CDC ROADM Applications and Cost Comparison

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Introduction

Colorless Directionless Contentionless (CD/C) ROADM architectures have recently generated considerable interest in the optical transport industry. CD/C ROADM is a relatively new type of architecture designed to offer additional flexibility and operational simplicity. Industry technical conferences are populated with papers focused on the architectural implementations and underlying component technologies used to construct CD/C ROADM nodes. While the technology and architectural benefits are appealing, a review and analysis of the fundamental applications and benefits of CD/C ROADM networks is missing from the discussion, along with a cost analysis of the different CD and CDC ROADM node architectures.

CDC ROADM Applications and Benefits

CD/C ROADMs offer additional architectural flexibility and operational savings, but questions remain whether the benefits and new network applications justify the additional cost and complexity of CD/C ROADM nodes. The three primary applications enabled by CD/C ROADM architectures are bandwidth pre-positioning, bandwidth on demand, and optical layer re-optimization/restoration.

Bandwidth Pre-Positioning

With bandwidth pre-positioning applications, carriers deploy "pools" of transponders and regenerators at major network locations, pre-connected to CD/C ROADM nodes. As additional bandwidth and services are required, an operator simply establishes A-Z wavelength connections across the network, using these pre-positioned transponders. New services can be established in minutes, as opposed to the months required under normal processes to engineer, order, receive, deploy, install, and provision new equipment. Service velocity and minimizing technician involvement are the key advantages of this application. Issues with bandwidth pre-positioning include the cost of "pooled" transponders and technician involvement with client-side service activation. If growth patterns are not predictable, pools of unused transponders or regenerators remain scattered throughout the network. These unused assets would be a stranded network expense. Over time, these stranded network assets may be utilized by ongoing network growth. While a CD/C ROADM enables pre-connection of the network side of a transponder, it still requires a technician to connect and activate the client-side optical interface. Given the technician involvement in client-side connections and provisioning, there may be little operational savings from pre-connection of the network interface.

Bandwidth On Demand

Bandwidth on demand is another commonly referenced application used as a rationale for implementing CD/C ROADM architectures. Most telecom services are provided on a fixed basis between two or more customer locations and remain operational 24 x 7 x 365. Over the years, the telecom industry has debated the feasibility of selling transport services "on demand" for fractional periods of time. For example, an enterprise customer may want a 10G wavelength service between primary and secondary data centers, but only require the service between midnight and 3 am to perform nightly backups and offsite archiving. Wavelength on demand services come with a whole host of their own issues, including whether a viable market exists for these types of services, and whether they generate a positive ROI for carriers. In addition to the increased OSS/billing complexity, it's unclear whether selling wavelength services for fractional periods improves financial performance for carriers, or simply lowers revenues as enterprise users shift to lower cost, fractional-use models compared to purchasing carrier bandwidth to accommodate peak demand periods.

Optical Layer Protection Switching and Re-Optimization

The most frequently cited application for CD/C ROADM networks is to enable optical layer protection switching and optical layer re-optimization. With optical layer protection switching, carriers can choose among several protection methods, including 1:1 protection with <50 ms switching for mission critical services, 1:n share optical protection, and dynamic mesh restoration. In particular, 1:n protection allows carriers to protect their optical layer services, but without having to reserve 50% of their network capacity for protection, as required with 1+1 protection. Mesh restoration is the ability to dynamically calculate and signal new routes at the time of a failure. Mesh restoration is typically used as a backup with 1:n optical protection, in case of secondary failures.

The optical layer poses some unique challenges to optical protection switching. The optical layer consists of physical fibers, lasers, and modulated signals running over those fibers. A host of optical impairments, such as optical loss, chromatic dispersion, polarization mode dispersion, and OSNR must be measured and managed on each optical span and route. At the physical layers, these optical impairments vary by fiber type, by modulation, by span distance, and by overall optical path distance (i.e. OSNR). ROADMs incorporate techniques to compensate for these optical impairments on the primary optical path. When a failure occurs, optical reach analysis must be performed on all potential protection paths. A path computation engine (PCE) could calculate the viability of each optical protection path in real time, but a simpler approach relies on optical reach tables.

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Optical reach tables define all reachable paths for every A-Z node combination in the network. Optical path reach tables can be calculated offline, utilizing vendor DWDM modeling tools, and periodically uploaded to the PCE. When a network failure occurs, the PCE selects a protection path from one of the available routes defined in the optical reach table. In addition to optical layer protection, many carriers are interested in the optical layer control plane for periodic re-optimization of the optical network, sometimes referred to as "optical defragmentation." Optical layer re-optimization enables carriers to periodically clean their network routes, recovering up to 20% of additional capacity. Over time, service churn results in fragments of stranded bandwidth scattered throughout a network. By re-optimizing their network connections, for example once every four months, the network can be "de-fragmented" and the stranded capacity recovered.[1,2]
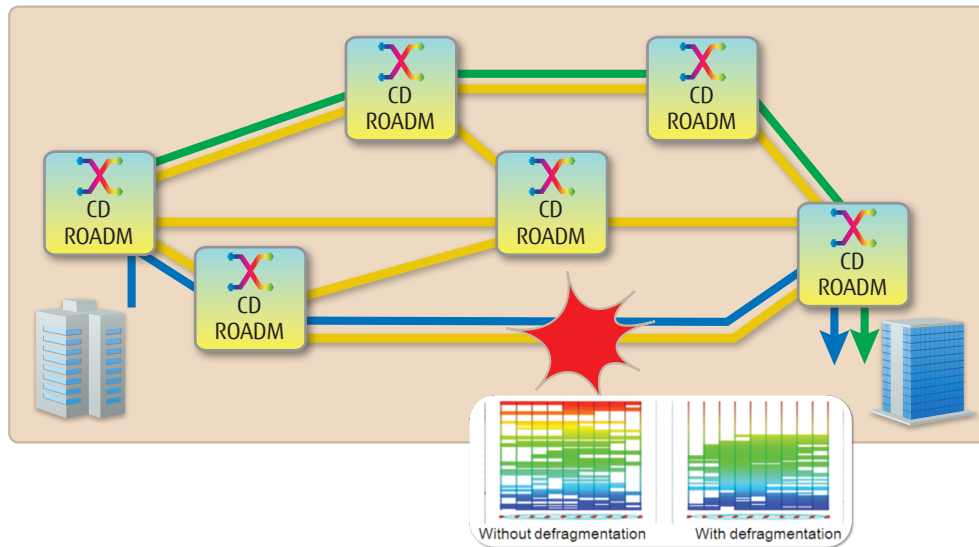

Figure 1: Optical Layer Protection Switching and Restoration

Comparing Classic, CDG and CDCG Architectures

A ROADM consists of optical amplifiers, optical switching, multiplexer/demultiplexer, transponder, and muxponder cards, enabling a complete, flexible, optical transport node, as shown in Figure 2. The mux/demux provides the connection point between the composite WDM layer and the individual channels or wavelengths, which are implemented with transponder and muxponder units. In classic ROADMs, the mux/demux is a passive device implemented with AWG technology, essentially a prism that separates each wavelength into individual input and output ports. AWG technology is widely utilized, reliable, and cost-competitive, but each wavelength is fixed to a specific physical port. Moving a transponder to a different wavelength, or to a different degree, requires manual technician involvement to unplug the transponder from one port and re-insert it into a different mux/demux port.
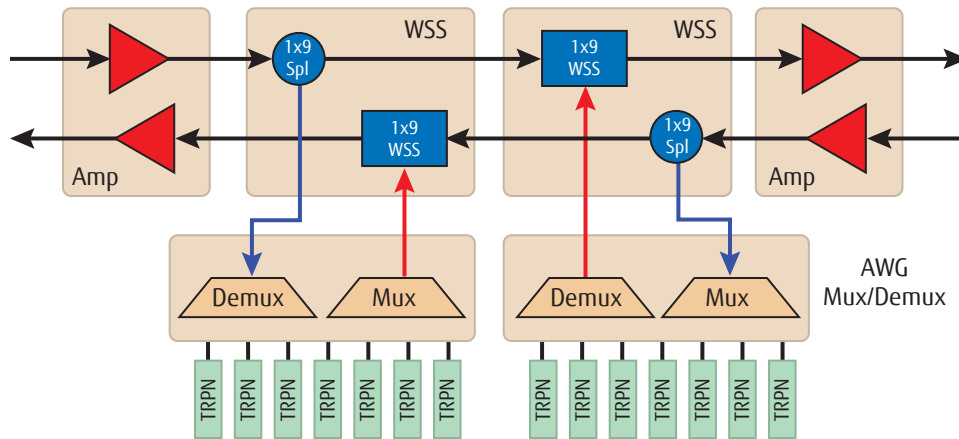
Figure 2: Classic ROADM Node Architecture

CD/C ROADMs allow wavelength reassignment without the need for manual intervention, but with the tradeoff of higher node complexity and costs. The two primary architectures under consideration are CD and CDC. Both architectures use a common optical core, but differ in how the drop side is implemented. Both CD and CDC ROADMs support flexible grid channel spacing, also known as "gridless" and sometimes labeled with a subtending "G," as CDG or CDCG ROADM.

At the optical core, CD/C ROADMs replace the broadcast and select architecture used on "classic ROADMs" with a route-and-select architecture based on 1x20 twin WSS modules, as shown in Figure 3. In addition, the fixed port AWG mux/demux is replaced with flexible drop-side architectures that allow any transponder or muxponder to be assigned to any wavelength and sent to any WDM degree.

Recently, the optical transport industry has shown more interest in the CDCG ROADM architecture, due to the additional "contentionless" feature. One limitation with CD ROADMs is wavelength contention. Wavelength contention occurs when wavelengths of the same frequency (i.e. color) terminate from different WDM directions (i.e. East, West, North, South). Since CD ROADMs don't allow "contention" on the drop side, careful network planning is required to ensure that wavelengths dropped at a given node are assigned unique frequencies. For many carriers, avoiding this additional planning and operational issue, required by CD ROADMs, is the justification for migrating to a CDC ROADM.
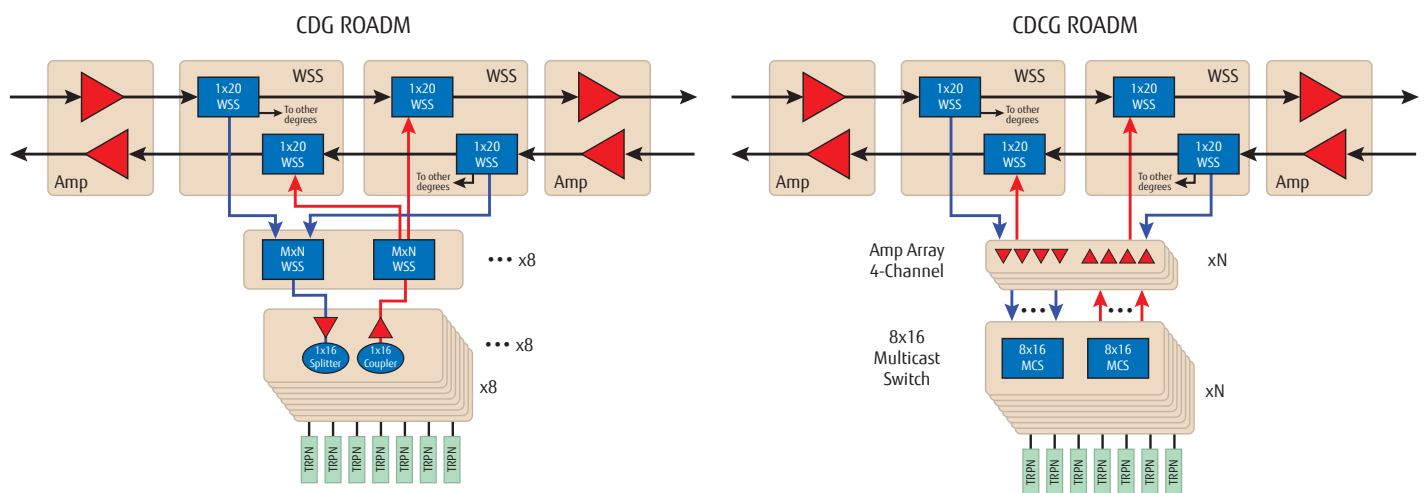

Figure 3: CDG versus CDCG ROADM

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With a CDCG ROADM, the drop side is implemented using 8x16 MCS modules, enabling any wavelength from any degree to be dropped to any client port (contentionless). The high insertion losses of the 8x16 MCS requires additional amplifiers for both add and drop directions, for each degree. Colorless capability is implemented by utilizing the inherent "tuning" feature of coherent receivers. Each coherent transponder "tunes" its optical receiver to the provisioned channel, essentially blocking or filtering all other channels present at the optical port. An important concern with CDCG architectures is the need for large numbers of amplifiers, or amplifier arrays, on the drop side as channel counts and node sizes increase.

CD/C ROADM Cost Comparison

To get a comparison between classic, CDG, and CDCG ROADMs, a cost analysis was performed based on a two degree (2D) ROADM (East/West) configuration, 88-channel drop capacity, without transponders. Since the transponders are common to all models, they were excluded from the pricing comparison, allowing an analysis of just the ROADM architectural differences. Many carriers refer to this as the "first cost," meaning the cost of the ROADM network prior to deploying any services (i.e. transponders). Figure 4 lists the primary optical components incorporated in the classic, CD, and CDC ROADM models. Figure 5 provides the corresponding normalized cost comparison of classic, CDG, CDCG ROADM nodes.

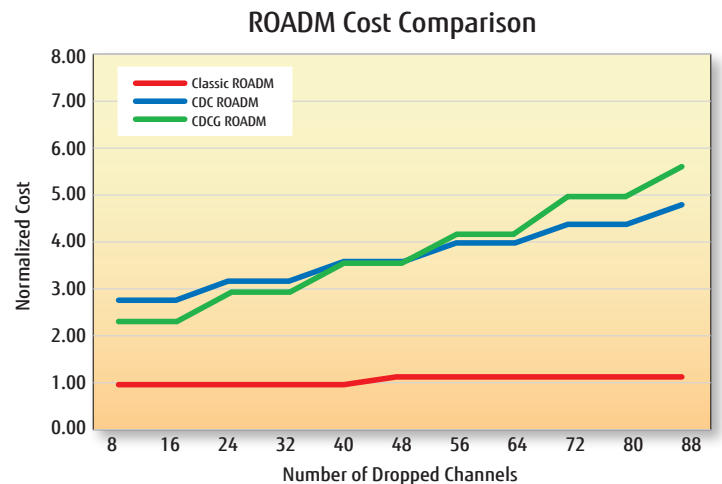|	Standard ROADM	CD ROADM	CDC ROADM
1x9 WSS	2	–	–
1x8 Splitter	2		–
44-Channel mux/demux	4	–	–
1x20 WSS	–	4	2
MxN WSS	–	2	–
1x16 Splitter	–	6	–
1x16 Coupler	–	6	–
Amplifiers, drop side	–	12	–
Amp Array, 4-channel	–	–	6
8x16 MCS switch	–	–	12

Figure 4: Optical Components

Figure5: ROADM Cost Comparison

The twin 1x20 WSS route and select architecture, combined with the 8x16 MCS, provides the flexibility to support colorless, directionless, contentionless, and gridless WSS network architectures. However, the additional optical components and amplifiers result in higher initial node costs.

For the purposes of the cost analysis, the classic ROADM configuration and pricing was normalized to 1.0, providing a baseline for comparison of the CD and CDC architectures. The results of the cost analysis show approximately 2.5x difference between similarly configured classic, CDG, and CDCG ROADM nodes, with the increase being primarily due to the use of twin 1x20 WSS modules in the core and 8x16 MCS in the drop banks. The CDCG ROADM is slightly less expensive than CDG ROADMs at low channel counts (<44), but increases at higher drop channels, primarily due to the increasing number of amplifier arrays required as channel counts increase.

While the initial cost difference between the ROADM nodes is significant, when compared to the true network costs with deployed 100G channels, any price differences are minimal. As 100G transponders or muxponders are added to the network, the cost of these devices begin to dominate the overall network costs. The relative cost differences between the classic, CDG, and CDCG ROADM nodes drop to 6–10%, a relatively small difference given the much more flexible and capable optical networks enabled by CDCG ROADM architectures. Figure 6 shows the previous model with 100G transponders.
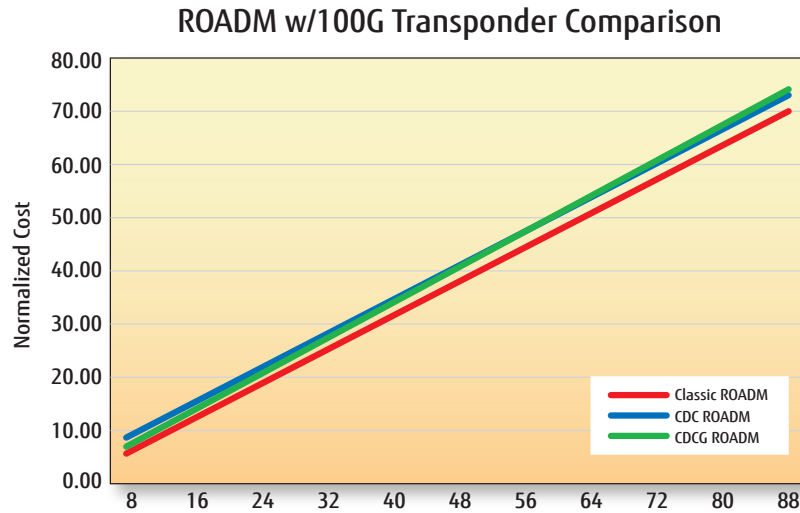
ROADM w/100G Transponder Comparison

Figure 6: ROADM Comparison with 100G Transponders

Summary

CDCG ROADMs offer additional network flexibility by enabling wavelength re-assignment and re-routing, optical layer 1:n protection switching, mesh restoration, and optical layer defragmentation, all without the need for manual technician involvement. However, this additional flexibility comes with increased node complexity and cost. The increased cost is primarily due to the additional WSS modules, amplifiers, couplers, splitters, and MCS modules required to implement CDC ROADMs. The cost difference between the CD/C architectures, with 100G channels, is only 6–10% in comparison with "classic" ROADM nodes. Between CD and CDC ROADM architectures, the industry appears to be favoring the CDC ROADM due the "contentionless" capability. In addition, CDC ROADM networks result in slightly lower cost for nodes with less than 4 Tb of drop capacity (i.e. ~40 channels of 100G). When the additional cost of 100G units is included in the analysis, the cost differences between all three network options is within 6–10%.

References

[1] Xi Wang, Qiong Zhang, Inwoong Kim, Paparao Palacharla and Motoyoshi Sekiya, "Utilization Entropy for Assessing Resource Fragmentation in Optical Networks" OFC NFOEC 2012, March 2012, Los Angeles, CA

[2] Xi Wang, Inwoong Kim, Qiong Zhang, Paparao Palacharla, and Motoyoshi Sekiya, "A Hitless Defragmentation Method for Self-optimizing Flexible Grid Optical Networks" ECOC 2012, September 2012, Amsterdam, The Netherlands

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Acronyms

Acronym	Definition
AWG	Arrayed Wave Guide
CD	Colorless Contentionless (Gridless)
CDG	Colorless Contentionless Gridless
CDC	Colorless Directionless Contentionless (Gridless)
CD/C	Colorless Directionless and/or Contentionless
CDCG	Colorless Directionless Contentionless Gridless
DWDM	Dense Wavelength Division Multiplexing
EDFA	Erbium Doped Fiber Amplifier
MCS	Multicast Switch
OSNR	Optical Signal-to-Noise Ratio
OSS	Operational Support System
PCE	Path Computation Engine
ROADM	Reconfigurable Optical Add/Drop Multiplexer
ROI	Return on Investment
Tb	Terabit
WDM	Wavelength Division Multiplexing
WSS	Wavelength Selective Switch