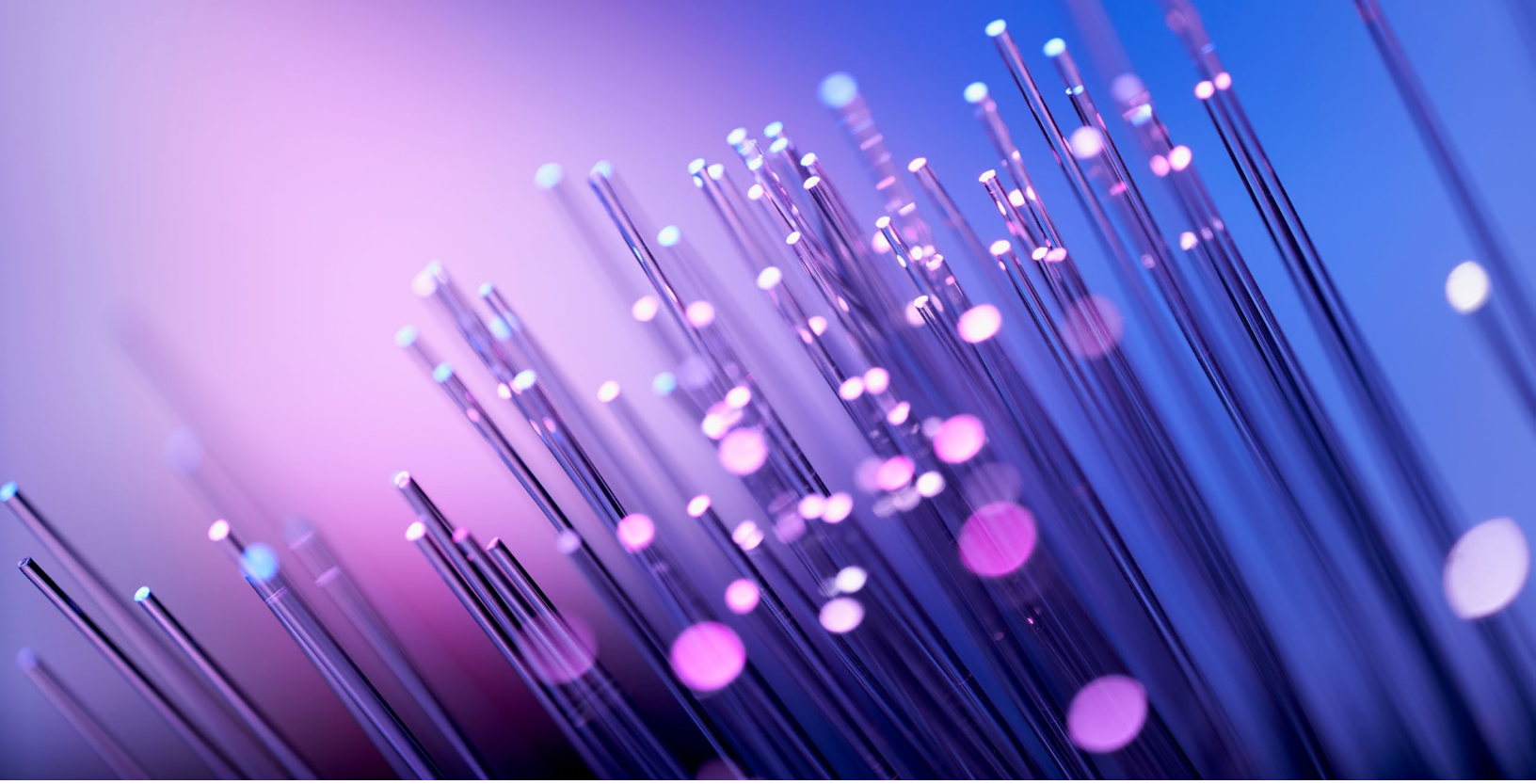


State of the Art Packet and
Optical Networking

ribbon

ROADMs Rule the Waves

ROADM Applications and Technologies Explained

White Paper

ROADMs - An Essential Fiber Optic Technology

DWDM (Dense Wavelength Division Multiplexing) optical networks are at the foundation of our global Internet economy. With an ability to transport over 100 information-bearing wavelengths on a single optical fiber, DWDM virtually nullifies the cost-per-bit of communicating information. This technology makes it economically viable for businesses to move their computing and storage to the cloud, and for consumers to stream video from anywhere. It is also an essential enabler for 5G and most other advanced telecommunications applications.

DWDM's world-transforming economics are powered by two technologies, which usually do not receive a lot of attention. They are:

Broadband amplifiers like EDFA and Raman amplifiers:

These amplify all wavelengths simultaneously on an optical fiber. Without amplifiers, it would be necessary to de-multiplex all the wavelengths on a fiber every 80 km or so, and amplify each wavelength individually. DWDM simply could not exist without broadband amplifiers.

Reconfigurable optical add/drop multiplexers (ROADMs):

These route wavelengths, under software control, from one end of the DWDM network to the other. This process does not require resorting to clumsy manual multiplexing and patch cords or expensive electronic conversion.

ROADMs benefit service providers in multiple ways:

Speed Up Service Provisioning

ROADMs add new service-transporting wavelengths to the network and route them across multiple network nodes quickly, using software control.

Reduce Capital Costs

Through 'all-optical' transport of service traffic, ROADMs dramatically reduce the need to perform expensive optical-electronic-optical (OEO) conversion within the network.

Increase Network and Service Availability

When failures such as fiber cuts occur, ROADMs can reroute wavelengths dynamically to maintain Service Level Agreements (SLAs).

What ROADMs Do

In a DWDM network, wavelengths transport customer traffic using Optical Transport Network (OTN) framing. Each wavelength transports either a single service interface (e.g. 10GE, 100GE, FC16, STM-64), or several service interfaces multiplexed together.

ROADMs are blind to the Layer 1 OTN traffic that the wavelengths carry. ROADMs operate on the wavelengths themselves at Layer 0 and perform three main functions, which are performed under centralized software control without on-site manual intervention.

Wavelength add/drop

ROADMs 'add and drop' individual wavelengths to and from DWDM links at nodes where customer traffic originates and terminates. In the figure, add/drop for the purple wavelength, with the customer traffic that it transports transparently, occurs at nodes A and J.

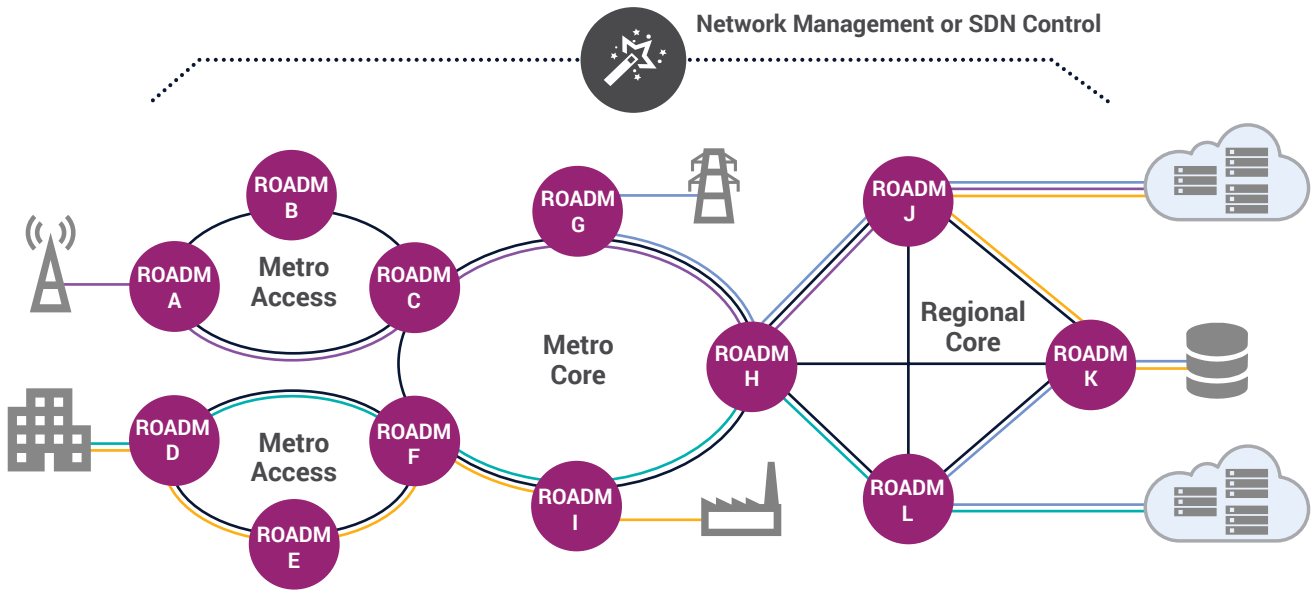
Wavelength pass-through

ROADMs 'pass-through' individual wavelengths at transit nodes, without having to break up the DWDM signals into their constituent wavelengths to undergo expensive conversion to and from an electronic signal. The purple wavelength 'passes through' nodes C, G, and H.

Power equalization

ROADMs monitor and equalize the optical power of all the wavelengths on a fiber to present amplifiers with a flat spectrum to maximize transmission performance.

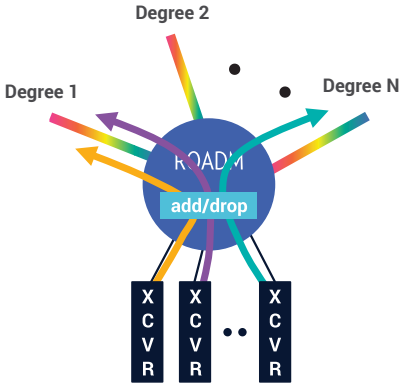
Wavelengths Routed End-to-End



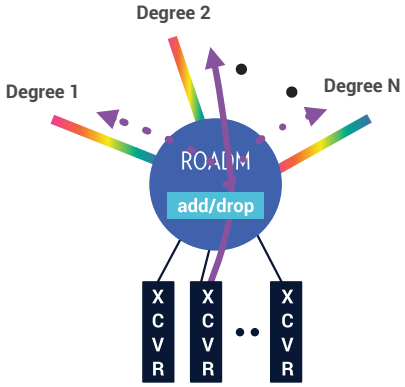
ROADM Configurations

The basic way to describe a ROADM is by its 'degree', which is the number of DWDM fibers that it terminates. As shown previously, nodes A-B-D-E-G-I sit on a ring and are 2-degree ROADMs, nodes J-K-L are 3-degree ROADMs, and nodes C-F-H are 4-degree ROADMs. In complex networks, it is common to have ROADMs with a high number of degrees, particularly when fiber paths are duplicated for redundancy.

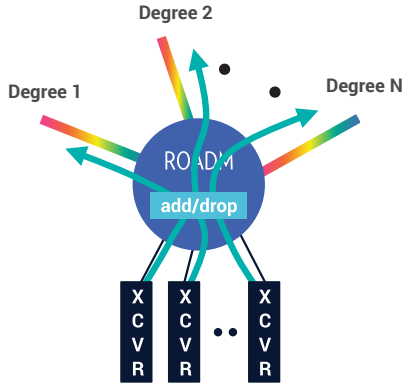
Another aspect of ROADMs is their flexibility to add and drop wavelengths. Advanced ROADMs typically support a mix of capabilities called Colorless, Directionless, and Contentionless. These capabilities are determined by the physical architecture of the ROADM, discussed below in more detail.



Colorless: Transmit (and receive) any wavelength from any add/drop port

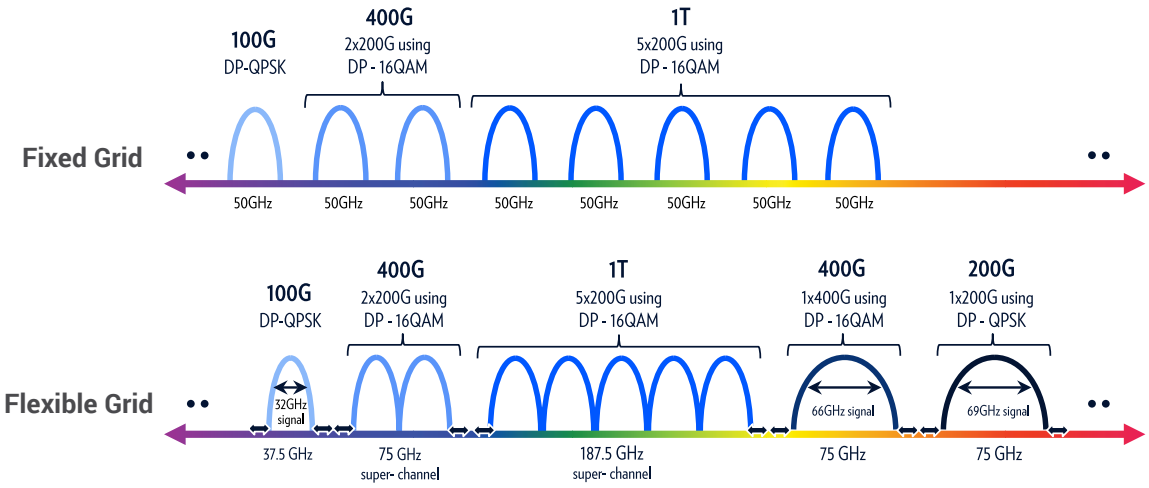


Directionless: Transmit (and receive) any wavelength in any direction



Contentionless: Transmit (and receive) the same wavelength simultaneously in multiple directions

An important consideration is support for flexible grid, also called flexible spectrum, or gridless. Until recently, DWDM networks used fixed grid 50GHz and 100GHz spacing. New continuous modulation techniques now require a wider variety channel widths for optimal performance. For example, a 200G signal may be generated that spans up to 1000 km in a 50GHz channel, but up to 2000 km in a 62.5GHz wide channel. There are also new requirements to bunch multiple carriers together in extra wide super-channels. Flexible grid enables this by supporting variable channel widths, typically in 12.5GHz increments with 6.25GHz channel center granularity. As the primary task of ROADMs is to route wavelengths across the network, it is becoming increasingly important that ROADMs allow flexible grid.

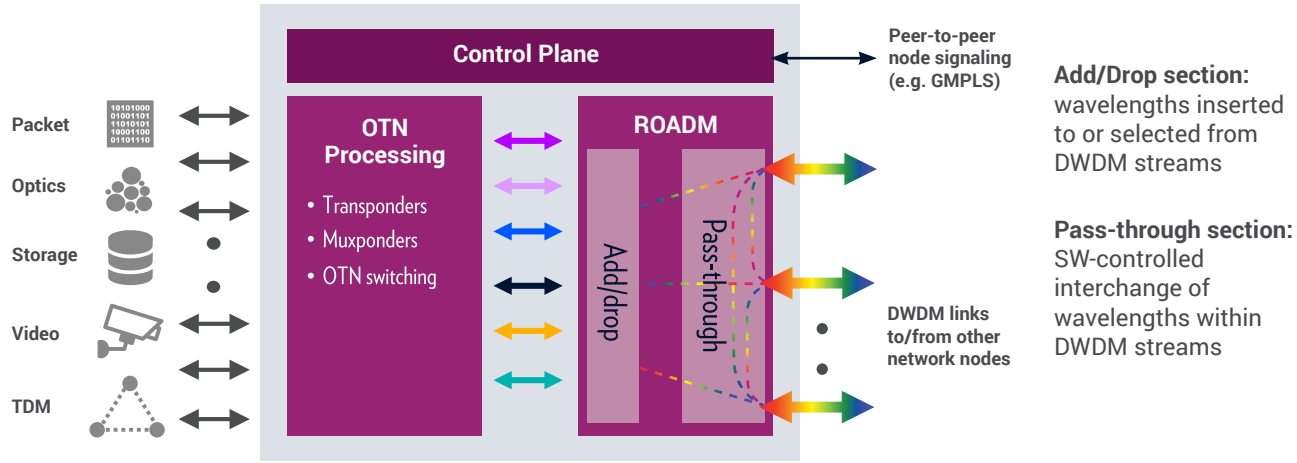


Provides up to 33% gain in spectrum efficiency over fixed grid

How ROADMs Work

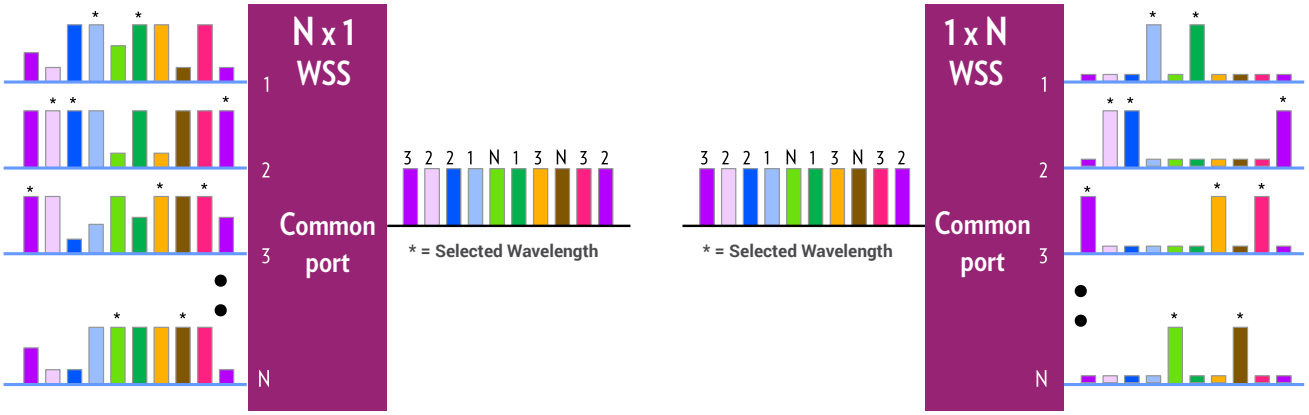
Let's start by looking at ROADMs in the context of an optical transport node. This has three major functional blocks: OTN Processing, the ROADM, and the Control Plane.

OTN processing uses transponders and muxponders, and in some configurations, service cards connected to an electrical switching fabric. It implements OTN framing and launches and receives service interface signals, individually or multiplexed, as colored wavelengths for transport on a DWDM fiber. These are the add/drop wavelengths entering the ROADM block, and appear below as single-color arrows. The ROADM block adds/drops these individual wavelengths to DWDM links going to other nodes. The ROADM block also passes through individual wavelengths from one DWDM link to another.



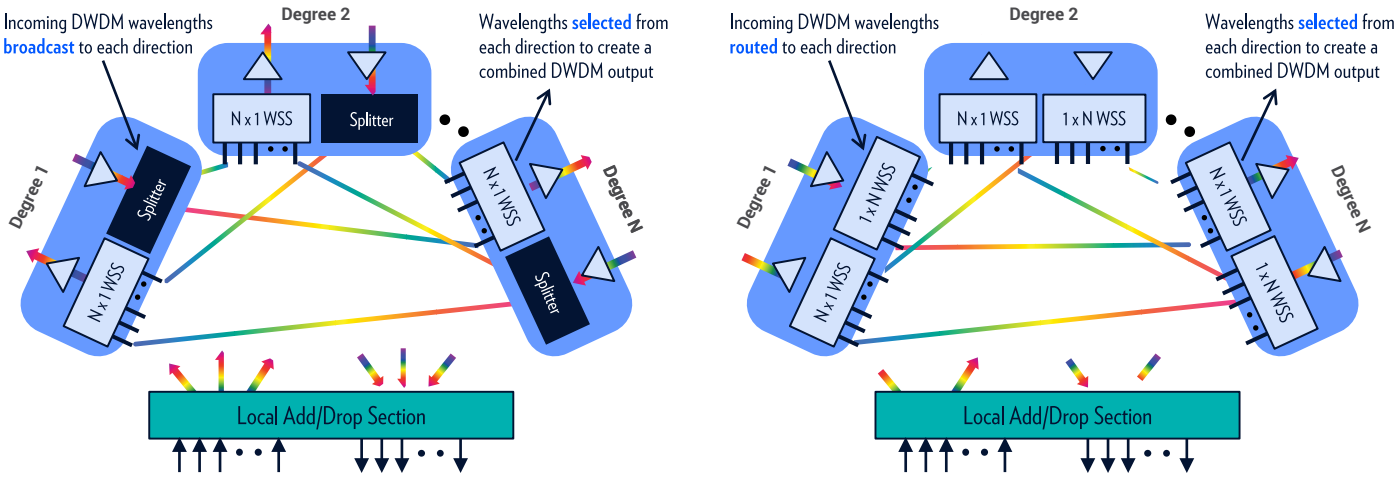
The Control Plane communicates with higher levels of network management to receive provisioning commands. It uses these to configure the OTN processing and ROADM blocks. It also communicates directly on a peer basis with Control Planes in other network nodes to implement WSON (Wavelength Switched Optical Networking) for dynamic wavelength restoration.

The main optical module used to implement ROADMs is the wavelength selective switch (WSS), which operates under software control and employs optical switching technologies, such as liquid crystal on silicon (LCOS) or micro-mirrors (MEMS). An N x 1 WSS selects wavelengths from multiple input fibers to a common output fiber, while a 1 x N WSS distributes DWDM wavelengths from a common input fiber to designated output fibers.



ROADMs use interconnected arrays of WSSs to inter-change wavelengths among the DWDM links, implementing the pass-through function. The internal WSS technology also equalizes the optical power of each wavelength to create a smooth DWDM signal for optimal transmission. The two main variants of ROADM architecture for interchanging wavelengths are:

- **'Broadcast-and-Select'**, uses a single WSS for each direction and provides optical performance suitable for up to 9-degree ROADMs.
- **'Route-and-Select'**, uses dual WSS for each direction and is suitable for larger ROADMs, currently, up to 20-degrees.



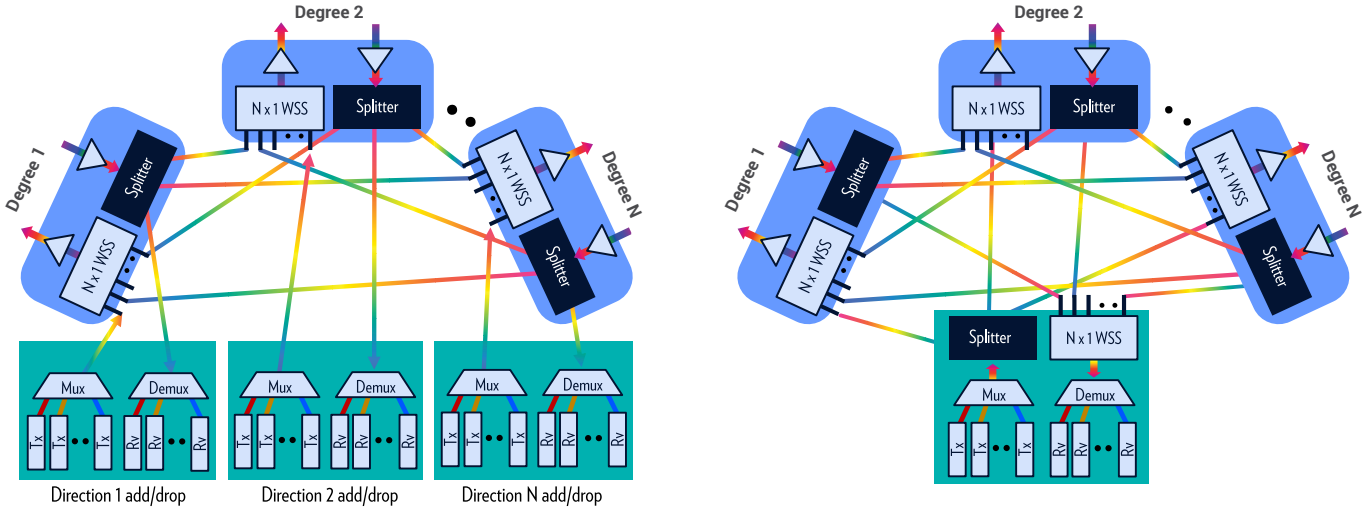
The other aspect of ROADM architecture focuses on implementing add/drop functionality. The next set of diagrams illustrates the progression from simpler to more complex add/drop variants:

Colored and direction-aware add/drop

- Add/drop selector employs standard fixed wavelength mux/demux.
- Specific wavelengths are tied to specific directions.
- Has lowest cost and lowest add/drop flexibility.

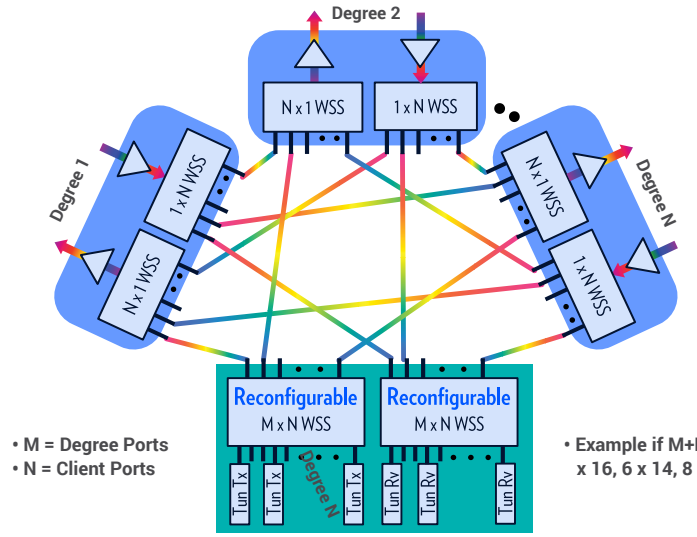
Colored and directionless add/drop

- Fixed wavelength mux/demux are still used which continues to tie the add/drop to specific colors.
- The addition of a splitter and a WSS in the add/drop selector adds directionless add/drop functionality.
- Modest increase in cost adds directionless functionality.



Colorless and directionless add/drop

- The fixed wavelength mux/demux are replaced by M x N WSS with tunable transceivers.
- Provides full colorless and directionless add/drop functionality under software control.
- More costly and much more flexibility.

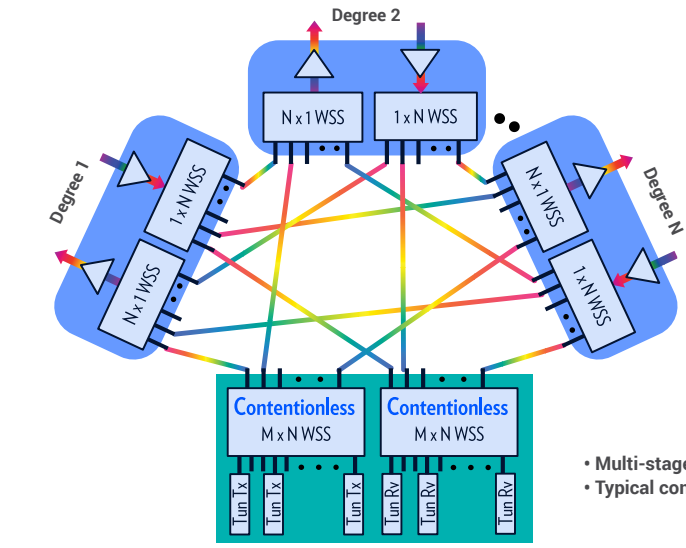


• M = Degree Ports
• N = Client Ports

• Example if M+N=20, can configure for 4 x 16, 6 x 14, 8 x 12

Colorless, directionless, and contentionless add/drop

- 'Contentionless' M x N WSS based on 2-stage MEMS and LCOS technology enables identical wavelengths to be received from, and added to, multiple directions. (Replaces poor performance multicast switching technology.)
- Provides full colorless, directionless, and contentionless add/drop functionality under software control.
- Most costly and most flexible configuration. Typically deployed at larger nodes in networks with numerous wavelengths, where maximum flexibility is needed.



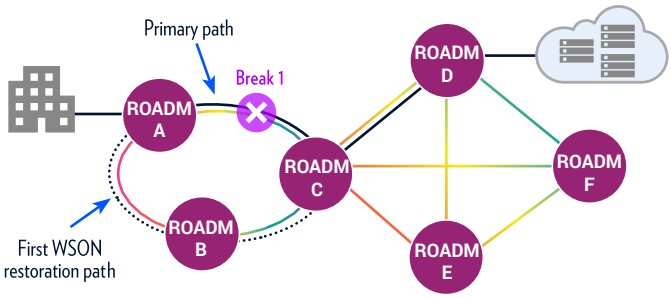
• Multi-stage wavelength switching
• Typical configuration is 8 x 24

Dynamic Restoration Application

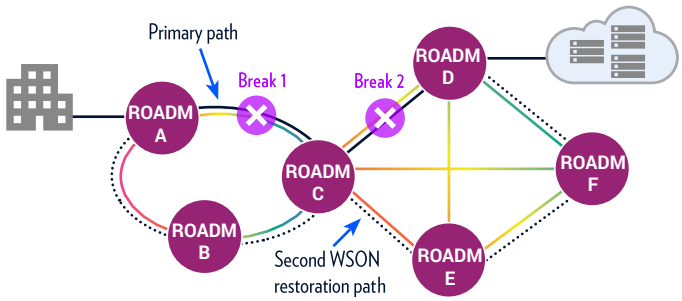
ROADMs are essential to implement WSON (Wavelength Switched Optical Network) dynamic restoration, which supplements conventional protection switching in the event of link failures. ROADM nodes communicate with each other using GMPLS signaling to discover network topology and make automated wavelength routing decisions. WSON is particularly attractive because it does not require any additional resources on day 1.

The following drawings illustrate WSON restoration for the access and the core. A light path connects an Enterprise location to a data center traversing nodes A-C-D. After an initial break in connectivity between A and C, WSON restores the wavelength around the ring, re-establishing the service along path A-B-C-D. Later, a second break occurs along C-D in the mesh portion of the network. Here WSON finds a spare light path available for the same color of wavelength and restores the service along path A-B-C-E-F-D.

WSON Restoration in Access



WSON Restoration in Core

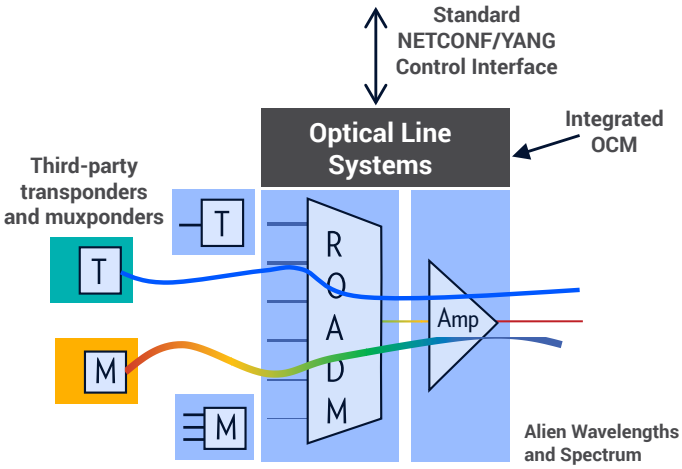


Disaggregation Application

Disaggregation allows network operators to pursue a best-of-breed approach to building optical networks. It relies on vendors creating standalone optical subsystems with well-defined control interfaces.

The primary approach is where a single vendor provides an Open Optical Line System (Open OLS) composed of ROADMs and amplifiers. These transport alien wavelengths and even alien spectrums from third-party vendors of transponder and muxponder subsystems, as well as the wavelengths and spectrums of the Open OLS vendor itself.

Initially, Open OLS is expected to be deployed for short-haul, point-to-point applications, like data center interconnects. Then, as experience is gained, it will be used for more complex metro and long-haul optical networking applications.



Ribbon Leading ROADM Solutions

Ribbon's Apollo packet-optical transport system delivers a full range of powerful and cost-efficient ROADM configurations for ring, star, and full mesh topologies.

Apollo ROADMs:

- Support both fixed grid 50GHz/100GHz channel spacing and flexible grid with 12.5GHz channel width and 6.25GHz channel center granularity.
- Integrate optical channel monitoring (OCM) for all output channels.
- Are software controlled through industry-standard NETCONG/YANG interfaces, enabling an Open OLS.

The following tables summarize notable Apollo ROADM cards and the benefits of Apollo ROADMs.

ROADM8x24_CDCF

- Colorless, directionless, and contentionless add/drop card, for up to 24 client ports and 8 degrees of network connectivity.
- Based on a revolutionary MEMS + LCOS design for high optical performance, replacing the previous low-performance contentionless approach, using multicast switches.

ROADM_20CF

- Colorless and directionless add/drop card.
- Field-configurable for different combinations of add/drop ports and degrees of network connectivity, including : 16 x 4, 14 x 6, 12 x 8, and 10 x 10.

ROADM_20TF

- Wavelength interchange card for up to 20 degrees of network connectivity, using a route-and-select ROADM architecture.

ROADM_9TF

- Wavelength interchange card for up to 9 degrees of network connectivity, using a route-and-select ROADM architecture.

ROADM_9FS

- Wavelength interchange card for up to 9 degrees of network connectivity, using a small-footprint broadcast-and-select ROADM architecture.

ROADM_4FS

- Wavelength interchange card for up to 4 degrees of network connectivity, using a broadcast-and-select ROADM architecture.
- Integrates two pluggable CFP2 MSA amplifiers (booster and/or pre-amp), enabling ultra-dense deployments.

Summary of Apollo ROADM Capabilities and Benefits

Apollo ROADM Capability	Description	Service Provider Benefits
MULTIPLE DEGREES OF CONNECTIVITY	Implement 2-degree to 20-degree ROADMs with 'broadcast-and-select' or 'route-and-select' architectures.	Optimize cost/performance of ROADM nodes for any network topology and range of metro, regional, and core networking applications.
ALL-OPTICAL WAVELENGTH ROUTING	Route individual wavelengths to 'pass through' over 20 ROADM nodes, all -optically and software-controlled.	Rapidly create end-to-end service-transporting lightpaths without expensive conversion to the electrical domain.
FLEXIBLE ADD/DROP	Configure any combination of colorless, directionless, and contentionless add/drop, with industry-leading high optical performance.	Automate end-to-end service provisioning, from client interface to client interface on a light path.
FIXED AND FLEXIBLE SPECTRAL GRID	Support either fixed-grid 50/100 GHz channel spacing, or flexible grid with 12.5 GHz channel width increments and 6.25 GHz channel center granularity.	Use advanced transmission schemes that optimize line rates for different span lengths and fiber link conditions.
INTEGRATED MONITORING AND EQUALIZATION	As an embedded capability, monitor and equalize all the wavelengths on an outgoing DWDM link.	Ensure uniform amplification of the entire DWDM signal to maximize transmission distance.
EFFORTLESS NETWORK MANAGEMENT	• LightSOFT® NMS point-and-click provisioning. • LightPULSE™ performance monitoring and trend reporting. • LightINSIGHT™ network analytics.	Operate the ROADM-based optical network effortlessly and with complete visibility.
SOFTWARE DEFINED NETWORKING (SDN)	Muse™ Orchestrator provides automated provisioning and network optimization applications.	Generate new revenues through services such as wavelength-on-demand and use capital more effectively through network optimization.
DYNAMIC WSON RESTORATION	Automated wavelength route restoration, based on ROADM nodes communicating with each other using GMPLS signaling.	Supplement or replace dedicated automatic protection switching, reducing costs and increasing service and network availability.
DISAGGREGATION	Configure Apollo ROADMs and amplifiers as a 'disaggregated' Open Optical Line System, controllable through standard NETCONF/ YANG interfaces.	Assemble optical networks flexibly with a best-of-breed approach.

ROADMs Rule

DWDM can be viewed as a set of multilane optical highways upon which our Cloud-Internet economy is built. In this comparison, ROADMs are a combination of the on/off ramps to these highways and the interchanges that allow information to effortlessly flow from one highway to another, without needing to exit and get on again.

Ribbon's Apollo ROADMs can be customized to fit any optical network need, from aggregation rings to dense core interconnects. Apollo ROADMs scale smoothly from 2 to 20 degrees, and support any combination of colorless-directionless-contentionless add/drops. They are available in dense, power-efficient configurations. Best of all, they can be implemented within an end-to-end Apollo solution, or as a disaggregated subsystem, controllable through standard interfaces.

Apollo ROADMs let you rule the wavelengths of your optical network.

Contact us to find out how to 'ROADM-ize' your optical network at rbbn.com

About Ribbon

Ribbon Communications (Nasdaq: RBBN), which recently merged with ECI Telecom Group, delivers global communications software and network solutions to service providers, enterprises and critical infrastructure sectors. We engage deeply with our customers, helping them modernize their networks for improved competitive positioning and business outcomes in today's smart, always-on and data-hungry world. Our innovative, end-to-end solutions portfolio delivers unparalleled scale, performance, and agility, including core to edge IP solutions, UCaaS/CPaaS cloud offers, leading-edge software security and analytics tools, as well as packet and optical networking leveraging ECI's Elastic Network technology.