Electrical & Photonic Networking:
Finding the Right Balance

Electrical and photonic switching technologies are often viewed as competing technologies. In truth, these two technologies have complimentary networking attributes, which must be combined in order to deliver optimal network architectures. The key is in striking the correct balance. In this paper, we examine the specific capabilities being sought of each technology, as well as their proper application in a core network.

Background

Economic efficiencies in backbone networks have historically been achieved by substituting electronic equipment with photonic equipment. The earliest example of this was the introduction of optical amplifiers, which took the place of electrical repeaters, required every 40-80 km. The reach capability of transponders still required full regeneration every 400-600 km. The trend of replacing electrical equipment continued with the introduction of ultra long-haul (ULH) photonics and optical add/drop multiplexers (OADM). Systems utilizing these technologies reduced electronic conversions on point-to-point spans, but still required electronics to network at multi-directional sites. The next step in this evolution, agile photonics, removes electronics from multi-way sites and extends the economic benefit of photonic networking across a larger portion of the network.

The opportunity to remove unnecessary OEO transitions in a network is economically compelling, but network functions that require electrical processing must still be accommodated. These functions include multiplexing, STS-based grooming, IP processing, or service layer performance monitoring. Also, the majority of connections in the long haul market are IP and STS-based demands of sub-wavelength size. There are two primary networking appliances that will have direct connection to the optical layer to serve these demands: routers and STS-1 based electronic cross-connects (EXC). The IP layer can feed directly into the optical layer when the port speed is OC-192 (10 Gb/s) or greater. When port speeds are smaller than this rate, the router port would be connected to a cross-connect for multiplexing up to the line rate.

To take full advantage of the cost savings offered by agile photonics, the grooming function should be moved towards the edge of the network. We also need to examine cross-optimization of the grooming and transport functions. The implications of migrating the grooming function to the edge of the core must be examined in the context of the network as a whole. The question is, where do these distinct technologies fit in a network, and what is the right balance?

North American Core Network Model

In order to properly examine the role of various technologies, it is useful to form reference network models. Consider a 100-node network model of a U.S. carrier backbone. To create a traffic pattern, a distant-dependent, gravity-weighted model was created with data-centric cities appropriately weighted. Three terabits of traffic, which represents ~15% of the total U.S. backbone capacity, was applied. The results are summarized in the following table:

	Unique A-Z Demand Pairs	Total Traffic (Tb/s)
DS-3 – OC-12	3481	0.6
OC-12- OC-48	520	0.65
OC-48- OC191	156	0.65
OC-192 +	60	1.2

Table 1. U.S. backbone network traffic breakdown

Approximately one-third of the traffic volume, which forms 60 unique A-Z pairs are of sufficient bandwidth to warrant dedicated OC-192 wavelengths. This is traffic that would be driven by backbone routers and EXCs. The vast majority of A-Z connection pairs are at a sub-wavelength rate and require mid-point grooming through an EXC to increase wavelength fill. Twenty to thirty large core nodes would be chosen as "grooming nodes", which essentially serve as STS-1 connection tandems. At these tandem sites, the EXCs would need to be capable of STS-level grooming to aggregate the traffic onto the express layer. In addition, they will provide local traffic multiplexing, carrier demarc (with service layer performance monitoring), and STS-1 based hairpinning (for test access and local grooming). All other locations have direct connections to several of these grooming nodes to increase networking efficiency. This has the effect of segmenting the network into 'Collector' and 'Express' layers (Figure 1).

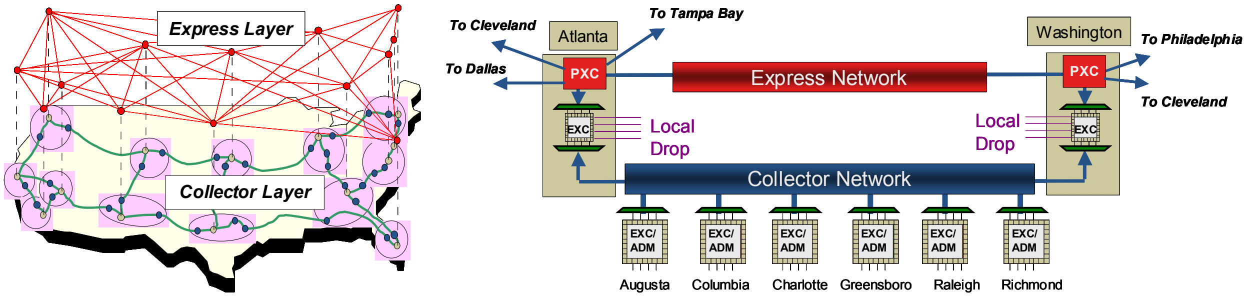

Figure 1. The layering of the U.S. backbone network

The groomed traffic model is added to the A-Z demand between the 20-30 cities networked in the Express layer and further adds to the fill in this network layer. The net result is 70% of the wavelength-kms reside in the Express layer, which represents the largest source of traffic growth and cost in the network. Grooming is still required in the express layer, despite the relatively large amount of traffic carried between a smaller number of nodes.

Express Layer Routing Results

By routing the groomed traffic over the express network, the following characteristics are found:

- The average connection length in the network is 2500- 3000 km

- The average distance between nodes is under 800 km
- 70-80 % of the wavelengths at any given multi-directional junction on the express layer are passing through

It therefore becomes evident that a solution is needed that enables cost reduction for connections passing through a node. This would also result in significant improvement to a networks' operational efficiency.

Network Architectures

Today, optical networks use point-to-point DWDM line systems, coupled with OADMs. They use back-to-back transponders at multi-way junction nodes. Transponders are required at junction sites due to the analogue engineering complexity and lack of a dynamic photonic system. Wavelength flexibility is achieved by terminating the photonic path with either a fiber patch panel, or an EXC. Recent advancements in technology enable agility in the photonic layer through a combination of photonic switching elements, gain-flattening amplifiers, ULH optics, dispersion compensation, and full spectrum tunability. These technologies make it possible for wavelengths to be photonically networked up to 3000 km through intermediate multi-directional nodes and OADMs, thereby eliminating OEO needs at all intermediate sites. The economic advantage of minimizing electronic switching is significant, as there is an approximately 20x cost difference to transit an electronic switching fabric, compared to a photonic switching fabric. We will now look at the different architectures.

Opaque Networking Architecture

Opaque solutions make use of point-to-point line systems that require OEO conversions for transiting all fiber junction sites. As mentioned, two architectures are prevalent in opaque networking: patch panel flexibility and EXC flexibility. Since the majority of the cost in passing through a node is wrapped up in DWDM interfaces, a strong argument can be made to pass all traffic through an EXC core for operational simplicity and flexibility. EXCs can manage the grooming, switching, regeneration, and wavelength conversion. In opaque systems, the EXC acts as a large managed regeneration bank, and the line system has a reach optimized around inter-nodal spacing (600-1000 km). VSR technology is emerging which will drop the cost of transitioning from the transponder to the switch and increase switch density. Every wavelength passing through this type of opaque node will require two DWDM TRs and four VSR interfaces. As the node starts to scale, this solution can get quite costly, and inefficient. In figure 2, we illustrate the two distinct junction node models in opaque networks.

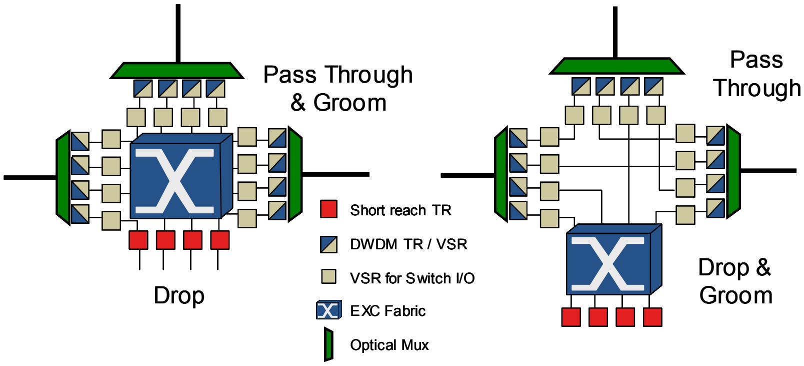

Figure 2. Opaque nodal architectures; EXC flexibility (left) and patch-panel flexibility (right)

Agile Photonic Architecture

In an agile photonic architecture, variable connection lengths can be accommodated on a single span. This ability, combined with photonic switching and ULH transponders, enables photonic bypass, which significantly alters the economics of backbone networking. Using these technologies, it makes sense to move the EXC out of the core, placing it between the collector and express layers. Figure 3 illustrates this equipment configuration at a multi-way site.

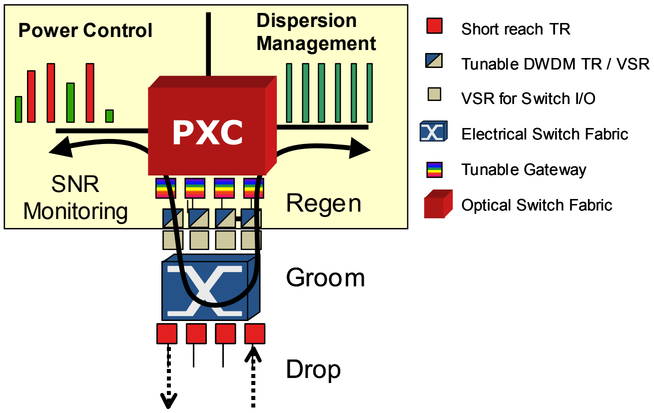

Figure 3. An example of a photonic node

The role of managing wavelength interconnection at the fiber level is done more efficiently and cost effectively (1/20th the cost) with a photonic switch (PXC) instead of an EXC. The PXC sits in the core switching wavelengths between fibers optically. Since the photonic layer is handling all pass-through traffic, this solution results in much smaller EXCs. Taking the EXC out of the core, and removing OEOs at intermediate sites also effectively removes the regeneration function of EXCs. As a result, wavelengths travel from source to sink in the optical layer, requiring a longer reach and a more adaptive line system. The reach of an agile photonic layer needs to be optimized around path lengths (2500-3000 km) rather than the link lengths (600-1000 km), as in the case of opaque networking.

Photonic and Electric Technology: Putting it Together

Capital and Operational Breakdown

The average node in an opaque network requires about 30% of the total OEO interfaces for traffic terminations, regeneration and intermediate grooming. The rest of the interfaces in the node are used to manage the wavelength level interconnection between fibers. These interfaces are here termed "hidden regens", since they are not required for true regeneration. The resulting network cost diagram in figure 4 shows that an agile photonic system has 40% network cost savings as a result of eliminating these hidden regens.

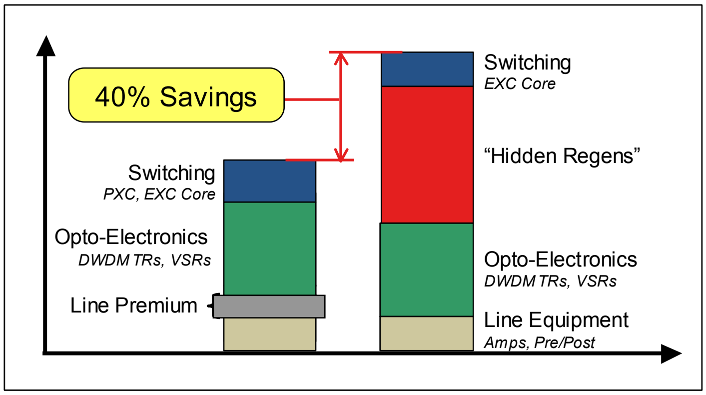

Figure 4. Network savings realized through the elimination of 'hidden regens'

In addition to pure cost savings, hidden regen elimination saves significant space and power, which is also of major concern to carriers today. An example of the space and power requirements of a fully filled four-way site is shown below.

	Power (KW)	Floor Space (racks)	EXC Core (Tb)	DWDM TRs	VSRs
Opaque	47	18	5	400	900
Agile Photonic	20	7	2	100	200

Table 2. A comparison between opaque and agile photonic nodes at a four-direction site

EXC Scale

A challenging area of electrical switch development is scale. From the network traffic displayed previously it is clear there is a need for STS-level grooming switches in the backbone network, but how can a switch be architected that is large enough to handle the massive growth expected in the core of the network? By tiering the network, pass-through traffic does not need to use switch ports on the sub-wavelength switch. This greatly reduces the size of the electrical switch core. The use of multiple fabrics is minimized, thereby significantly reducing intramachine connections that add cost and operational complexity. Figure 5 illustrates, in a network context, the resulting EXC core requirements in the case of having an agile photonic core, or not.

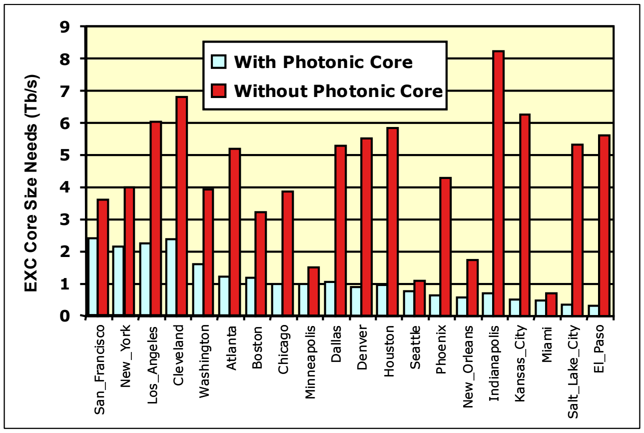

Figure 5. Predicted EXC core sizing for express nodes in the backbone network

A Balanced Approach

There is an active industry debate surrounding OEO versus OOO switching in the optical core. Next-generation networks will require both technologies. The function of sub-wavelength management and grooming will continue, but building a 100% opaque network will cause space, power, and capital problems going forward. A more economical approach is to drop & groom traffic as necessary, and create pipes as full as possible at the edge. Another desirable trait will be the establishment of transparent networking deep into the core of the photonic network. A marriage between electrical switch functions at the edge and photonic networking in the core will deliver the most operationally agile, cost-effective core networking solution.