NOKIA

Understanding ROADM add/drop architectures

Comparison of MCS and MxN WSS technologies for CDC-F ROADMs

Technical white paper

The introduction of colorless, directionless, contentionless, flex-grid (CDC-F) ROADMs has led to vast improvements in optical networking performance, flexibility, and efficiency. When first introduced, CDC-F ROADMs were based on multicast switch (MCS) technology within the ROADM add/drop section to move, steer, or re-route wavelengths. The recent introduction of MxN WSS modules offers an alternative technology for implementing CDC-F ROADMs.

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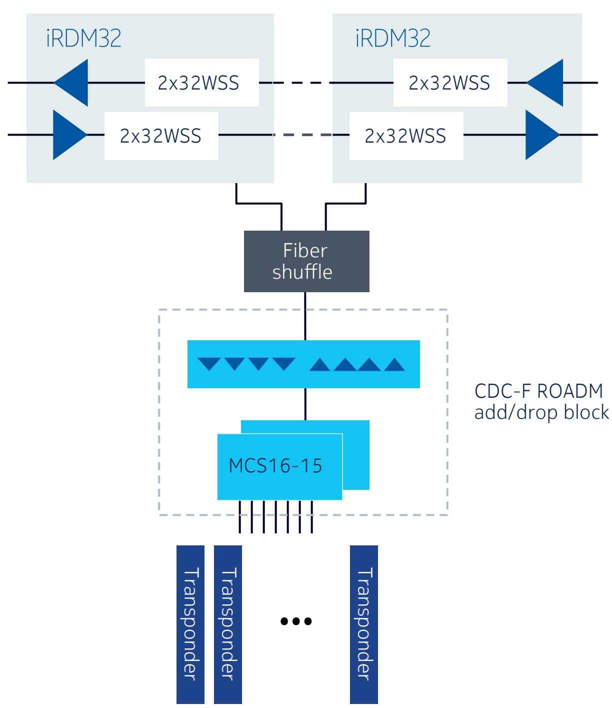
Introduction

Modern CDC-F ROADMs networks have gained wide industry acceptance due to their flexibility, simplified operations, and improved efficiency. These new ROADM architectures automatically move, steer, and reroute wavelengths, without the need for costly, time consuming, manual changes required on previous generations of mux/demux-based ROADMs. Advanced optical layer restoration applications take advantage of this new flexibility to vastly improve network utilization and reliability. Supporting flexible channel sizes, wavelength capacities, and baud rates, CDC-F ROADMS ensure carrier networks are compatible with new generations of coherent transponders. Since their introduction in 2016, the industry has a seen a dramatic shift to these newer, more modern, more flexible CDC-F ROADM architectures.

ROADM add/drop – technology engine

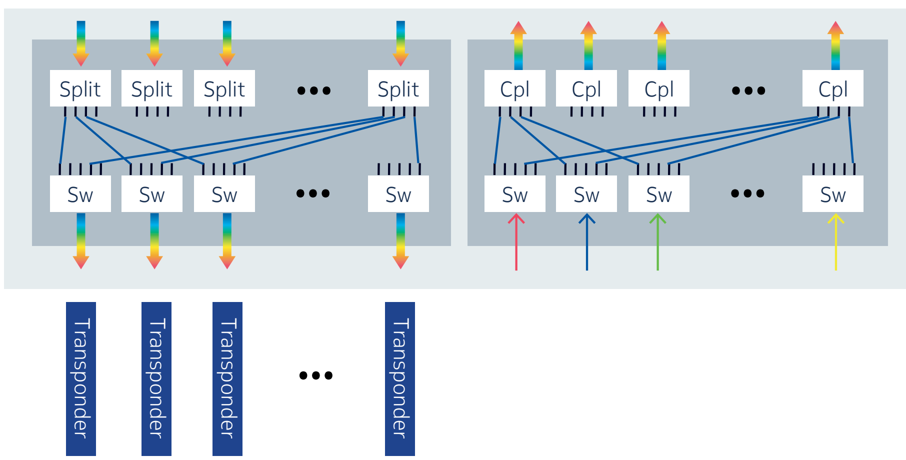
Modern CDC-F ROADM nodes are composed of ROADM line units, CDC-F add/drop blocks, transponders, and a fiber patch panel, also known as a "fiber shuffle" that provides interconnection between the functional blocks, as shown in Figure 1. Within the ROADM node, the add/drop block implements the colorless, directionless, contentless and flexible grid (CDC-F) capability. The add/drop block enables any transponder to be connected to any incoming port (colorless), any port to be connected to any ROADM line degree (directionless), while avoiding wavelength interference (contentionless), all without requiring manual fiber changes or manual intervention. The add/drop block is the engine that powers a CDC-F ROADM node.

Figure 1. CDC-F ROADM Node Architecture (MCS)



When first introduced, CDC-F ROADMs incorporated multicast switch (MCS) technology to implement the CDC-F add/drop architecture. As shown in Figure 2, an MCS module consists of an array of splitters, couplers, and optical switches. Each northbound MCS splitter/coupler port is connected to a corresponding ROADM line degree (ie direction) via an amp array card and fiber shuffle patch panel. In the drop direction, wavelengths from each WDM line degree are simply split to each client port, where optical switches select the provisioned degree (ie direction). In the add direction, the optical switches connect each transponder port to their provisioned WDM line degree, where couplers combine all wavelengths headed in the same WDM direction.

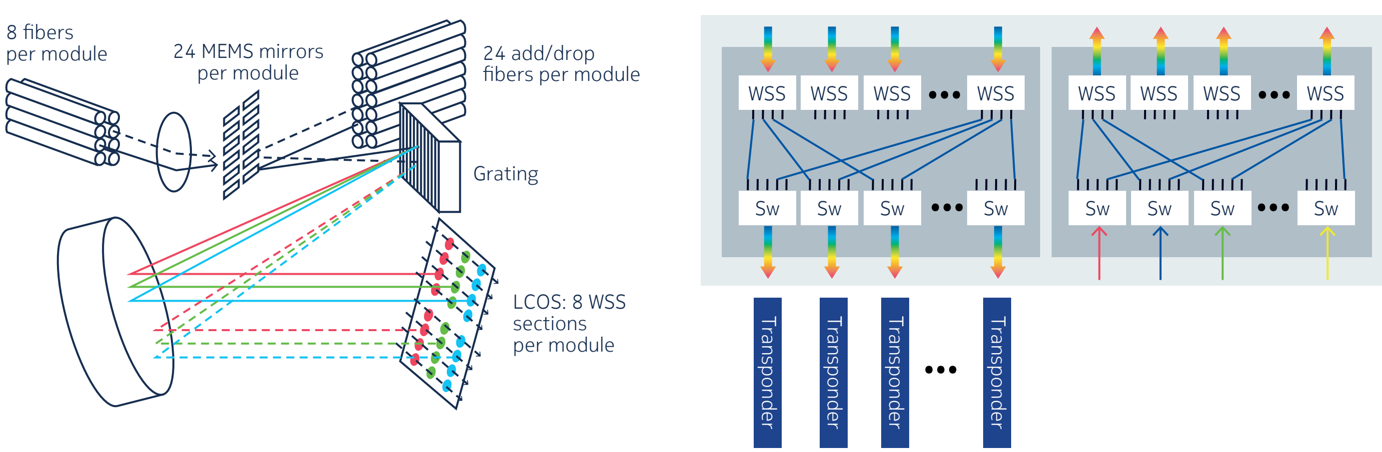
Figure 2. Multicast Switch (MCS)



MCS modules are available in several sizes, including 8-degree with 16 client ports (MCS8x16) and 16 degree with 15 client ports (MCS16x15). Since MCS cards rely on simple power splitters and couplers that divide power across all 16 transponder ports, the insertion loss on MCS units tends to be moderately high, at approximately 14 dB. Due to the high insertion loss, array amplifiers are needed in MCS add/drop blocks to provide acceptable optical power levels for the WDM line units, as shown in Figure 1.

Recently, a contentionless MxN WSS technology was introduced as another option to support CDC-F add/drop architectures. Within an MxN WSS unit, the optical splitters and couplers used in a Multicast Switch (MCS) architecture are replaced by dual 8x24 or dual 16x24 WSS modules, as shown in Figure 3.

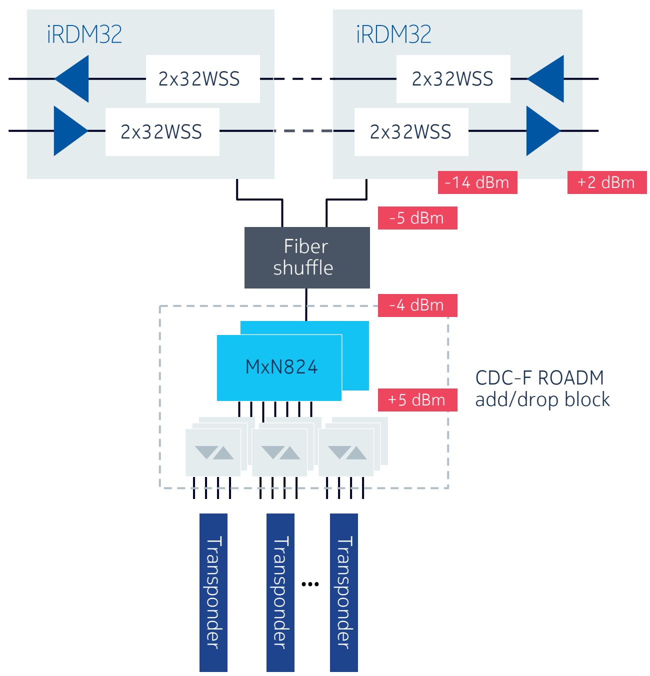
Figure 3. 8x24 WSS diagram and MxN module



Replacing the optical splitters and couplers used in an MCS architecture with MxN WSS modules reduces the insertion loss. However, the larger, more complex MxN WSS components result in physically larger cards, typically requiring 3-slot widths, along with slightly higher ROADM prices.

The MxN WSS can be paired with amplified splitter/coupler cards to provide additional transponder port capacity, as shown in Figure 4. In this example, a single MxN WSS unit is paired with (1:4) amplified splitter/coupler cards to provide up to 96 client side transponder ports per MxN WSS add/drop block.

Figure 4. CDC-F ROADM Node Architecture (MxN WSS)



MCS vs MxN WSS comparison

The optical networking industry supports both MCS and MxN WSS based architectures, with both technologies providing the same colorless, directionless, contentionless, flexible grid interconnections between transponders (or alien wavelengths) and WDM line degrees. Both MCS and MxN WSS architectures enable wavelength re-provisioning and re-routing, without manual involvement or manual changes. While MCS and MxN WSS based architectures offer similar operation and performance, there are important differences with each technology.

MCS based ROADM architectures can be configured with eight (8D) or sixteen degree (16D) nodes, and support node capacities with up to approximately 500 transponder add/drop ports. Due to their simpler internal technology, multicast switches (MCS) tend to be smaller in size, requiring fewer ROADM shelf slots, than MxN WSS alternatives. As a mature technology, MCS components are widely available from multiple component suppliers, ensuring a diverse supply chain with independent production capacity.

MCS cards have moderately high insertion loss, requiring the use of amp arrays within the add/drop block to ensure proper optical power levels. Since MCS modules are based on optical splitters, couplers, and switches, where wavelengths are simply “coupled” in the add direction, low-noise transponders with low “out-of-band” noise specifications should be used to ensure good OSNR performance.

MxN WSS based architectures are ideal for nodes with very large add/drop port requirements. When combined with amplified splitter/coupler cards, MxN WSS architectures can support up to 1000 transponder ports. Similar to MCS based systems, MxN WSS modules are also available in both eight degree (8D) and sixteen degree (16) configurations.

As a result of their more complex underlying technology, MxN WSS cards tend to be higher priced and a slightly larger than MCS options. In addition, the MxN WSS components are currently single-sourced in the industry.

Table 1. Comparison summary

Comparison	MCS	MxN WSS
Supports CDC-F add/drop	Yes	Yes
Up to 16D nodes	Yes	Yes
Supports 33-120 GBaud wavelengths	Yes	Yes
Add/drop client ports	~500	~1000 w/splitter/coupler
Card size	1 or 2 slots	3 slots
Insertion loss	Moderate	Lower
Add/drop amplifiers	Yes - Amp array	Yes - in many applications
Support low Tx launch power coherent pluggables	–	With ASC2/ASC4 amplification
Industry suppliers	Several	Single
ROADM node pricing	Lower	Slightly higher

Optical performance comparison

Both MCS based and MxN WSS based architectures can be configured to provide approximately the same network performance – similar wavelength capacities and optical reach over a given route. However, achieving good OSNR performance levels requires add/drop amplification on many MxN WSS applications, similar to existing MCS based architectures.

Ensuring proper optical power levels within each ROADM stage is critical to both ROADM and network performance. System vendors pay particular attention to two key optical power parameters:

- Per channel power levels at the input to the WDM line units (add direction)
- Per channel power levels into transponder Rcv port (drop direction)

Both of these power levels must be controlled within acceptable ranges for proper ROADM operation. When the losses through the add/drop stage become too large, or the incoming Transponder Tx power levels are too low, additional amplification (gain) is required in the add/drop stage to maintain acceptable per channel power levels.

MCS units have moderately high insertion losses, requiring amplifier arrays in MCS add/drop blocks to boost the optical power levels, as shown in Figure 1. One of the rationales for MxN WSS based architectures was the hope that the lower MxN WSS insertion loss might preclude the need for amplification in the MxN WSS add/drop block. Unfortunately, many MxN WSS based applications will require similar add/drop amplification to ensure proper internal power levels and achieve comparable OSNR performance.

A short example highlights how optical power levels affect ROADM add/drop architectures and internal amplification requirements. The red boxes in the Figure 4 indicate the per channel power levels needed in the add direction in order to meet the -14 dBm egress amplifier power target. Based on the worst case insertion losses of the WDM line card, the fiber patch panel, and the 8x24 MxN WSS add/drop stage, transponders with approximately +5 dBm Tx power are required for direct connection into the MxN WSS add/drop block. While there are industry transponders incorporating transmit amplifiers (EDFA) and supporting up to +5 dBm output power, many transponders fall within a more typical range of -2 to +2 dBm output power. These nominal industry transponders require some type of additional amplification in the MxN WSS add/drop block to meet the power requirement of the ROADM line units and to avoid OSNR penalties that result from operating at too low power levels.

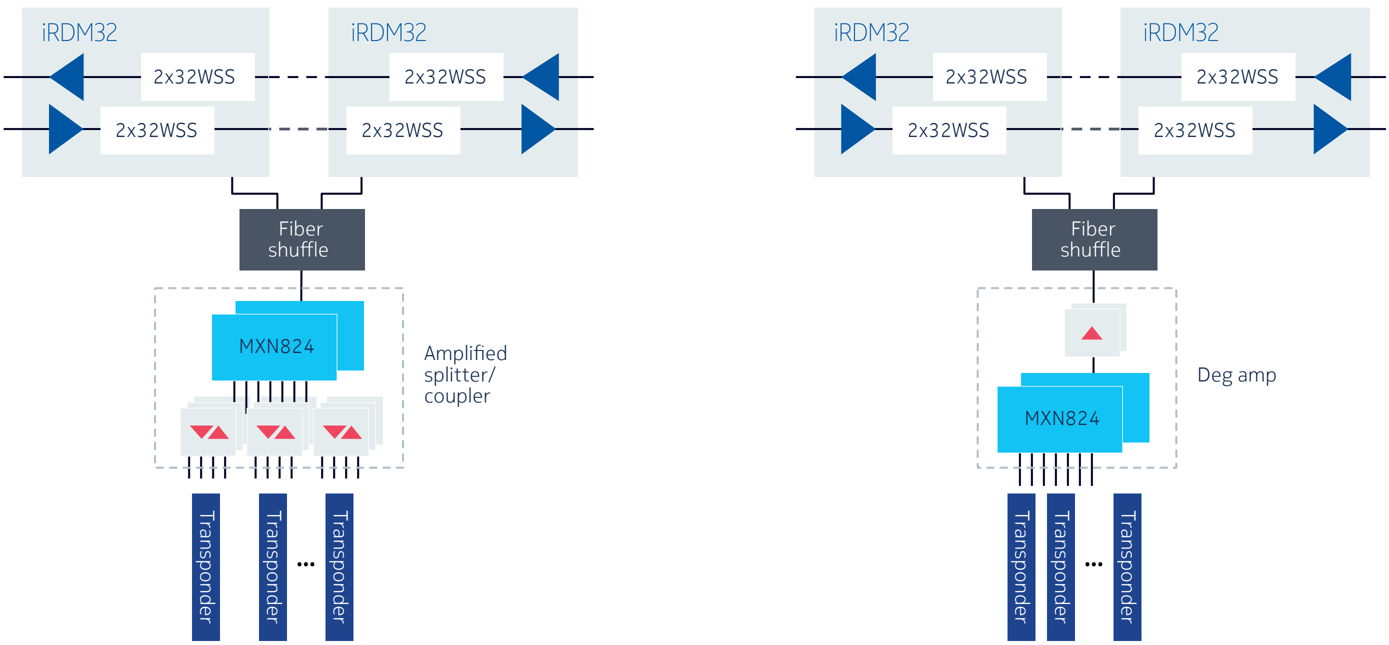
Vendors can incorporate Tx amplifiers, or Rcv amplifiers, or both in their card based transponders, which ensures MCS and MxN WSS based ROADM networks remain compatible with future generations of coherent technology. Optical networks have steadily evolved to higher capacity and higher baud rate wavelengths, with the trade-off of larger channel sizes. Traditional 33 Gbaud 100G wavelengths are carried in 50 GHz channels, while newer 62 Gbaud signals are typically carried in 75 GHz channels and 90 Gbaud signals in 100 - 125 GHz channels. As channel sizes increase, higher per channel powers are needed to maintain constant power per Hz, known as power spectral density (PSD). With small EDFAs incorporated into the transponder, constant power spectral density can be maintained, regardless of the provisioned wavelength capacity, baud rate, and modulation formats. Transponders with more nominal transmit power levels (-2 to +2 dBm), or even lower power levels found on the new 400ZR/ZR+ coherent pluggables, will need amplification in MxN WSS ROADM add/drop blocks, similar to existing amp arrays used in MCS based architectures.

There has been some industry discussion over where the additional add/drop amplifiers should be located, either as part of an amplified splitter/coupler stage shown in Figure 5a), or as a single degree amplifier shown in 5b). When using card based transponders with nominal to high transmit powers, in -2 dBm to +5 dBm range, either approach is acceptable. However, with the introduction of new, lower power (-10 dBm) coherent pluggables, the degree amplifier method (5b) becomes less practicable due to a number of factors, including:

- Large range of transponder input powers (-10 dBm to +5 dBm)
- Limited MxN WSS port isolation and power balance across WSS ports
- High OSNR penalties when using low power coherent 400ZR/ZR+ pluggables

Nokia implements the amplified splitter/coupler method (5a) which enables the use of new, lower power coherent pluggables and offers the added advantage of increased transponder ports and node capacity.

Figure 5a) Amplified splitter/coupler and 5b) WSS Degree Amplifier



In addition to maintaining proper optical power levels within a ROADM, there are a number of additional parameters that affect wavelength OSNR and impact overall network performance, including:

- Power level balance across wavelengths within the same add/drop block
- Transponder OSNR specifications
- Transponder Out of Band (OOB) noise specifications (MCS)
- WSS port/channel isolation (MxN WSS)
- Polarization Dependent Loss (MxN WSS)

Each of these parameters affects the OSNR penalty applicable to WDM network designs. Some of these issues are more impacting to MxN WSS based architectures (WSS port isolation, PDL) and others more impacting on MCS based systems (OOB noise). In general, with proper optical power level management within the ROADM node, OSNR penalties due to these other factors can be limited to manageable levels with either MCS or MxN WSS architectures.

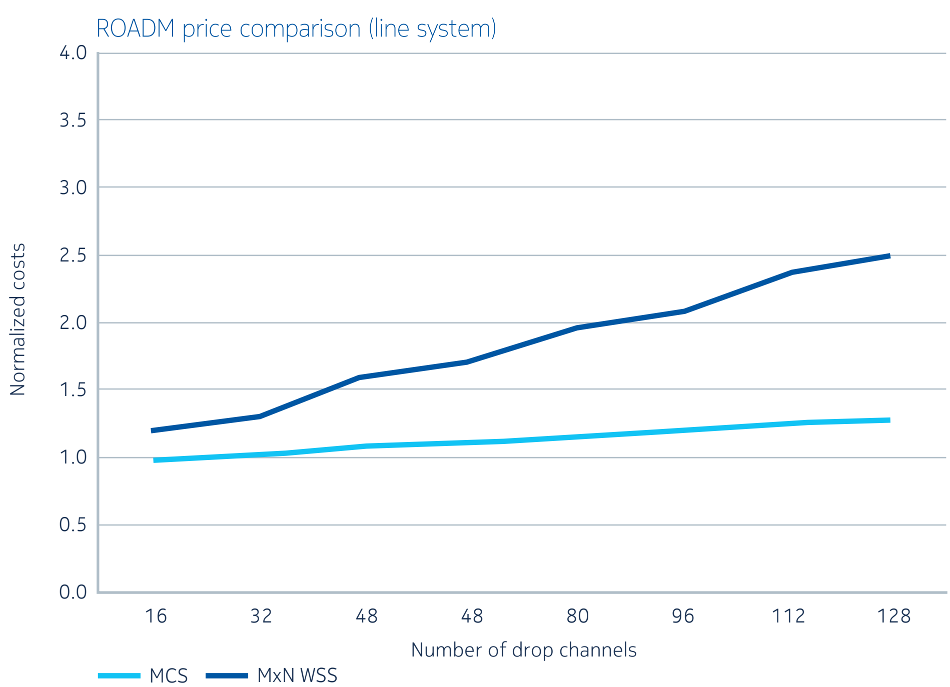
Pricing differences

While both MCS and MxN WSS methods provide similar contentionless, directionless, colorless, and flexible-grid (CDC-F) interconnections between transponders and WDM line units, there are commercial impacts between the two architectures. The pricing comparison shown in Figure 6 is for comparable eight degree (8D) CDC-F ROADM nodes: 1) an MCS based ROADM with MCS add/drop blocks and amp arrays, and 2) an MxN WSS based ROADM using MxN WSS (8x24) add/drop blocks with 2-port amplified splitter/coupler cards (ASC2). Transponders were not included in the models, since they would be common to both systems.

The MCS node is lower priced than comparable MxN WSS ROADM nodes, with the amount of the difference dependent on MxN WSS assumptions utilized in the model. For example, the MxN WSS ROADM node can be based on 2-port (ASC2), or 4-port (ASC4) amplified splitter coupler cards. In addition, the number of client ports supported by each amplified splitter coupler affects pricing differences in the comparison. In real world networks, it's not always possible to fully fill splitter coupler groups, as wavelengths route to different locations, or are provisioned as GMPLS optical restoration wavelengths. The comparison shown in Figure 6, is based on ASC2 amplified splitter coupler cards, providing six independent amplified 1x2 splitter couplers. Half of the ASC2 ports are fully filled with two wavelengths each, and half of the groups are provisioned for a single wavelength. While the MCS node will always be lower priced than comparable MXN WSS node, the exact pricing differential is dependent on the cards and configurations required by each application.

The pricing differences are due to the new MxN WSS module that incorporates more complex dual 8x24 WSS technology, as well as the addition of the amplified splitter coupler cards, which scale linearly with the number of channels

Figure 6. MCS vs MxN WSS ROADM price comparison



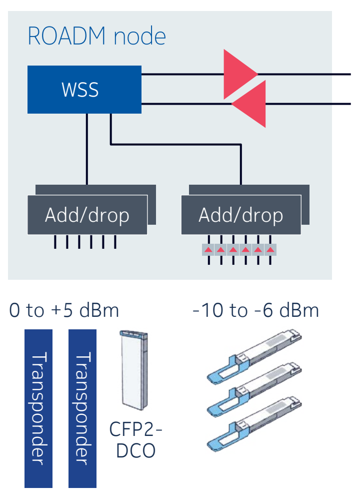
Coherent pluggable impacts

While there has been significant industry interest in 400ZR/400ZR+ coherent pluggable modules, especially for use in metro point-point DCI applications, these small-sized coherent pluggables impose issues when used over general purpose metro and regional CDC-F ROADM networks (see Lightwave Understanding 400ZR/OpenZR+/400ZR+ Optics)

Due to their small size and limited power dissipation, coherent pluggables have much have lower Tx launch powers (-10 dBm) and lower Tx OSNR (~34 dB) than comparable card based transponders, which typically support (~0 dBm) Tx power and (45 dB) OSNR. The lower incoming Tx levels are one reason MxN WSS ROADM nodes require additional amplification in the add/drop block to maintain proper per channel power levels, as shown in Figure 5.

In addition to managing per channel power levels at each stage within a ROADM node, the power levels across channels must be balanced to within a few dB to ensure optimal node and network performance. The wide range of incoming power levels from new 400ZR/400ZR+ modules (-10 dBm) and traditional card based transponders (0 to +5 dBm) will require segmenting channels into separate ROADM add/drop blocks, based on incoming power levels, as shown in Figure 7.

Figure 7. Separation of low Tx power coherent pluggables



Future-proofing optical networks

The additional optical layer flexibility provided by CDC-F ROADMs enables powerful new optical layer protection and restoration techniques, improves network capacity and utilization, and reduces overall networking costs. Network operations that once required costly, time-consuming, manual changes can now be fully automated.

Both MCS and MxN WSS technologies functionally perform the same contentionless, directionless, colorless, and flexible grid (CDC-F) function for ROADM add/drop architectures and both can be configured to provide similar network performance. MCS based architectures offer lower ROADM node costs than MxN WSS versions and result in slightly smaller physical node sizes. While MxN WSS based systems support very large add/drop port counts (> 600 ports) and are better suited for use with use with new, low Tx power coherent pluggables, when coupled with amplified splitter/coupler cards. Many MxN WSS based applications require some type of add/drop amplification, similar to existing MCS base solutions, to ensure acceptable optical power levels within the ROADM and provide comparable OSNR performance. Fortunately, the optical networking industry supports a wide choice of both MCS and MxN WSS solutions, including vendors who provide both options as part of their WDM product portfolios.

Abbreviations

ASC2	Amplified splitter coupler 2-port
ASC4	Amplified splitter coupler 4-port
CDC-F	Colorless, directionless, contentionless, flexible-grid
dB	Decibel
DCI	Data center interconnect
EDFA	Erbium doped fiber amplifier
GHz	Giga-hertz
Gbaud	Giga-baud
MCS	Multicast switch
OOB	Out of band
OSNR	Optical signal-to-noise ratio
PDL	Polarization dependent loss
PSD	Power spectral density
Rcv	Receive
ROADM	Reconfigurable optical add drop multiplexer
Tx	Transmit
WDM	Wavelength division multiplexing
WSS	Wavelength selective switch

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