attempts to establish a lightpath through each of the route from the routing table taken in sequence, until an end-to-end route with a required wavelength is found. If no available route with required wavelength is found from the list of alternate routes, the connection request is blocked. In the situation when more than one required wavelength is available on the selected end-to-end route, a wavelength assignment mechanism is applied to choose the best wavelength. Although the computational complexity of this algorithm is higher than that of FR, it provides comparatively lesser call blocking than the FR algorithm. However, this algorithm may not be able to find all the possible routes between a given source-destination pair. Therefore, the performance of FAR algorithm in terms of call blocking is not the optimum.

2.3.3 Least Congested Routing

Least congested routing (LCR) predetermines a sequence of end-to-end routes is for each source-destination pair similar to FAR. Depending on the arrival time of connection requests, the least-congested routes are selected among the predetermined routes. The congestion on a link is measured by the number of wavelengths available on the link. If a link has fewer available wavelengths, it is considered to be more congested. The disadvantage of LCR is its higher computational complexity, and its call blocking is almost same as in FAR.

2.3.4 Adaptive Routing

In adaptive routing (AR), end-to-end routes between source-destination pairs are chosen dynamically, depending on link-state information of the network. The network link-state information is determined by the set of all connections that are currently in progress. The most acceptable form of adaptive routing is adaptive shortest-cost-path routing, which is well suited for use in wavelength-routed optical networks. Under this approach, each unused link in the network has a cost of 1 unit, whereas the cost of each used link in the network is considered α. When a connection arrives, the shortest-cost path between source-destination pair is determined. If there are multiple paths with the same distance, one of them is chosen at random. In shortest-cost adaptive routing, a connection is considered blocked mainly when there is no route with required wavelength between source-destination pair. Since adaptive routing considers all the possible routes between source-destination pair, it provides lower call blocking, but its setup time is comparatively higher than other routing algorithms.

AR requires extensive support from the control and management protocols to continuously update the routing tables at the nodes. Moreover, AR is more preferable for centralized implementation and less accepted to the distributed environment.

The functionality of the above mentioned routing algorithms are explained with the help of a sample example network, as shown in Fig. 2.1. It consists of 14 nodes (representing cities) and 21 bi-directional optical links. The fixed shortest route or primary route, alternate route, and adaptive route from source city CA to destination city L are shown in solid-red, dotted-green, and dashed-blue lines, respectively. Furthermore, the congested links are denoted as α. If a connection request for a connection from source city CA to destination city L arrives, only AR can be able to find an end-to-end route between CA and L.

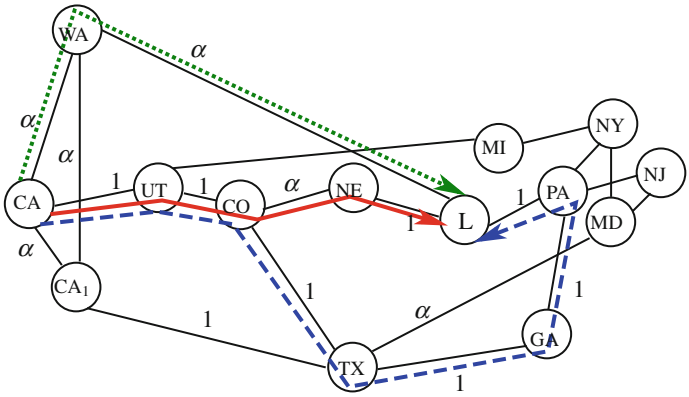


Fig. 2.1 Fixed/primary (*solid-red line*), alternate (*dotted-green line*) and adaptive (*dashed-blue line*) routes are shown between source city CA to destination city L

Table 2.1 Summaries of different routing algorithms

Problem	Approach		Ref	Performance analysis			On/Off line
				BP	AST	TC	
Routing + First-fit	Static	FR	[17]	Higher BP than others	Lower AST than others	O ($L_1 \cdot W \cdot Z$)	Off line
		FAR	[18]	Lower BP than FR	Higher AST than FR	O ($L_2 \cdot K \cdot W \cdot Z$)	Off line
		LCR	[22]	Almost same as FAR	Almost same as FAR	O ($L_3 \cdot K \cdot W \cdot Z$)	Off line
	Dynamic	AR	[19]	Lower BP than others	Higher AST than others	O ($L_2 \cdot N^2 \cdot W \cdot Z$)	On line

L_1, L_2, L_3, W, K, N, and Z are the length of the longest fixed route for any node pair, the length of the longest candidate route for any node pair, hop count of the longest candidate route, number of wavelengths per fiber link, the maximum number of candidate routes for any node pair, the number of nodes in the network, and total number of connection requests in the network, respectively

Significant amount of works addressing different issues of routing have been reported in the literature. Table 2.1 [24–26] summaries the major routing algorithms, comparing their performance in terms of blocking probability (BP),[2] average setup time (AST)[3] and time complexity (TC).

2.4 Wavelength Assignment

Wavelength assignment algorithm is used to select a suitable wavelength between a given source and destination pair when multiple feasible wavelengths are available on the end-to-end route of a connection request. Wavelength selection may be performed either after finding of a route for a lightpath or in parallel during the route selection process. In without wavelength conversion networks, the required wavelength for a lightpath is chosen in a manner which attempts to reduce call blocking for subsequent connection requests, while ensuring that no two lightpaths share the same wavelength on the same fiber link. Since wavelength assignment problem can be formulated as a graph coloring problem, it is an NP-Complete problem and therefore a number of heuristic solutions have been proposed in the literature [6, 27–42]. Among these heuristics, some significant heuristics, such as first fit, least used, most used, and random wavelength assignment policies are briefly discussed in the following subsections.

2.4.1 First Fit

In first fit (FF) policy [6, 27–30], the wavelengths are indexed and a list of indexes of available and used wavelengths is maintained. This policy always attempts to choose the lowest indexed wavelength from the list of available wavelengths and assigns it to the lightpath to serve the connection request. When the call is completed, the wavelength is returned back to the list of available wavelengths. By selecting wavelengths in this manner, existing connections will be packed into a smaller number of wavelengths, leaving a larger number of wavelengths available for future use. To implement this policy, no global information of the network is required. FF wavelength assignment policy is considered to be one of the best policy due to its lower call blocking and computational complexity.

[2]The blocking probability is defined as a ratio of the number of blocked connection/bandwidth requests to the number of connection/bandwidth requests in the network.

[3]The average setup time is defined as a ratio of total execution time in the network to the number of successful connections.

2.4.2 Least Used

Least used (LU) policy [6, 27, 29] assigns a wavelength to a lightpath from the list of available wavelengths which has been used in the minimum number of fiber links throughout the network. If several available wavelengths share the same minimum usages, FF policy is used to select the best wavelength among all the feasible wavelengths. By selecting wavelengths in this manner, it attempts to spread the load evenly across all wavelengths.

2.4.3 Most Used

Most used (MU) policy [6, 27, 29] has been used to assign a wavelength to a lightpath from the list of available wavelengths, which has been used in the maximum number of fiber links throughout the network. Similar to LU, if several available wavelengths share the same maximum usage, FF policy is used to break the tie. By selecting wavelengths in this way, it attempts to provide maximum wavelength reuse in the network.

2.4.4 Random Wavelength Assignment

In random (R) policy [27–29], a list of free or available wavelengths is maintained. When a connection request arrives in the network, this policy randomly selects a wavelength from the list of available wavelengths and assigns it to the lightpath used to serve the connection request. After assigning a wavelength to a lightpath, the list of available wavelengths is updated by deleting the used wavelength from the free list. When call is completed, the wavelength is again added to the list of free or available wavelengths. By selecting a wavelength at random manner, it can reduce the possibility of choosing the same wavelength by multiple connections in the situation when wavelength assignment is done in a distributed manner.

To illustrate the functionality of the above mentioned wavelength assignment policies, we use an example network segment as shown in Fig. 2.2. Both the wavelengths λ_1 and λ_2 are available from node-13 to node-10. If a connection request arrives at node-13 for establishing a lightpath to node-10, following strategy may be adopted. FF policy selects the wavelength λ_1. Wavelengths λ_1 and λ_2 have been used eight times and four times, respectively, in the network segment. Therefore, λ_1 and λ_2 can be used for LU and MU wavelength assignment policies, respectively. Random policy selects any of the two wavelengths with an equal probability.

Significant amount of works addressing different issues of wavelength assignment problem have been reported in the literature. Table 2.2 summarizes some major wavelength assignment policies comparing their performance in terms of two major parameters, namely, blocking probability (BP) and time complexity (TC).

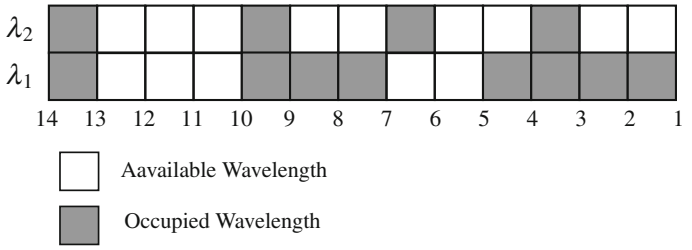


Fig. 2.2 Wavelength-usage pattern for a network segment

Table 2.2 Summaries of different wavelength assignment policies

Problem	Approach	References	Performance analysis		Applicable NW
			BP	TC	
Wavelength assignment + Fixed routing	Max Sum (MS)	[29]	In multi-fiber, MS outperforms when load is high	O $(L_1 \cdot W \cdot N^3 \cdot Z)$	Single/multi-fiber networks
	Relative Capacity Loss (RCL)	[29]	In single fiber, RCL performs well when load is high	O $(L_1 \cdot W \cdot N^3 \cdot Z)$	Single/multi-fiber networks
	Min product (MP)	[29]	MP performs well under low load	O $(L_1 \cdot M \cdot N \cdot W \cdot Z)$	Normally used in multi-fiber networks
	Least-loaded (LL)	[29]	LL performs well under high load	O $(L_1 \cdot M \cdot N \cdot W \cdot Z)$	Normally used in multi-fiber networks
	Least used (LU)	[6, 27, 29]	LU perform well under high load	O $(L_1 \cdot E \cdot W \cdot Z)$	Single/multi-fiber networks
	Most used (MU)	[6, 27, 29]	MU perform well under low load	O $(L_1 \cdot E \cdot W \cdot Z)$	Single/multi-fiber networks
	Random (R)	[27–29]	Higher BP than FF but almost close	O $(L_1 \cdot W \cdot Z)$	single/multi-fiber networks
	First fit (FF)	[28–30]	Lower BP among LU, MU, R	O $(L_1 \cdot W \cdot Z)$	single/multi-fiber networks

L_1, E, M, N, W and Z are the length of the longest fixed route for any node pair, total number of links in the network, total number of fibers in the network, total numbers of nodes in the network, number of wavelengths per fiber link, and total number of connection requests respectively

From the literature, it has been revealed that the majority of connection requests are in the Mbps range and a single wavelength channel in a WDM based system can support an enormous bandwidth of the order of 100 Gbps which is commercially available [43]. This has opened up a new opportunity in the form of traffic grooming which is discussed in the next section.

2.5 Traffic Grooming

In WDM based wavelength-routed optical networks, traffic grooming [27, 44–46, 46–51] has been used to multiplex a number of low-speed connection requests onto a high-capacity wavelength channel for enhancing channel utilization. Different kinds of multiplexing mechanisms [50] have been applied for traffic grooming in the different domains of optical networks, such as (i) space division multiplexing (SDM), (ii) frequency division multiplexing (FDM), (iii) time division multiplexing (TDM) and (iv) packet division multiplexing (PDM). However, most of the research in traffic grooming mainly focus on TDM approach.

A.L. Chiu et al. [45] proved that the traffic grooming problem in WDM based optical network is NP-complete [23]. They shown that the bin packing problem can be transformed into the traffic grooming problem within a polynomial time. However, integer linear programming (ILP) formulation can be used to obtain an optimal solution for a smaller size network. In this direction, J. Wang et al. [47, 51] formulated traffic grooming problem as ILP. The limitation of the ILP approach is that the numbers of variables and equations increase exponentially with increase in network's size. By relaxing some constraints in ILP formulation, it may be possible to obtain optimal result for reasonable-size networks. The results of ILP may provide the insight and intuition for developing efficient heuristic algorithms for handling traffic grooming in a large network. In this direction, K. Zhu and B. Mukherjee [27, 50] presented two heuristics on traffic grooming, namely, (i) maximizing single-hop traffic (MST) and (ii) maximizing resource utilization (MRU) to increase the network throughput for large networks. Depending on the number of lightpaths allowed in a connection route, traffic grooming mechanisms have been mainly classified into two categories, namely, (i) single-hop grooming and (ii) multi-hop grooming. These approaches are briefly discussed in the following subsections.

2.5.1 Single-hop Traffic Grooming

Single-hop traffic grooming aggregates calls on a single lightpath to eliminate intermediate electronic processing. In single-hop traffic grooming, low-data-rate client traffic can be multiplexed onto wavelengths and all traffic that is carried over a given wavelength channel is switched to the same destination port. This type of traffic

grooming does not have the capabilities of switching traffic at intermediate nodes. The grooming unit in this case is a traffic aggregation unit. The single-hop traffic grooming scheme has limited grooming capability since it can groom only traffic from the same source node to the same destination node. Therefore, this end-to-end grooming scheme restricts a connection to use only a single lightpath. As a result, the bandwidth of a lightpath cannot be shared by traffic from different source-destination pairs. Although the computation complexity and traffic delay in the network using single-hop traffic grooming is lower than that of using multi-hop traffic grooming, the performance of single-hop traffic grooming in terms of channel utilization is not the optimum. Figure 2.3 shows how a connection, denoted as C_1, is being carried by a lightpath, say L_1, from node-1 to node-9 using the single-hop traffic grooming scheme.

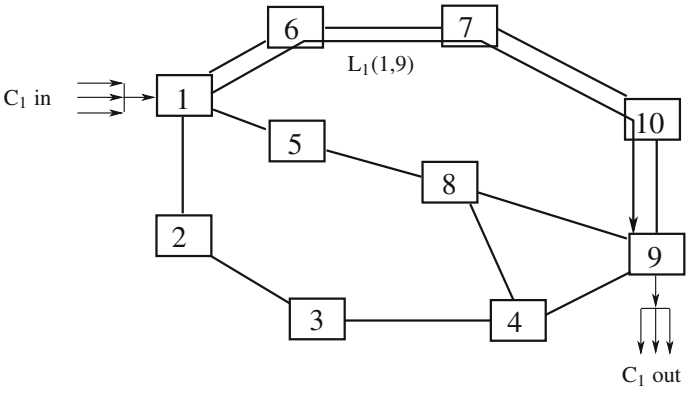


Fig. 2.3 Example of single-hop traffic grooming

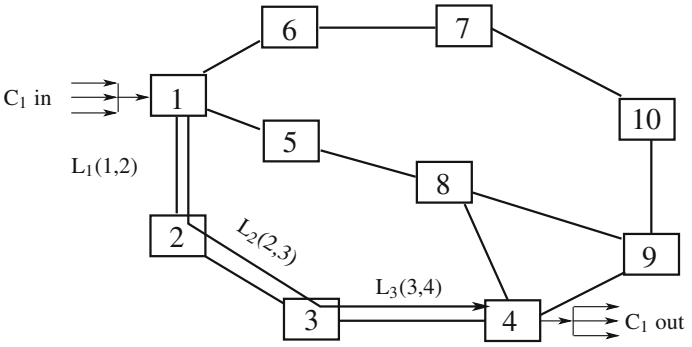


Fig. 2.4 Example of multi-hop traffic grooming

Table 2.3 Summaries of different traffic grooming mechanisms

Problem	Traffic	References	Network architecture	Outcomes
Wavelength assignment + Fixed routing	Dynamic and static	[52, 53]	Single-hop and multi-hop optical ring	(i) Minimizing transceiver cost (ii) Study of dynamic traffic
	Egress and static	[45]	Unidirectional ring with egress node (single-hop) and bi-directional ring (single-hop)	(i) Proof of NP-completeness (ii) Optimal solution for uniform traffic on egress ring
	Static	[54, 55]	Bi-directional ring with odd number of nodes (single-hop)	(i) How to group timeslots (ii) Maximal and super node model for distance dependent traffic
	Static	[56]	Unidirectional and bi-directional ring (single-hop)	(i) Greedy heuristic for grooming arbitrary traffic (ii) Heuristic for circle construction for non-uniform traffic.
	Static	[27, 47]	Unidirectional and bidirectional ring (single-hop)	(i) Simulated-annealing-based heuristic for traffic grooming (ii) Greedy heuristic for single-hop and multi-hop grooming
	Poisson	[57–59]	Multi-hop mesh network	(i) Maximize channel utilization (ii) Maximize network throughput
	Poisson	[6, 27]	Single-hop mesh network	(i) Maximize channel utilization

2.5.2 *Multi-hop Traffic Grooming*

Multi-hop traffic grooming can aggregate calls on several lightpaths to enhance the channel utilization. Here, connections from different source-destination pairs share the bandwidth of a lightpath. Depending on the architectures of different grooming optical cross-connects (OXCs), multi-hop traffic grooming can be categorized into two types, namely, (i) multi-hop partial-grooming and (ii) multi-hop full-grooming. The details description about different types of grooming OXCs with their corresponding grooming schemes can be found in [27, 50]. The multi-hop full-grooming OXC can provide best performance in terms of resource utilization and blocking characteristics, but it can only be implemented using the opaque technology. Therefore, it requires a significant amount of electronic processing, which produces traffic delay in the network and increases the network setup cost. The multi-hop partial grooming approach offers reasonable alternative when full grooming is not necessary in each and every node. Figure 2.4 shows how a connection, denoted as C_1, can be carried by multiple lightpaths, such as L_1, L_2, and L_3 from node-1 to node-4.

Significant amount of works have been reported in the literature to address the different issues of traffic grooming. Table 2.3 summarizes the major traffic grooming mechanisms from literature.

It has been revealed from the literature survey that traffic grooming mechanism has emerged as an emerging technology which has been incorporated with the RWA approach to further enhance the utilization of optical channel capacity [59]. As a result, nowadays a single fiber can carry a huge amount of information which is of the order of Tbps range. A relatively important issue is survivability or fault management which plays a crucial role in WDM based optical networks. We discuss about fault management in WDM based optical networks in the next section.

2.6 Fault Management

Nowadays, WDM based optical networks are designed in such way that they have the capabilities to quickly detect, isolate and recover from a failure. Failure recovery [60] in an optical network is defined as "*the process of re-establishing traffic continuity in the event of a failure condition affecting that traffic, by re-routing the signals on diverse facilities after the failure*". A network is defined as survivable [60], if the network is capable to recover failure in the event of a fault occurrence. Many studies [27, 61–64] have been carried out for fault management in WDM based optical networks. In this direction, D. Zhou et al. [61] and S. Sengupta et al. [65] summarized the solutions of recovery mechanisms for ring and mesh based optical networks. WDM based optical networks incorporate two types of fault recovery techniques [27, 60, 64], namely, (i) protection based and (ii) restoration based, which are discussed in the following subsections.

2.6.1 Protection

In protection, backup paths carry signals after the fault occurrence and they are computed prior to fault occurrence, but they are reconfigured after the fault occurrence. S. Ramamurthy et al. [66] investigated different protection techniques from an implementation perspective. It has been observed from their study that most of the earlier research have concentrated on single node/link failure at a given instant. However, recent research has started to address the dual failure problems in optical networks. In this direction, H. Choi et al. [67], M. Clouqueur et al. [68], N. Bao et al. [69], and V.Y. Liu et al. [70] addressed the dual failure problem in optical networks. Protection techniques have been classified based on resource sharing into two categories - (i) dedicated protection and (ii) shared protection, which are discussed as follows.

2.6.1.1 Dedicated Protection

In dedicated protection [27, 60], a dedicated path is reserved for each working path, an example of this is shown in Fig. 2.5. It has been observed from the literature survey that two types of dedicated protection [27, 60], namely, (i) 1+1 protection and (ii) 1:1 protection have been mainly considered for recovery purpose.

- **1+1 Protection**: In 1+1 protection technique, from the source node optical signal is transmitted both on the working path as well as on the backup path. If the working path fails, the signal is switched over to the backup path and thus continues with data transmission. To avoid ambiguity, before sending signal on the backup path, the source node waits for some amount of time, denoted as t_1, after sending signal on the working path. The waiting time, t_1, may be computed depending on either the difference in propagation delay between the working path and the backup path

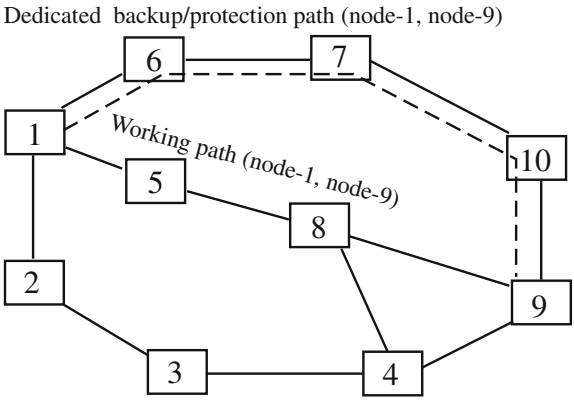


Fig. 2.5 Example of dedicated backup/protection path from node-1 to node-9

or the failure-detection time. If the kth bit of data reaches the destination at time, say t_2, through the working path, the same kth bit should reach the destination at time, say t (where, $t \geq t_1 + t_2$) through the backup path. If the destination node receives the $(k - l)$th bit at that time, the fault controller detects a fault on the working path. Therefore, the signal is switched over to the backup path to retransmit the kth bit.

- **1:1 Protection**: 1:1 protection technique does not allow transmission of signal on the backup path. However, the backup path is used to carry some low-priority preemptable traffic. If any fault occurs on the working path, the source node is notified by some protocol and then the signal is switched over to the backup path. Some data may be lost in the network, and the lost data can be recovered by retransmitting at the source node.

2.6.1.2 Shared Protection

Although dedicated protection can provide more reliability in the network, but it is unable to utilize the network resources properly. To overcome this problem, shared protection technique [27, 60] has been applied in optical networks. In shared protection, a backup path is shared among all the working paths (1:M), but the working paths are not activated simultaneously. Therefore, the recovery time using shared protection is longer compared to dedicated protection. Figure 2.6 shows an example of using shared protection. Two working paths, as for example 1-6-7-10-9 and 1-2-3-4-9 from node-1 to node-9 share a backup path 1-5-8-9, as the backup path is link and node disjoint to both the working paths.

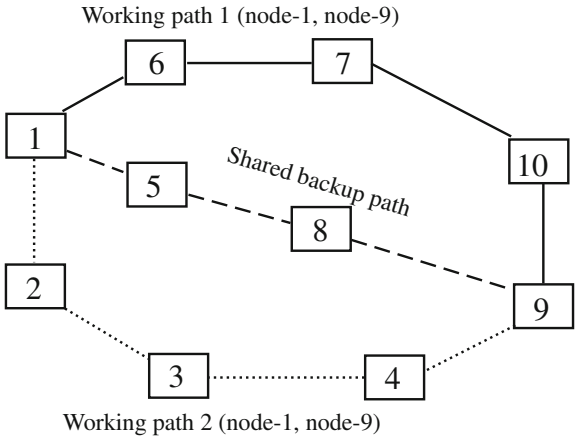


Fig. 2.6 Example of shared backup/protection path from node-1 to node-9

2.6.2 Restoration

In restoration [27, 60, 64, 71, 72], backup paths are computed dynamically on the basis of link-state information after the fault occurrence, and hence it can provide more efficiency in terms of resource utilization compared to protection. As restoration technique can find the backup paths after the fault occurrence, therefore the recovery time of restoration is slower compared to protection. Depending on the type of rerouting, restoration can be classified mainly three categories, namely, (i) link restoration, (ii) path restoration and (iii) segment-based restoration. Link restoration [64] discovers a backup path of the failed connection only around the failed link. In path restoration [64], the failed connection independently discovers a backup path on an end-to-end basis. Segment-based restoration [64] discovers a segment backup path of the failed connection. Among these restorations, link restoration is considered to be a fastest restoration technique. However, the recovery time of path restoration is the maximum.

2.7 Conclusion

This chapter presented a comprehensive survey on the existing works related to the problems addressed in this book. With a detailed understanding of the state of the art, the research contributions are presented in the subsequent chapters.

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