HEAVY READING

White Paper

Building a Fully Flexible Optical Layer with Next-Generation ROADMs

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Introduction

The optical networking industry is in the midst of a Reconfigurable Optical Add Drop Multiplexer (ROADM) renaissance. While early-generation ROADMs brought operators some benefits in provisioning optical bandwidth and reducing technician truck rolls, they lack much of the flexibility operators need – particularly at the end-points of a connection where wavelengths are added to and dropped from the network.

Over the past 18 months, a new generation of ROADMs has emerged that promises the flexibility to achieve highly automated mesh networking at the photonic layer. The key components of this new ROADM generation include: color independent or "colorless" functions; direction independent or "directionless functions; freedom from wavelength contention or "contentionless" functions; and flexible use of the International Telecommunication Union (ITU) grid, or "flexible spectrum."

Significantly, interest in these functions and their benefits cut across operator types and is global.

This white paper provides a timely update on the evolution to next-generation ROADMs, from technology, application and service provider adoption perspectives. The paper provides the latest operator and supplier thinking on colorless, directionless, contentionless and flexible spectrum technologies. Among the topics covered are:

- The different technology building blocks in play for CDC-F, such as advanced Wavelength Selective Switch (WSS) elements, route and select architectures, multicast switches and coherent receivers
- Emerging applications for CDC networks, such as network defragmentation and optical layer restoration
- Operator timelines for migrating to next-gen ROADM networks
- Beyond 100G transport and the emergence of the "Super Channel"

Colorless, Directionless, Contentionless Overview

Colorless, directionless and contentionless functionality, commonly abbreviated as "CDC," form the core of the emerging generation of ROADMs. A fourth function called flex spectrum or flexible grid is also important, though it is less linked technically to CDC. Arguably the fourth generation of ROADMs, for the purposes of this paper we term ROADMs with the collective group of functions as next-generation ROADMs.

In this section, we define the core set of colorless, directionless and contentionless functions.

Colorless

Current-generation ROADMs are limited by fixed add/drop transceiver and wavelength assignments. When a wavelength is selected in existing ROADM 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 the 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. (We will discuss architecture options later in this paper.) 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. As described above, 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 is still has limitations that could require manual intervention in some cases. In other words, the colorless/directionless network is still not completely flexible.

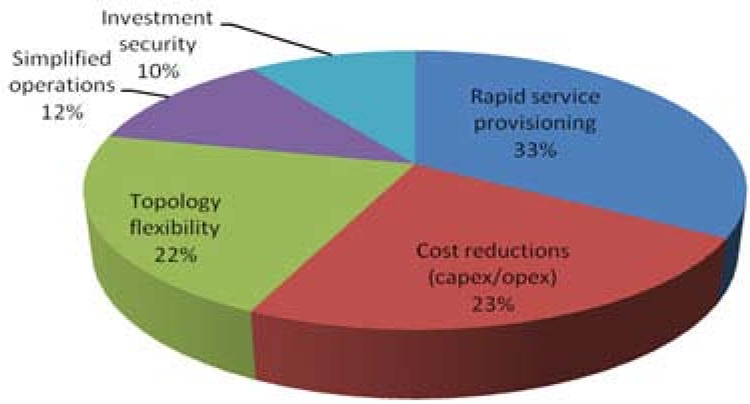
The problem is that wavelength blocking can concur when two wavelengths of the same color converge at the same WSS structure at the same time. This causes network contention. Operators must avoid this potential blocking/contention situation by partitioning the add/drop structures so that different colored 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, it means that 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 (without any 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.

Value Propositions for Operators

In September *Light Reading* led a webinar, sponsored by BTI Systems, on next-generation ROADMs, during which we asked audience participants to select the primary operator benefit of NG ROADMs. **Figure 1** shows the poll results of the 51 network operators that responded to the question.

Figure 1: Primary Operator Benefit for NG ROADM Networks



N=51
Source: Light Reading Webinar "Next-Generation ROADMs," September 2001

The network operator responses indicate that rapid service provisioning through "touchless" activation is the number one perceived benefit (33 percent of the vote) but that cost reductions measured in both capex and opex, and topology flexibility are also of critical importance. Simplified operations through automation and investment security weighed in as secondary requirements.

In our recent interview with BT, Business Development Director Dave Hook cited the need to reduce operations requirements as the primary driving force behind their transport network evolutions – including ROADMs – "with the goal of a zero touch architecture as the Holy Grail." Among the key benefits of NG ROADMs, according to Hook, are:

- Ability to respond to identify and respond to root failures much more quickly than in the past
- Reconfigurability at the optical layer
- The ability to improve fiber utilization
- Reduced power consumption

On this last point, Hook notes that "BT has a commitment to reduce its carbon footprint considerably," so the ROADM benefits line up nicely with the organization's corporate goals. We note this to underscore a point that is raised repeatedly in our ROADM discussions with operators: NG ROADMs are rarely being evaluated in isolation but are in integral component of their transport network evolution.

Implementations & Technology Building Blocks for CDC

From "Broadcast & Select" to "Route & Select"

A key to practical CDC implementation is the move from broadcast and select node architectures to route and select. Current networks use broadcast and select in which all channels coming into a node are broadcast to all of the degrees in the node. A WSS determines which channels move on (i.e., the select function). Multiplexing and demultiplexing functions are performed by colored Arrayed waveguide gratings (AWGs) that are provisioned on a per-degree basis and hard-wired in place. Thus, there is no flexibility of color or direction (degree) in current ROADM nodes.

To move to CDC implementations using the current broadcast and select architecture, however, quickly becomes problematic. The reason is that existing 1x9 WSS elements do not have sufficient ports to accommodate the degree requirements combined with the add/drop port requirements of the CDC structures. For example, a 1x9 WSS at an 8-degree node has little room remaining for add/drop. One alternative has been to move to higher port count WSS elements – particularly 1x20 WSS elements. Such an implementation would leave 12 ports for add/drop functions, even in an 8-degree node.

Figure 2 provides a comparison of broadcast and select and route and select based on CDC ROADM requirements.

Figure 2: Broadcast & Select Versus Route & Select Architectures

ELEMENT	REQUIREMENTS	DRIVER	BROADCAST & SELECT	ROUTE & SELECT
WSS	High port count	Support sufficient number of colorless and directionless modules	No	Yes
	Higher node isolation	More ports and high density modulation	No	Yes
	Flexible spectrum	400 Gbit/s+ channels	No	Yes
	Faster switching	Dynamic wavelength restoration	No	Yes
	Compact device	Single/dual slot line cards	No	Yes
Node	Channel grooming for add/drop	Enable multi-cast switch CDC	No	Yes
	Lower express loss	Higher OSNR for 100G, 400G	No	Yes

Source: JDSU, 2011

However, the problem is that it is extremely difficult to build high port count WSS elements that meet requirements in node isolation, switching speeds, size and cost. Today, no such high port count WSS meeting these requirements exist.

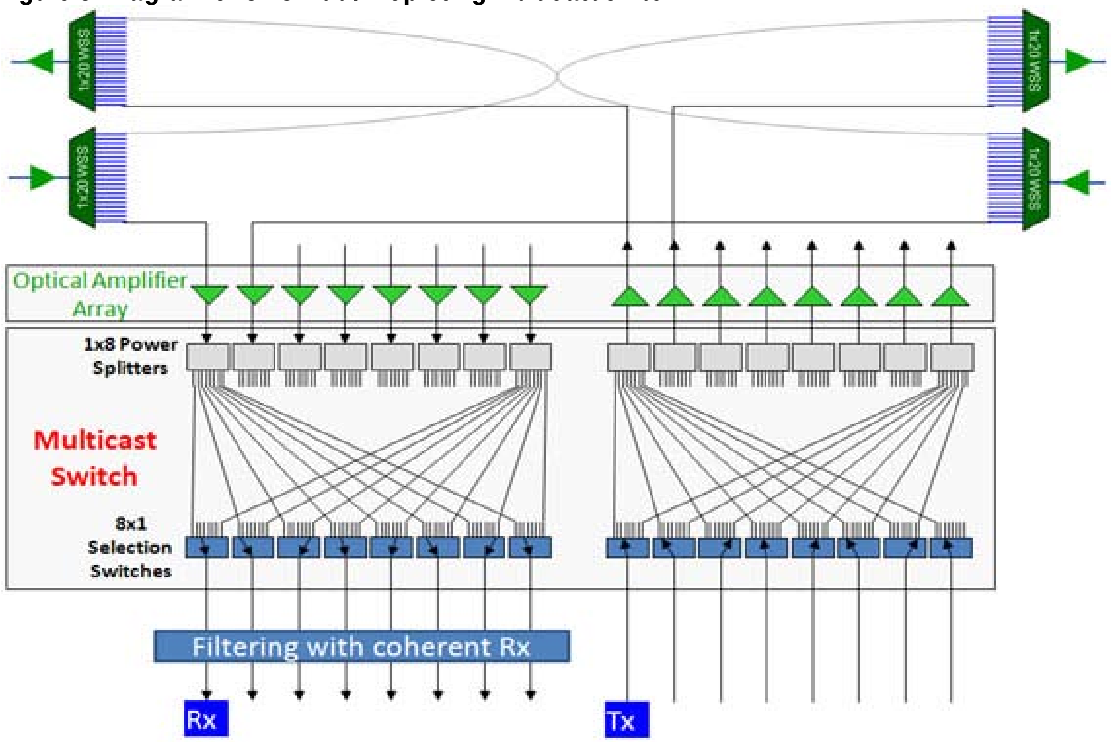
As a result, the drive is to address CDC requirements through a new route and select architecture that can use available WSS technologies (including 1x20 WSS elements) and meets all of the performance requirements.

In a route and select architecture, a second WSS element is added in place of a splitter on the broadcast side – giving the node the ability to block a wavelength at either the route side or the select side. While the architecture adds an additional WSS to the mix, it reduces the difficult performance requirements – such as higher node isolation – and improves OSNR (by eliminating high-loss splitters).

Multicast Switches and Coherent Receivers

In addition to route and select, a CDC architecture also requires an MxN switch in the mux/demux chain. The MxN switch provides the ability to route any input to any output. There are different ways of achieving the MxN switched add/drop, but gaining favor is the use of a combination of power splitters and modest port count 1xN space selection switches (as illustrated in **Figure 3**).

Figure 3: Diagram of CDC Add/Drop Using Multicast Switch



Source: JDSU, Heavy Reading, 2011

Initially, there was some interest in using larger-scale optical space switches (OXCs) to deliver the add/drop flexibility required by CDC, but over the past year this interest has waned as these switches are relatively large and costly. Another gating factor for OXCs has been the lack of support for flexible spectrum. Currently, the multicast switch architecture described above is preferred among equipment manufacturers.

After passing through the multicast switch, filtering is required. This can be done optically with a tunable filter array, but, with coherent detection being used in 100G transport and in many 40G deployments, coherent receivers can be used for filtering – eliminating the need for tunable filter arrays. Operators and systems suppliers like this option because it simplifies design, reduces size considerably, reduces power requirements and lowers overall costs. When coherent detection is not available – such as in 10G DWDM networks and in direct detect 40G networks – the tunable filter array can still be used.

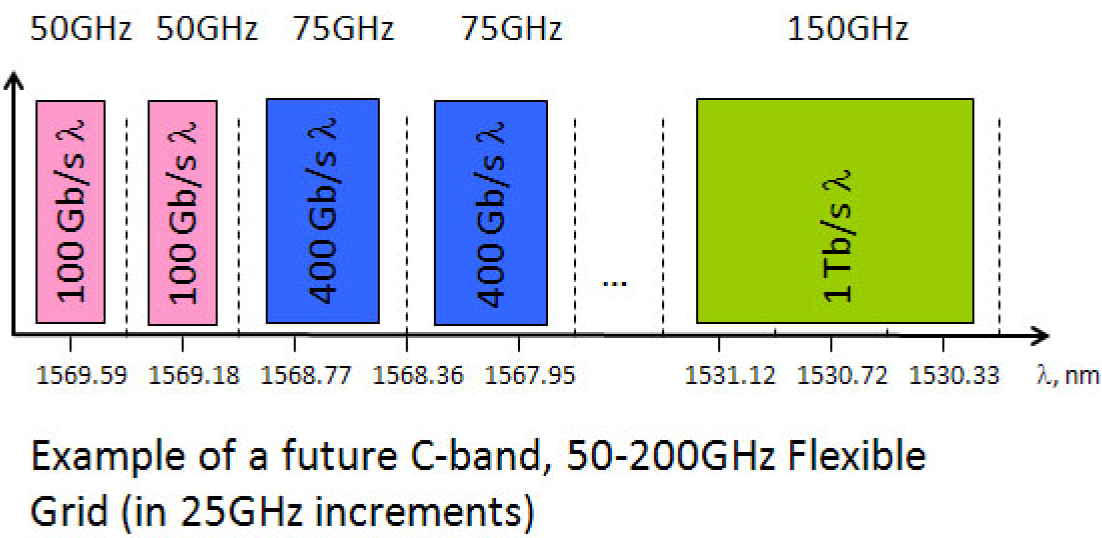
Flex Spectrum/Flexible Grid Overview

Flexible ITU Grid or Flex Spectrum

A fourth key concept in NG ROADM architectures is the concept of the flexible spectrum. (Note, 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 100Gbit/s transport. For speeds beyond 100 Gbit/s – i.e., 400 Gbit/s or 1 Tbit/s – more than 50 GHz of spectrum will almost certainly be required. Network operators would also like to be able 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 25GHz granularities, or even 12.5 GHz. ROADM nodes supporting a flexible grid could operate at any speed that is based on increments of 25GHz spacing, such as 75GHz spacing or 125GHz spacing, etc. See **Figure 4**.

Figure 4: Illustration of Flexible Spectrum Architecture



Source: Verizon, 2010

Verizon has been the most vocal operator proponent of flex spectrum, but the views resonate with other operators, as well. Verizon's Glenn Wellbrock views flex spectrum as the lynchpin of the entire NG ROADM function set. The following is a statement Wellbrock made at *Light Reading*'s Packet-Optical Transport Evolution conference in May.

> *"If you buy into [Flex Spectrum], then the rest of the next-gen ROADM roadmap quickly comes into place. If you want a flexible bandwidth grid, then you have to give up the filters underneath. And if you give up the filters underneath, then you're going to have to look at ways to switch traf-*

> *fic optically. And, if you are going with an optical switch, then the best approach is to deploy colorless, directionless, contentionless."*

Wellbrock stresses that the plan is not to get rid of the ITU grid. "We believe that would be a nightmare," he said. Rather, it's a more granular use of the spectrum.

Operator Considerations for Flex Spectrum

In this paper we have deliberately divided the flex spectrum discussion from the CDC portions. Of the four building blocks, flex spectrum is the most future-looking of the group and brings with it additional considerations beyond the flex spectrum supporting WSSs. These include optical channel monitors, Raman amplification, flex-capable mux/demux structures and node architectures, as well as network control. Not all of these pieces are currently available and the presence of the WSS alone is not sufficient.

We note that not all operators are in favor of moving to flex spectrum, at least in the near term, as the 400G+ channel capacities that flex spectrum will address are certainly many years in the future. While Verizon, as noted above, is a strong supporter of flexible spectrum, AT&T has been taking a more cautious approach.

For operators that are not interested in flex spectrum capabilities, a green field strategy for 400G+ transport is a viable option. Using this strategy, operators will use CDC ROADMs for their 10G, 40G and 100G network deployments over the next five years (or longer). When the time comes for 400G+ DWDM networks requiring greater than 50 GHz of bandwidth, these operators will move to new DWDM systems and new ROADMs. The key advantage of this strategy is that operators do not need to worry today about a migration that is many years away.

As AT&T Optical Systems Researcher Sheryl Woodward stated on an October 2010 *Light Reading* ROADM webinar:

> *Given AT&T's scale and historical growth, by the time we wish to deploy 400G, our 40G/100G transmission systems will probably be reaching their capacity, and we will be ready to deploy new systems employing the latest technologies.*

Clearly, there is some risk for operators that 400G+ may happen sooner than anticipated, but on the side of these more cautious operators we note that:

- 10G systems have dominated long haul transport for more than a decade (and counting)
- 100G transport is just beginning in earnest this year and works with 50GHz fixed grid
- The ITU-T and IEEE have yet to determine what the next rate beyond 100G will be

From an equipment suppliers' perspective, we see manufacturers building flex and CDC systems to address both CDC and CDC-F bids with the same platform. In this case, the flex spectrum functions are needed in the WSS and components but may not be deployed as a flex network.

Emerging Applications for NG ROADMs

This section examines some emerging applications for NG ROADMs.

Photonic Layer Restoration

Photonic layer restoration is commonly cited by operators as a driver for moving to CDC ROADMs. Automated restoration is performed at the electrical layers – primarily with Sonet/SDH at Layer 1 and migrating to OTN – or is done manually. With the advent of CDC ROADMs, operators now have the option of performing restoration at the photonic layer. The key benefit here is that the Layer 0 is less costly – both in capex and opex – than higher electrical layers. Therefore, moving more functions from the electrical layers down to the photonic layer reduces the burden on the electrical layers and can save operators on both capex and opex.

Prior to the CDC ROADMs and the extension of ROADM reconfigurability to the add/drop locations, photonic layer restoration was simply not an option. Restoration could only take place at the electrical layers. With CDC ROADM networks, operators will have the options of restoring electrically or optically and – with control plane interoperability – will be able to coordinate restoration between the two layers. (We emphasize that we are talking only about restoration functions here and note that protection functions will remain in the electrical layer even as restoration moves to the photonic layer.)

Network Defragmentation

Several operators are identifying network defragmentation as another potential application for CDC ROADM networks. The term and concept are derived from PC hard drives which, over time, store memory inefficiently with pockets of unused memory here and there. PC defragmentation rearranges memory so that it is stored in the most efficient way, therefore boosting PC performance.

Similarly, optical networking routes are built out over time and not very efficiently. While there is certainly pre-planning that goes into any network build, the reality is that the best route on the first day of operation may not be the best route five years down the road when new routes have been built, old routes have been decommissioned and traffic patterns have changed. With CDC ROADM networks, operators will be able to "reset" the photonic layer to make the most efficient use of the fiber capacity, all at the touch of a button.

Both Verizon and AT&T have been vocal supporters of this application.

Dynamic IP Load Balancing

Dynamic IP load balancing is another potential application for CDC ROADMs in which Layer 3 and Layer 0 interact using the generalized multiprotocol label switching (GMPLS) control plane standard. The goal is to speed up the provisioning of circuits between routers by directing the routers to request the required bandwidth directly from the optical layer. In May 2011, Ireland's research and education network HEAnet reported a successful test of the dynamic IP application between Juniper Networks routers and ADVA ROADM/DWDM equipment.

Here, we note that multi-layer control plane interoperability is essential. Both Juniper and ADVA have a deep partnership that helped this demonstration succeed, but there is no standard for multi-layer control plane interoperability.

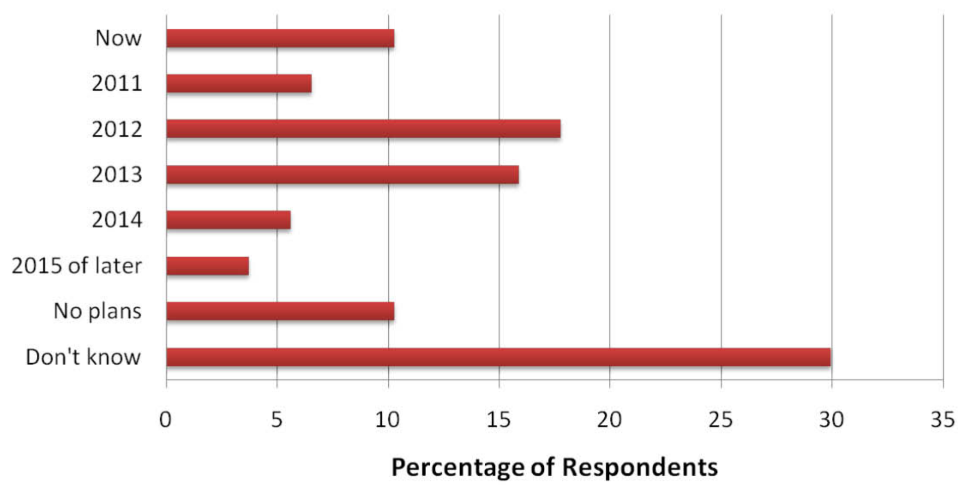
Outlook & Future Directions

Heavy Reading conducted a multi-client study on next-generation transport, including ROADM evolution, and published the results in December of 2010. This was based on a survey of network operators around the world and included 111 qualified network operator respondents. We asked the operators about their timelines for wide-scale deployments of CDC architectures, and the results are shown in **Figure 5**.

For CDC ROADMs, 2012 and 2013 are expected to be the biggest years, according to the survey, with 34 percent of respondents expecting wide-scale deployments of CDC ROADMs within their networks during these two years.

We note the uncertainty among the group of respondents. Thirty percent of the group selected "Don't know/not sure" for this question, indicating, we believe, that these organizations are in early phases of evaluating the technologies. This is not surprising because these functions are just now starting to get designed into systems level product.

Figure 5: Operator Expectations for Wide-Scale CDC ROADM Deployments

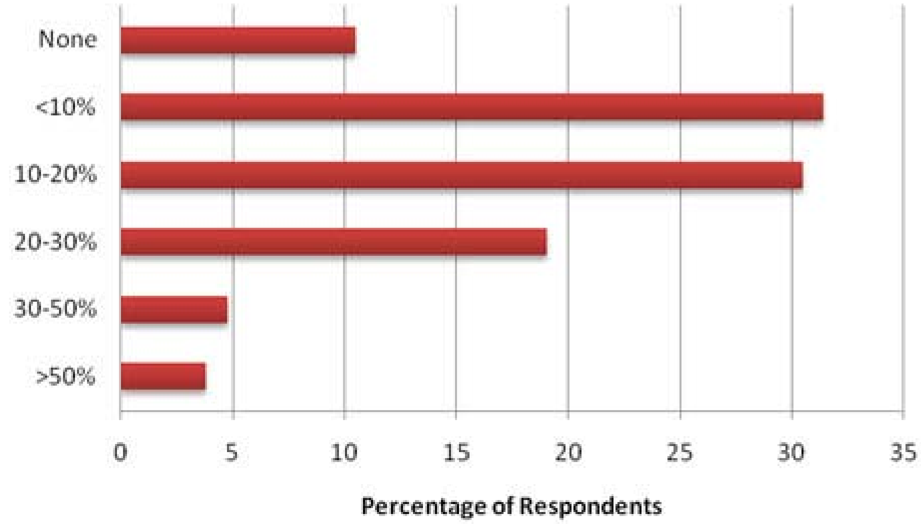


N=107

Source: Operator Plans for Core Packet-Optical Transport: A Heavy Reading Multi-client Study, December 2010

Clearly, pricing is a major factor in operator's decision to deploy new network architectures. A big part of the NG ROADM value proposition is savings on total cost of ownership at the network level – including both capex and opex. But are operators willing to pay more for this technology at the system/node level? We asked operators about expected price premiums (at the system/node level) for CDC ROADMs. The survey results are shown in **Figure 6**.

Figure 6: Expected Pricing Premium for CDC ROADM Architectures



N=105

Source: Operator Plans for Core Packet-Optical Transport: A Heavy Reading Multi-client Studv. December 2010

According to the survey results, there is a premium to be paid for CDC functionality but it is relatively modest at the node level, from single-digit percentages up to 20 percent, according to 62 percent of respondents. An additional 19 percent of the survey group said they are willing to pay a premium of 20 to 30 percent at the node level. Only 11 percent of respondents said that there is no premium to be paid for CDC functionality.

Next Steps

Commercial Availability of Systems

First, we note that it is very early days in the migration to next-gen ROADMs. For CDC functionality, the building blocks discussed in this paper do exist and are being designed into systems, but we are not aware of any commercial deployments of CDC ROADMs based on these technologies. For flex spectrum, meanwhile, the components are available but network software control is still a work in progress. We view the flex spectrum functionality as further off than CDC functions.

Multi-layer Control Plane Standardization

Some – but not all – of the value proposition for next-generation ROADMs is tied to multi-layer control plane interaction, such as Layer 1 (OTN) and Layer 0 or even Layer 3 (IP) and Layer 0. For widespread adoption of any of these multi-layer-dependent applications, operators will require multi-layer control plane interoperability among suppliers. The problem is that no standard exists. The Optical Internetworking Forum (OIF) is leading this multi-layer interoperability work, but this is in the early development phase. We think that operators will pressure suppliers to accelerate these activities.

Migration to the Metro

Most of the discussion around next-gen ROADMs over the past year has been around long haul/core networks. This may not be surprising since the earliest ROADMs were also driven initially by the long haul market before moving into the metro. With next-generation ROADMs, we are already starting to see interest in bringing CDC functions in particular to metro systems. Operators, such as BT, see a strong application for CDC in the metro and the long haul. Furthermore, looking at the optical transport market overall, *Heavy Reading* sees greater growth potential in the metro versus the long haul. In this context, it should not be surprising to see CDC functions built into metro-focused systems in the not-too-distant future. If the price points are right, we think that operators will be interested.

Finisar Perspective: Next-Generation ROADM Technology Available Now

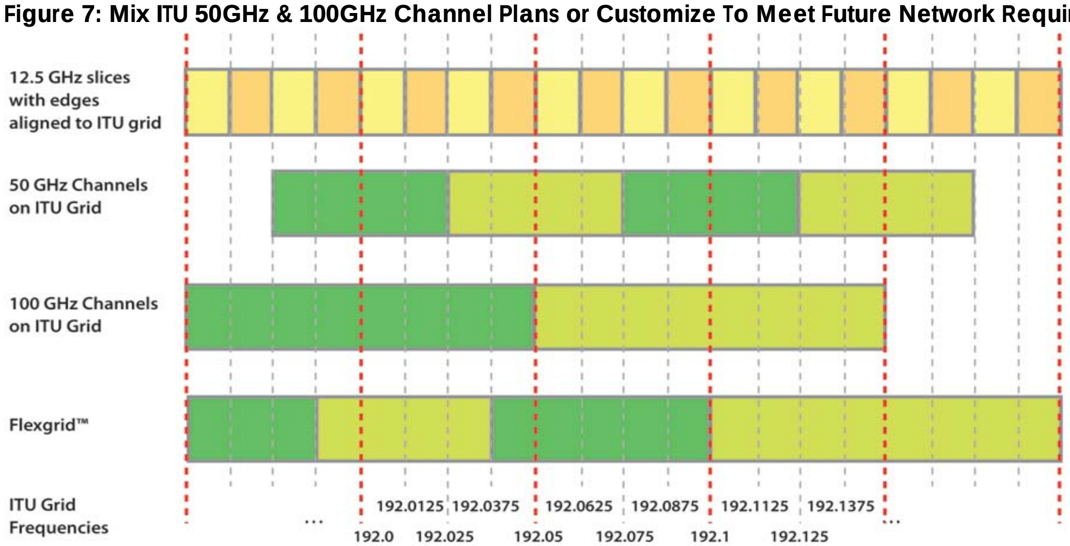
ROADM deployments in the core, metro and, ultimately, edge networks are enabling network operators to significantly reduce opex and capex. Furthermore, the never-ending demand for more cost-effective transmission (that is, lower cost per Gbit/s per mile) is driving network operators to carefully plan potential ROADM deployments to ensure that they are forward-compatible with a diverse range of future modulation formats and corresponding channel bandwidths.

Flexgrid™ technology from Finisar

In a typical telecom network, the available optical bandwidth for each transmission channel is limited by the channel bandwidth of the ROADMs in the network (due to their channel filtering characteristics), hence the need for "bandwidth-flexible" ROADMs. For current and future ROADMs, this primarily means that the WSSs that form the core switching element of the ROADM are capable of supporting flexible channel allocation.

The key to a bandwidth-flexible ROADM is the ability to independently control the channel bandwidth and center frequency of each channel of the WSS that comprises the heart of the ROADM. Flexgrid™ technology from Finisar, featured across Finisar's full range of WSS devices from 1x2 to 1x20, enables control over channel bandwidth in 12.5GHz increments, corresponding to 6.25GHz control over center frequency. Once deployed, channel plans are configurable "on-the-fly," meaning that channel bandwidths can be tuned to most efficiently carry future demand as it arises. Furthermore, by aligning 12.5GHz slot edges to the ITU grid, Flexgrid™ offers full backwards compatibility with both the standard 100GHz and 50GHz ITU grids, as illustrated in **Figure 7**.

Figure 7: Mix ITU 50GHz & 100GHz Channel Plans or Customize To Meet Future Network Requirements



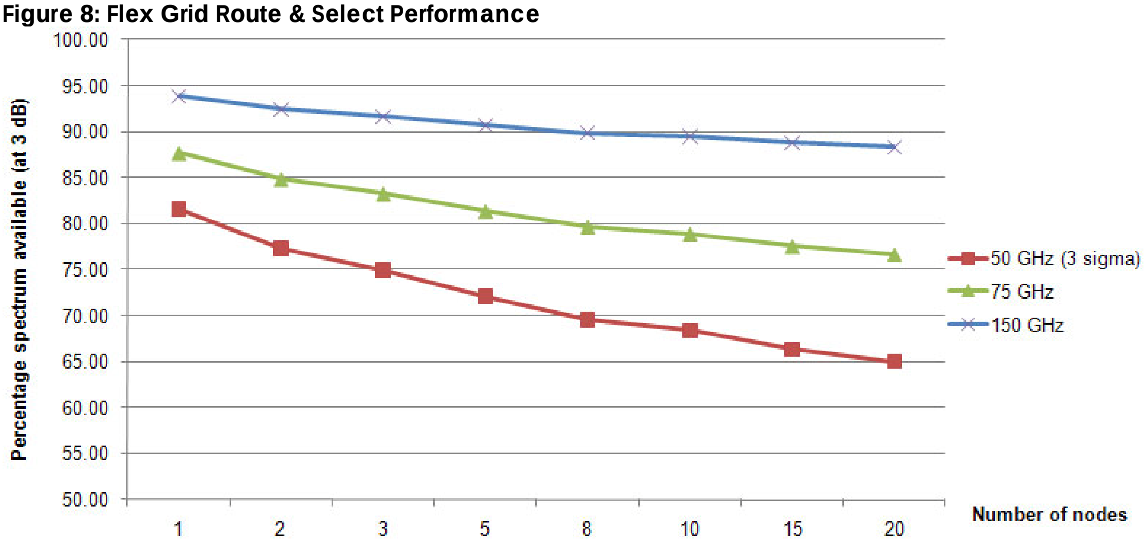
Source: Finisar, 2011

CDC Technology From Finisar

WSS devices are increasingly used to provide colorless add/drop functionality in ROADMs, replacing colored add/drop blocks that require fixed wavelength per port allocation, such as AWGs. To enable directionless functionality with a high percentage of add/drop capability, WSS devices with port counts greatly exceeding the degree of the ROADM node are required, with one WSS port from every ingress direction connected to a single common add/drop structure. Furthermore, as DWDM networks have evolved over the last decade from point-to-point systems and rings toward more meshed configurations, the number of connections at each node has increased significantly. As the degree of meshing within a network continues to grow, the need to interconnect more nodes without overlaying a new network requires the development of high port count WSS solutions.

Finisar's new 1x16 and 1x20 WSS high port count devices enable service providers to address higher nodal capacity while offering superior performance across express (through traffic) ports, thereby minimizing end-to-end system penalties, while maximizing the number of ports available for CDC add/drop modules. Enhanced filter bandwidth technology integrated into these products enable current and future high speed signals to travel longer distances and through more ROADM nodes. **Figure 8** illustrates the capability of Flex Grid Route and Select to support required bandwidth of today's 100 Gbit/s over multiple nodes and also the increasing spectral efficiency enabled by employing higher bit rates and wider contiguous bandwidth channels in concatenation.

Figure 8: Flex Grid Route & Select Performance



Source: Finisar, 2011

LCoS Technology From Finisar

The key enabler of Finisar's WSS platform for next-gen ROADM systems is Liquid Crystal on Silicon, or LCoS, a cutting-edge switch technology used to produce the industry's most feature-rich, field-upgradeable and cost-effective WSS modules. LCoS is used in all Finisar WSS devices from 1x2 to 1x20.

JDSU Perspective: The Portfolio of Devices for the Next-Generation Optical Network

Reconfigurable optical networks have become standard and have evolved through several generations over the past ten years. Evolving through wavelength blockers, PLC-based ROADMs and several generations of WSS's, JDSU has been the pioneer with each generation, improving the performance and feature evolution while reducing device cost and size. That legacy continues in the next generation of reconfigurable optical networks that require a new set of optical components to meet the needs of network operators.

The next generation of ROADM optical networks integrates several new features, such as CDC, more rapid reconfiguration and more extensive optical performance monitoring, to further increase the photonic layer flexibility, capability and automation. This enables dynamic traffic management applications, such as photonic restoration and load balancing, to provide a more efficient, adaptable and scalable network. Also, noise-sensitive 100 G requires low noise amplification and less total node loss. Looking beyond 100 G, network-wide support for flexible-spectrum channel allocation and higher isolation is required for more complex modulation formats. Finally, cost effectiveness and compact form factors are imperatives.

The following describes the suite of new and novel optical components to be released by JDSU in 2HCY12. These components work together to form the Self-Aware Network unprecedented flexibility, capability and scalability with the performance required to cost-effectively support 100 G and beyond.

Wavelength Management & Monitoring

A current ROADM node uses a 1xN WSS in a broadcast-and-select architecture. However, to simultaneously support all the necessary requirements for the next generation, a route-and-select architecture is replacing this approach (refer back to **Figure 3**). This architecture uses a WSS on both the inbound and outbound sides of each node degree so that wavelengths entering the node are routed to their provisioned destination rather than being broadcasted. This architecture has four key advantages. First, channel isolation is accomplished across two WSS devices (route-and-select) rather than only one (select only). This decreases the isolation requirement of each WSS, a central challenge to high-port-count (HPC) WSS design.

Second, the ability to direct channels to the multicast switches in the filterless CDC modules is central to cost effectiveness and compactness. Third, relaxing the isolation requirement permits reducing the physical size and increasing the switching speed – all while supporting a large number of WSS ports. Fourth, the total insertion loss is reduced for channels transiting the node requiring less amplification and higher OSNR.

To enable this route-and-select architecture that requires two WSSs per degree, JDSU is developing a twin 1x20 WSS that includes two independent 1x20 WSSs in a single, compact package. Based on advanced LCoS technology, the twin 1x20 WSS will support True Flex Spectrum, 10 dB better isolation than available in today's WSSs, and faster switching. With 20 ports, nodes will be able to simultaneously support eight degrees and 25 percent CDC add/drop of the node's maximum total throughput capacity while still having the ability to support in-service expansion capability up to 100 percent. More than eight degrees can be supported.

To measure and provide feedback on the optical network, JDSU is developing an optical channel monitor (OCM) designed for advanced networks – including flex spectrum. Within flex spectrum networks, channel allocations and widths cannot be defined in advance and the push for greater spectral efficiency (information capacity) is intensifying increasing power density at channel edges. Suitably monitoring these channels requires a high-resolution OCM capable of measuring the full continuous C-band spectrum at enhanced resolutions. This will allow accurate measurement of arbitrarily located channel edges and intra-Flex-Spectrum-channel features. The next-generation JDSU OCM will incorporate multiple independent optical inputs for more efficient multipoint monitoring in a single, compact and cost-effective package.

Colorless, Directionless & Contentionless

The cost, size and power density of a CDC multiplexer and demultiplexer are critically important. Therefore, the industry is converging on leveraging the channel-filtering capability of the coherent receiver in conjunction with the multicast switch to provide a lowest-cost and smallest-form-factor solution by avoiding the significantly high cost, loss and size of a WSS-like filter array prior to the receiver and transmitter. For this application, JDSU is developing a dual 8x16 multicast switch module in a single, highly compact and cost-effective package.

The novel switch design also supports very high isolation, fast switching, low excess insertion loss, low power and low polarization-dependent loss (PDL). As it does not incorporate filtering, it is fully compatible with flex spectrum networks. If 10G operation is needed, the JDSU low-cost tunable filter array can be subtended. Compensating for the significant fundamental loss of the multicast switch requires an array of optical amplifiers. Depending upon the power and performance requirements, JDSU can provide several compact solutions for optical amplifiers ranging from an array of low-cost, discrete amplifiers to more integrated solutions.

Low Noise Amplification

To extend the un-repeatered reach of higher-cost, 100 G and faster signals that require higher optical signal-to-noise ratios (OSNR), the amount of optical noise added to the signal per span must be reduced. JDSU is enhancing its leading optical-amplifier portfolio and expertise by releasing hybrid Raman-Erbium doped fiber amplifiers which combine the low-noise-amplification advantages of Raman pumping the transmission fiber with the cost-effective and compact amplification of conventional EDFAs. This combination permits increasing link OSNR by the several dBs required to maintain critical reach distances for 100 G and faster.

Summary

The next generation of flexible optical networks will offer a significant set of enhanced capabilities and features. To cost effectively support these features and the performance needed, nearly all key building blocks of today's optical network must be re-optimized. JDSU is building upon its legacy as a ROADM and optical-network-component leader by developing a full suite of key innovative components for next-generation networks.