8:30am-9:00am(Invited)
TuC1

Evolution of Optical Networking

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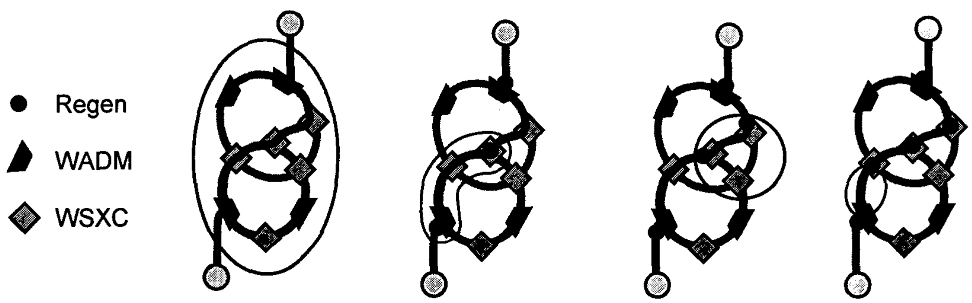
Introduction

Over the past several years, there has been an industry-wide push to examine the combination of WDM and optical switching technologies to provide a configurable optical layer for national scale and metropolitan transport applications. Early on, the vision of this optical layer was one in which signals were transported transparently through a national scale network without regeneration along the way [1,2]. After preliminary experimental work, it became clear that the transparent reach distances over which WDM signals could be transported in such configurable optical networks was limited by physical constraints to about 2000 km [3], which is shorter than necessary on most continents. Recognition of this led to two alternate proposals. One became known as the "Opaque" network solution because it used regeneration on every channel at every configurable point in the network [4]. This solves the problem of limited reach, but introduces many more regenerators into the network, which are one of the more costly components of the equipment. The other approach became known as "Islands of Transparency" because smaller transparent sub-networks were defined that were connected via regeneration sites to form a national scale network [5]. This approach solves the problem of expensive regenerators, and allows the sub-network size to be tailored to the reach length that can be achieved. But even then, a reach length of 2000 km is not enough to handle the WDM ring sizes that would be needed in the West and Southwest regions of the United States.



Network	All-optical	Managed Reach	Sub-networks	Opaque
Management	Simple	Complex	Modest	Simple
Limitation	Technology	Management	Reach length	Fabric size
Pro	Flexibility	Fewest regenerator	Manageable	Evolutionary
Con	Impairments	Interworking	Limited scalability	Highest cost

Figure 1. Network architectures that range from 'opaque' to 'all-optical' are driven by the cost of regeneration.

A fresh look at this problem indicates another potential network solution. In this case, each wavelength path in the network is routed in the network in such a way that regenerators are placed at known sites and at distances that are consistent with the reach length of the technology. This approach minimizes the number of regenerators, but requires that the route length of each link of the network be recorded and communicated to adjoining network management systems each time a new wavelength path is established.

These network solutions are coming in response to rapidly growing demands for voice, transaction data, and internet traffic, which shape the new WDM network topologies and approaches. For example, the characteristics of internet traffic set the reach length needed for internet backbone applications, and the cost savings of a managed reach approach are linked to these traffic characteristics and to the technically achievable reach length. The United States long-distance network is used as an example to illustrate these points. It indicates that for internet traffic, a managed reach network with achievable reach lengths of 2500 km or so can virtually eliminate redundant regenerators and significantly reduce equipment costs, as compared to other approaches.

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Traffic Demand Growth and the Value of Extended Reach Length

A comprehensive traffic demand and growth study has been performed for a USA network consisting of 46 major cities connected by 63 fiber links [6]. The network topology is similar to those used by current USA long-distance carriers. In this study, revenue-bearing traffic demands between city pairs are computed for voice, transaction data, and internet applications separately, and the growth of each of these three components of the traffic estimated from available trends. These traffic demands are used to determine the required capacity, taking into account peak-to-average ratios, framing overheads, and TDM channel loading inefficiencies. Each demand pair is routed in the network using the shortest distance available, and network statistics are recorded describing the number of channels per link, the number and location of regenerator sites, the number of channels dropped at each city, and the total number of channels entering a city. These are used to understand the required reach length and the network economics. The aggregate network traffic demands and growth rates for this study echo the well-known point that internet traffic, if it continues to grow at its present rate of about 150% per year, will dominate the network in a few years

One important observation from the traffic studies is that the average connection distance for internet traffic is significantly longer than that for voice traffic. A span distances of 600 km, as is ordinarily used today, satisfies more than 60% of the connections for voice traffic. But for internet traffic, which is not distance dependent as is voice traffic, a reach length of about 3000 km is sufficient to satisfy 60% of the connections. If the reach length is shorter than this, then unnecessary regeneration is needed on many internet backbone connections.

To quantify this concept, a cost study was performed for the USA network described above, considering four different scenarios[7]. The first scenario assumes that the configurable WDM layer is achieved by "Opaque" crossconnects that consist of transcievers surrounding an electronic switch fabric. The other three scenarios assume that the managed reach approach is employed, where configurability is achieved with optical switch fabrics, allowing only those channels needing regeneration to be handled by transcievers and electronic switch fabrics. These four scenarios show that a modest investment in optical fabrics for configurability, coupled with technologies that achieve a reach length of 2500 km or more, can result in a 40% overall reduction in network infrastructure costs.

Of course long reach technologies require introduction of a combination of new transmission approaches, such as optimized fibers, Raman amplification, near-perfect dispersion compensation, RZ modulation formats, and Forward Error Correction coding techniques. But these are well within the scope of today's capabilities at rates up to 10 Gb/s [8]. Additional challenges include providing technological solutions for optical performance monitoring and optical network management of such managed reach networks [9].

Summary

Traffic growth for internet applications will likely dominate long-distance networks in the foreseeable future, which presents opportunities for new optical layer approaches that are tailored to internet traffic characteristics. One important difference between the traffic patterns generated by internet applications is that the internet connections on average are significantly longer than the conventional voice connections, which allows for network cost savings by combining long reach transport with optical switching technologies to route and manage those connections. Fortunately there is an industry-wide effort to create the required technology for such a managed reach optical layer. The value of the optical layer will be more effectively achieved as reach lengths increase to match internet traffic needs.

References

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