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Protection and Restoration Schemes in Optical Networks: A Comprehensive Survey

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ABSTRACT

Fault management has become critical in managing survivability of high speed networks. Impact of failure is aggravated with extremely high volume of traffic carried on WDM (Wavelength Division Multiplexing) networks. In a WDM network, failure of a network element may cause failure of several optical channels leading to large data loss which can interrupt communication services. In this paper, existing protection and restoration techniques proposed for optical network are critically reviewed and analyzed. It is concluded that a hybrid of existing protection schemes can be implemented depending on service differentiation, type of optical network and tradeoffs in speed, efficiency, restoration time and cost. Existing work has to be expanded on incorporating intelligence in Optical Networks which can result into efficient management of faults thereby providing protection and restoration.

Key words: Optical Network, Protection, Restoration, Survivability, WDM

1. INTRODUCTION

In a wavelength-routed WDM networks, the optical signal spectrum is carved up into a number of non-overlapping wavelength bands, thus allowing multiple wavelength channels to co-exist on a single fiber. The failure of a network element may result in the failure of several optical channels, thereby leading to large data and revenue losses. Interruption of high speed nearly 50 Tb/s optical data offered by WDM optical network, lead to huge waste of information. This gives high importance to the issue of survivability of optical network [1]. Survivable network architectures are based either on reserving backup resources in advance called protection or on discovering spare backup resources in an online manner called restoration [2].

1.1 Fault Management Schemes

Fault management in optical network is done through reserving backup resources in advance called protection or discovering spare backup resources in an online manner called restoration as defined by Mohammad Ilyas and Hussein T.Muftah [2], which can be further classified as path protection/restoration and link protection/restoration as shown in Figure: 1.

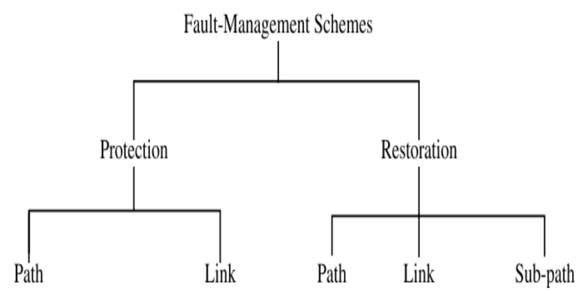


Figure 1: Fault Management Schemes [2]

Following is the brief description of optical network Fault Management schemes:

1.1.1. Link Protection

Backup paths and wavelengths are reserved around each link on the primary path during connection setup. When a link fails, all the connections traversing the failed link will be rerouted around that link and the source and destination nodes of the connections traversing the failed link would be unaffected by link failure.

1.1.2 Path Protection

Source and destination nodes of each connection statically reserve a primary path and a backup path on an end-to-end basis during connection setup the. When a link fails, the source node and the destination node of each connection that traverses the failed link are informed about the failure and backup resources are utilized. Figure: 2 shows mechanisms for restoring connections

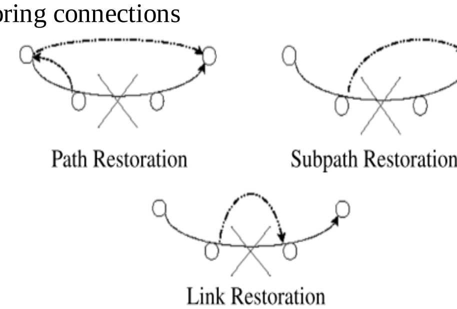


Figure 2: Restoration Mechanisms [2]

1.1.3 Link Restoration

In the event of a failure, the end nodes of the failed link participate in a distributed algorithm to dynamically discover a new route around the link, for each active wavelength that traverses the link. When a new route is discovered around the failed link for a wavelength channel, the end nodes of the failed link reconfigure their OXCs (Optical Interconnects) to reroute that channel onto the new route. Connection is dropped in case no new route and associated wavelength can be discovered for a broken connection.

1.1.4 Path Restoration

The source and the destination nodes of each connection independently discover a backup route on an end-to-end basis and such a backup path can be on a different wavelength channel. When a new route and wavelength channel is discovered for a connection, network elements such as OXCs are reconfigured appropriately, and the connection switches to the new path. Connection is dropped in case there is no new route

1.1.5 Sub-Path Restoration

When a link fails, the upstream node of the failed link detects the failure and discovers a backup route from itself to the corresponding destination node for each disrupted connection. Upon successful discovery of resources for the new backup route, intermediate OXCs are reconfigured appropriately and the connection switches to the new path. If sufficient resources are not available connection is dropped.

2. EXISTING RESTORATION AND PROTECTION TECHNIQUES

2.1 Restoration Techniques

Mohammad Ilyas and Hussein T.Muftah [2] classifies restoration methods depending on the functionality of the cross-connects. Depending on the traffic demands restoration methods can be Static, where the traffic matrix is known in advance, Dynamic, in which connections are set up as and when they arrive without any previous knowledge of the arrival time. Depending on type of network control restoration method can be centralized, which is implemented for smaller networks with a controlled traffic matrix, Distributed, in huge networks where connections arrive in a distributed manner and each node does its own computation for routing and provisioning. Restoration methods can also be classified depending on the primary performance metric like Restoration speed, blocking probability, link utilization, scalability, or restorability. Brief description of Restoration methods as classified in Figure: 3 is as following:

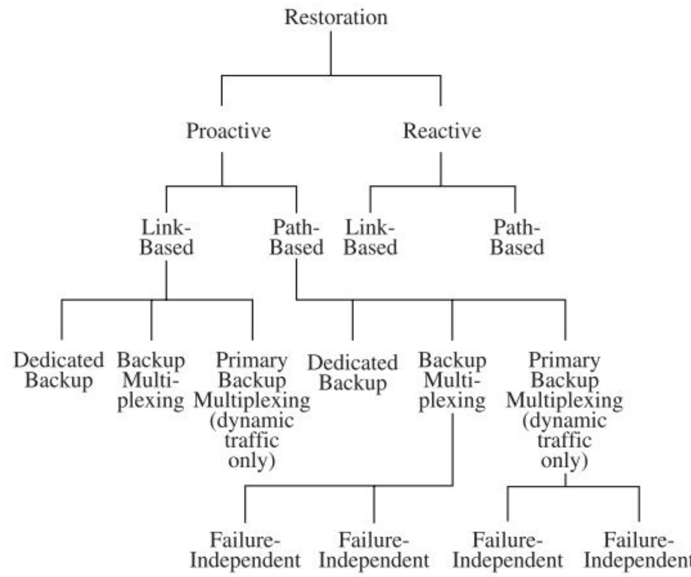


Figure 3: Types of Restoration [2]

2.1.1 Proactive Scheme

In this scheme alternate routes are pre calculated. After the fault occurs, the connection is simply rerouted to the previously calculated route.

2.1.2 Reactive Scheme

Alternate routes are calculated after the actual fault occurs. Typical reactive schemes flood packets into the network after the fault to look for free capacity and to set up the new path.

2.1.3 Link Based Scheme

Reroute the demand around the failed link

2.1.4 Path Based Scheme

A complete new path is used as alternate path. Schemes with dedicated backup reserve the backup route for the particular demand.

2.1.5 Backup Multiplexing

This allows other backup paths to share the same wavelength on one or more links. This technique is based on single fault assumption, which says that at one time only one link or node will fail. So if two backup paths are fault disjoint, they can share the same backup wavelength under the single fault assumption, since only one of the sharing backup paths will be activated and thus no conflict will occur.

2.1.6 Primary Multiplexing

A primary path may be set up on a wavelength that is backup for one or more demands So during the life of the primary demand, the backup becomes unusable and comes back into service once the primary demand is over.

2.1.7 Failure-Dependent Scheme

This is further classification of path-based schemes where the backup path is dependent on the particular failure (link/node). Thus a backup path is available for each possible failure on the path.

2.1.8 Failure-Independent Scheme

These scheme find a link and node disjoint path and make it the backup path. Thus regardless of which link or node has failed, this path can be used.

2.2 Protection Techniques

Guido Maier, Achille Pattavina , Simone De Patre and Mario Martinelli [3] classifies optical network protection methods as shown in Figure: 4 which are briefly discussed as follows:

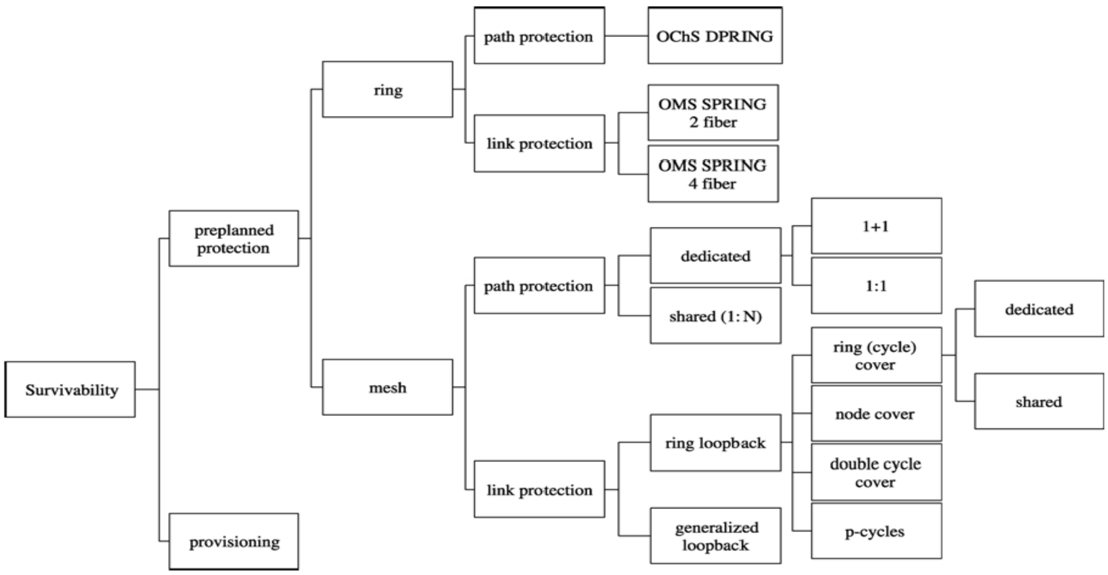


Figure 4: Classification of protection techniques implementing survivability in the WDM layer [4]

2.2.1 Path Protection in Ring Networks- OCh-DPRing (Optical Channel Dedicated Protection Ring)/1+1 Dedicated Protection/WDM SHR (Self Healing Ring)

OCh-DPRing scheme as shown in Figure: 5 is applied to rings that use two fibers to propagate the signals in opposite direction. Path protection is designed using both the fibers to establish two counter propagating light paths around the ring [3].The source node transmits on both the working and protection links simultaneously.

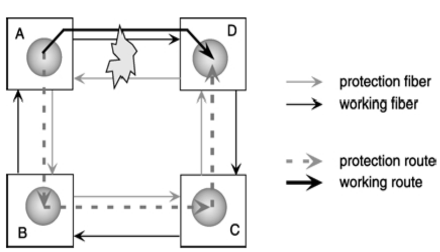


Figure 5: OCh-DPRing [4]

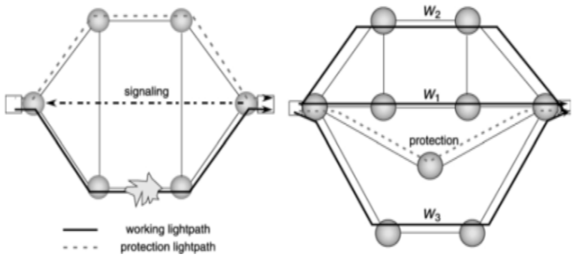
2.2.2 OMS link protection-OMS-SPRing (Optical Multiplex Section-Shared Protection Ring)

Depending on physical design OMS-SPRing can be further classified as two fiber or four fiber mode. In four fiber system for each fiber pair, second pair is reserved for backup traffic.

In two fiber system, on each fiber from a couple of fibers in one direction, half of WDM channels carry working traffic while other half are used as spare resources to protect some other link [3].

2.2.3 Dedicated Path Protection in Mesh Network

Both 1+1 and 1:1 dedicated path protection are possible. In 1:1 protection as shown in Figure: 6, transmission occurs on the working link only, while the protection link may be either idle or used to transmit low-priority traffic. Upon failure of the working lightpath, the protection lightpath will then be used.



(a) (b)

Figure 6: Path Protection in a Mesh Network: (a) 1:1 Dedicated Protection; (b) 1:3 Shared Protection [4]

2.2.4 Shared Path Protection/ 1: N

Allows spare wavelengths to be shared by a number of working light paths as shown in Figure: 7. N protection light paths share all their WDM channels.

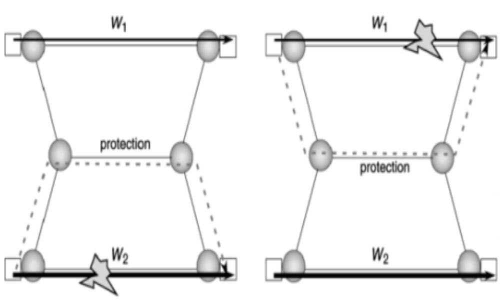


Figure 7: Shared Path Protection in a Mesh Network: Protection Light Path for W1 and W2 share a common fiber [4]

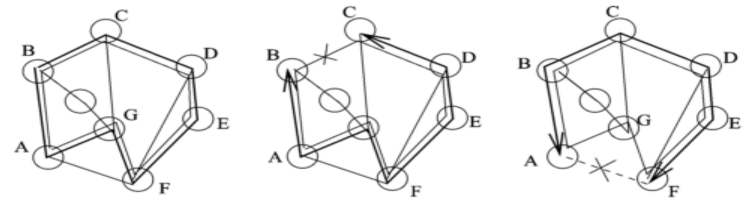
2.2.5 Ring Loopback (Link Protection in Mesh Networks)

Network is decomposed in several set of fibers and each set is managed as a single ring. After decomposition each ring is equipped with OMS protection system [3] Ring loopback technique is further classified in Ring Cover, Node Cover, Double Cycle Cover and P-Cycles. In *Ring Cover* each link must at least belong to one ring.

In *Node Cover* set of rings is chosen such that each node belongs to 1 or more rings and each link belongs to atmost 1 ring

Double Cycle Cover is a 4 fiber ring cover technique with assumption that each network link comprises a pair of counter propagating working and a pair of counter propagating protection fibers [4].

P-Cycles can be regarded as pre-conFigure:d protection cycles in a mesh network. P-cycles are able to protect on-cycle links. Furthermore, a p-cycle is able to protect straddling links as shown in Figure: 8.



(a) (b) (c)

Figure 8: P-Cycle: (a) A Cycle Traversing Nodes A-G. (b) Protection of a Failure on Cycle. (c) Protection of a Failure on Straddling Path [7]

2.2.6 Generalized Loopback technique

Muriel et al. discussed this approach to eliminate the use of rings [5]. Instead, a primary (secondary) digraph (corresponding to a set of unidirectional fibers or wavelengths) is backed up by another secondary (primary) digraph (corresponding to a set of unidirectional fibers or wavelengths in the reverse direction of the primary (secondary) digraph). After a failure occurs, stream carried by the primary (secondary) digraph is broadcast along the failed link onto the secondary (primary) digraph.

3. RELATED WORK : SURVEY

P-Cycles introduced pre provisioned 1: N protection in optical mesh networks. In P-Cycles, fault finding and traffic rerouting can take long time but protection circuits are preconFigure:d. *Ahmed E. Kamal* [6] proposed 1+N protection concept in which a P-Cycle can be used to protect a number of bidirectional connections, which are mutually link disjoint, and also link, disjoint from all links of the p-Cycle. This technique results into outage time of maximum p-Cycle propagation delay. *Ahmed E. Kamal* illustrates the implementation of hybrid 1+N technique for protection of straddling links and 1: N technique for protection of on-cycle links. Investigations done by *Amir Askarian, Suresh Subramaniam , Ma¨ıt´e Brandt-Pearce Charles L. Brown* [7] shows that P-Cycles can be more subject to failures in practical environment but selection of smaller p-cycles is less susceptible to failures. P. P. Sahu [8] proposed a restricted shared protection (RSP) scheme that provides restriction on the sharing of some of the backup light paths and proved from reliability theory that RSP network reliability is more than that of existing shared protection (SP) network reliability. It is also observed that though blocking probability in RSP network is more than that of SP, blocking probability reduction using alternate path routing in case of RSP is more than that of SP. In Journal of Selected areas in

Telecommunications [9] difference equations are used to define, study and calculate traffic and the available network capacity of the WDM mesh networks. In International Journal of computer Science and Information Technology [10] both alternate path routing and partial placement of wavelength converters is used for reduction of blocking probability. *Guoliang Xue , Weiyi Zhang , Tie Wang and Krishnaiyan Thulasiraman* [11] introduced PPP (partial path protection) scheme where one active path is protected by a collection of backup paths with each backup path protecting one or more links on active path. Investigations carried out by *Sunil Gowda and Krishna M. Sivalingam* [12] resulted in reduction in blocking probability and the number of converters required at each node to achieve a given blocking probability. These results were based on few algorithms like CFPR (conversion free primary routing), converter multiplexing technique in backup paths and backup path relocation scheme. *Ellinas, G and Gebreyesus-Hailemariam* [13] investigates novel approaches for decomposing optical mesh networks to ring covers of minimum length. *Saeedinia, R* [14] reviewed Cross-layer design for survivability and problem of lightpath embedding and investigated the problem of survivability in Shared Risk Link Groups (SRLGs) and Probabilistic SRLGs in face multiple network failures. Investigations carried out by *Mohammad Syuhaimi Ab-Rahman* [15] shows that Hybrid restoration technique with OXADM (Optical Interconnect Add Drop Multiplexer) enables the linear, ring and multiplex protection mechanism to be integrated in single optical network, and type of failure will activate the desired protection mechanism. *Amir Askarian, Yuxiang Zhai, Suresh Subramaniam, Yvan Pointurier, and Maïté Brandt-Pearce* [16] implemented cross layer techniques for improving the survivability of all-optical networks by decreasing both the blocking probability and the susceptibility of the network to failures.

4. COMPARISON

P-Cycles prove to have speed like ring networks and efficiency like mesh networks when used in optical network protection [17]. *Wayne D. Grover and John Doucette* [18] concludes that, being based on closed cyclic paths of protection capacity, p-cycles offer ring-like speed and pre-conFigure:d simplicity but are essentially as efficient as span-restorable mesh networks thereby offering three to six times greater demand-carrying capability than rings for a given transmission capacity. *Rodrigo et al.* [19] compared the performance of three different restoration schemes for all-optical networks (link, sub path and path) and indicated that path restoration is the best reactive scheme for all-optical network without wavelength conversion. *Monika Jaeger, Ralf Huelsermanna, Dominic A. Schupkeb, René Sedlakc* [20] showed that capacity efficiency of shared-protection in opaque networks, approaches path restoration and shared path protection. Path restoration, shared path protection, and link protection have comparable efficiency in transparent networks, which is better than dedicated protection. Studies carried out by Jaeger et al. shows that p-cycles need much fewer resources than link protection and dedicated protection. *Siti Nur Fariza binti Halida, S.M.Idrus, M.A.Farabi, Nadiatulhuda Zulkifli* [21] showed from the analysis that dedicated path protection is one of the schemes which can guarantee the survivability of optical network. Investigations carried out by *Daniel R. Jeske and Ashwin Sampath* [22] shows that while 1+1 demand architectures enjoy both fast restoration times and high availability, but with highest cost. 1+1 dedicated protection networks are more expensive than their shared mesh counterparts by 15-45%. With only a modest amount of over-provisioned capacity, shared mesh architectures can provide availability characteristics competitive even with 1+1 designs at a substantially lower cost.

5. CONCLUSION AND FUTURE SCOPE

It is imperative to develop appropriate protection and restoration schemes because of the high data rate on light paths in WDM optical networks to prevent any data or revenue loss. Classification of existing protection and restoration strategies that can be adopted for WDM networks is presented in this paper. Existing protection and restoration strategies are compared. It is expected that in future real life networks, there will be a hybrid of different resilience schemes. Hybrid scheme will be selected depending on a service differentiation, type of optical network and tradeoffs in speed, efficiency, restoration time, and cost. Optical network architectures provide the intelligence required for efficient routing and fast failure recovery in core networks. The work needs to be further expanded on optical networks with intelligence required to efficiently manage faults in networks thereby providing protection and restoration. New optical devices such as DWDM (Dense Wavelength Division Multiplexing) multiplexers, ADMs (Add Drop Multiplexers) and OXCs are making possible an intelligent all optical core where packets are routed through the network without leaving the optical domain.

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