Networking Benefits of a Long-Reach, High-Bandwidth, IP-Optimized DWDM Platform

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Abstract: We demonstrate the equipment hardware, fiber route and cost savings in backbone applications stemming from long-reach, high-bandwidth, IP-optimized DWDM platform enabling the provisioning of unidirectional optical circuits using customary bidirectional interface cards.
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1. Introduction

The exponential growth in demand for higher data transmission capacity has been fueled in the last several years by growing Internet traffic between networked devices, the advent of the Internet of Things (IoT), video on-demand, and the development of cloud-based services [1]. The continued proliferation of smart devices, the increased adoption of high bandwidth applications, such as video and music streaming, video conferencing and big data initiatives, and the increasing prevalence of cloud computing are not only driving an increased demand for bandwidth but also developing new traffic patterns which means in certain cases asymmetry of traffic: unlike symmetrical services like SONET/SDH, the IP traffic, which is the main traffic carried by backbone networks, is asymmetric in nature as observed for, e.g., video watching and downloads of OS upgrades on smartphones [2].

Measurements made for 57 IP link pairs between routers on a major US-wide backbone network show that the asymmetry of real traffic is significant [3]. A ρ symmetry ratio of a connection was defined in [3], in such a way that ρ equals 0 for a link with traffic flow in just one direction, and 1 for a link with identical traffic in the two directions. The analysis of link traffic data over eight-week interval lead to $\rho_{Network} = 0.5$, meaning that a significant number of meaningless bits were transmitted in the network with no revenue-generating payload due to the use of bidirectional, symmetric wavelengths as delivered by the current DWDM optical networking platform hardware.

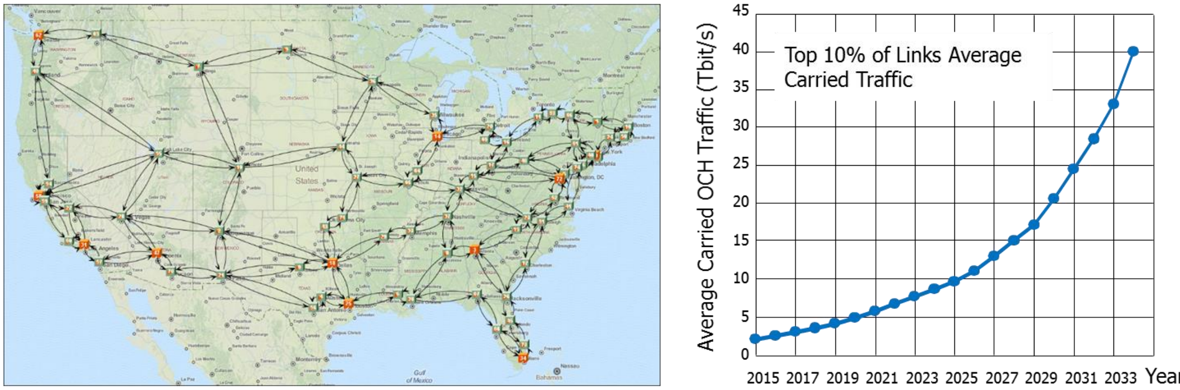
This article describes the use a long-reach, high-bandwidth DWDM platform that is IP-optimized in the sense that unidirectional optical circuits can be provisioned using the customary bidirectional interfaces. The benefits of these three features are assessed in term of hardware resources that are required and network cost when the capacity transported over a US-wide backbone network linking datacenters grows with time.

2. Network modeling

The network simulations for this study were done using a modified version of the open source tool Net2Plan (developed at Universidad Politécnica de Cartagena, Spain) as a framework to store and display the network data in which the IP-optimized DWDM simulation algorithms were run. For this study, the continental US reference network CORONET was used as in [3]. A full mesh set of 55 bidirectional IP traffic demands were generated between eleven areas of data centers. The traffic weighting and locations of these data centers were determined by [4], which shows data centers in the following 11 cities: NYC (241 data centers), Washington DC (196), San Francisco (178), Los Angeles (153), Dallas (150), Chicago (141), Atlanta (84), Seattle (72), Miami (67), Phoenix (62), and Houston (60). These 11 cities are highlighted in red color in Fig. 1(a).

A total of three optical line system configurations were simulated to show benefits of reach and spectral bandwidth which consisted of the following: a 90-channel EDFA-only configuration with 2000km reach, a 90-channel hybrid EDFA/Raman configuration with 4500km reach, and a 150-channel all-Raman configuration [5] with 3800km reach. All reachability figures for the three line systems are based upon the current generation coherent 100G DP-QPSK modulation format at 50GHz channel-spacing with an average of 92km spans between in-line amplification sites. The reachability distances were determined by OSNR benefits of the hybrid EDFA/Raman system approximately 2.5 times the reachability at short wavelength compared to the EDFA-only solution. For the all-Raman system, additional penalties for L-band are considered which reduces the reachability to 3800km.

For each of the three optical line system configurations, two simulation sets were done for accommodating the generated IP-traffic demands. The first simulation that was done was the typical bidirectional optical channel circuit configurations that are currently deployed in DWDM long-haul optical networks. The second simulation was the IP-optimized optical channels which allows for provisioning of unidirectional optical channels. Both simulations use the same set of transponder equipment with the only difference being how the software configures the card.



(a) (b)

Fig.1. (a) CORONET CONUS topology map, (b) Average traffic carried on top 10% of busiest links in network.

For this study, we used a moderate traffic growth matching the top 10% of the busiest routes in the simulated network (Fig1. 1(b)) with the traffic growth expected in [6]. This study uses an 18.8% percent IP-traffic growth year-over-year throughout the network over a twenty-year period.

Within the simulation, a full-mesh of IP-traffic demands are generated between data centers with an average asymmetry ratio of 0.5 which is derived from the results of [3]. An asymmetry ratio of 0.5 indicates that there is twice as much IP-traffic flowing in one direction compared to the opposite direction of the demand. In our simulations, this asymmetry ratio is uniformly distributed between 0.25 and 0.75 and the direction of asymmetry is randomized. The traffic demands are routed with Dijkstra's algorithm with weights as the link lengths in kilometers on an auxiliary version of the graph in which the link exists in the auxiliary graph only if there is available capacity (i.e. number of channels with 50GHz spacing) for new wavelengths. This results in alternative paths to be taken before resorting to lighting up additional fiber pairs.

A variety of network design metrics are outputted from these simulations including total IP-traffic, total optical channel traffic, total number of transponders, spectrum utilization, bottleneck link utilization, transponder port utilization, route quality, and yearly and cumulative summaries of total network cost. Total costs of the network are composed of fiber leasing costs, operations and maintenance costs, space and power costs, in-line amplification equipment costs, ROADM site costs, and transponder costs.

3. Benefits of key features

3.a. Long reach – Long reach capability enabled by Raman amplification reduces the number of regeneration sites required over long optical data paths, leading to a reduction of about 20% in the number of transponder cards throughout the network. The difference in the number of transponder cards between hybrid EDFA/Raman (4500km reach) and all-Raman (3800km reach) amplification schemes is only about 3%.

3.b. High bandwidth – Fig. 1(b) shows that the capacity on top 10% of the busiest routes in the simulated network exceeds the capacity offered by EDFA-only or hybrid EDFA/Raman configurations in 2024 (assuming 100G channels). At this point of time, the total spectrum usage across the whole network (and not only for the busiest routes) is about 53% for EDFA-only or hybrid EDFA/Raman configurations, and 31% for all-Raman equipment. High bandwidth offers more room for optical channels, thus delaying the need to equip new fiber pairs (which leads to the need to deploy and operate additional common equipment) to meet capacity demands on the busiest routes.

3.c. IP-optimized – In the proposed IP-optimized DWDM platform, unidirectional optical circuits can be provisioned using customary bidirectional interface cards: an interface card in node A can transmit an optical wavelength to node B while the transmit port of the interface card in node B can transmit an optical wavelength to another node different from A. Such a DWDM platform configuration does not fully follow the ITU-T standards; it requires no new hardware development or evolution, but a software architecture enabling to provision OCH in different ways (unidirectional or bidirectional depending on the traffic needs). Therefore the proposed IP-optimized DWDM platform does not induce extra cost as assumed in [3] where new hardware was required to implement the proposed approach.

The capability to provision unidirectional optical circuits avoids the transmission of unnecessary bits as imposed by bidirectional optical circuits, leading to an about 25% decrease in the number of 100G transponders across the network. The interface cards of the proposed IP-optimized DWDM platform being equipped of both transmit and receive ports, it may happen that one of the ports is not used. Simulations indicated that about 5% of ports are unused across the whole network, which could potentially be used for bandwidth-on-demand.

4. Network Cost impacts

Cost figures for the DWDM equipment are based on Ovum data showing average selling prices in industry for the equipment as well as a yearly reduction based on forecasts [7]. Operation, maintenance, space, power, and fiber leasing expenses are based on network data such as a monthly lease within a 20-year IRU. Different cases have been studied, including operators leasing the fiber infrastructure or operators who own the fiber infrastructure. Pan-European networks have been studied as well.

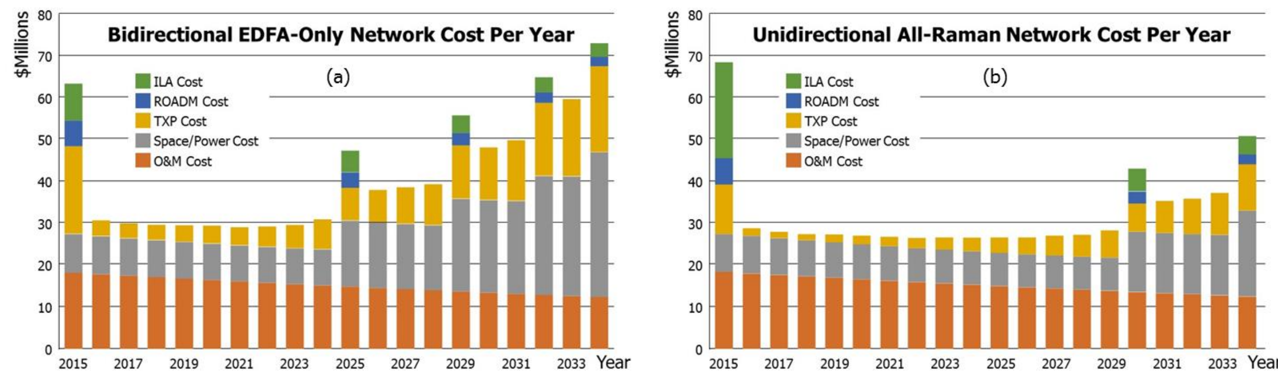


Fig.2. (a) Network cost per year with bidirectional provisioning in EDFA-only network, (b) Network cost per year with unidirectional provisioning in all-Raman network.

Fig. 2 represents the cost structure for bidirectional provisioning in EDFA-only network (a) and unidirectional provisioning in all-Raman network (b) in the case where the operators own the fiber infrastructure in a CORONET-like network. The costs are driven by the equipment CapEx and OpEx (space, power, operation and maintenance). The extra cost required in the first year for longer reach and higher bandwidth as enabled by all-Raman amplification is partly compensated by the lower number of transponders in the unidirectional all-Raman network approach; this extra cost is quickly recouped after two years of operation with yearly savings ranging from $2M to $29M, the highest savings being observed in the years when new fibers pairs need to be lit in the bidirectional EDFA-only network approach to respond to the traffic growth.

4. Conclusion

The benefits offered by the proposed long reach, high bandwidth, IP-optimized DWDM optical networking platform stem from three key features: long reach, wide spectrum and unidirectional provisioning. The benefits are additive, resulting in a reduced number of transponders across the network, a reduced number of fibers required, and leads to a lower network cost for operators owning or leasing the fiber infrastructure.

Unidirectional provisioning of optical circuits are enabled by a new software architecture that has been developed on a fully featured DWDM platform (based on customary bidirectional interface cards), with a general availability of the first software release planned in the first quarter of 2016.

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