Shared Mesh Restoration in Optical Networks

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1 Introduction

Optical transport networks have been traditionally based on ring architectures, relying on standardized ring restoration protocols such as SONET BLSR and UPSR to achieve fast restoration (50 msec). However, many carrier core networks are indeed meshed, consisting of backbone nodes interconnected by point-to-point WDM fiber links in a mesh interconnection pattern. Given this realization, and the many operational drawbacks of ring-based networks (such as provisioning across multiple rings, stranded capacity, inflexibility to handle traffic forecast uncertainties), it is therefore not a surprise that carriers have evolved, or are considering evolving, their core network architecture from ring to mesh. Such mesh networks are based on next-generation Optical Cross-Connects (OXCs) that support fast, capacity-efficient shared path restoration. There has also been interest in intermediate architectures (for example, those improving on traditional span-based restoration [1] or based on "p-cycles" [2]) that also try to achieve the speed of ring restoration in ways more closely aligned with traditional ring architectures. As mesh networks are replacing ring-based networks, operators are faced with changes in the way they operate their network. The increased efficiency and robustness of mesh networks, compared to ring-based networks, has to be managed appropriately to actually achieve those benefits. In this paper, we discuss four key economic and operational benefits from mesh optical networking. They are (1) end-to-end routing and provisioning, (2) fast and capacity-efficient restoration, (3) re-provisioning, and (4) re-optimization. They contribute in various ways to network cost savings and higher network and service reliability in mesh networks compared to traditional ring-based networks.

2 Mesh Routing and Provisioning

In mesh networks, routing and provisioning of connections, or lightpaths, are carried on an end-to-end basis by computing and establishing a primary path, and a back-up path in case of protected service [3,4]. In the case of dedicated mesh protection, the back-up path is dedicated to protecting a unique primary path. With shared mesh restoration, backup paths can share capacity according to certain rules. In both cases, the back-up paths are pre-established and unique, or failure independent. Restoration is guaranteed in case of single failure by ensuring that primary and back-up paths are mutually diverse, and in the case of shared back-up paths, by ensuring that sharing is only allowed if the corresponding primary paths are mutually diverse. Then, the primary paths cannot fail simultaneously in case of a single failure, preventing any contention for the back-up capacity. This is different from dynamic re-provisioning where a back-up path is computed and established after the failure occurs, and after the failure has been localized, using any remaining available capacity. Dynamic re-provisioning can still complement dedicated mesh protection and shared mesh restoration by providing a mean, albeit slower, to recover in case of multiple failure scenarios. Diversity of routes in a mesh optical network is defined using the notion of Shared Risk Link Groups [3,4]. A set of optical channels that have the same risk of failure is called a Shared Risk Link Group (SRLG). SRLGs are configured by network operators with the knowledge of the physical fiber plant of the optical network. Most SRLGs can be expressed as one or a combination of three possible primary types described in Figure 1. Appropriate diversity of primary and back-up paths, as well as sharing rules of back-up capacity, guarantee successful restoration in case of single link/SRLG failure, or single link/SRLG and node failure (with more restrictive rules). Compared to traditional ring-based protection or dedicated mesh protection, shared mesh restoration allows considerable saving in terms of capacity required [3-5]. In addition, the backup resources can be utilized for lower priority preemptible traffic in normal network operating mode. Restoration of shared mesh protected lightpaths may be slower than with dedicated protection, essentially because it involves signaling and path-setup procedures to establish the backup path, yet is still within the realm of SONET 50 msec restoration times [6]. Restoration times will be generally proportional to the length of the backup path and the number of hops, and if recovery latency is an issue this length must be kept under acceptable limits. However this constraint may increase the cost of the solutions, as it is sometime more cost-effective to use longer paths with available shareable capacity than shorter paths where shareable capacity must be reserved[1].

[1] An appropriate cost model in the route computation algorithm can handle this tradeoff.

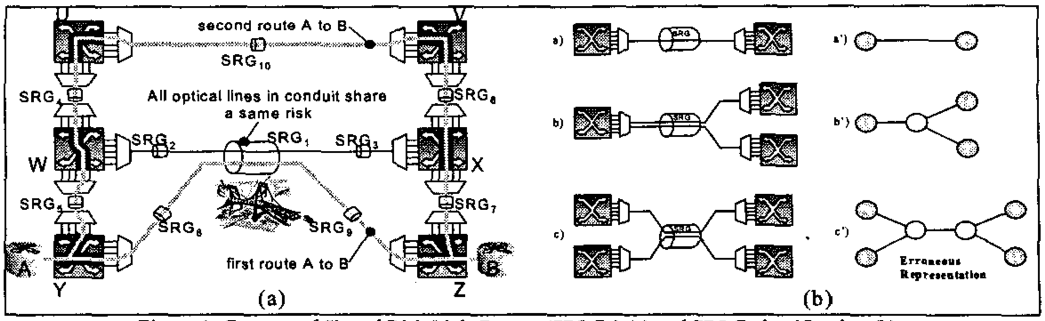

Figure 1: Concept of Shared Risk Link Groups (SRLGs) (a) and SRLG classification (b)

3 Mesh Restoration

Contrary to ring-based architectures where restoration speed on a given ring is relatively well-known, restoration speeds in mesh networks will vary, as a function of the networks size, routing of lightpaths (both primary and back-up paths), loading of the network, and failure location. It is therefore critical to possess tools that allow network operators to estimate the restoration times that would be experienced in a live network. Such modeling tools should be used in conjunction with network dimensioning, planning and optimization algorithms and tools to validate the restoration performance of a network design, or modify the design to achieve the desired restoration performance. The restoration performance tool models the actual restoration protocol and signaling to determine restoration times after a failure[2] and should be calibrated against lab results. Restoration simulation studies involve the failing of conduits, which result in the simultaneous failures of the multiple primary lightpaths that traverse these conduits, and the determination of the maximum restoration times corresponding to the last lightpath restored. A study presented in [6] is representative of a what-if type study to determine the range of restoration latencies that can be expected upon single link or node failures from shared mesh restoration (~ 100 msec). Such results have been compared with and found to be similar to measurements from real networks.

4 Mesh Re-Provisioning

While fast restoration (~ 100 msec) is an important aspects of service availability, more critical yet is the ability to recover from multiple failures quickly as opposed to the several hours it takes in practice to replace a damaged equipment in a central office. Service availability in mesh network has been studied [7]. One of the key factors improving service availability is the ability to recover from multiple failures, with, for example, a combination of restoration for the first failure, and re-provisioning at the network management layer for the subsequent failure(s). Re-provisioning tries to establish a new backup path when restoration on the original backup path does not succeed. Re-provisioning uses existing spare capacity and unused shared capacity to find a new backup path on which to immediately restore the failed lightpath. Note that re-provisioning may fail if there is not enough capacity available. Re-provisioning can dramatically increase the service availability in a mesh network. Service unavailability results from multiple concurrent failures and the time it takes to fix the failures (e.g., hours if a fiber cut in a remote area needs to be repaired). Re-provisioning a lightpath that becomes unavailable following a double failure improves the service availability of the network, by reducing the time that the service is unavailable from hours to tens of seconds[3].

5 Mesh Re-Optimization

During the network operation, requests for services are received and provisioned by the EMS/NMS using an online routing algorithm. Both the primary and backup paths of each new demand are computed according to the current state of the network, i.e., the routing algorithm takes into account all the information available at the time of the connection request to make the appropriate routing decision. As the

[2] It can use a discrete event simulation engine.

[3] This is particularly significant in trans-oceanic networks where the time to repair a damaged undersea cable could be as much as 48 hours.

network changes with the addition or deletion of fiber links and capacity and traffic patterns evolve, the routing of the existing demands becomes sub-optimal. Re-optimization by re-routing the backup and/or primary paths gives the network operators the opportunity to regain some of the network bandwidth that is currently being misused. In particular, re-routing only the backup paths is an attractive way to regain some of the protection bandwidth and reduce backup path length while avoiding any service interruption. Fig. 2 illustrates how re-optimization temporarily eliminates the difference between the current solution and the best-known off-line solution that is achievable under the same conditions.

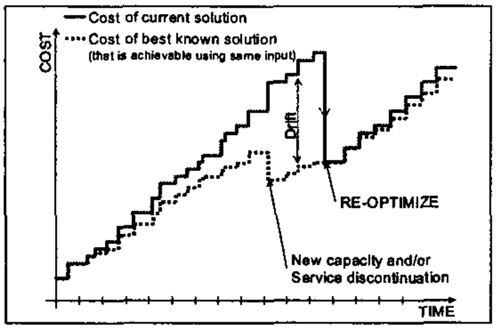

Figure 2: Cost-benefit of re-optimization

The importance of re-optimization to the network is threefold. Firstly, the reduced number of protection ports used translates in freed protection capacity, which could then be used to carry new services. Secondly, the reduction in backup path length translates to reduction in protection latency [8]. Finally, re-optimization allows network operators to make use of new nodes and links as they are deployed in the network.

6 Conclusion

Long-haul national networks utilizing optical switches are becoming *intelligent mesh networks*. They offer service providers the ability to support many new operational capabilities. They are (1) end-to-end point-and-click routing and provisioning, (2) fast capacity-efficient shared mesh restoration with times comparable to SONET ring restoration times, (3) re-provisioning of connections in the event of double failures and (4) network re-optimization to regain some of the network capacity that is not optimally used. In this work, we have discussed these many operational aspects of optical mesh networks. In addition, network planning and design of mesh networks, while not addressed here, is expected to be much more robust to traffic forecast uncertainties than ring-based designs, where stranded capacity is an expensive reality. Finally, maintenance of mesh networks is another area of interest where new approaches will be required to address the non-locality of interaction between maintenance activities.

References

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