THE COX NATIONAL BACKBONE: BUILDING A SCALABLE OPTICAL NETWORK FOR FUTURE APPLICATIONS AND NETWORK EVOLUTION

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Abstract

Cox Communications has recently begun building out a national DWDM optical backbone which will run over a combination of owned and leased dark fiber spanning over 12,000 miles. While Cox could have leased transport capacity from a national carrier for this purpose, the build vs. leased capacity analysis showed the higher costs of leased transport would not be economical in the future. In the final analysis, the business case for building and operating this network was based primarily on the rapid growth of Cox's cable modem data services alone. However, this network provides additional incremental economic benefits by allowing cost savings elsewhere in the network (e.g., by building consolidated national headends) and by enabling new revenue generating service opportunities not traditionally addressed by cable operators (e.g., a national footprint for commercial services or cell service backhaul).

Two paramount design considerations for the network were total cost of ownership and service reliability. Other important considerations were network scalability, network flexibility, and the ability to rapidly turn up new bandwidth and services. To meet these requirements, Cox is implementing its national backbone with digital ROADMs (reconfigurable optical add/drop multiplexers).

INTRODUCTION

Cox Communications undertook this project for two main reasons: costs and scalability. Since 2001, with the demise of the @Home consortium, Cox had leased intercity transport from a variety of interexchange carriers. These costs had steadily risen as bandwidth needs increased and as consolidation occurred among the various carriers. The business case for this national backbone network was a classic example of build versus buy with several unknowns thrown in for fun. For example, we had to anticipate the market dynamics of the future lease alternatives while also forecasting the demand for future services that had not been clearly defined.

However, there were some very compelling "knowns." History had shown that our cable modem and business Internet traffic had doubled every twelve to eighteen months with corresponding complexity and cost increases. Speed increases for cable modem and business services were common with a corresponding increase in packets being delivered over the existing leased backbone. Backbone circuits were filling at a rapid pace with long delays in getting new links in service. To compensate for the delay in adding capacity, we were having to order new circuits at about a 65% fill point due to the long lead times that some interexchange carriers had in their order fulfillment processes.

It is interesting to note that while the costs of transporting a megabit for a mile had declined in the period from 2003 to 2007, the bandwidth needs far outpaced this declining cost rate. Figure 1, below, shows the aggregate bandwidth growth of Cox's network for the last 18 months. With demand continuing to increase, the business case was relatively straight forward.

Another driving factor in the decision to build this network was operational simplicity. In the current mode of operating, Cox had to coordinate multiple entities in the turn-up of a new circuit. First, we would contact the interexchange carrier about three to five months before a cross section was expected to exhaust its existing bandwidth with a circuit order for a new intercity link. This was followed up with equipment orders to up to four vendors for DWDM and SONET last mile connections from the interexchange carrier's POPs to the Cox regional data centers where the circuits terminated. Circuit turn up, interexchange carrier acceptance testing, and end-to-end throughput verification would follow. The entire process would take months from inception to completion. If Cox owned its own national network, especially one in which circuits could be seamlessly engineered from a remote, centralized center, then capacity additions could be enabled quickly and with far less complexity than the leased mode.

A third driving factor in the decision to build a national backbone was one of flexibility. We had experienced unanticipated demand where we could not respond fast enough using leased circuits. One example of this was a market request to connect multiple 10 Gig circuits from a data center in one region to a colo facility in another. Because we had to wait on Type 2 carrier circuits, we missed the opportunity to serve this customer.

One side benefit that has emerged for Cox's national backbone that was not considered in the original business case is rapid disaster recovery. During the California fires in the fall of 2007, several fiber cables were burned, and capacity for Cox's San Diego and Orange County markets was diminished. The question arose as what would have been the impact had this national fiber network been in place. The answer came back that we would have been able to re-home several wavelengths with a few keystrokes that would have bypassed the damaged fiber. The modular design of the DWDM equipment we are deploying in our backbone is such that the minimum bandwidth that is installed in any cross section is 100 Gb/s. In many cross sections, this full capacity is not assigned on day one, making available some

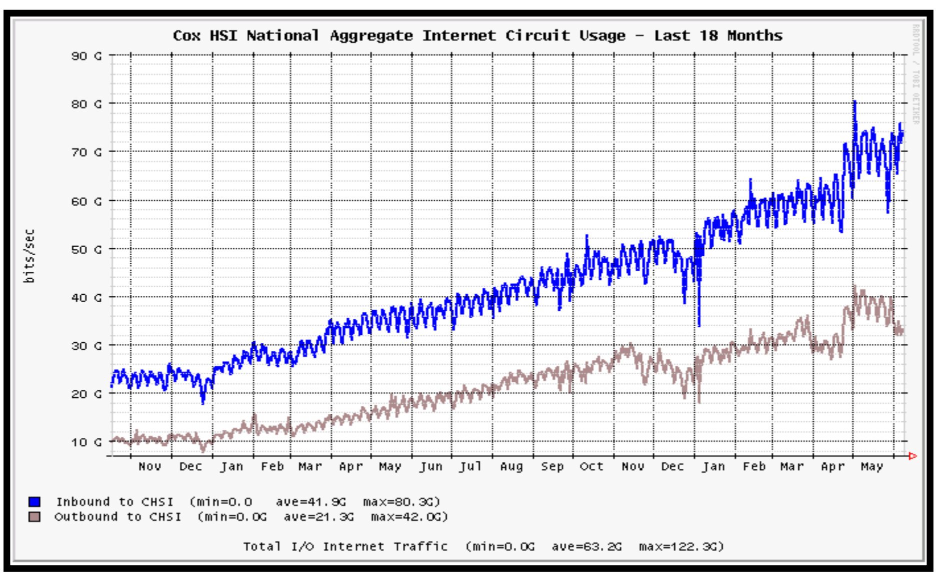

Figure 1 -- Cox Communications Aggregate Internet Bandwidth Growth

Figure 2 -- Map of Cox's Backbone Network

wavelengths that can be used for protected services or that can flexibly be assigned as needed for unusual circumstances. While each potential disaster cannot possibly be anticipated, it is good to note that some outages can be recovered from rapidly with a flexible DWDM network design that can provide end-to-end, any-to-any connectivity between all nodes on the network. The network that emerged from these design considerations is shown in Figure 2, below.

NETWORK APPLICATIONS

Cox's primary use of the national backbone will be for Internet access for our cable modem customers. We have designed our routing tables so that any Internet traffic that can be passed directly at peering centers egresses from our network at these locations. While we still have several locations around the country with Tier 1 Internet transit ports, due to the costs of delivering traffic to these portals, we easily justify the costs of building our backbone into the national and regional peering centers. We have points of presence in Palo Alto, Dallas, Atlanta, Ashburn, New York, Los Angeles, and Chicago.

Cox also uses the national backbone to deliver voice signaling and bearer traffic. We have several soft switches that are used for regional control of the VoIP endpoints. For example, we have a softswitch in Atlanta that controls the VoIP call setup for multiple markets across the country. Signaling traffic from these markets flows over the backbone to Atlanta for hundreds of thousands of calls each day. Network reliability is of the utmost importance since these calls include 911 and other potentially life threatening emergency calls. Long distance traffic also rides the backbone. We have class 4 control points such that any calls that originate in a Cox market and terminate in another Cox market is transported over the backbone's IP infrastructure and are terminated on trunking gateways in the remote endpoint. These trunking gateways not only connect these calls to Cox's local telephony network, they also connect to the local Public Switched Telephony Network. The incremental savings of providing these services over our own facilities amounts to millions of dollars a year.

A very interesting byproduct of having a national backbone is the ability to provide national distribution of high quality video content. One of the needs in a Hybrid Fiber Coax architecture is to maximize the use of the available spectrum on the coax plant. We have begun to digitize channels and distribute as many into a 6 MHz QAM channel as we can at a quality level our customers' expect. Most multisystem operators have settled on statistically multiplexed groups of 12 MPEG2 standard definition channels with a maximum of two MPEG2 high definition channels per QAM. Our marketing groups continue to ask for more channels and higher quality, especially given the marketing hype from the Direct Broadcast Satellite industry about "hundreds" of high definition channels. A technical solution to this competitive threat was needed. While MPEG4 is a possible solution, the millions of MPEG2 capable set top boxes that are in our customers' homes means that solution is still a way off in realistic deployment scenarios. A solution that could be deployed faster was needed. Technology is available today using specialized encoders and closed-loop statistical multiplexers to enhance the capacity of a 6 MHz QAM. The cost of these encoders and multiplexers is prohibitive to deploy in every headend across the country. With available bandwidth on a national backbone, the economics of a couple of centralized digital encoder headends and nationwide IP distribution of multiplexed HD content are very attractive. By centralizing the encoding to only a few locations, Cox will be able to provide hundreds of high definition choices and several hundred standard definition choices to all markets across the country. As well, the higher cost, closed loop encoders would provide a quality that is indistinguishable from the current generation of encoders in use in most headends. The national backbone enables the video feeds to be fixed routed using MPLS so that the path from any one of the national headends arrives at a receive site from two diverse paths at all times.

Cox commercial business services also benefits from this national footprint. Inter-market services such as Ethernet Private Line, High Capacity point-to-point services, and point-to-multipoint WAN services can now be offered to business customers throughout Cox's service area. Cox was already providing some lower capacity services using the leased transport capacity. With a larger capacity network of its own, Cox can offer up to 10 Gigabit per second services on a competitive basis. In partnerships with other carriers and other Local Exchange Carriers, we can serve any location in the United States.

NETWORK DESIGN CONSIDERATIONS

In the selection of the DWDM vendor and the dark fiber provider for this project, there were two overarching design considerations: first, the total cost of ownership of the network, and second, the reliability of the end-to-end services. Each market was to be designed so that no single point of failure exists in the network. This includes dual entrance facilities to each building, bypassing some locations with manhole fiber splices instead of entering the building and patching through a fiber cross connect, redundant power, and back-up power at every location where we deployed electronics. Hut spacing and the quality of the interoffice fiber also made a big difference in the overall design and costs of the network. While closely spaced re-gen sites might seem like they would increase reliability, the trade-off of increased electronics costs did not justify the extra benefits. What emerged was a balanced network that met reliability and throughput needs while maintaining reasonable hut spacing across the country. It is interesting to note the variability of hut spacing as shown in Figure 3, below.

Selection of a dark fiber vendor was pretty limited in that we wanted to use a single provider for as many cross sections as we could. This would build a good relationship with that provider as well as simplify the operational handoffs in fiber restoration and turn-up. Another criterion was the quality of the fiber itself. Significant penalties would accrue if the overall fiber types were such that extra re-gens or extraordinary dispersion compensation would be required. Figure 4, above, shows that the vast majority of fiber for the Cox national backbone is Corning E-LEAF, the desired fiber from a design standpoint.

There were many available options for optical networking equipment and technologies, but after evaluating these options against Cox's network requirements, Cox decided to build its network with digital ROADMs. Digital ROADMs perform an optical-electrical-optical (OEO) conversion for every DWDM wavelength at every node. While this may seem expensive, modern photonic integrated circuits (PICs) have reduced this cost substantially. For reconfigurability, the OEO conversion allows the use of integrated digital electronic switches in the ROADM instead of all-optical wavelength-only switches.

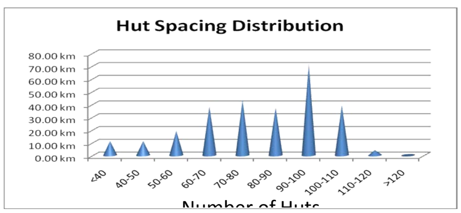

Figure 3 -- Distribution of Hut Spacing Distances

Digital ROADMs typically perform a 3R (regenerate, reshape, retime) operation at every node for every wavelength, and this significantly reduces the optical engineering complexity for digital networks built with these ROADMs. What used to be a large and complex engineering problem for deploying all-optical ROADMs, the necessity of calculating worst-case performance characteristics for a number of optical parameters for every path for every wavelength in the network, is reduced to a simple span engineering solution for digital networks. In a digital network, only individual optical spans between adjacent nodes must be engineered to guarantee any-to-any connectivity of every node in a network. Moreover, the digital ROADM's 3R OEO architecture eliminates the cumulative optical impairment limitations of all-optical ROADMs and permits unlimited node counts and network sizes and flexibly supports multi-degree mesh networks.

Network flexibility was a major engineering criteria for the Cox national backbone. Some DWDM solutions would force a custom design with Dispersion Compensation Modules engineered for the maximum point-to-point span distance anticipated at the time of the initial engineering of the route. While a network could be designed in this manner, it would lock the solution into a specific set of origination and termination points. If there was an unanticipated need, the network would have to be re-designed and possibly reconfigured. This is not a problem with a digital DWDM ROADM that provides 3R regeneration of the optical signal at every re-gen and terminal location. Network re-routing and short-term bandwidth needs can also be accommodated easily with the add/drop nature of the digital network.

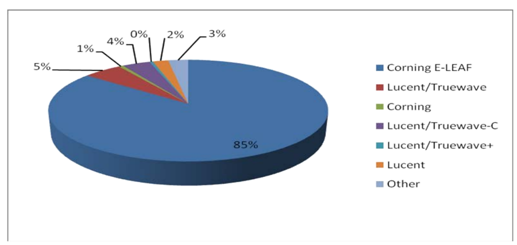

Figure 4 -- Fiber Types in the Cox Backbone

Protection alternatives were hotly debated topics during the initial design phase of the national backbone. Cox made the decision to use layer 3 protocols as the main protection mechanism in the network. While we could build a network that was completely redundant, cost analysis showed that if each wavelength were protected on a 1:1 basis that the equipment costs would increase by 80%. This was primarily due to the fact the protected service would always require an equivalent and dedicated amount of transport capacity for protection as the primary path. One of the features of a digital ROADM, since it is not based upon transponders for transport, is that it allows you to have one wavelength protect multiple other wavelengths. In general, we have settled on a 9:1 protection scheme such that one wavelength in each cross section is available for maintenance or backup bandwidth. In some cross sections where we have through routes from one market to another that bypass the local add/drop function, we are setting aside additional protection wavelengths, again on a many-to-one protection scheme. While we are incurring some increased costs, the overall protection costs are still much lower than 1:1 protection, and in turn we have increased route survivability and provided flexible bandwidth configuration alternatives that provide operational benefits to the network.

OPERATIONAL CONSIDERATIONS

When you think of the operational implications of a national fiber optic network there are some key concepts that come to mind such as rapid capacity activation, detailed performance monitoring, specific alarm notifications that are pertinent to the problem, the ability to rapidly isolate trouble, and having positive assurance that services are being delivered as expected. Let's delve into these in more depth.

Rapid capacity activation is enabled in this network through a combination of upfront engineering and the use of digital ROADMs. Cox has taken the steps to position the chassis and re-gen sites for one year's forecasted growth. Once the chassis and common equipment such as network management cards and bandwidth multiplexers are installed, adding bandwidth capacity on the digital ROADM is relatively easy and is accomplished in 100 Gb increments by adding line cards. Rarely would any one cross section experience more growth than that in one year.

Client interfaces are only required when services are actually turned up. When additional services are needed, individual client optical modules will be sent to the two endpoints a couple of days ahead of the need. Technicians, either Cox personnel or SmartHands technicians in remote collocation environments, will slot the daughter boards as instructed in a work package. The ROADM will then signal through its data communications channel to the centralized provisioning center of the presence of the new plug-ins. Using point-and-click provisioning, electronic cross connects would then be made to pass the incoming traffic to the appropriate output port, wavelength, and timeslot. End-to-end routing of the new services is accomplished remotely via a GMPLS control plane, and no truck rolls are required to intermediate sites in the path, and no additional optical layer engineering is required. End-to-end connectivity can be established in a matter of days instead of the months it takes in a leased circuit environment.

During a turn-up event, the ability to generate a test signal from the client interface itself would be useful and would enable remote confirmation of circuit continuity even if there was not a technician present with a portable test set. This is very easily possible in a digital world. One of the benefits of a digital ROADM is that performance monitoring is provided for every wavelength at every optical to electrical conversion point. In a digital optical network, this occurs at every node. With a G.709 digital wrapper applied to each service path in the digital ROADM, bit error rate (BER) testing may be carried out prior to service turn-up using an internally generated pseudo-random bit stream or on live services in real time.

Every service interface has a corresponding set of performance statistics derived from the G.709 overhead. Appropriate threshold crossing alerts can then be set to notify the Network Operations Center of any degradation in services as well as the specific span in the network where this degradation has occurred. From the viewpoint of maintaining a national fiber optic network, this type of visibility is paramount to providing reliable services.

Along with the performance monitoring on a span by span basis, another attribute that is necessary in a national optical network is alarm filtering and suppression. If there is a major outage in the network, there could be hundreds of alarms generated from loss of services in all of the daughter circuits that ride over the system. An intelligent Network Management System is required to filter those alarms, suppressing the non-pertinent ones. Consistent naming conventions and intelligence embedded in the alarm processing system provide information that will assist in pointing the technicians to the correct source of the problem and allow more rapid service restoration.

Finally, a wonderful feature in a digital ROADM is the ability to loop back sub-rate interfaces at any electrical conversion point in the network. This loopback capability can be applied at a re-gen site, add/drop location, or terminal location to quickly isolate intermittent trouble. It will be used in Cox to sectionalize the network between maintenance entities where we have contracted maintenance activity in certain cross sections of the country to an outside party.

NETWORK GROWTH AND EVOLUTION

If optical transport networks simply grew linearly, then network engineering and operations would be a straightforward matter. As we all know, this is rarely the case: services grow faster than expected and not always where expected, new services are introduced, new nodes need to be added, and sometimes whole cable systems are sold to or acquired from other MSOs. All this points to the necessity of engineering a network today for maximum flexibility tomorrow. Key elements of this requirement are scalability, rapid service turn-up and cutover, non-disruptive upgrades and node additions, guaranteed any-to-any connectivity between any two nodes in the network, and an optical layer that requires little or no re-engineering as the network evolves.

Digital ROADMs provide a reasonable solution to all these requirements, and this is possible because a digital ROADM, due to its OEO and digital switching architecture, segregates the optical layer from the service layer. This makes service delivery independent of optical layer engineering and brings unique capabilities to the network. At the optical layer, network design is reduced to simple span-by-span optical engineering, and once the initial span has been engineered, adding additional bandwidth is accomplished by adding line modules with no additional optical layer engineering required.

In the initial network design, one simply provides a pool of available bandwidth at the optical layer. This pool of bandwidth is then used as a resource to be allocated to services as they are turned up. Allocation is implemented at the node through the integral digital switch, and allocation occurs across the network under the control of a GMPLS control plane. This allows services to be routed through the network via any combination of nodes that have available bandwidth along the path. Providing sufficient bandwidth is available at the optical layer, it is possible to connect any two nodes in a digital network with any service.

Treating optical layer bandwidth as an allocatable resource has other benefits, as well, including bandwidth conservation. Because the digital switch in a digital ROADM mediates between the optical layer and the service layer, it can aggregate and groom multiple sub-rate services onto a single optical layer lambda. For example, multiple GigEs can be groomed onto a single 10G wavelength. And it can do this on a service by service, wavelength by wavelength, and span by span basis, ensuring optimum usage of available bandwidth throughout the network. In a similar fashion, super-lambda services can be created by allocating one high-bandwidth service across multiple optical layer lambdas. For example, a 40G client service can be allocated across four 10G lambdas for transport at the optical layer. This allows 40G services to be transported across a network designed for 10G services, and without any network re-engineering.

Digital ROADMs, because of their inherent ability to switch services over any available bandwidth in the optical network, provide significant network migration capabilities which can be used at any time to reroute traffic through the network for load balancing or bandwidth optimization or to perform maintenance operations such as adding a new node in the network. Digital ROADMs typically provide a bridge-and-roll function that allows a second, parallel path to be created through the network between two end-nodes carrying live traffic. Once this "bridge" is created, traffic is "rolled" onto the second path in under 50 ms, and the first path is then free for re-use or can then have maintenance operations performed on it without disrupting live traffic.

The digital ROADM's ability to reroute services through the network in real time can also be used to provide flexible service protection options that eliminate the need for providing dedicated, redundant optical paths for every service on the network. Using shared protection, sufficient additional optical layer bandwidth is provided for service protection in the initial network design, and this additional capacity can be allocated on the fly to support alternate routing of any failed path. Should a fiber cut or equipment failure occur, the GMPLS control plane recognizes this and immediately and automatically reroutes traffic around the failed path. This provides a cost-effective protection mechanism without the need for dedicating 1:1 protection bandwidth that cannot then otherwise be used.

Finally, digital ROADMs permit multi-degree mesh networks to be efficiently designed and turned up. In this case, the ROADM's integral digital switch is simply used to switch service traffic onto the appropriate optical layer interface for the intended mesh path. No complex optical layer engineering is required because the additional degrees coming off a node are still treated as single spans at the optical layer. This capability allows a national network to be built with integral regional networks and thus allows regional and national traffic to be carried over a common network. The mesh nature of such a network provides more traffic routing and protection options than traditional rings.

SUMMARY AND CONCLUSION

Cox's construction of a national fiber optic based network has positioned Cox to economically provide expanded services for the residential and business communities that it serves. It has also given Cox a competitive advantage in rapidly responding to changes in offers from Incumbent Local Exchange Carriers and Direct Broadcast Satellite companies. The scalability of the Cox national backbone and the digital ROADM used to implement it will also provide Cox a way to deliver business services that have not been offered by an MSO in prior years and is an excellent complement to the Cox local "last-mile" network. Given Cox's operational excellence, this network will provide for outstanding levels of service for higher speed data offerings, expanded video lineups, and reliable voice applications, both wired and wireless, for years to come.