Network Elements

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Overview

Optical Networks Evolution

Optical Networks

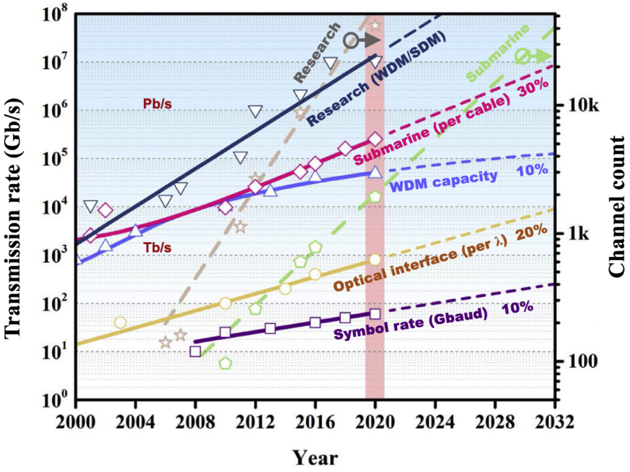

Figure: Evolution of optical communication networks.

Optical Networks

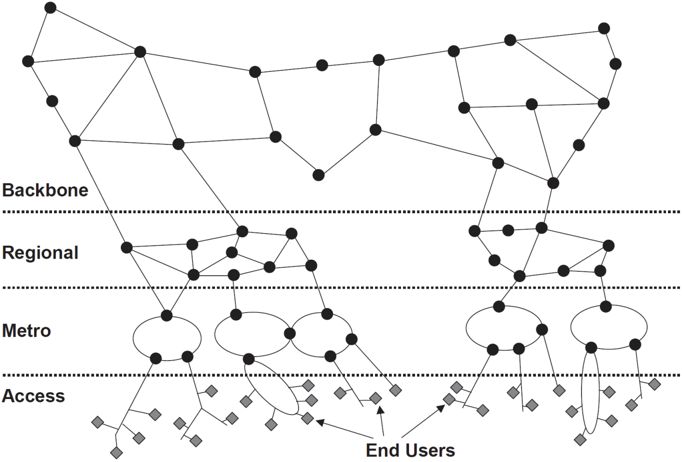

Figure: Networking hierarchy based on geography. Each geographical hierarchy has its own number of served customers, required capacity, geographic extent, implementation technology, and traffic behavior.

Optical Networks

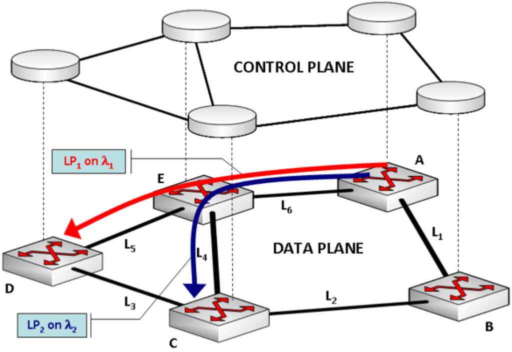

Figure: Data plane and control plane.

Optical Networks

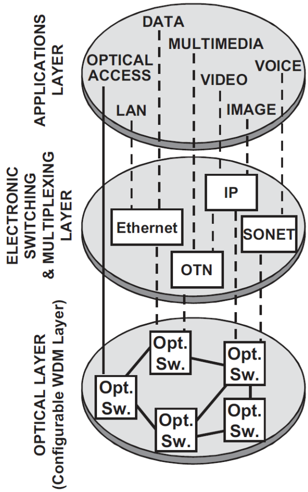

Figure: Three-layered architectural model. Currently, the optical layer is usually based on wavelength division multiplexing (WDM) technology with configurable optical switches.

Optical Networks

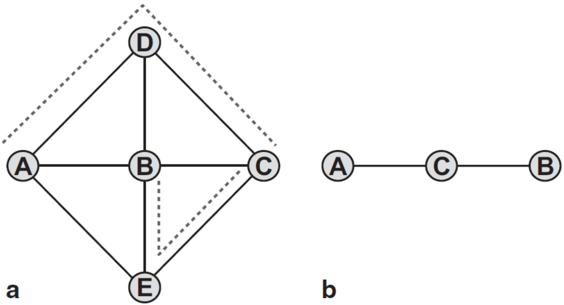

Figure: a The solid lines represent the physical fiber-optic links and the dotted lines represent the paths of two routed wavelengths. b The two wavelength paths create a virtual topology where the solid lines represent virtual links. The virtual topology can be modified by establishing different wavelength paths over physical topology.

Optical Layer Interfaces

SONET signal	SDH signal	Bit rate
STS-1, OC-1	–	51.84 Mb/s
STS-3, OC-3	STM-1	155.52 Mb/s
STS-12, OC-12	STM-4	622.08 Mb/s
STS-48, OC-48	STM-16	2.49 Gb/s (2.5 Gb/s)
STS-192, OC-192	STM-64	9.95 Gb/s (10 Gb/s)
STS-768, OC-768	STM-256	39.81 Gb/s (40 Gb/s)

Figure: Commonly used SONET/SDH signal rates.

Optical Layer Interfaces

OTU type	Nominal bit rate
OTU1	2.666 Gb/s
OTU2	10.709 Gb/s
OTU3	43.018 Gb/s
OTU4	111.810 Gb/s

Figure: OTN transport rate hierarchy.

ODU type	Nominal bit rate
ODU-Flex (CBR)	~ Client signal bit rate
ODU-Flex (GFP)	N × ~ 1.25 Gb/s
ODU0	1.244 Gb/s
ODU1	2.499 Gb/s
ODU2	10.037 Gb/s
ODU3	40.319 Gb/s
ODU4	104.794 Gb/s

Figure: OTN switching/multiplexing rate hierarchy.

Network Topology

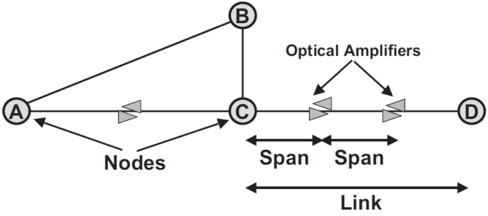

Figure: Nodes, links, and spans in a network topology.

Optical Network Elements

Bragg Grating

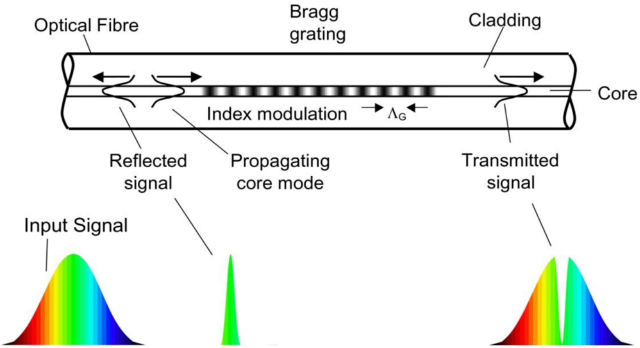

Figure: Fiber Bragg grating.

Arrayed Waveguide Grating

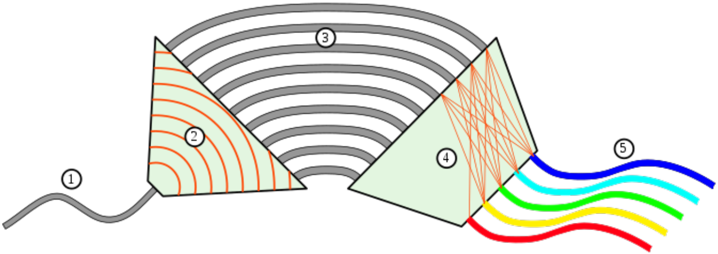

Figure: The incoming light (1) traverses a free space (2) and enters a bundle of optical fibers or channel waveguides (3). The fibers have different length and thus apply a different phase shift at the exit of the fibers. The light then traverses another free space (4) and interferes at the entries of the output waveguides (5) in such a way that each output channel receives only light of a certain wavelength. The orange lines only illustrate the light path. The light path from (1) to (5) is a demultiplexer, from (5) to (1) a multiplexer.

WSS

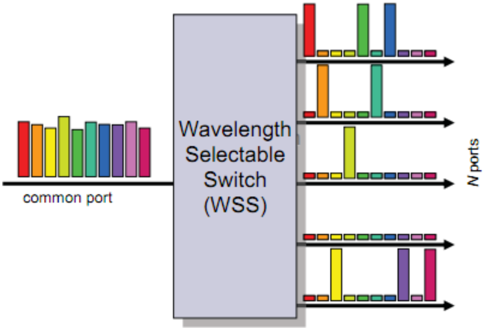

Figure: Wavelength selective switch (WSS).

WSS

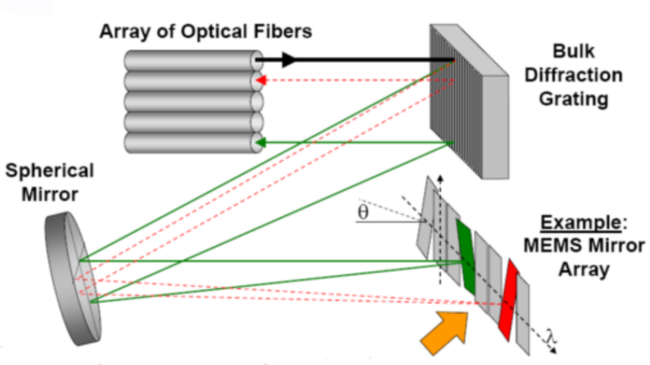

Figure: WSS implementation using diffraction grating and MEMS.

Transponder

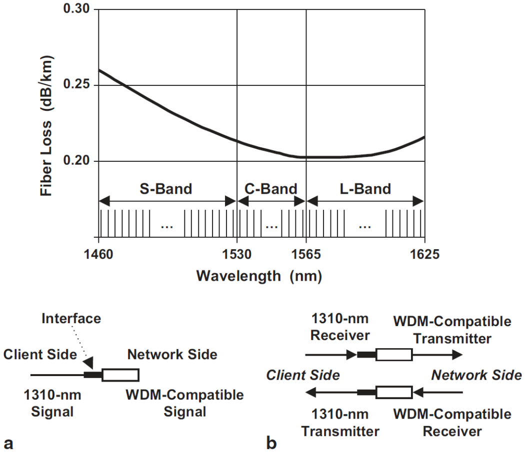

Figure: a A simplified depiction of a WDM transponder that converts between a 1310 nm signal and a WDM-compatible signal. b A more detailed depiction of the WDM transponder, which emphasizes its bidirectional composition. There is both a 1310 nm transmitter/receiver and a WDM-compatible transmitter/receiver. The interface converts the client optical signal to the electrical domain. The electrical signal drives a WDM-compatible laser. Transponders may be tunable or fixed. Some transponders may have tunable input filtering.

Terminal

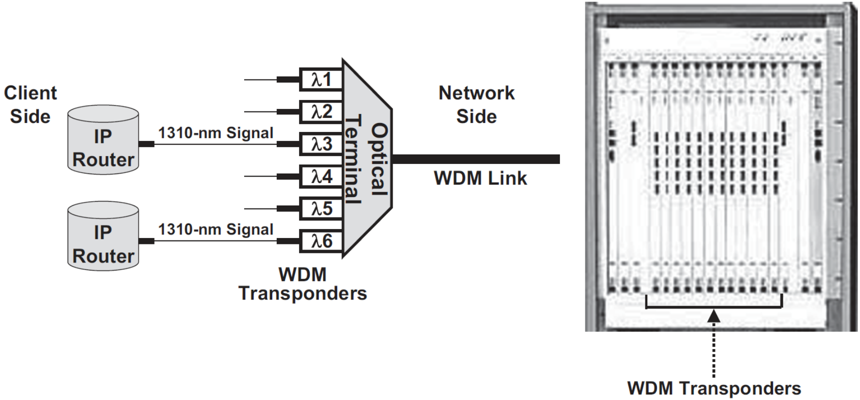

Figure: A representation of an optical terminal equipped with WDM transponders. The 1310-nm signal is sometimes referred to as gray optics, to emphasize that the client signals are nominally at the same frequency, in contrast to the different frequencies (or colored optics) comprising the WDM signal.

Terminal

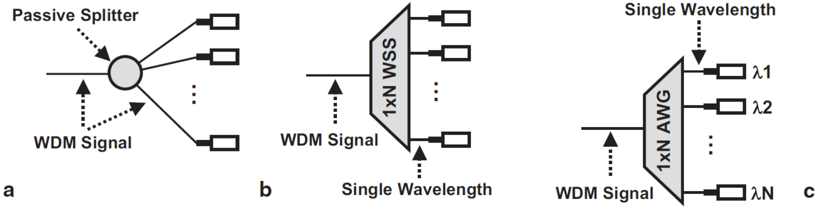

Figure: Three optical-terminal architectures, the first two of which are colorless. a The passive splitter architecture has high loss and the transponders must be capable of selecting a particular frequency from the WDM signal. b The WSS architecture limits the number of transponders that can be accommodated to N. d The architecture based on the arrayed waveguide grating (AWG) is not colorless; a transponder of a given frequency must be inserted in one particular slot. The architectures differ in terms of attenuation, cost, and configurability.

O-E-O Architecture

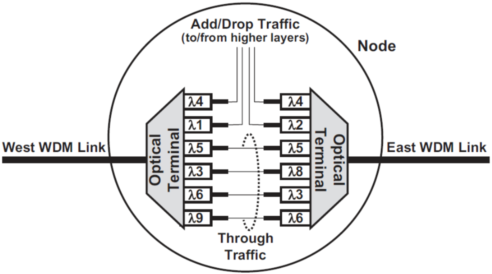

Figure: O-E-O architecture at a degree-two node (without automated reconfigurability). Nodal traffic is characterized as either add/drop traffic or through traffic. All traffic entering and exiting the node is processed by a transponder. Note that the through traffic can undergo wavelength conversion. The O-E-O provides advantages such as signal regeneration, interoperability, performance monitoring, and wavelength conversion; however, it suffers from high cost, dissipated power, hard migration, and scalability.

O-E-O Architecture

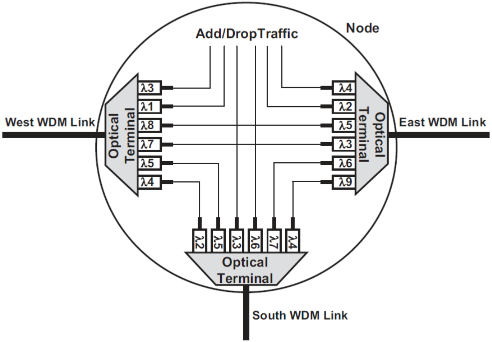

Figure: O-E-O architecture at a degree-three node (without automated reconfigurability). There are three possible directions through the node. The path of a transiting connection is set by interconnecting a pair of transponders on the associated optical terminals.

O-E-O Architecture

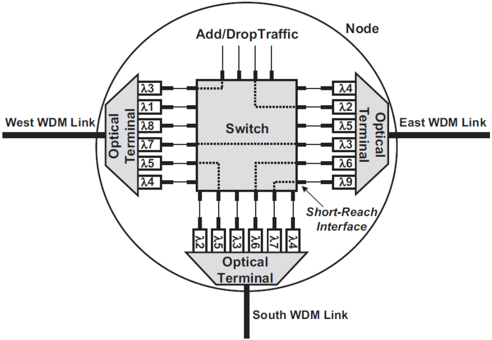

Figure: A switch is used to automate node reconfigurability. The particular switch shown has an electronic switch fabric and is equipped with short-reach interfaces on all of its ports.

Transparent Architecture

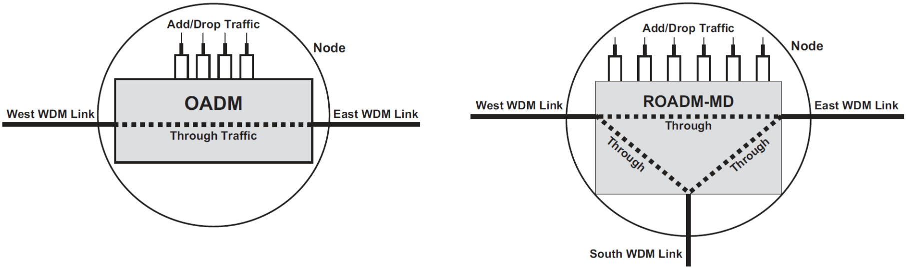

Figure: Reconfigurable optical add/drop multiplexer (ROADM) at a degree-two node. Transponders are required only for the add/drop traffic. The through traffic remains in the optical domain as it transits the node. Optical-bypass technology is potentially more scalable in cost, space, power, and heat dissipation. However, in this architecture, signal regeneration, performance monitoring, and wavelength conversion are not possible for the through traffic.

Hybrid Architecture

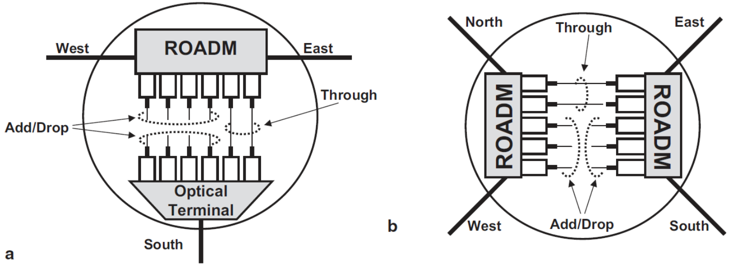

Figure: Degree-three node with one reconfigurable optical add/drop multiplexer (ROADM) and one optical terminal. b Degree-four node with two ROADMs. In these quasi-optical-bypass architectures, some of the transponders are used for transiting traffic that crosses two different network elements at the node.

Two/Multi-degree Node

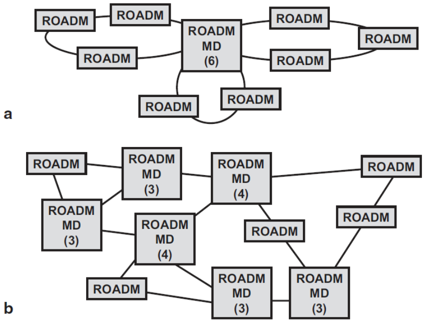

Figure: a A degree-six multi-degree reconfigurable optical add/drop multiplexer (ROADM-MD) is deployed at the junction site of three rings, allowing traffic to transit all-optically between rings. The remaining nodes have reconfigurable optical add/drop multiplexers (ROADMs). b In this arbitrary mesh topology, a combination of ROADMs, degree-three ROADM-MDs, and degree-four ROADM-MDs is deployed according to the nodal degree.

ROADM Architecture

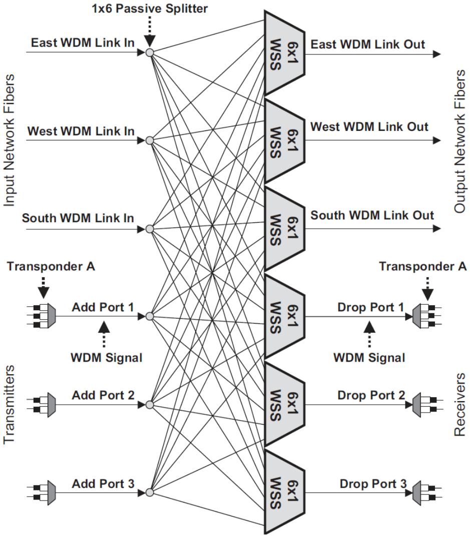

Figure: One example of a broadcast-and-select ROADM architecture, with the number of add/drop ports equal to the number of network fibers. This architecture allows multi-cast; however, it suffers from splitter loss.

ROADM Architecture

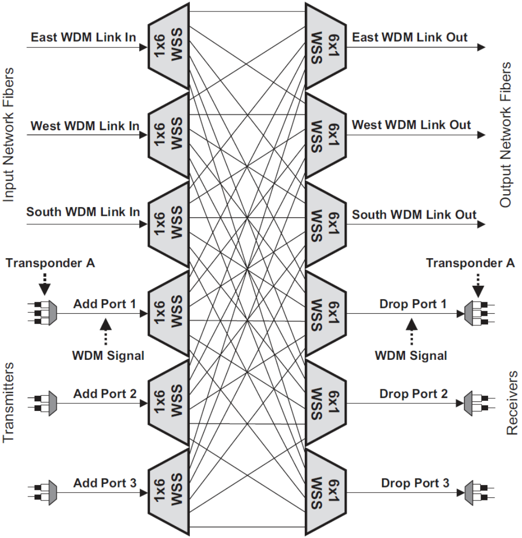

Figure: One example of a route-and-select ROADM architecture, with the number of add/drop ports equal to the number of network fibers. This architecture usually does not allow multi-cast, eliminates the splitter loss, and reduces noise and crosstalk.

ROADM Architecture

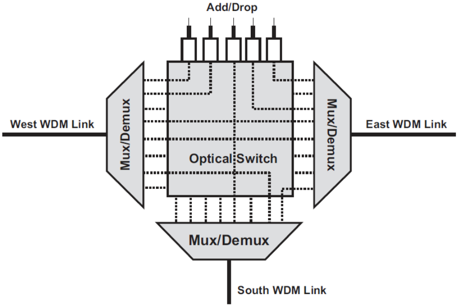

Figure: Wavelength-selective ROADM architecture. AWG is sufficient for this architecture. The optical switch can be implemented using MEMS. The biggest drawback of the this architecture is its scalability.

ROADM Properties

ROADM Properties

- Cascadability
- Automatic Power Equalization
- Colorless
- Directionless
- Contentionless
- Gridless
- Multicast
- Separability
- Wavelength resue
- Interoperability

Cascadability

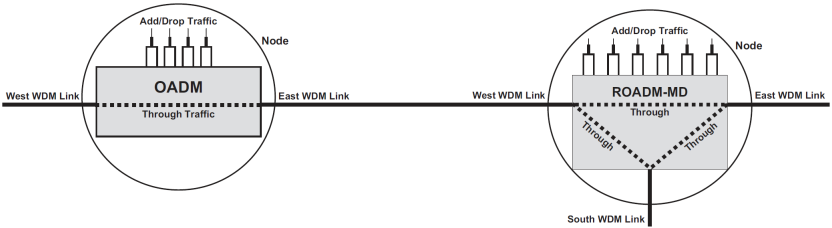

Figure: Major factors in determining ROADM cascadability is the amount of loss in the through path and quality of filters. Path loss and filtering quality are the limiting factors for cascadability of the broadcast-and-select and route-and-select architectures.

Power Equalization

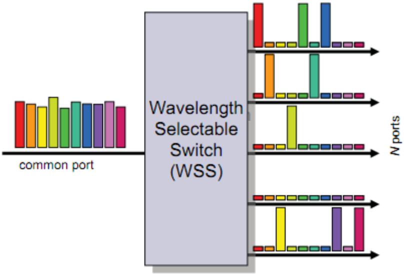

Figure: WSSs, as the building blocks of ROADMs, are typically capable of automatic power equalization. Unbalanced power levels result from uneven amplifier gain and different origins of the traffic streams.

Colorless

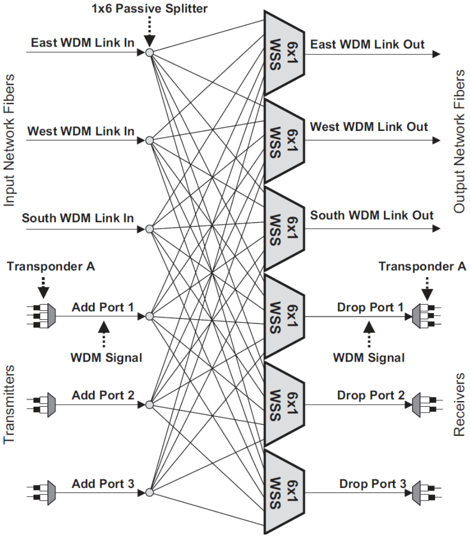

Figure: The add/drop architectures based on passive splitters/couplers and/or WSSs are colorless; the architecture based on AWGs is not.

Directionless

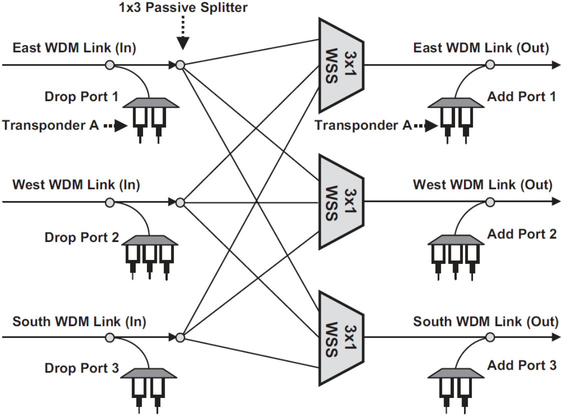

Figure: One example of a non-directionless broadcast-and-select ROADM architecture. Transponder A can add/drop only to/from the East link.

Contentionless

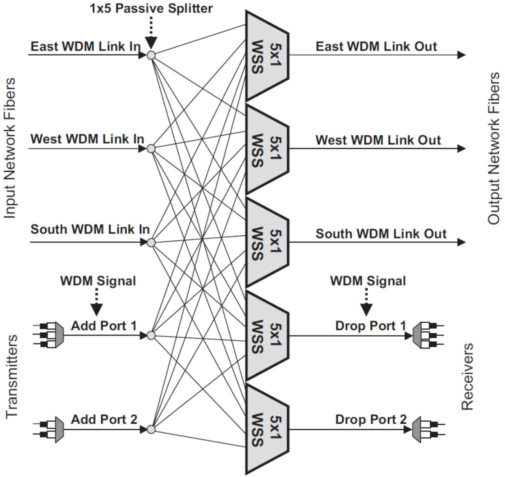

Figure: ROADM with three network links but only two add/drop ports. If it is desired to establish three connections, one per network link, each using the same wavelength, then wavelength contention on an add/drop port will block one of the connections.

Gridless

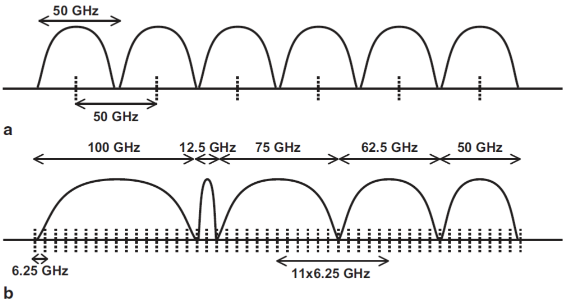

Figure: a Wavelengths aligned on a 50-GHz grid. Each wavelength requires 50 GHz of bandwidth. b Wavelengths aligned on a 6.25-GHz grid. As specified by the International Telecommunication Union (ITU), each wavelength requires $N\times$ 12.5 GHz of bandwidth, where N is an integer.

Multicast

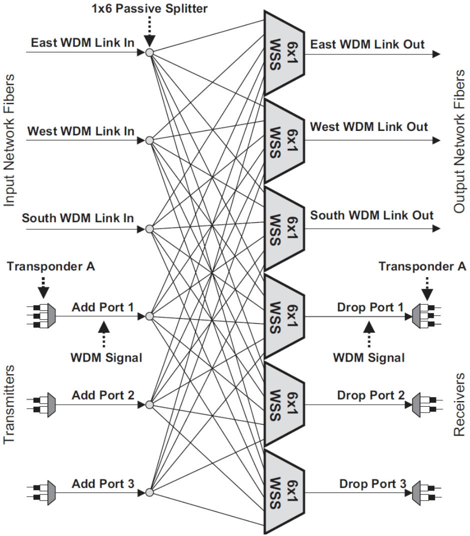

Figure: The broadcast-and-select architectures supports various multicasting scenarios.

Separability

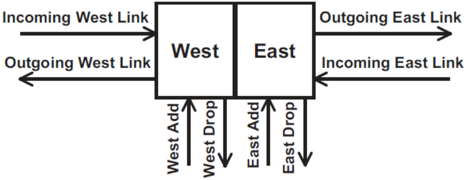

Figure: The desired East/West separability for failure and repair modes is shown, for a non-directionless ROADM.

Wavelength Reuse

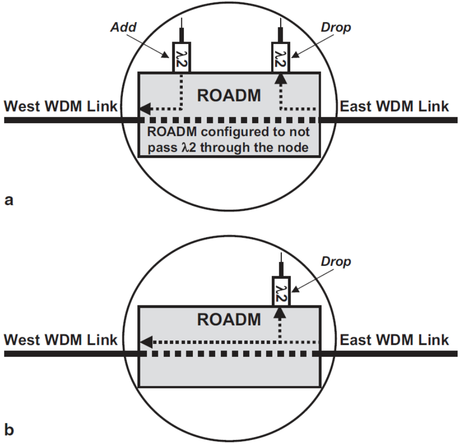

Figure: a A reconfigurable ROADM with wavelength reuse. A wavelength (λ_2) is dropped from the East link. The ROADM is configured to not pass this wavelength through the node, so that the same wavelength can be added on the West link. b A ROADM without wavelength reuse. The wavelength that is dropped from the East link continues to be routed through the node such that the same wavelength cannot be added on the West link.

Interoperability

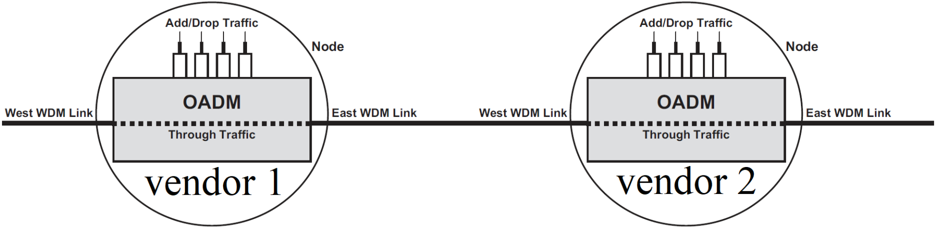

Figure: Standard interfaces allow two ROADMs from different vendors connect to each other.

Optical Switches

Optical Switch Types

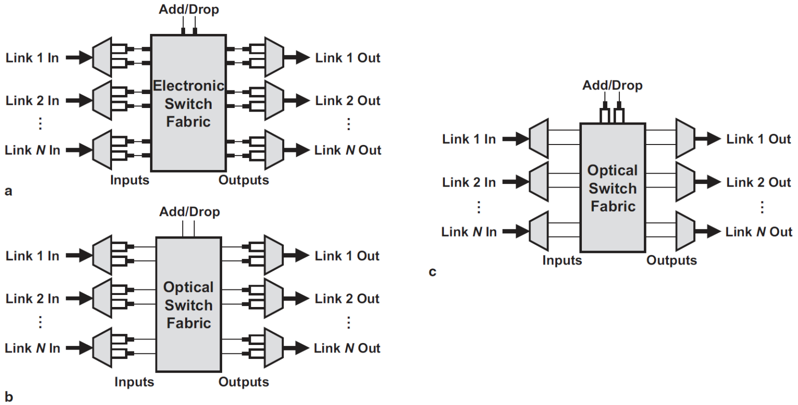

Figure: Examples of optical switch (optical cross-connect) architectures. a OEO-E-OEO architecture with electronic switch fabric and electronic interfaces on all ports. b Photonic switch with OEO-O-OEO architecture that switches the 1,310-nm optical signal. c A wavelength-selective all-optical switch with O-O-O architecture. Note that it does not imply that the switch supports optical bypass, nor does it imply that the switch fabric is optical.

Fiber Cross-Connect

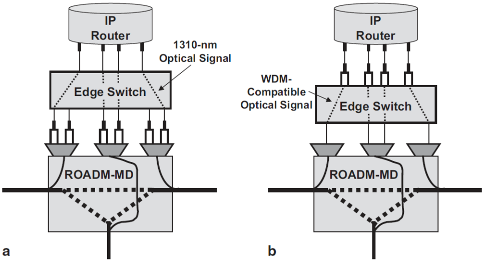

Figure: An edge switch used in conjunction with a non-directionless ROADM-MD in order to add configurability. As shown, the edge switches operate as fiber cross-connects (FXCs). In a, the 1,310 nm optical signal is switched; in b, the WDM-compatible optical signal is switched. The architecture that results in fewer required transponders depends upon the number of clients (e.g., Internet Protocol (IP) routers) and the traffic patterns.

Grooming Switch

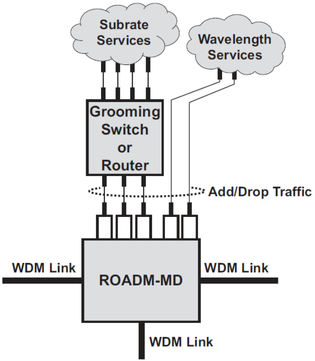

Figure: Grooming switch deployed at the nodal edge with a wavelength level switch at the core. The wavelength-level switch can provide optical bypass. Only the sub-rate services that need to be groomed at the node or that need to be added/dropped at the node are processed by the grooming switch.

Hierarchical Switch

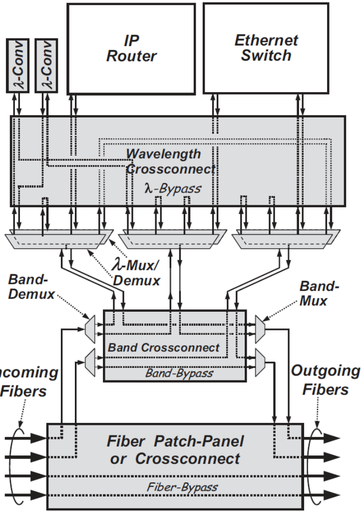

Figure: A three-level multigranular hierarchical switch, allowing fiber-bypass, band-bypass, and wavelength-bypass. In the figure, each fiber contains two wavebands, and each waveband contains four wavelengths. Wavelength conversion (e.g., via back-to-back transponders) is used to groom the wavebands.

Optical Reach

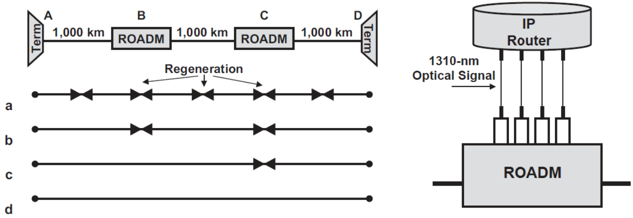

Figure: Optical reach is the maximum distance an optical signal can be transmitted before it degrades to a level that requires the signal be regenerated. A Connection between Nodes A and D with: a 500-km optical reach; b 1,000-km optical reach; c 2,000-km optical reach; and d 3,000-km optical reach.

The End