Understanding the trade-offs associated with sharing protection

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Abstract: The network economics of shared and dedicated protection schemes are investigated and compared in an AON and EON architecture.

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1. Introduction

Protection wavelengths make up a significant portion of the bandwidth in the backbone network, and methodologies used to optimize this bandwidth can seem compelling. By sharing protection, the number of lambda kilometers in the network decreases, therefore reducing effective amplifier and fiber costs. Although sharing bandwidth is an effective way to reduce line costs, there is an offsetting cost as additional interfaces are needed at intermediate sites to enable access to the shared protection bandwidth. This paper compares the trade-offs between two architectures, an electrical-optical network architecture (EON) and an all-optical network architecture (AON). Both architectures are investigated with shared and dedicated protection schemes.

Spectral efficiency has significantly lowered the per bit costs of fiber and amplifiers resulting in nodal based OEO costs dominating network cost. It has been shown that 70 % of backbone network cost is in the node [1]. With increased reach performance and optical bypass capabilities a significant number of OEO points can be removed from the network. But by removing OEO points in the network, the carrier is removing potential electrical switch points where protection could be shared.

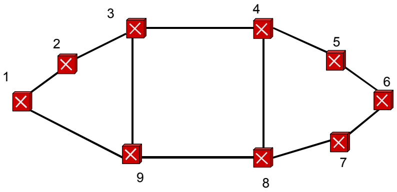

Figure 1. Nine-node network

2. A Simple Example

Consider a nine-node network separated by links of 1000 km, with one wavelength demand between every site in the network as depicted in Figure 1. Two different architectures are examined to determine economic efficiency. An EON architecture which used OEO switches at all sites, and an AON network which used all optical switching are illustrated in Figure 2. In order to achieve millisecond restoration times all protection switching was done at the electrical level. For both architectures dedicated and shared protection schemes are examined.

The EON architecture used a point-to-point line system and electrical switching at all node sites. Line Regeneration was not required.

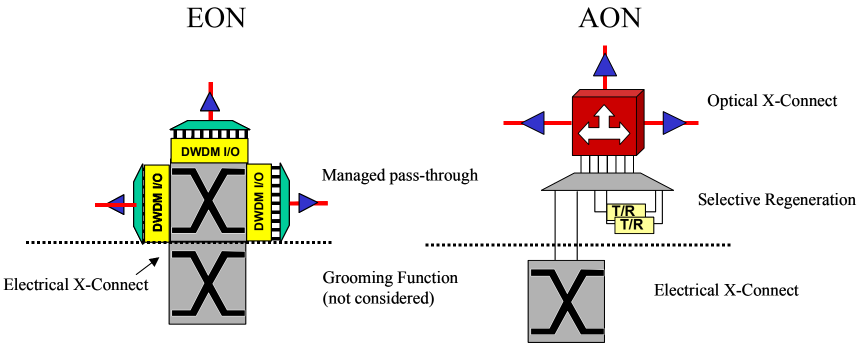

Figure 2. Generic architectures shown for EON and AON models

The AON architecture minimizes the number of OEO points in the network by using photonic bypass at mid-points. wavelengths in the optical layer as long as possible. Photonic switches are located at all nodes to enable optical by pass. OEOs are required for "on ramp", "off ramp" and regeneration functions.

Each demand in the AON case is dedicated optically from end to end. By minimizing electrical points, the AON architecture is also minimizing protection switching points. As a result, all protection switching must be done at the network end points, thus dedicated protection is assumed. Regeneration is only provided where required for reach purposes.

A P-cycle is a pre-configured protection loop which can be shared by several working paths. Drawing on the logic of the BLSR, the P- cycle enables sharing of protection with near mesh-like efficiencies, and ring like switching times. [2] By grooming at the edge, working wavelengths can be dedicated end to end, just as they are in the dedicated protection scheme. The protection loop is broken up where optical channels are added/dropped. This protection mechanism is examined.

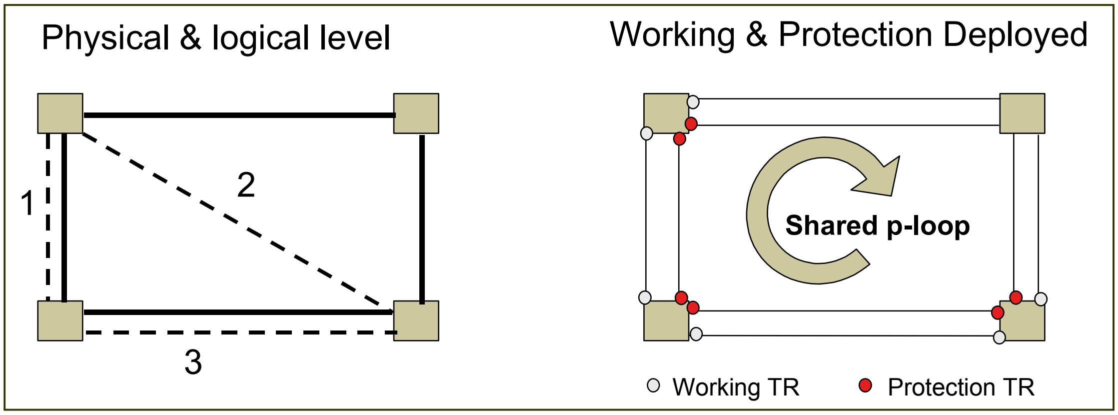

Figure 3. An example of a p-cycle

To get an approximate comparison of the two architectures, a simple weighting was used. All network components were normalized to the transponder. An amplifier is approximately the value of 5 transponder cards. In order to enable the extended reach of an AON solution, a 30 % premium is attached to both the transponder and amplifier in this architecture. The EON architecture was assigned a reach of 1000 Km and the AON architecture was given a reach of 3000 Km. Switching costs are assumed to be the same for both architectures.

2. Nine Node Network Results

Table 1. Cost breakdown of a nine node network

	EON Dedicated Protection	EON Mesh Protection	AON Dedicated Protection	AON P-Cycle
Total TRs	418	328	188	176
Working TRs	154	154	72	72
Protection TRs	264	174	72	80
Regeneration	0	0	44	24
Wavelength Links	209	164	209	171
Relative Cost	602	472	452	375

From table 1, the EON architecture is able to reduce wavelength links and TRs by ~20 % by sharing protection. This is in line with results demonstrated in the past [3]. The EON architecture is always more expensive than the AON, irrespective of protection scheme. In larger networks with more optical pass through the difference between AON and EON would be more dramatic.

The p-cycle approach actually has fewer OEOs than the dedicated solution. This is due to reduced regeneration requirements as electrical points can serve a double purpose, sharing protection and regenerating the optical signal. As the optical paths are broken up to share protection the path lengths become shorter and regeneration requirements are reduced.

3. Availability Considerations

No comparison between protection types would be complete without considering availability. AON architectures try to eliminate electrical points in the network, and thus the distance between switching points increases. In the backbone network, availability is driven by fiber cuts as they are the dominant cause of unavailability. A comparison is shown between dedicated and shared protection schemes in EON and AON architectures. The fiber failure rate is 1/1000 km/yr and the Mean Time To Repair (MTTR) for a fiber failure is 24 hours. The average availability can be used as a comparative metric since the same connections are used in all scenarios.

Availability in a dedicated protection scheme, can be calculated by taking the probability of both working and protection paths failing simultaneously. The total availability must also consider the probability of nodal failures.

$$A_{tot} = A_{node1} * A_{node2} * A_{disjo\,\mathrm{int}\,paths}$$

$$A_{disjo\,\mathrm{int}\,paths} = 1 - (U_{path1} * U_{path2})$$

Dedicated protection, with receive end switching can easily achieve sub 50 ms restoration times. Failure detection requires approximately 10 ms, switching to the protection channel takes tens of milliseconds. The total restoration time for a 1+1 connection will be ~ 30 ms.

The availability of a P-cycle is calculated in the same way as ring availability. Each working path is combined in a loop with its corresponding protection path. To share as much protection bandwidth as possible, rings are extended. The added size makes p-cycle availability slightly lower than its dedicated equivalent. P-cycle restoration should be similar to the times expected of a BLSR ring. 50 ms restoration times are possible in small rings but could get as high as 100-150 ms as rings become larger. [3]

The calculation of link based mesh availability is done slightly differently. It is assumed that a single failure is 100% restorable, but a double failure on any particular connection will cause outage. Since the link based restoration algorithm restores a single link failure with more than a single link, the protection path will be longer than the working path. To maximize sharing of protection bandwidth, the protection paths are often much longer than working paths.

Below is a table that illustrates a comparison between protection types and availability calculated from the nine node network explained in the previous section.

Table 2 Availability of nine node network

Protection Type	*Average Availability (%)*	*Restoration Times*
Dedicated	99.994	~30 ms
Link Based Mesh	99.985	~100-500 ms
P-cycle	99.990	~100-150 ms

The results were obtained with [4] and are inline with expectations. As the protection techniques extend the protection routes to share bandwidth, their respective availabilities will decrease. It should be noted that link based mesh restoration can improve if there is sufficient bandwidth provisioned to recover from double failures. P-cycle availability can also improve if the size of the loop considered is decreased.

4. Conclusions

Judging by the nine node example, a significant percentage of OEO conversions can be eliminated by using an AON architecture. A protection scheme based on BLSRs, called P-cycles, has been proposed to be able to share protection within the AON architecture. The P-cycle approach had fewer OEO conversions and used fewer wavelength kilometers than the dedicated model without suffering a significant availability penalty. P-cycles were found to be nearly as effective as mesh algorithms at reducing bandwidth requirements while requiring 46 % fewer OEO conversions.

5. References

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