Dynamic O-O-O Switching in Large Scale Core Optical Networks

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Abstract: We present a systematic analysis of all-optical dynamic switching in large scale core optical networks including theoretical studies, network level simulations using novel topology abstractions, and switching technologies and cost efficiencies.

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1. Introduction

Next generation core optical networks demand a high degree of agility, efficiency, and resiliency under heavy load and on a global-scale. Research targeted at addressing these challenges has demonstrated capital and operational cost savings, improved network efficiency and novel on-demand services enabled by a well-engineered dynamic optical layer. [1-3]. In addition to control plane and algorithm technology availability, cost, and complexity, the performance and cost of optical switching technology factors heavily into the commercial viability of dynamic optical transport in core network systems. Research suggests that future node traffic may be as high as 1000 optical channels with up to 50% Add Drop Ratio (ADR). One of the critical challenges is the implementation of efficient traffic grooming and flexible optical reconfiguration technologies to maximize optical bypass, reduce node cost, and provide bandwidth-efficient network equipage responding gracefully to traffic changes and unexpected network outages. As the core component in the optical node, Reconfigurable Optical Add Drop Multiplexers (ROADM) play a critical role to carry out these functionalities [4]. They must evolve to support multi-degree capability as networks scale and become increasingly mesh connected. They also require colorless [5] and directionless [6] operation to allow for dynamic add-drop, and sharing and reusing of local node resources.

In this paper, we present results from comprehensive studies of next generation core networks. A novel and efficient Technology-agnostic Topology Abstraction (TA2) technique is developed to analyze and optimize large scale complex networks in general. Comparison between static and dynamic optical core network is performed using this technique. The impact of Optical-Optical-Optical (all optical) switch fabric in ROADM is presented with an updated cost analysis.

2. Technology-agnostic Topology Abstraction (TA2)

Today, some degree of abstraction is used to manage network resources, using interface adapters that expose a suite of high-level parameters describing node functionality. Adapters obscure key blocking and contention constraints for a specific node implementation, and/or tie their interfaces (and the system's resource management algorithms) too tightly to a given technology. TA2 uses a common abstract topological representation for each and all levels of the network. The representations extend down to an abstract network model of the essential connection structure inside a node, as illustrated in Figure 1, and extend upward to address successive (virtual) levels of functionality across the entire network. With one representation approach common to all levels of resources, we accurately exploit all network element capability, and remain independent of the switching technology.

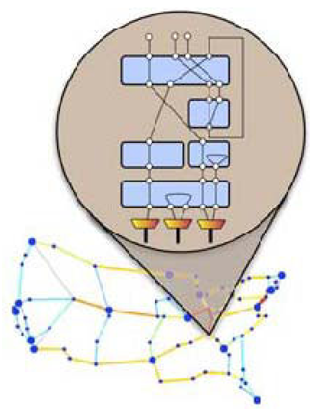

Figure 1: Technology independence from unified multi-level topology abstraction

For example as shown in figure 2 (a), a communication between "node a" and "node g" is depicted in different levels. Level 0 represents geographical connectivity, optical signal propagates from city a to city g via cities b, c, d, e, and f. Level 1 represents connectivity at the wavelength layer (i.e., a wavelength-continuous light path between endpoints of an edge). The topology abstraction at this level captures/represents the activities at the wavelength layer. For this example, the signal switches wavelength/regenerates at city c and city e, and is optically bypassed at cities b, d, and f. Level 2 represents the activities at the sub-wavelength layer: among the two cities c and e where the signal undergoes OEO conversion, only one city c performs sub-lambda grooming to the signal. Using the same principle, more levels can be added to depict the entire network. Resources such as network cost, node capacity, and interference propagates upwards and augmented at the top level. The optimum routing path is calculated based on the augmented information at the top level. Once a top-level route is found, it is recursively mapped into the corresponding lower level routes and switching commands. Port cost is low for optical bypass, and high for full-service IP. The TA2 algorithm chooses paths to maximize bypass at the lowest possible layers to reduce cost. If we assign a ratio of router to TDM (SLG) switching to optical lambda (transponder) port cost of 5:1.2:1, and compare the relative port costs of the core network with and without dynamic provisioning, the result is >60% cost saving for the core network over today. The dramatic reduction in the number of router ports shown also reduces the burden of scaling routers as traffic increases. The simulations also showed that higher degree dynamic provisioning provides more robust network protection.

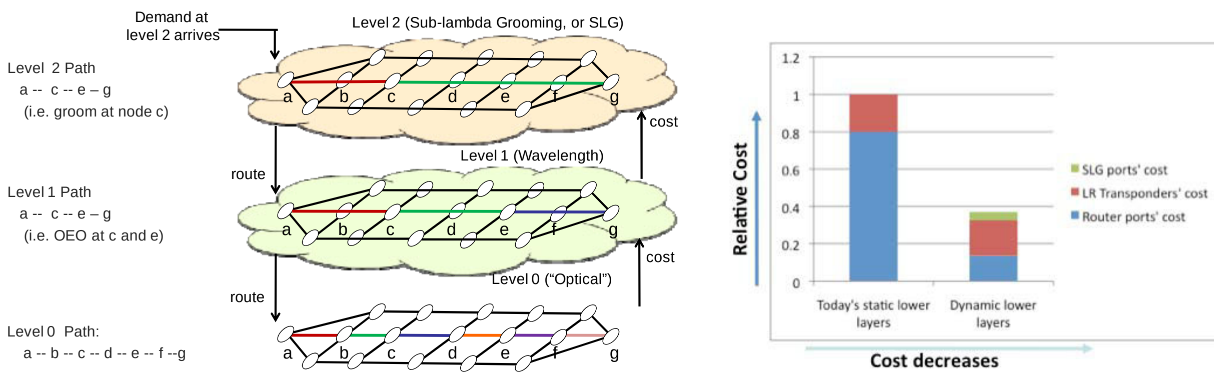

Figure 2: (a) An example of Technology-agnostic Topology Abstraction. (b) Simulated of cost comparison between core networks with static lower layers and dynamic lower layers.

3. WSS Based versus 3D Switch Based ROADM Architectures

ROADMs are the core component to implement dynamic provisioning at the wavelength layer. Among various ROADM architectures, Wavelength Selective Switch (WSS)-based and 3D Switch-based architectures are the most studied.

WSS-based ROADM architecture is comprised of a network of WSS devices and optical power slitters. Since commercially available WSS devices only offer port configuration up to 1x9, multiple WSS devices must be cascaded to form WSS combos with larger port counts. This approach imposes grouping constraints where optical channels with the same wavelength cannot be present within same WSS combo, resulting local transponders to be grouped with non-repeating wavelengths. This introduces provisioning constraints to the network management and makes it difficult to achieve high degree of agility, efficiency, and resiliency in performance with the optical layer.

3D Switch-based architectures offer grouping constraint free solution, however with relatively higher cost. 3D switch technologies include 3D MEMS technology and piezoelectric (PZT) based 3D active collimation technology. 3D switches can directly replace the entire power splitter and WSS switch network in the ROADM architecture, greatly simplifies the node structure. 3D switch technologies based ROADM architectures offer colorless and directionless functionalities. Compared to WSS based architectures, 3D switch based architectures do not impose transponder grouping constraints, making this approach an ideal solution from the technology prospective. Historically, 3D switches primarily serve the automated patch panel industry. Using the same price point of the 3D switch in the patch panel industry, the cost of the 3D switch based ROADM architectures is close to an order of magnitude higher than those of comparable WSS based architectures. This significant cost disadvantage has been a key reason preventing 3D switch being fully accepted in ROADM architectures. However, recent technology advances have been lowering cost dramatically.

4. ROADM Switch Fabrics Cost Analysis

Past pricing comparisons of switching technologies need to be re-evaluated in the face of ever-increasing manufacturing scale of the 3D switch technologies, and the ever-changing market economy. Innovative technologies in low cost electronics controls, precision optical closed-loop beam controls, and PZT active collimation engineering have been major drivers in cost reduction of the 3D switches.

Figure 3 (a) shows our recent normalized cost (as the function of ADR) comparison between WSS based and 3D switch based ROADM architectures. The calculation assumes an envisioned traffic demand of 1000 channels in a 5 degree node and up to an ADR of 50%. The cost of grouping option 1 of WSS based architecture is shown curve (1). It imposes lower grouping constraint of 9 with lowest cost at low ADR, but relatively high cost at higher ADR. Curve (2) presents the cost of grouping option 2 of the WSS based architecture, with lowest cost across all ADR but imposes a server grouping constraint of 71 at a ADR of 50%.

Current, established 3D MEMS technology still demands high price points (curve 3), however, emerging 3D MEMS technologies are offering more competitive per-port pricing (curve 4), comparable to that of the WSS approaches. In addition, 3D PZT active collimation based technologies are also competitive as the ADR increases (curve 5). Without the significant cost advantage, WSS based ROADM architectures become much less attractive due to the grouping constraints.

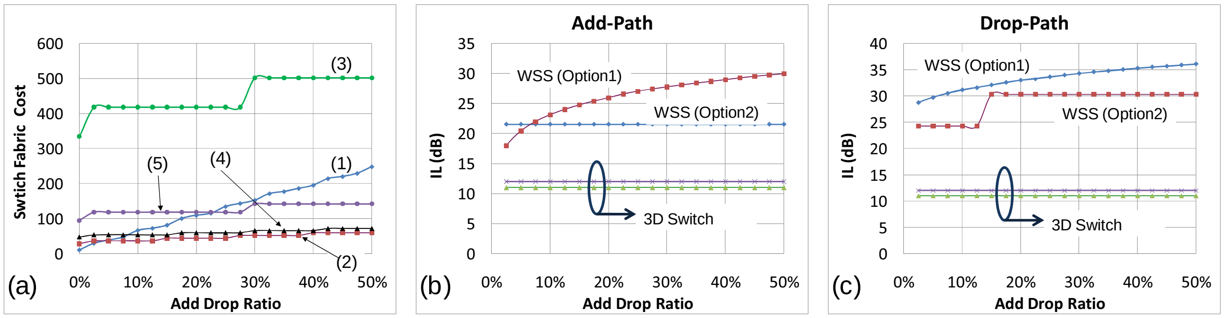

Figure 3: (a) Schematics of WSS based ROADM architecture. (b) Schematics of 3D switch based ROADM architecture. (c) Strict-sense non-blocking CLOS network configuration. (m=2n)

In addition, 3D switch based architectures also offer superior performance including lower insertion loss, lower power consumption, and faster switching speed. The comparison of insertion loss in add-path and drop-path are shown in Figure 3 (b) and (c). Insertion loss of 3D switch based architectures is an order of magnitude lower than that of WSS based due to the high number of WSS cascading layers. Table 1 shows the detailed overall comparison between the WSS based and 3D switch based architectures.

Table 1: Overall comparison among various ROADM architectures

	Cost	**Insertion loss**	**Switching speed**	**Grouping constraint**
WSS	High (option 1) Low (option 2)	>20dB	50 ms	Low (option 1) High (option 2)
3D MEMS	Comparable to WSS	<15 dB	25 ms	None
3D PZT active collimation	Comparable to WSS	<15 dB	19 ms	None

5. Conclusions

In this paper, we present results from comprehensive studies of next generation core networks using a novel TT2 network analysis technique, specifically the impact of dynamic switching in next generation core networks. The performance and cost analysis comparison between WSS based and 3D switch based colorless and directionless ROADM architectures is also studied. Based on the analysis, we can reasonably conclude that for high traffic capacity, high ADR, 3D switch based technologies offer a superior solution both from technical perspective and business perspective. Compared to their WSS counter part, 3D switch based OADMs offer grouping-constraint-free, low insertion loss, high switch speed operation with the same cost efficiency in high traffic high ADR applications.

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