Evaluating Efficiency of Multi-Layer Switching in Future Optical Transport Networks

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Abstract: This paper evaluates multi-layer switching architecture vs. all-optical and all-digital switching architectures. Further, the value of incorporating super-channels is evaluated to determine benefit. A real world network model is utilized to quantify and compare results.

OCIS codes: (060.4250) Networks; (060.4256) Networks, network optimization

1. Introduction

Network bandwidth is growing significantly at approximately 40% year over year mainly driven by mobile, cloud and video. As a result there is an increasing requirement from optical transport networks for additional capacity, higher spectral efficiency and lower cost per bit.

To cope up with the increasing high capacity demands, next generation DWDM systems would require line rates greater than 100 Gb/s. Super-channels are the next-generation technology to increase spectral efficiency and maximize fiber capacity [1]. This will be complimented by the introduction of flexible grid WDM channel plan, to the existing CDC (colorless, directionless and contentionless) architecture of the multi-degree reconfigurable optical add drop multiplexer (ROADM) to become the fundamental building blocks of the next generation DWDM photonic layer [5].

While advances in optical transport technologies enable the network capacity scale to multi Tb/s per fiber pair, network planners need to consider not just fiber capacity, but also what mix of service types are expected to traverse the transport network. Prior studies have indicated that even in 2017, 90% of the client services would be 10G or below, while the network line rate has reached 100G and beyond [2]. A digital switching architecture enables the integrated sub-wavelength grooming capability at every add/drop node can provide up to 4x greater bandwidth efficiency in typical long-haul networks [3].

The proposed multi-layer switching architecture in the next generation optical network nodes integrates the digital OTN switching with ODU0 granularity and super-channel based reconfigurable optical switching. It combines the benefits of digital switching architecture for sub-wavelength grooming leaving no stranded line side capacity and super-channel based optical switching for operational simplicity and greater degree of flexibility for express traffic.

In this paper, we present the results of a network architecture analysis showing the cost savings in the optical transport networks with multi-layer bandwidth management in the network node.

2. Node Switching Architectures

While analyzing the multi-layer switching architecture, three principal node architectures in the optical transport network can be described as:

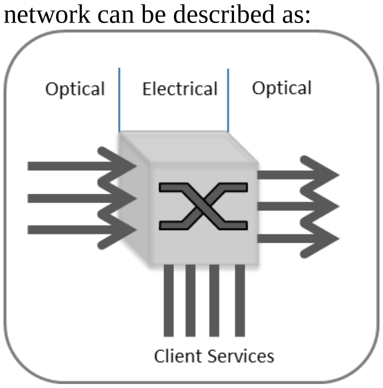


Fig. 1(a) Digital Switching Architecture

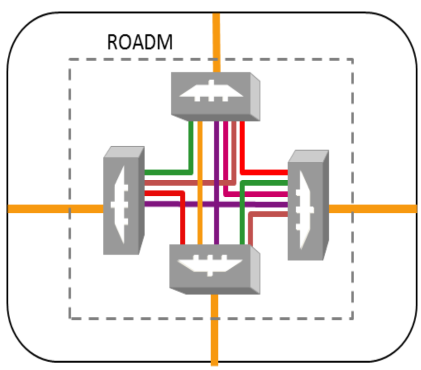


Fig. 1(b) Optical Switching Architecture

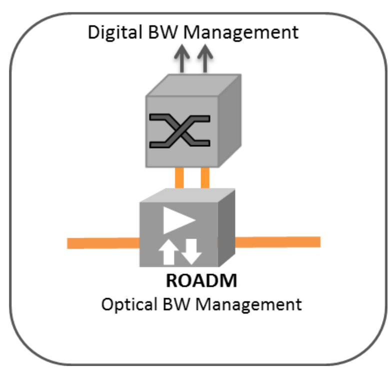


Fig. 1(c) Multi-Level Switching Architecture

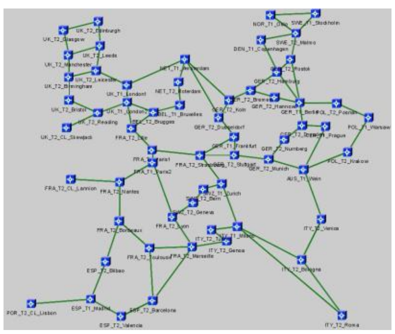
As shown in Fig 1(a), digital switching architecture enables grooming available at every node by integrating the DWDM line modules and digital switching in a single digital transport chassis. This architecture uses OTN standard and provides digital wrapper and OTN multiplexing technologies for an efficient mapping of clients onto line side bandwidth. The benefit of integrated switching architecture is the elimination of extra interconnects between DWDM and any external grooming device in addition to removing the need for manual grooming.

In all optical switching architecture, Fig 1(b), the client services are groomed using a muxponder and mapped to a DWDM wavelength. Once the client signals are groomed on the wavelength, the node uses Wavelength Selective Switch (WSS) based optical switching. There are various versions of muxponder providing variety of client services ranging from 10Gb/s to 100Gb/s. The client signals cannot be individually accessed at intermediate nodes without terminating the entire wavelength and manually re-grooming the client signals onto the wavelengths as needed.

As shown in Fig 1(c), multi-layer switching architecture has integrated optical and digital bandwidth management. It provides flexible ROADM layer with super-channel based optical switching and ODU0 level OTN digital switching. This gives reconfigurable super-channel based optical switching for high flexibility and unconstrained sub-wavelength digital switching for efficiently filling the client services in the line waves.

3. Network Model and Traffic Model

For our study on the impact of multi-layer switching on network cost, we consider a network topology representative of a typical pan-european long-haul network with 58 nodes and 81 links (Figure 2). Multiple fiber types of varying lengths make up the network's links. We identify potential regeneration points in the network using link engineering calculations over various paths. Figure 2 provides relevant network statistics. We used equivalent line system and line module performance across all compared switching architectures. We assume 100 Gb/s per wave and 80 waves per fiber pair. We model traffic on this network according to three specific categories: 50% population, 35% datacenter and 15% international (details in [4]). We consider the following service interfaces for the demands: {1, 2.5, 10, 40 and 100} Gb/s and the distribution of the interfaces is according to industry analyst projections [2].



Network Statistics	
Total Fiber Distance	26,629km
{Nodes, Links}	{58, 81}
Avg. Nodal Degree	2.7
Classification {T1, T2, T3}	{17, 26, 17}
Avg. Link Distance	328.75km
Avg. Span Distance	83.47km
Avg. Link Utilization {Y1, Y5}	{10%, 54%}

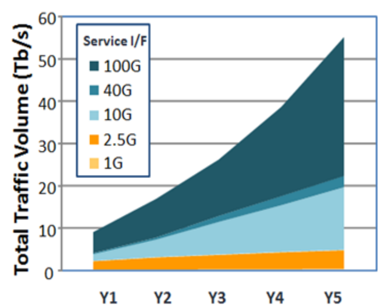


Figure 2 Pan European Network Model Specifications

3. Results

3.1 Comparison – Multi Layer vs. Optical vs. Digital Switching

In the first part of our study (Figure 3), we compared the total number of 100G ports required for each of the switching architectures. With digital switching, grooming is done at every node. Therefore, when there are fewer demands, it maximally fills the 100G waves. However, when the demand increases, all-optical switching becomes much more efficient than all-digital switching because demands can fully-fill the wavelengths. Penalty for digital regeneration for grooming can outweigh the benefits of grooming under those circumstances.

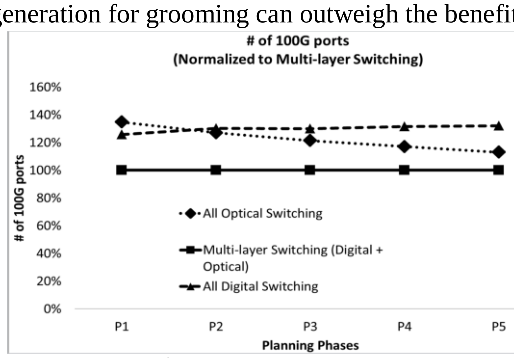


Figure 3 Number of 100G Ports provisioned in Pan European Network

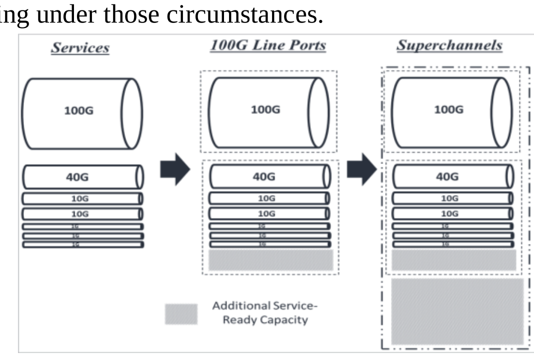


Figure 4 Grooming of Client Services in Super-Channels

Multi-layer switching combines the benefits of both types of switching and uses minimum number of 100G waves under both situations: (1) when the demand is low and the wavelengths are not filled (2) demand is high and the wavelengths can get well filled. The result shows multi-layer switching uses 13-22% less number of 100G ports than the best performance of either all-optical or all-digital switching architectures. Multi-layer switching uses digital grooming for better-filling of the wavelengths, while for fully-filled wavelengths, it optically expresses through the nodes without regenerations for grooming purposes. Therefore, from network planning perspective, network planners should consider multi-layer switching architectures right from the initial planning phase to deploy the lowest cost networks.

3.2 Super-Channel based Multi-Layer Switching

In the results presented above, granularity of optical transport has been 100G. With rising network bandwidth demand, super-channels will be the next-generation technology to increase spectral efficiency and maximize fiber capacity. Flex-grid based super-channels, in simple terms, pack more 100G channels in a given spectrum by removing guard bands and get transported in Nx100G granularity. As explained in Figure 4, 100G line ports are filled using digital grooming of sub-100G services with similar path characteristics. With super-channels, Nx100G demands having similar path characteristics are packed together as a super-channel and that become the granularity of optical transport. With approximately 40% demand growth, this becomes the more efficient mode of transport compared to 100G transport. Our results with 500G (i.e. 5x100G) super-channels show (Figure 5) that there is 7-29% additional service-ready network capacity and service providers can monetize this capacity as and when needed without additional truck-rolls. This significantly reduces the OPEX as with super-channels, there are fewer line-cards, implying less install time, less maintenance and improved reliability. Therefore, with the increase in demands, multi-layer switching combined with super-channels can provide the most logical way to scale the network capacity.

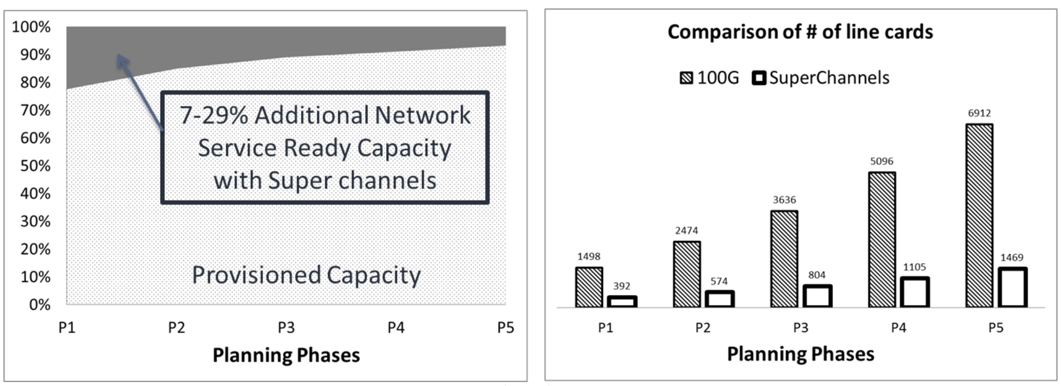


Figure 5 Benefits of using Super-Channels

4. Conclusion

To cater evolving network dynamics, the next generation optical transport networks should deploy network nodes with multi-layer switching that combines the benefits of ROADMs and integrated digital OTN switching. Our network study shows that multi-layer switching reduces the total number of 100G ports by 13-22% compared to all-optical and all-digital switching. Furthermore, it shows that super-channel level switching offers additional service ready capacity with significant opex benefits.

5. References

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