**NThF1.pdf**

# En Route to Grouping-Constraint Free, Colorless Directionless ROADMs

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**Abstract:** WSS-based ROADM architecture limits local transponder wavelengths to a grouping constraint. 3D-switch-based architecture offers powerful solution without grouping constraint. This paper presents an updated performance and cost analysis comparing WSS-based and 3D-switch-based ROADM architectures.

**OCIS codes:** (060.4250) Networks; (060.4510) Optical Communications; (060.1155) All-Optical Networks

## 1. Introduction

Next generation core optical networks demand a high degree of agility, efficiency, and resiliency in under heavy load and on a global-scale. Research targeted at addressing these challenges under DARPA's CORONET program 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, the performance and cost of optical switching technology factors heavily into the commercial viability of dynamic optical transport in core network systems. As envisioned by the DARPA CORONET Program, 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 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.

Among various ROADM architectures, Wavelength Selective Switch (WSS) based and 3D Switch based architectures are mostly studied. Due to the maturity of WSS technology and well-scaled manufacturing processes, WSS based architectures provide an ideal low cost solution, however they have a drawback of limiting local transponder wavelengths to a grouping constraint. Due to the common port configuration, WSS device does not permit input/output optical channels overlap in the same wavelength. 3D Switch based architectures such as 3D MEMS, offer grouping constraint free solution, however with relatively higher cost.

In this paper, we present an updated performance and cost analysis based on DARPA CORONET program, comparing WSS-based and 3D-switch-based ROADM architectures.

## 2. WSS Based ROADM Architectures

Figure 1(a) shows the schematics of a typical WSS based ROADM architecture which is composed 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 together to form WSS blocks with larger ports counts. The major drawback of the WSS device is its grouping constraint where optical channels with the same wavelength cannot be present within same WSS block. Local transponders need to be configured into groups as shown in Figure 1 (a), transponders with the same wavelength cannot be permitted within the same group. This imposes a provisioning constraint to the network management and makes it difficult to achieve high degree of agility, efficiency, and resiliency in performance with the optical layer.

In the WSS approach, there are two options to carry out transponder grouping: Option one is to fix the number of transponders per group and increase the number of groups; Option two is to fix the number of groups and increase the number of transponders within each group. For CORONET-envisioned traffic demand of 1000 channels with a maximum 5-degree-node and up to 50% ADR, option one offers the minimum grouping constraint of 9. This means only every 9 transponders need to emit different wavelengths. However, Option one has the least cost efficiency of

248 total units of 1x9 WSS devices to support the entire node. Option two offers the maximum grouping constraint of 71, however with the most cost efficiency of only 60 units of 1x9 WSS devices for the entire node, resulting in a much more cost effective solution. In addition to the grouping constraints, WSS based architecture also present comparatively slow switching speed in the range of 50 ms and excessive insertion loss due to high number of cascading layers.

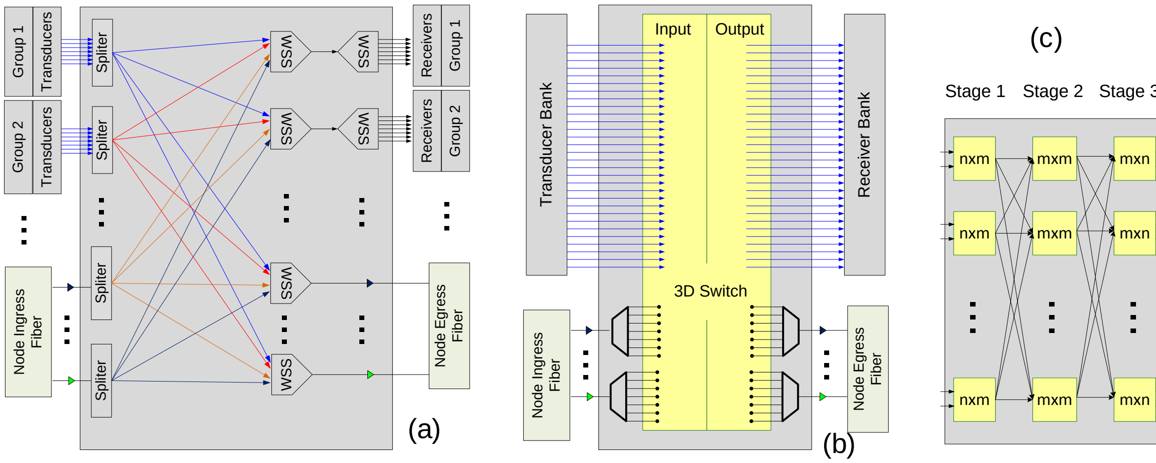


Figure 1: (a) Schematics of WSS based ROADM architecture. (b) Schematics of 3D switch based ROADM architecture. (c) Strict-sense non-blocking CLOS network configuration. (m=2n)

## 3. 3D Switch Based ROADM Architectures

3D switch technologies include 3D MEMS technology and piezoelectric (PZT) based 3D active collimation technology. In the PZT based 3D active collimation technology, piezoelectric transducers steer and align the collimator pairs with great accuracy. As shown in Figure 1(b), 3D switches can directly replace the entire power splitter and WSS switch network in the ROADM architecture, greatly simplifies the node structure. Since 3D switch technologies provide true colorless and directionless switching, the 3D switch based 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.

There are two approaches to implement the ROADMs with 3D switches: the first approach is to use a large single 3D switch for the entire ROADM. This approach is more cost effective but additional protection is required in case of switch failure. This protection can be implemented by operating two large single 3D switches in parallel [7]. To date, the largest single 3D switch commercially available only offers 320x320 ports count.

The other approach is to construct a CLOS network [8] using multiple 3D switches. Figure 1(c) shows the schematics of a strict-sense non-blocking CLOS network configuration. For a k input and k output strict-sense non-blocking CLOS network with nxm switch as the building block, a total of 3 x (k/n) switches are needed. Note that for standard symmetric switches, only half of the input ports in stage 1 and half of the output ports in stage 3 are used (m=2n). Similar to the WSS network, the CLOS network also mitigates the risk of single switch failure by a network of switch. Due to the high numbers of switch units and the cost related to labor intensive fiber connections within the CLOS network especially in high ports counts, this approach incurs more cost than the single large switch approach.

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. Relative 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 2 (a) shows our recent normalized cost (as the function of ADR) comparison between WSS based and 3D switch based ROADM architectures. The calculation assumes a CORONET 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 switches 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.

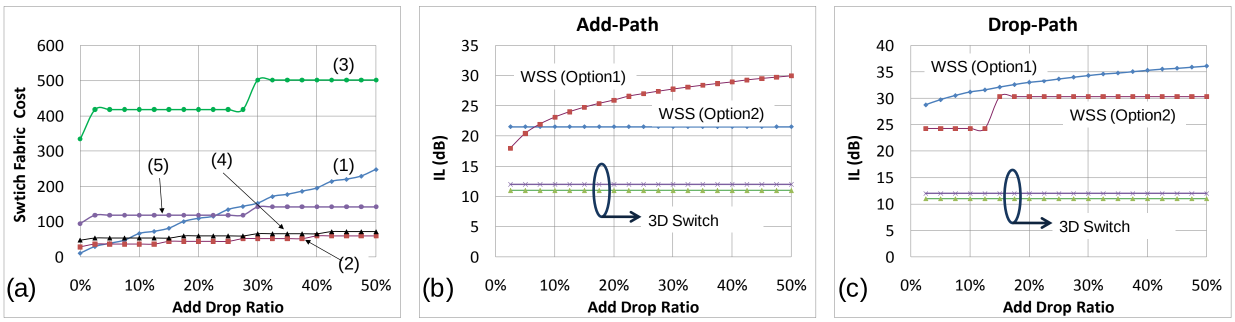


Figure 2: (a) Cost comparison between WSS based and 3D switch based switch fabric. (b)& (c) Insertion loss comparison between WSS based and 3D switch based switch fabric.

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 2 (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 the performance and cost analysis comparison between WSS based and 3D switch based colorless and directionless ROADM architectures. 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 as well. 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.

The authors gratefully acknowledge support for this work by the Defense Advanced Research Projects Agency (DARPA) CORONET program under contract number N00173-08-C-2010.

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