HEAVY READING

White Paper

Next-Generation ROADM Architectures & Benefits

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Introduction

Since their commercial introduction in the early 2000s, ROADMs have evolved through three main generations: wavelength blockers (first generation); two-degree (or direction) planar lightwave circuits (second generation); and multi-degree wavelength selective switches, or WSSs, (third generation). Today, WSS-based ROADMs are widely deployed in operator networks globally.

Classic ROADM architectures – particularly, those based on WSS – allow for adding, dropping and express-routing traffic through network nodes and deliver benefits such as simplified planning, better bandwidth utilization, simplified and reliable network engineering, and reduced truck rolls at intermediate nodes along a route. However, these WSS architectures, which include a single WSS for each direction (or degree) at the node, are limited by:

- Fixed wavelength assignments to specific ports
- Fixed direction assignments for multiplexers (i.e., North only, South only, etc.)
- Partitioned add/drop structures due to wavelength-contention conflicts

Today, the ROADM market is in the midst of a transition to the fourth generation of ROADM subsystems characterized by the introduction of four new functions: colorless, directionless, contentionless and flex spectrum. Automating end points of optical connections is a major focus of the next-generation (NG) ROADM system.

This white paper provides an overview of NG ROADMs and discusses the primary drivers and benefits of NG ROADM networks for operators. We discuss the benefits from both a near-term and a longer-term perspective, including the value of combining a flexible photonic layer with SDN.

NG ROADM Network Building Blocks

NG ROADMs consistent of four primary functions: colorless, directionless, contentionless and flex spectrum/flex grid, typically denoted by the acronym CDC-F. The functions can be deployed all together or in different combinations, such as CD, CDC, or CDC-F, etc. Each of the NG ROADM functions is described in more detail below.

Colorless

Existing ROADMs are limited by fixed add/drop transceiver and wavelength assignments. When a wavelength is selected in these deployments, the transceiver must be manually connected to the correct mux/demux port at the add/drop site. While express nodes benefit from the presence of ROADMs, the add/drop sites must be physically wired and rewired whenever a change is made.

New "colorless" ROADM node architectures provide the means for building ROADMs that automate the assignment of add/drop wavelength functionality. There are several variations for building colorless ROADMs, but they typically involve using additional WSSs in place of different multiplexers and demultiplexers in the ROADM subsystem. Regardless of architecture approach, the end result is that any wavelength (color) can be assigned to any port at the add/drop site, completely by software control and tunable transponders (now widely deployed), without a technician on site.

Directionless

Directionless and colorless ROADMs are increasingly being discussed together as "must haves" for true optical layer flexibility. Existing ROADMs are directionally dependent, meaning that add/drop port pairs and the transponders connected to them are fixed to an outgoing direction (i.e., North only, South only, etc.). Changing the direction of a particular transponder requires physical rewiring by a technician. Directionless ROADMs, by contrast, allow any wavelength to be routed to any direction served by the node, by software control and without physical rewiring.

Contentionless

Colorless and directionless ROADMs have been under discussion within the industry for some time. Newer is the concept of contentionless ROADMs networks. Driving the operator requirement for contentionless ROADMs is the fact that, even with colorless and directionless functionality, a ROADM network still has limitations that could require manual intervention in some cases. In other words, the colorless/directionless network is still not completely flexible.

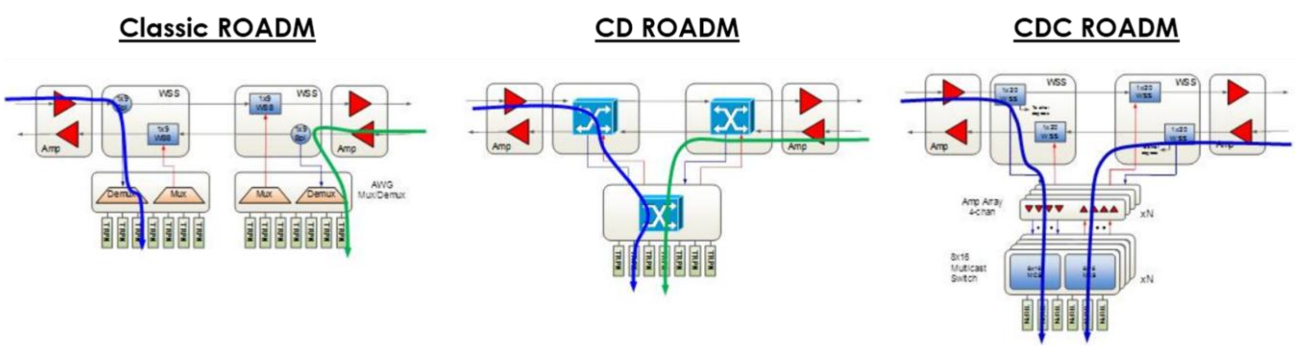
The problem is that wavelength blocking can occur when two wavelengths of the same color converge at the same WSS structure at the same time, causing network contention. Operators must avoid this potential blocking/contention situation by partitioning the add/drop structures so that different colored wavelengths are associated with different structures – thus eliminating the possibility for two red wavelengths to converge on the same add/drop structure simultaneously.

While this level of engineering does resolve wavelength contention potential from a provisioned perspective, operators sacrifice a level of dynamic flexibility and may require additional add/drop structures to accommodate particular wavelength channels. A contentionless architecture, by contrast, allows multiple copies of the same wavelength on a single add/drop structure (with no partitioning restrictions).

A colorless/directionless architecture combined with true contentionless functionality is the end goal of any network operator that has deployed – or is planning to deploy – a ROADM network. Such architectures, known as CDC, give them the ultimate level of flexibility at the optical layer.

Figure 1 shows the architectural differences between the different types of ROADMs.

Figure 1: Illustration of Classic & NG ROADM Variants



Source: Fujitsu, 2015

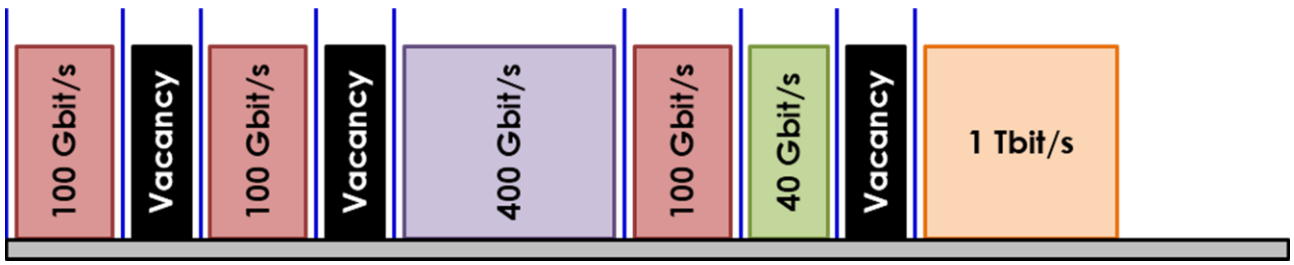
Flexible ITU Grid or Flex Spectrum

A fourth key concept in NG ROADM architectures is the concept of the flexible spectrum. (Note that this functionality has also been called "gridless" and "flexible grid," all describing the same capability.) The flexible spectrum is a way for operators to future-proof networks that will ultimately need to contend with transport speeds beyond 100G transport.

For speeds beyond 100G – i.e., 400G or 1 Tbit/s – more than 50 GHz of spectrum will almost certainly be required. Network operators would also like to be able to accommodate those future speeds on the same 40G and 100G ROADM networks.

The proposed solution is a more granular version of the ITU grid that breaks spectrum down to 12.5GHz granularities. ROADM nodes supporting a flexible grid could operate at any speed that is based on increments of 12.5GHz spacing, such as 75GHz spacing or 125GHz spacing, etc. See **Figure 2**.

Figure 2: Illustration of Flexible Spectrum Architecture



Source: Fujitsu, 2015

Near-Term Benefits of NG ROADM Architectures

A combination of factors has come together today to greatly accelerate the adoption of NG ROADMs, including the following:

- Many classic ROADM networks are aging, requiring operators to put out RFPs for new ROADM networks. As noted, some ROADM networks have been in operation for nearly 15 years.
- Higher-density 1x20 WSS devices have been introduced by components makers at prices that are more economical to systems suppliers compared to early versions.
- Coherent 100G is beginning to move from long-haul networks to metro/regional networks. As operators move to metro coherent 100G, they are simultaneously upgrading their Layer 1 and photonic metro infrastructure.
- Advanced modulation schemes and super channels, enabled by coherent detection, are leading operators to future-proof their ROADM networks by deploying flex spectrum hardware today, in anticipation of variable channel widths in the future.
- The software control protocols and standards required to automate the ROADM hardware have advanced and matured over the past three years.

Heavy Reading identifies three primary near-term benefits to operators deploying NG ROADM architectures, some of which are interrelated. The primary benefits are:

- Opex and capex cost reductions
- Rapid bandwidth/capacity provisioning
- Topology flexibility and simplified operations

Opex & Capex Reduction

Opex reductions are delivered primary via the "touchless" provisioning and activation of network bandwidth, in particular by automating the activation of the end points of photonic layer circuits. As noted, classic ROADM systems delivered a level of automation in the network by enabling touchless provisioning of bandwidth at intermediate sites along a route but still require technicians on site to the provision the connections at the entry and exit locations of the circuit.

CDC functionality eliminates the need for these technician truck rolls, thus saving on labor costs as well as in time to provision. Another important opex benefit delivered through automation is the reduction of manual errors and dirty connectors – occurrences that can be completely avoided through automation.

In addition to opex savings, operators also see benefits on the capex side, particularly through the ability to boost fiber utilization. Driving up fiber utilization, delays and reduces the need for additional equipment buying on the network. BT is one operator that has done a significant amount of research in using flex spectrum to boost fiber utilization.

Combining ROADMs with OTN switching yields even greater fiber utilization/capex savings benefits when compared to using ROADMs alone. OTN is important because it provides grooming for sub-wavelength-level traffic (such as Sonet/SDN and Gigabit Ethernet), meaning that wavelength get highly filled before they are switched at the ROADM layer. Additionally, a centralized OTN switch fabric provides more efficient grooming than an OTN muxponder-based system because a central fabric can groom traffic across line cards.

Further capex savings are achieved by integrating large-scale OTN switching and ROADMs within the same system. This integrated architecture eliminates the costs of short-reach optics connecting separate DWDM and OTN switching boxes.

Fujitsu is one supplier that has conducted extensive network modeling showing the capex savings benefits of combining OTN and ROADM switching compared to using a ROADM layer alone. Simulating a large metro network with 40 ROADM nodes, 45 spans and a mix of 550 services, Fujitsu's simulation showed the OTN-ROADM network reduced wavelength costs by more than 25 percent compared to the ROADM-only network model. Accounting for the added costs of the OTN layer, the model showed a network capex reduction of about 20 percent.

Rapid Bandwidth/Capacity Provisioning

In addition to saving opex by eliminating the human element, automation greatly accelerates bandwidth and capacity provisioning. Operators view the ability to respond to capacity needs quickly as a key differentiator in an intensely competitive telecom environment. In addition, rapid capacity and services turn-up is a key component to cloud services delivery.

These revenue-generation and service-differentiation benefits of NG ROADMs should not be under-estimated. In past Heavy Reading surveys, these benefits have rated in some cases as highly as opex/capex savings. In addition, most recently we are seeing that optical initiatives that can be tied more closely to revenue boosting goals are moving up the organization's priority list more quickly than the traditional opex/capex savings plays.

Topology Flexibility & Simplified Operations

Greater flexibility is hallmark of CDC-F ROADMs, which deliver reconfigurability not just at intermediate nodes along an optical route, but at the end points as well. Historically, in order to change traffic direction, a technician had to physically pull individual connectors from one WSS element (East, for example) and plug it into the WSS in the desired direction (North or South, etc.) By automating those end-point connections, CDC ROADMs greatly improve network flexibility at the photonic layer and simplify operations (which contributes to opex savings).

Flex spectrum delivers another element of flexibility at the photonic layer. As discussed, flex-spectrum ROADMs support today's 10G, 40G and 100G 50GHz fixed-grid wavelengths, but are also future-proof for tomorrow's 400G or 1T, or whatever bit rate and channel spacing is adopted.

In the absence of flex-spectrum ROADMs, operators would need to build greenfield networks for 400G bit rates and beyond, while maintaining their 10G, 40G and 100G systems on their legacy fixed-grid networks.

Figure 3 summarizes the different NG ROADM functions, associated technologies and primary applications.

Figure 3: NG ROADM Functionality Comparisons

FUNCTION	DEPLOYMENT TECHNOLOGIES	APPLICATIONS
Colorless	Splitter for coherent receivers; twin 1x20 WSS for colorless add and drop	Photonic layer OCh restoration for ASON/ GMPLS network; rapid provisioning; "touchless" network operation; OCh XC with lower power consumption; simpler network planning
Directionless	Twin 1x20 WSS per node; route and select; coherent receivers	
Contentionless	Add several groups of colorless and directionless 1x20 WSS per node; splitter for coherent receivers; multicast switches/ MxN switches	
Flexible Spectrum	LCoS or DLP WSS, flex OCMs, Raman amplification, advanced control	400G and/or 1 Tbit/s per channel DWDM networks

Source: Heavy Reading

Near-Term Considerations for Operators

Classic ROADM to CDC-F ROADM Migration

Most DWDM systems vendors on the market don't allow CDC-F ROADMs on the same DWDM systems that housed their classic ROADMs. Instead, most vendors have introduced CDC-F ROADM functions on new systems introduction, which also have other next-generation functions such as coherent 100G, OTN switching fabrics, and others. As a result, moving from classic ROADMs to CDC-F ROADMs often marks a significant decision point for operators that requires new systems purchases and additional decision-making about their 100G and switched OTN roadmaps.

Although in the minority, some DWDM systems vendors do offer CDC-F ROADMs as shelf-addition upgrades to their existing classic ROADM systems. These systems allow operators to mix and match their classic ROADM and CDC-F network nodes and eliminates the requirement for full overbuild networks of CDC-F.

While the shelf addition approach to CDC-F ROADMs can greatly simplify the ROADM upgrade process for operators, they still must perform due diligence on vendor systems functionality roadmaps – particularly, we believe, coherent 100G. Even if 100G is not in the operator's immediate future, they should have a migration plan in place. Furthermore, while 40G once loomed as a stepping-stone from 10G to 100G, industry momentum has shifted overwhelmingly in favor of 100G, and 40G is fading rapidly.

CD or CDC Migration

Although we have discussed CDC-F functions together in the context of NG ROADMs, in reality colorless, directionless, contentionless and flex spectrum are discrete functions that can (technically) be deployed separately and in isolation. Over the past three years, there has been much debate over the right combination of functions to include. In particular, debate has focused on the pros and cons of deploying full CDC networks versus deploying colorless and directionless in combination, without the added contentionless functions.

As described earlier in the report, the CDC architecture gives operators full flexibility in automating provisioning of any wavelength to any port in any direction and eliminates the potential for two wavelengths of the same color to converge on the same port (i.e., wavelength contention).

To do this, contentionless nodes must introduce new hardware in the form of multicast switches, such as 8x16 switches for large nodes or 4x4 switches for smaller nodes. These multicast switches are required in order switch wavelengths on add/drop structures such that two blue wavelengths, for example, will never converge on the same port. They do this, however, at a higher cost at the node level.

As an alternative, some operators have deployed CD-only architectures to lower their node-level costs and instead use network planning and engineering to ensure that same-colored wavelengths can't converge on the same port. This does limit flexibility, and it requires greater complexity in network planning.

In the past two years, we have seen a shift in trends from operators mainly preferring to build CD-only ROADMs to, more recently, operators preferring the full flexibility option of CDC from Day 1.

Flex Spectrum Migration

Although Heavy Reading does not see an imminent migration to 400G deployments (either in core or metro networks), we do see strong operator interest in adding flex-spectrum ROADM functionality on Day 1 as part of their NG ROADM deployments. The primary driver for this preference is a desire to future-proof their networks in anticipation of 400G (or higher) bit rate requirements in the future.

Unlike other NG ROADM functions discussed in the paper, flex spectrum mandates a hardware change – from micro-electro-mechanical systems (MEMS)-based ROADMs to liquid crystal on silicon (LCoS) for most ROADM suppliers, so the change is a big deal. Operators want assurance that their hardware is "flex spectrum-ready," even though 400G is not a factor in their three-year network plans. With the hardware in place, flex spectrum becomes a software feature that can be turned on when (or if) needed in the future.

Long-Term Benefits of NG ROADM Architectures

This section looks at the operator benefits of multi-layer and multi-vendor control plane, focusing on IP layer and photonic layer control plane interoperability. It then discusses carrier SDN as the enabler for achieving these benefits.

Multi-Layer, Multi-Vendor Control Plane Interoperability

A multi-layer control plane allows for the provisioning of connections across multiple network layers, such as some combination of photonic (Layer 0), OTN (Layer 1), Ethernet (Layer 2) and IP (Layer 3) layers. By coordinating interaction across layers, operators will be able to take coordinated actions in recovery against failures.

Major network operators, including Deutsche Telekom and Telefónica, among others, have demonstrated significant capex savings potential in particular by using multi-layer restoration combining IP layer fast reroute with photonic layer control. For example, DT has conducted simulations using colorless and directionless ROADMs and multi-layer control for router bypass applications. In the simulations, DT has applied IP layer protection to all high-priority traffic and a slower photonic layer protection to all best-effort traffic.

Using the combination of IP layer and photonic layer recovery schemes resulted in router interfaces savings of 24-27 percent compared with using IP layer protection only. The calculated savings comes from needing fewer router ports to provide required levels of service for the different classes of customers.

Note that while many of the near-term benefits described in this paper so far center on opex savings, the IP and optical multi-layer restoration benefits cited by DT are capex benefits, generated by using available network capacity more efficiently.

Telefónica is another major operator that has been a strong champion of the benefits of multi-layer and multi-vendor integration. Similar to DT, Telefónica has conducted real-world scenario simulations coordinating IP layer and optical layer restoration. For example, Telefónica demonstrated the ability to achieve carrier-grade availability (i.e., 99.99 percent) by using either the present mode of operation (PMO) of 1+1 protection, or using different combination of protected regions and unprotected regions.

The capex savings argument was based on the ability to achieve carrier-grade availability using less equipment than required with traditional full 1+1 protection. Cited capex savings ranged from 12.5 percent at the low end to 37.5 percent at the high end.

Additionally, Telefónica work has extended beyond capex savings to show opex and revenue-generation benefits of multi-layer integration as well, including:

- Maintaining high availability while extending mean to repair (MTTR); and
- Activating new services in less than 50 seconds (compared to hours without employing multi-layer control planes)

Migration to SDN-Based Photonic Layer Control

The advent of Carrier SDN brings new opportunities for photonic layer control, and with it new applications and benefits for network operators.

Software control in optical network has existed for more than a decade, primarily through ASON and GMPLS-based control planes. These protocols have been used to build large-scale Sonet/SDH and (more recently) OTN mesh networks that save network resources with 1:N protection (as opposed to 1+1). AT&T, for example, launched its first Sonet mesh network in 2001 and expanded it to more than 500 switched core nodes.

Furthermore, vendors that build both IP and optical product lines have long demonstrated multi-layer control plane interaction, producing efficiency benefits similar to those that have been described above. However, these control planes have been limited to single-vendor implementations, even when standardized protocols, such has GMPLS, have been used. As a result, operators have been unwilling to commercialize such proprietary, single-vendor networks.

The big promise of SDN for the transport network is to provide the open, standardized control plane that will enable real-world implementations of multi-layer and multi-vendor networks – exactly what has been missing for operators to move from demonstration and simulations to commercial deployment.

Despite its promise for transport networks, there are challenges ahead for SDN. While operators and vendors recognize the promise multi-layer and multi-vendor software control, there is no consensus on what the SDN standards should be. Among the options are:

- OpenFlow: The original SDN protocol was built for campus networks and is getting extensions to make it suitable for carrier networks, but the progress is slow, and a number of alternative solutions are proliferating.
- IETF control plane extensions: This umbrella term covers many of the alternative approaches being used, including Path Computation Element Protocol (PCEP), Network Configuration Protocol (NETCONF), Application-Layer Traffic Optimization (ALTO) and Border Gateway Protocol Link-State (BGP-LS), among others.

The call for SDN standards consensus is becoming urgent, particularly among the network operators furthest along in their SDN use-case development, and we believe there will be significant progress on this front throughout 2015. Still, until the SDN standards path is clear, operators will withhold their investments.

Conclusions

The evolution of the flexible photonic layer continues. Today, the industry is in the midst of its transition to the fourth generation of ROADMs, bringing end-to-end automation to the photonic layer for the first time. While the concepts of CDC-F ROADMs date back a few years, the commercialization of these systems is accelerating now, based on a combination of factors including aging classic ROADM networks, WSS technology and cost improvements, coherent 100G migration to metro/regional networks, and software control maturation and standardization.

In the near term, operators deploying combinations of CDC-F ROADM functionality will benefit from opex reductions from end-to-end photonic layer automation; capex reductions from greater fiber utilization, topology flexibility and simplified operations (which translates to additional opex savings); and rapid bandwidth and capacity provisioning (which increases operator revenue). In addition, the capex savings are boosted further when the ROADM layer is integrated with a switched OTN layer.

In the longer term, the benefits of CDC-F ROADMs are tied to multi-layer provisioning and IP and optical layer integration in particular – one of the Holy Grails of optical networking since the advent of DWDM. While single-vendor, multi-layer integration is possible today, SDN brings the promise of multi-vendor, multi-layer integration. While many operators may not be ready for this step today, it is clear that a CDC-F ROADM layer is a prerequisite to any implementation of SDN at the photonic layer.