Leveraging Photonic Flexibility in Multi-layer Resilient Networks

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Abstract: Planning and operation of large-scale deployments of photonic networks and working with a variety of constraints to offer a resilient photonic layer.

1. Introduction

With the advent of large-scale network deployments of photonic networks built on varying degrees of colorless, directionless, contentionless, and gridless technologies, the photonic layer itself has become able to offer resiliency. This has required the development of planning tools to take advantage of the flexibility present in the photonic layer to restore traffic in the event of outages. Such tools need to help explore the tradeoffs in network architecture, route viability across both home and restoration paths, execution of failure simulations, visualizations to help convey the results, and ultimately network control to provide centralized planning.

2. ROADM Architecture Constraints

In the past several years, the industry has been introducing ROADM architectures which offer a great deal of flexibility in wavelength routing. However, the choice of add/drop structure can provide different cost optimizations while introducing a degree of routing constraints. For example, fixed point-to-point services may be provisioned on direct attach ports (CDA), while restored services are provisioned on colorless, directionless (CD) or colorless, directionless, contentionless, (CDC) ports. While CDC add/drop structures provide the most flexibility, they may not be required at all sites. A hub site with many degrees and lots of services may require CDC, but smaller spoke sites may lend themselves to CD add/drop structures.

Another key enabler has been the introduction of gridless deployments which have introduced flexibility in defining Media Channel (MC) granularity. Gridless line systems are leveraged both to support the evolution of increased spectral width Network Media Channels (NMC) (due to increased modulation rates) and the ability to route a group of NMC in a common MC to increase spectral efficiency on the link. While fixed grid line systems dictate a one size fits all approach, flex grid line systems offer an ability to further optimize spectrum utilization and accommodate different spectral width signals.

3. Photonically Restored Services

While ROADMs have been used for some time to provide rapid service turn up, it is relatively recent that mesh network topologies with photonically restored services are seeing large scale deployment. A primary use case of photonic restoration is in environments where the network may experience multiple fiber conduit / shared risk outages. In general, higher layers will provide rapid restoral of connections while the photonic layer can restore both connections and capacity to the network. Network planning at higher layers can ensure connectivity for single shared risk failures, while the photonic layer repairs events that might otherwise isolate services in the event of more than one shared risk failure.

In comparison to higher layer routing constraints, some fundamental constraints for the photonic layer are the need for contiguous spectrum availability across multiple links and whether the route provides sufficient margin to recover the optical signal. While a real time path computation engine (PCE) can generally perform the spectrum allocation, it may do so in a greedy way without consideration for spectral blocking that may occur going forward. Furthermore, the type of analysis performed to ensure route viability is time consuming enough that is generally not performed in real time during a restoration event.

For a non-restorable service, the number of routes to consider is bounded by the number of services. However, for a restorable service, one must validate there are enough viable diverse routes to provide the desired service availability.

4. Viability Constraints

Where an end-to-end route is not viable for a given service rate, there are some options to consider. One is to introduce regen into the route. This provides an opportunity in the planning phase to optimize where best to place such regen to both make the route viable and maximize its ability to be used by restoration paths associated with the service. A regen placed in the 'home' path of the service can then essentially become an include constraint for restoration paths associated with the service. Where constraining the service to utilize regen deployed in the home route does not provide enough route diversity, regen may be placed in the network which are not dedicated to a specific service. Such regen are sometimes referred to as "free pool" or shared regen. Once again, the physical placement of such shared resources wants to be performed in a network planning phase to maximize their reuse across multiple services and to logically assign them into restoration paths.

Another consideration is to trade spectral efficiency for route viability by utilizing an MC with more than one NMC to carry a given service rate. An example of this use case would be to carry a 400GbE client on 2x200G NMC bonded together by FlexO.

A final consideration is to provide full capacity for the home route and some set of restoration paths, but to allow the photonic layer to reduce its rate for a given modulation class on restoration paths that otherwise would not be viable. This must be understood to reduce the amount of client traffic carried and wants to be coordinated with higher layer clients using aggregated links such that one or more links can be disabled or by using FlexE to adapt the client rate to that delivered by the modem.

In network operation, route margin can be impacted by issues arising in the network. While margin can be actively monitored for the current route of a service by the modem itself, there is a desire to proactively monitor planned restoration paths. This can be done through monitoring the SNR performance of each link in the route and creating an estimate of the overall route performance. If a given route is found to not be viable, the service's restoration plan can be updated to avoid the issue.

5. Failure Simulations

In order to validate the network plan, it is necessary to perform failure simulations to determine if it can meet the desired availability goals. This phase of network planning is used to ensure that enough spectral capacity is present in the network and to understand the impact of potential wavelength blocking. Given some of the network environments where photonic restoration is being deployed, there is a desire to model the performance in the presence of multiple concurrent shared risk failures in the network.

In some of the most demanding environments, there is a significant probability of two or more concurrent shared risk failures present in the network. That leads to the desire to benchmark the performance for all 2 or even 3 concurrent shared risk failures. The actual network, however, may experience a distribution of concurrent shared risk failures beyond which it is practical to simulate all such cases. As another validation benchmark, it is useful to simulate a random sequence of shared risk failures which represent a distribution of failures. Such a distribution can based on a metric such as the average number of N fiber cuts / fiber span length / time interval, e.g. N cuts per 1000km per month. The value of N can be based on customer experience or derived from historical data.

An important metric to consider when analyzing the simulation results is to understand the availability provided to the higher layer interconnect. One or more photonic layer services often have diversity constraints between them as they represent redundant interconnect for higher layers. As such, there is a desire to report on the resulting availability of the diverse service group.

6. Visualization

Given all the interrelated constraints, it is important to provide visualizations to help provide insight to network behavior. Such visualizations can include obvious views of how the service is routed, but also how the spectrum is allocated along the path of the service along with context of what other services may share that route and/or how other diverse services are routed.

In the context of running failure simulations, it is desirable to be able to get the summarized results of such simulations, but also to be able to easily identify which events may have led to service issues. Once identified, those events want to be able to be easily re-created in simulation and their impact on service visualized. To provide additional insight, views on how the spectrum is utilized across the entire network for both the home and accumulated results of failure simulations is desired.

7. Summary

With the deployment of colorless, directionless, contentionless, and gridless ROADMs, the photonic layer now offers a practical means to provide mesh restorable services. In order to fully leverage this flexibility, a set of tools and planning capabilities is described.