The bridge to possible

Optical Networking Fundamentals

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BRKOPT-1007

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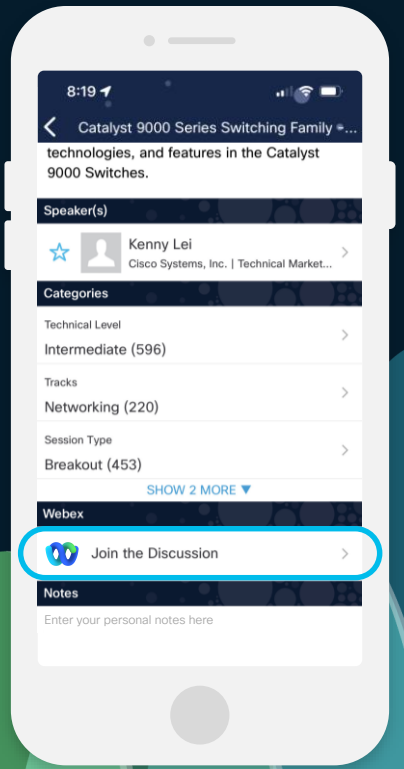
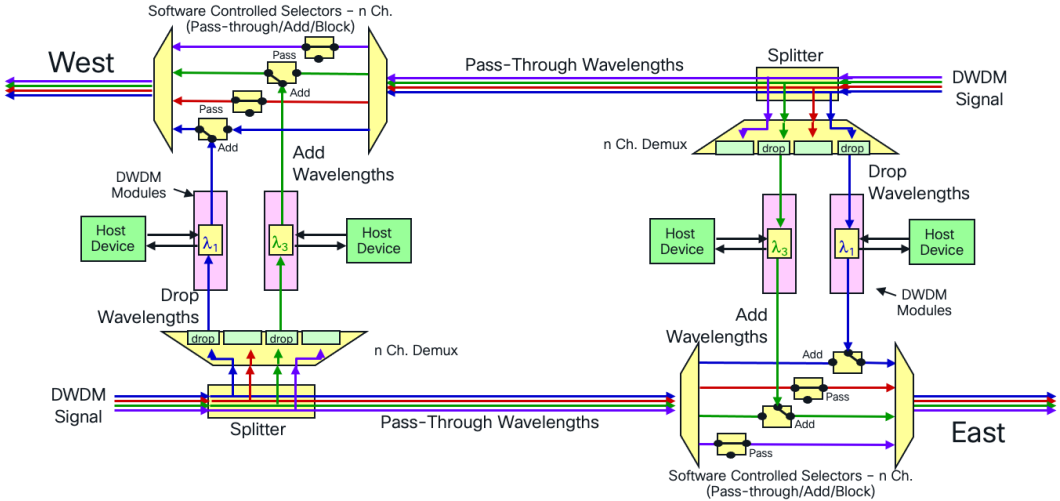


Agenda

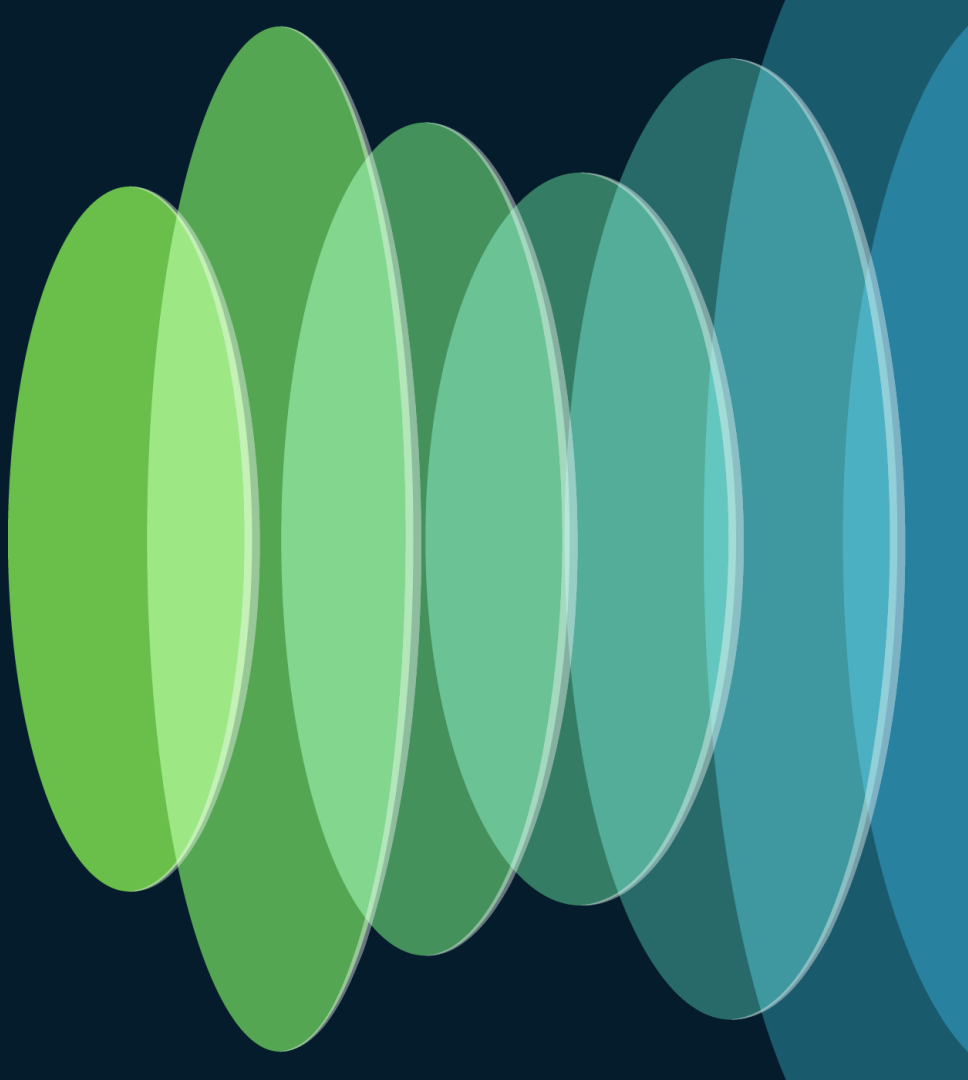
- Introduction
- What is DWDM?
- Optical Fiber Crash Program
- DWDM Components
- DWDM in Routers
- Conclusion

Traditional IP Engineer's view of Optical Networking



- Grey optics connect buildings/floors together, a mystery beyond
- Layer 1 demands a different skillset from Ethernet
- Fiber optic technology has a steep learning curve
- Traditional Engineers understand IP, not Transport, hard to find both skillsets
- Fiber optic networks are costly

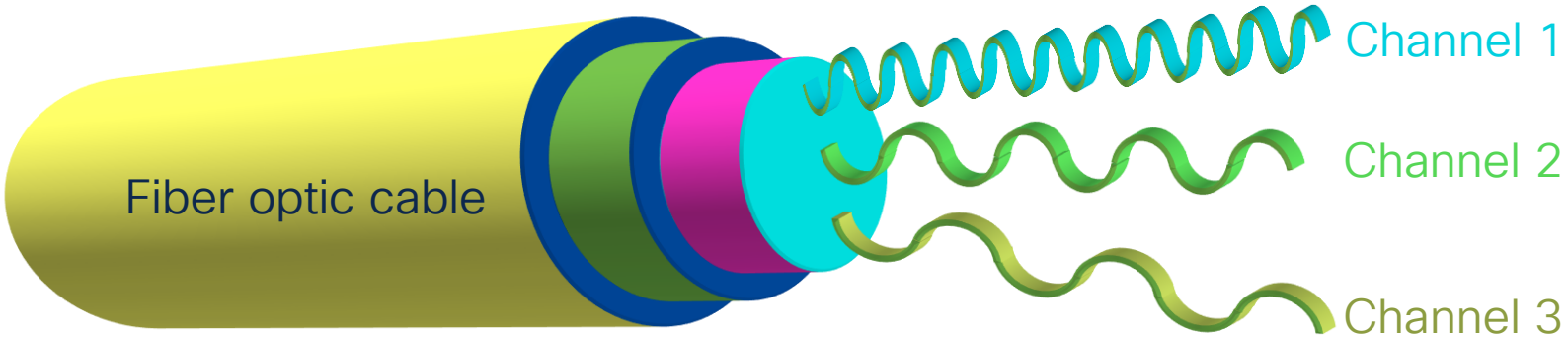
What is DWDM



What is WDM – Wavelength Division Multiplexing

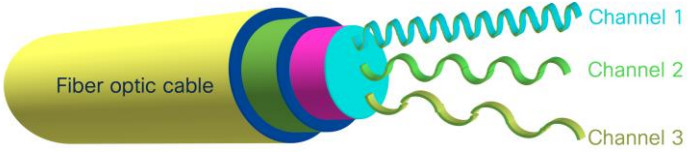
Optical (light) signals of different wavelengths do not interfere with each other on a fiber

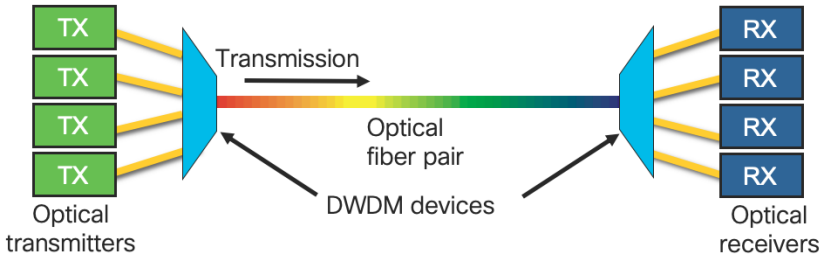
Each wavelength represents an independent optical channel



WDM is Agnostic

- Protocol Agnostic—Any-Rate Ethernet, TDM, Fiber Channel, etc.
- Bit-Rate Agnostic—Each Wavelength can be different bit-rates
- Allows Infrastructure Evolution to meet your needs – i.e. Future Rates



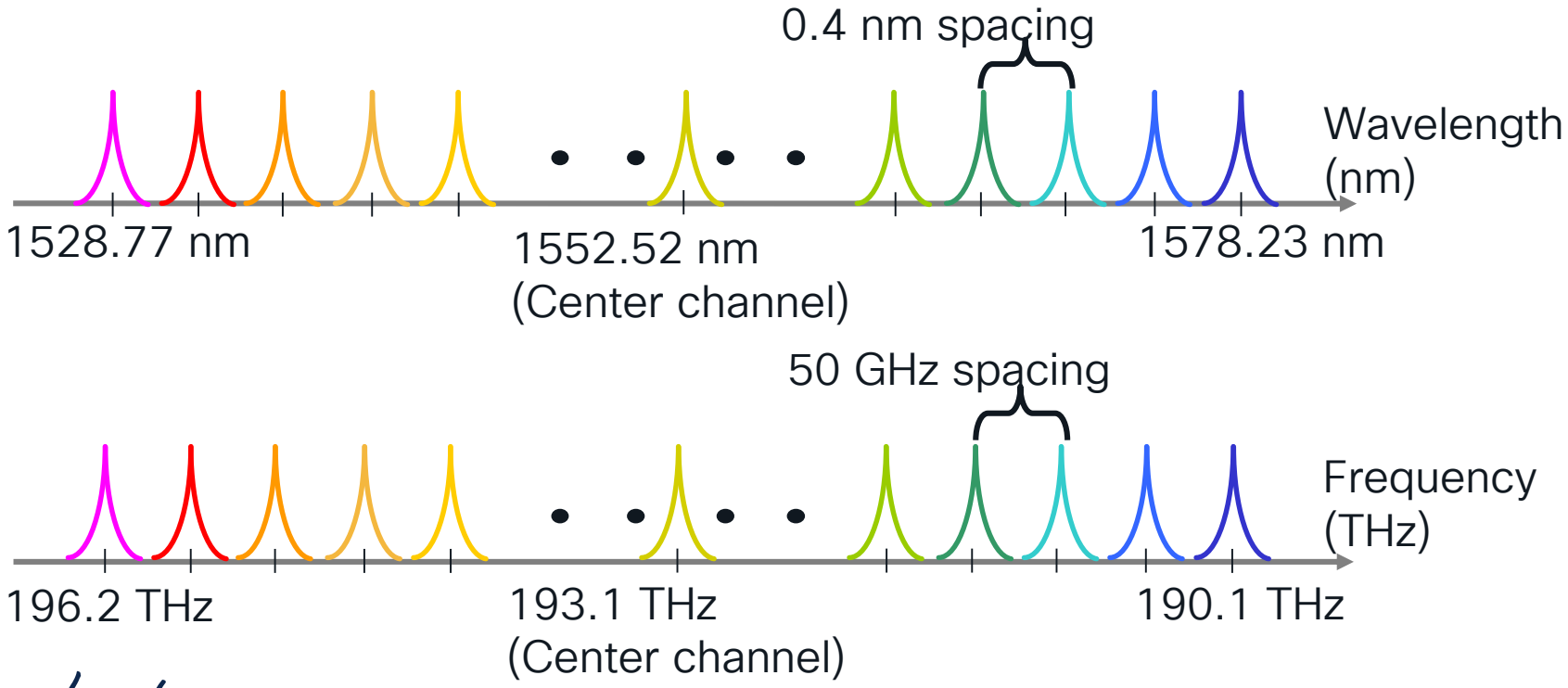


xWDM Channel Overview

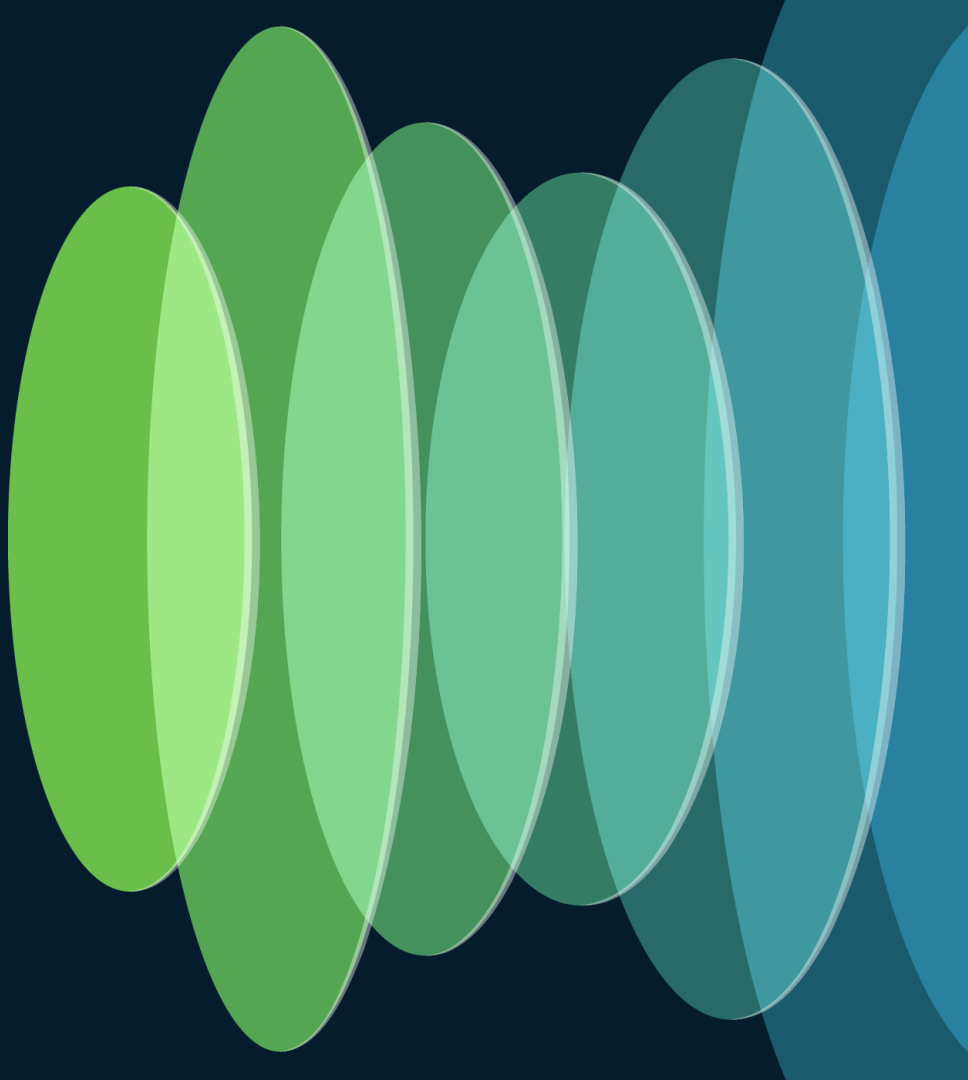
	WDM	CWDM	DWDM (C-Band)
# of Wavelengths	Typically 2	Typically 8	Typically 40/80/96-channels and beyond with Flex
Typical Wavelengths	1310nm and 1550nm	1471nm, 1491nm… 1591nm, 1611nm	1528.77nm… 1566.72nm
Channel Spacing	N/A	20nm	100GHz/50GHz 0.8nm/0.4nm and lower Flex Options as well
Applicable Standards	N/A	ITU-T G.694.2 18 Wavelengths are incl. in Standard	ITU-T G.692

ITU-T Grid

ITU wavelengths = lambdas = channels centered around 1550 nm (193 THz)



Optical Fiber Crash Program



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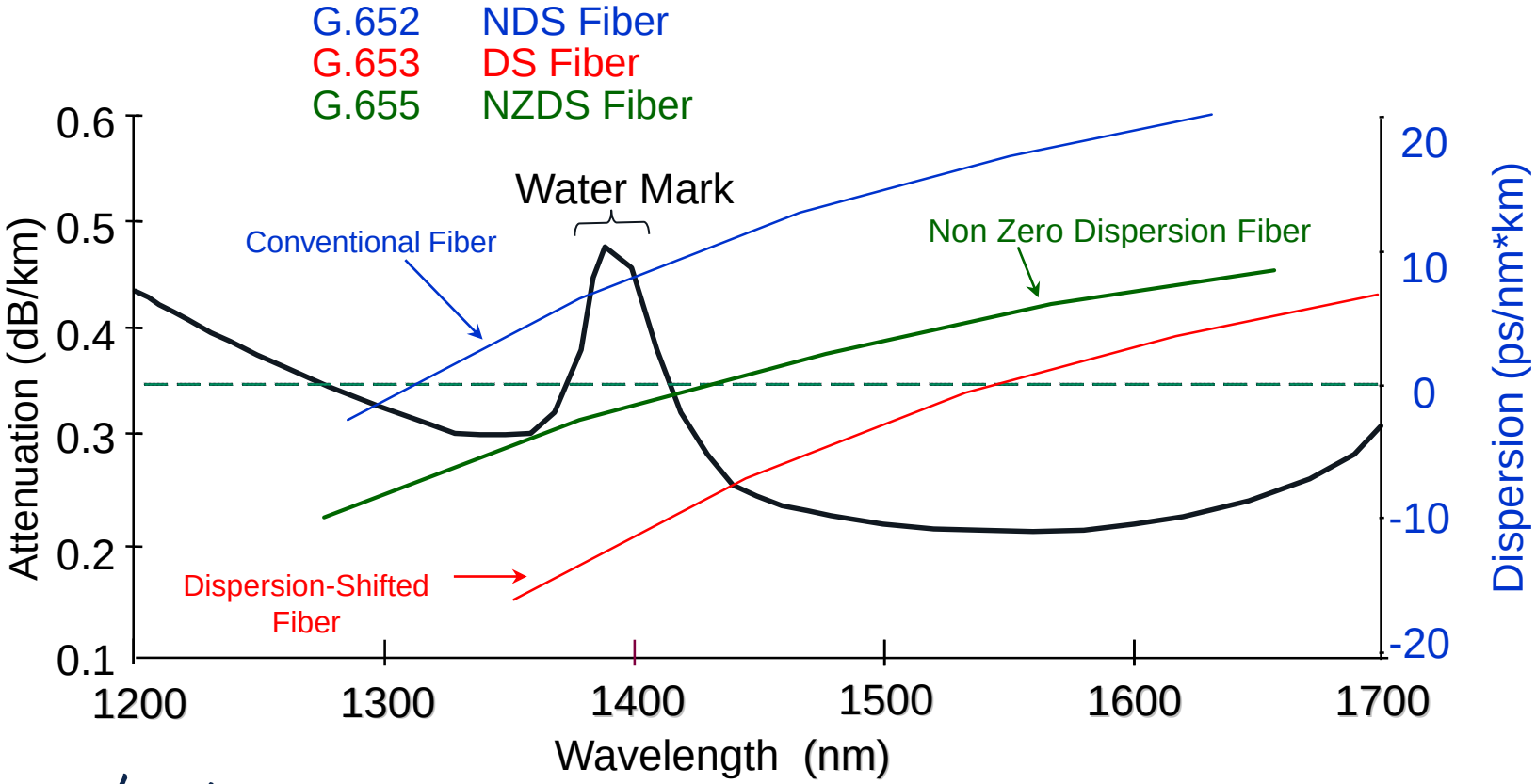
Applications for Different Fiber Types

Fiber Type	Application Notes
SMF (G.652) NDSF	• Good for Single-Channel at 1310 nm • OK for Single-Channel at 1550 • Good for DWDM (w/Dispersion Mgmt when needed)
DSF (G.653)	• OK for Single-Channel at 1310 nm • Good for Single-Channel at 1550 nm • Bad for DWDM (C-Band) (causes non-linear effects)
NZDSF +/- (G.655)	• OK for Single-Channel at 1310 nm • Good for Single-Channel at 1550 nm • OK for DWDM (C + L Bands)
Extended Band (G.652.C) reduced water peak	• Good for Single-Channel at 1310 nm • OK for Single-Channel at 1550 nm • OK for DWDM (With Dispersion Mgmt.) • Good for CWDM (>8 wavelengths)

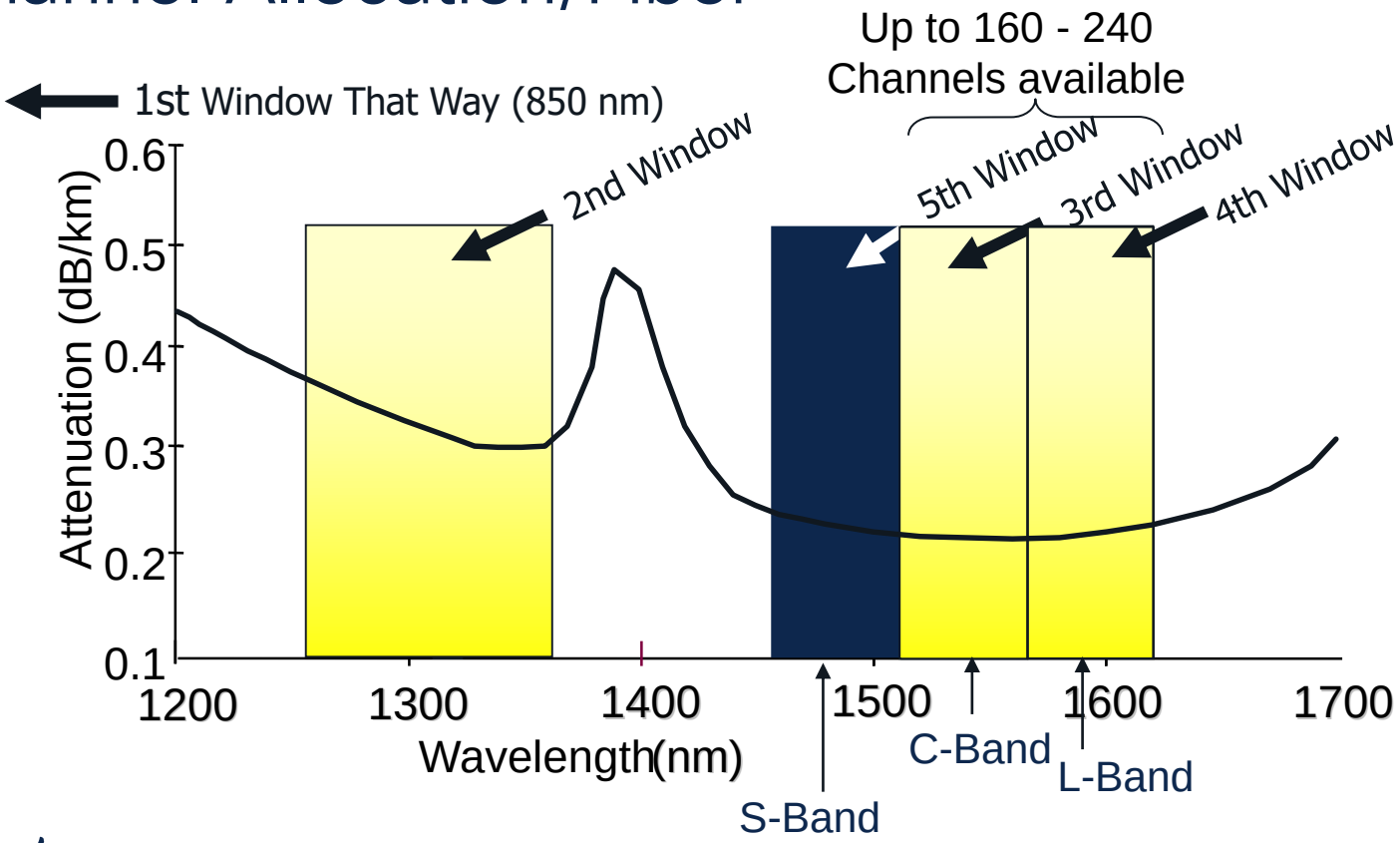
1

2

Fiber Evolution

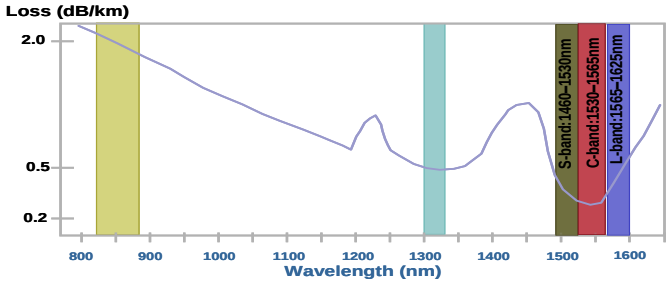


Channel Allocation/Fiber

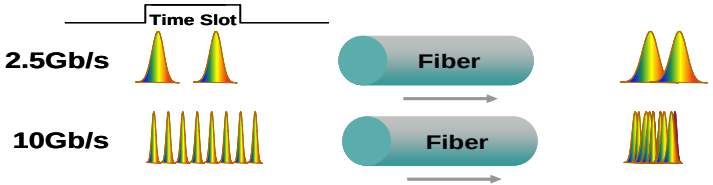


Transmission Impairments

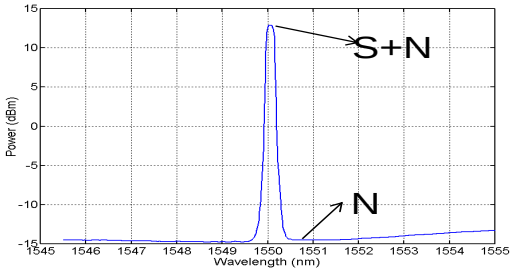
Attenuation—Loss of Signal Strength



Chromatic Dispersion (CD)—Distortion of pulses

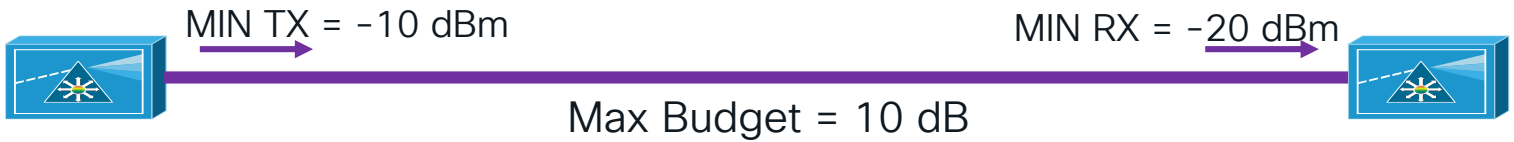


Optical Signal to Noise Ratio (OSNR)—Effect of Noise in Transmission



Attenuation: Optical Budget

Basic Optical Budget = Tx Output Power – Rx Input Sensitivity



Engineered links usually assume 0.25dB/km or worse for 1550nm transmission
Simply…10dB Budget = 40km
Real Fiber Loss Measurements are preferred (i.e., OTDR, Laser Source/Meter)

Optical Budget is affected by:

- Fiber attenuation
- Splices
- Patch Panels/Connectors
- Optical components (filters, amplifiers, etc.)
- Micro and Macro Bends in fiber
- Contamination (dirt/oil on connectors)

Laser Output Power and Receiver Sensitivity and dBm

- Fiber loss expressed in dB but transmitter/receiver power is expressed in dBm
- This is why both the transmitter output power and the receiver sensitivity is expressed in dBm:

$$Power_{dBm} = 10\log(P_{mW}/1mW)$$

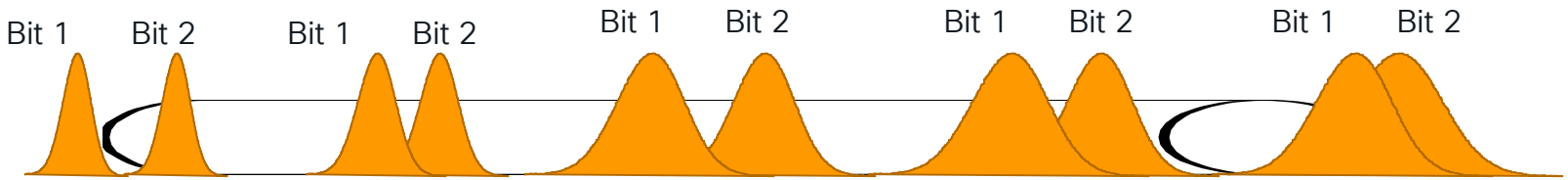
dB and dBm are additive, hence the simplification

Examples:

- 2mW is $Power_{dbm}$ = 10log(2mW/1mW)=3dBm
- 1mW is $Power_{dbm}$ = 10log(1mW/1mW)=0dBm

dB is decibels and dBm is decibels-milliwatt

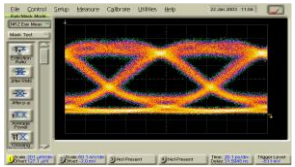
Chromatic Dispersion (CD)

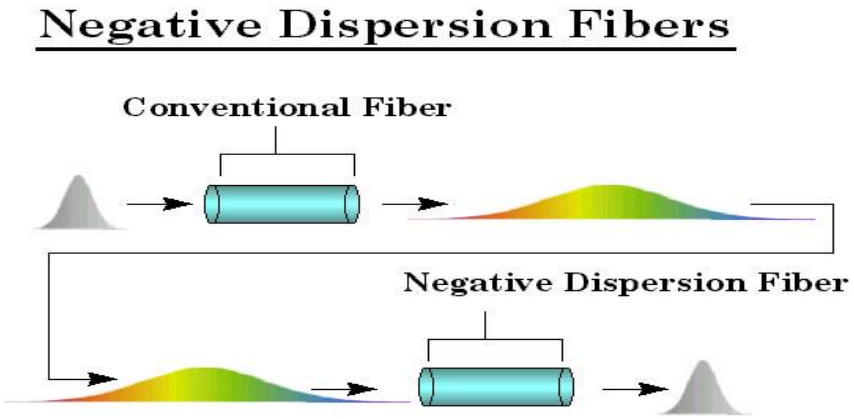


The Optical Pulse tends to Spread as it propagates down the fiber generating Inter-Symbol-Interference (ISI)

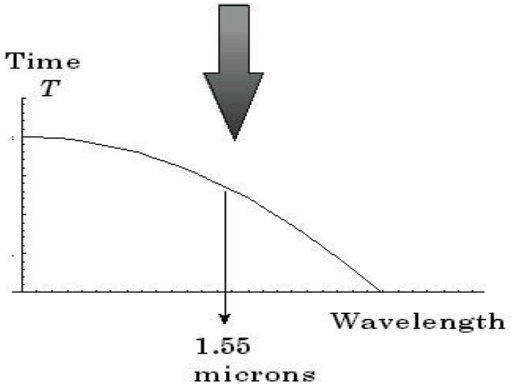
- Total dispersion is a function of the length of fiber and its dispersion factor – linear value
- Can limit transmission distance for 10G and above wavelengths
- Can be compensated by:
  - Using negative dispersion fiber modules (DCM/DCF) - adds losses
  - Electronically with Coherent Optics generally at 100G and higher

Solution for Lower Speed Signals: Dispersion Compensating Unit





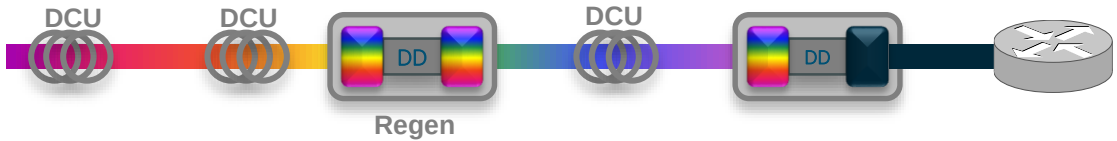
DCUs use fiber with chromatic dispersion of opposite sign/slope and of suitable length to bring the average dispersion of the link close to zero.



Solution for Higher Speed Signals: Coherent Detection

Direct Detection

- Must correct for impairments in the physical domain (insert DCU's)
- Forced to live with non-correctable impairments via network design (limit distance, regenerate, adjust channel spacing)
- Dumb detection (OOK), no Digital Signal Processing, only FEC

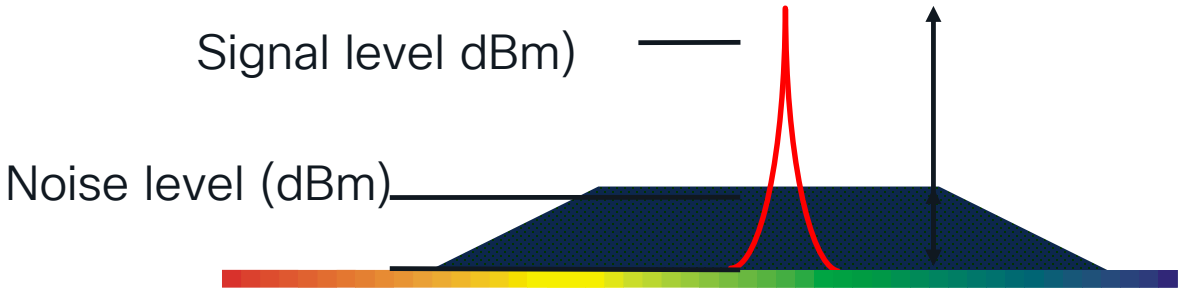


Coherent Detection

- Moves impairment correction from the optical domain into the digital domain
- Allows for digital correction of impairments (powerful DSP) vs. physical correction of impairments (DCU's). Adds advanced FEC
- Massive performance improvements over Direct Detection

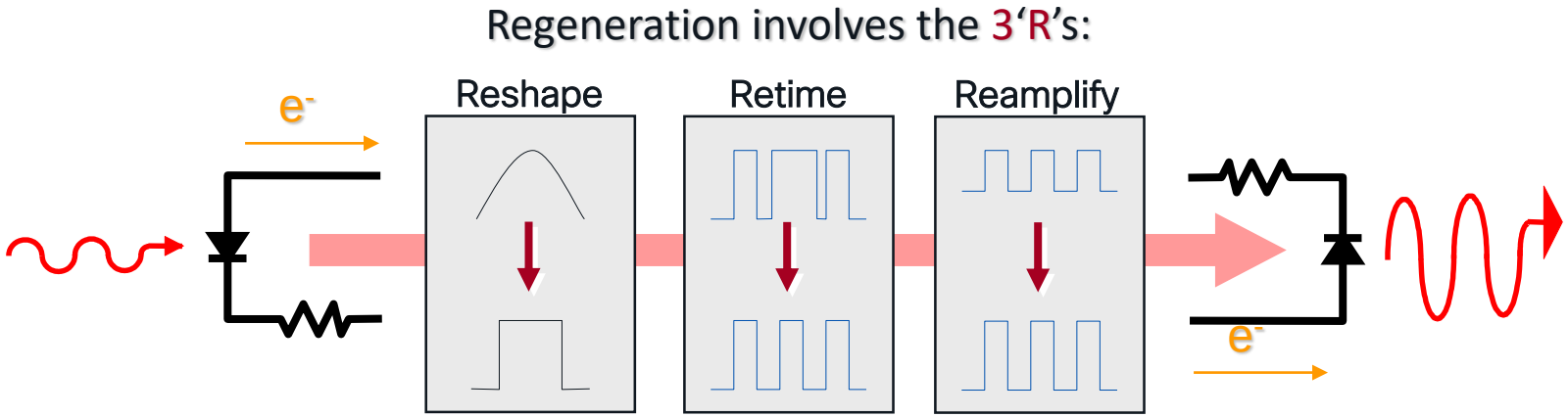
Optical Signal-to-Noise Ratio (OSNR)

- OSNR is a measure of the ratio of signal level to the level of system noise
- As OSNR decreases, possible errors increase
- OSNR is measured in decibels (dB)
- EDFAs are the source of noise



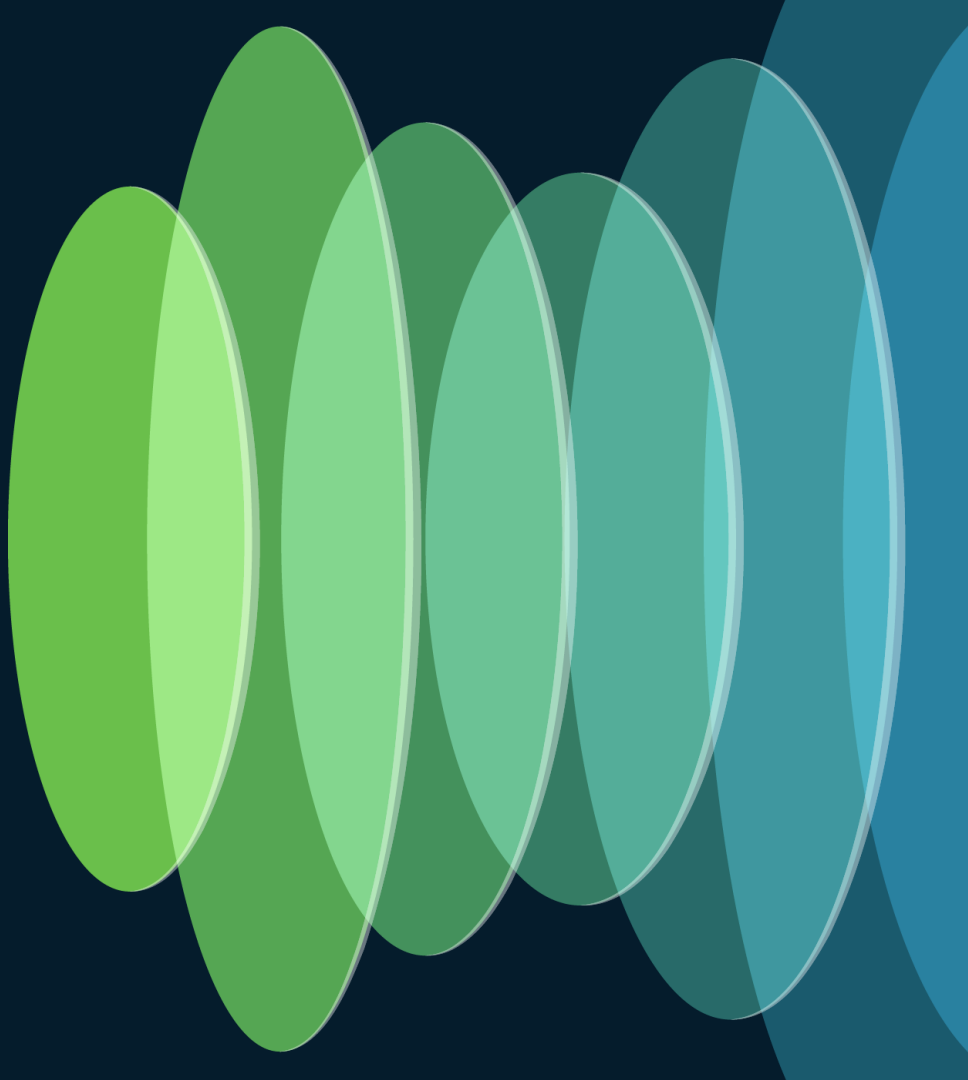
$$OSNR = \frac{\text{Signal level}}{\text{Noise level}}$$

Final Solution: Regeneration



- Bit-Rate and Protocol Specific
- Most Costly Solution for multi-channel WDM Networks – 2x Interfaces required for every Channel

DWDM Components

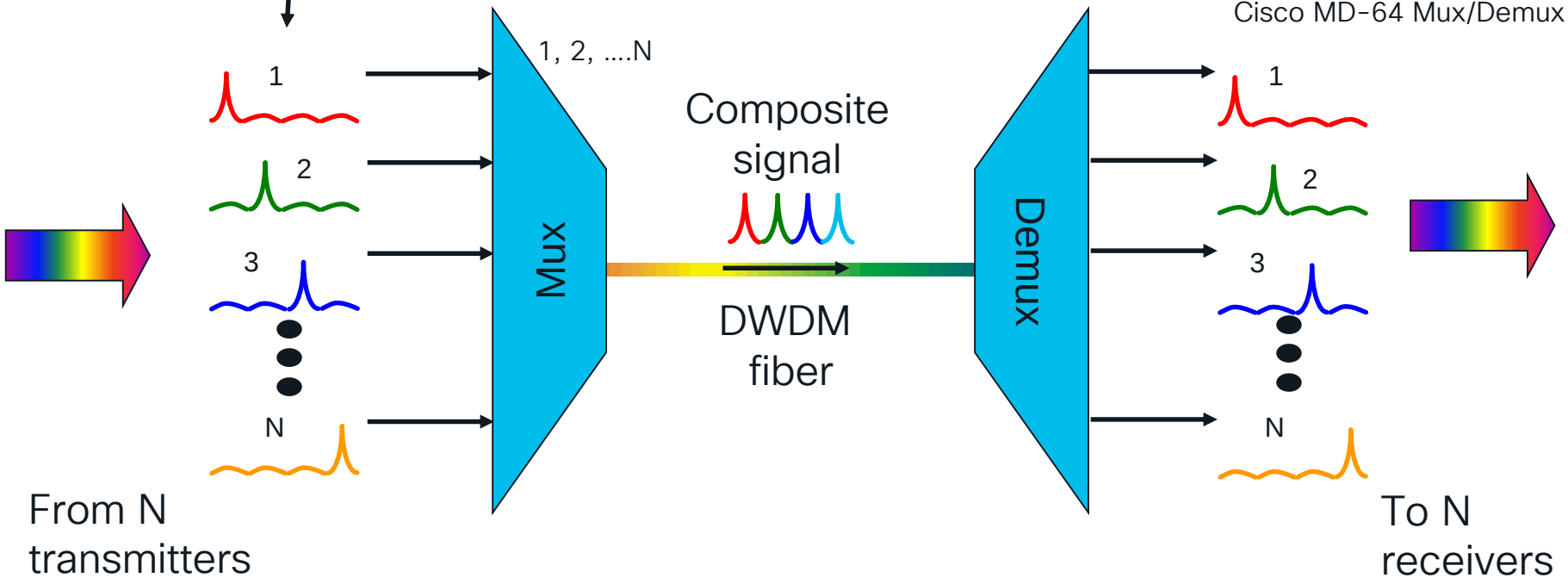


Typical Components of DWDM Systems

- DWDM Mux/Demux filters
- Optical Add/Drop Multiplexers (OADMs)
- Reconfigurable OADM (ROADM)
- Optical amplifiers (EDFA or RAMAN)
- Transponders/Muxponders

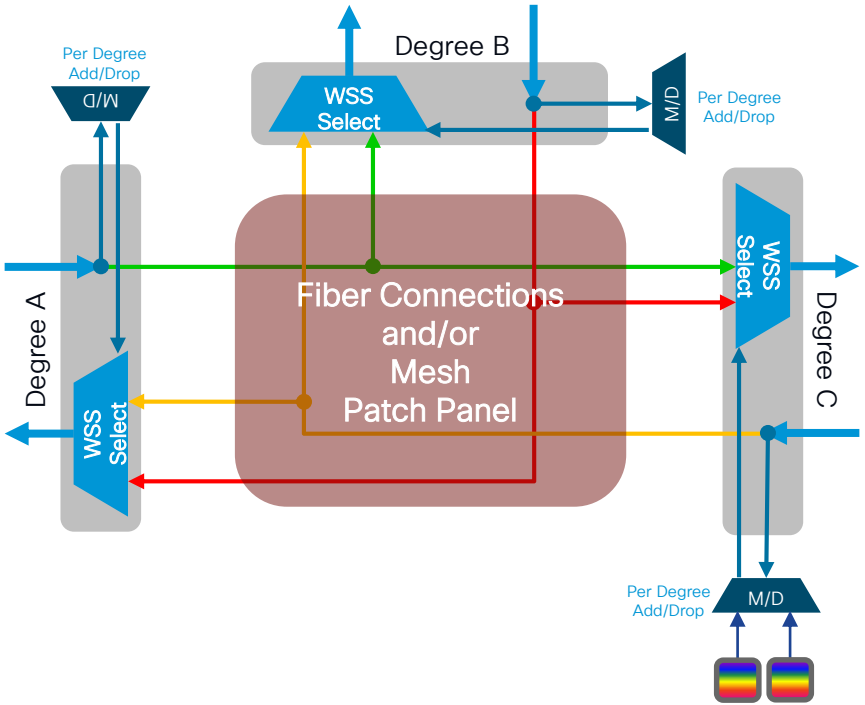
DWDM Mux and Demux Filters Block Diagram

Cisco MD-64 Mux/Demux

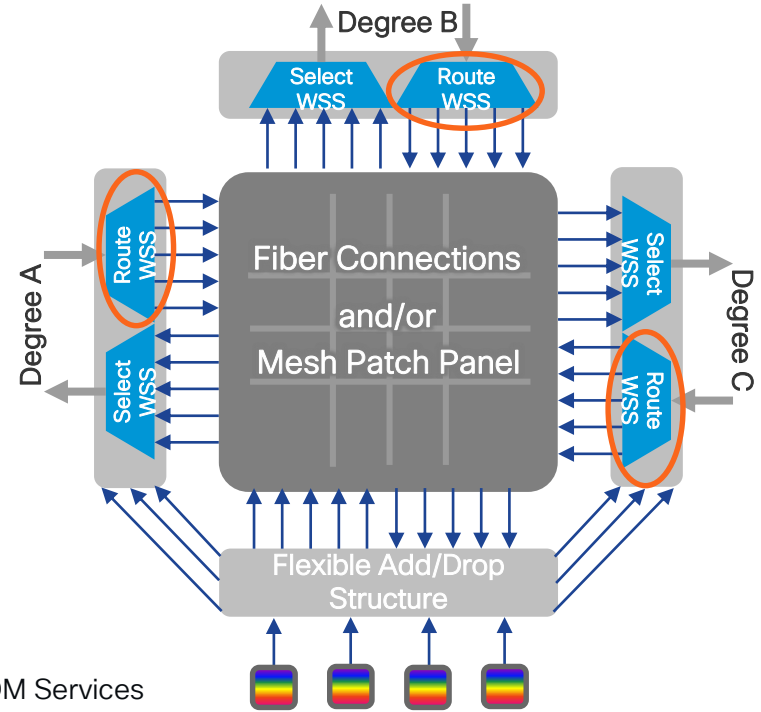


ROADM Types

“Broadcast and Select” Architecture



“Route and Select” Architecture



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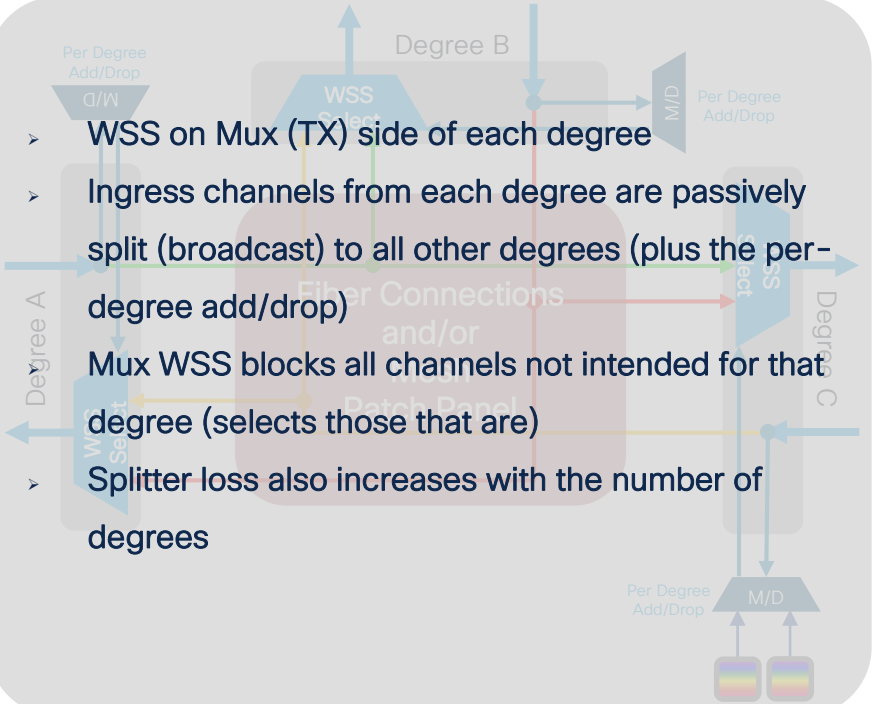
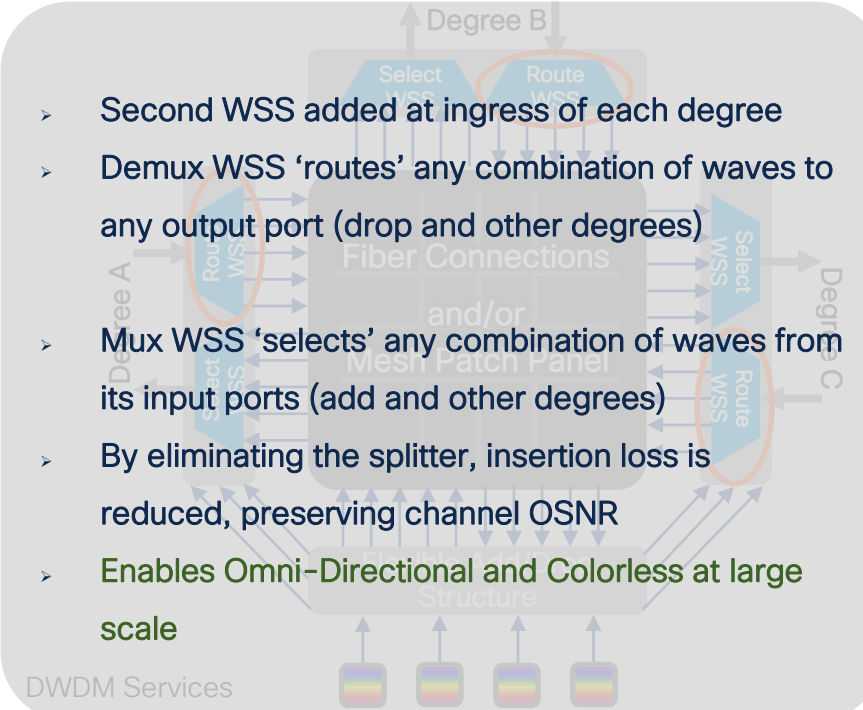


- WSS on Mux (TX) side of each degree
- Ingress channels from each degree are passively split (broadcast) to all other degrees (plus the per-degree add/drop)
- Mux WSS blocks all channels not intended for that degree (selects those that are)
- Splitter loss also increases with the number of degrees

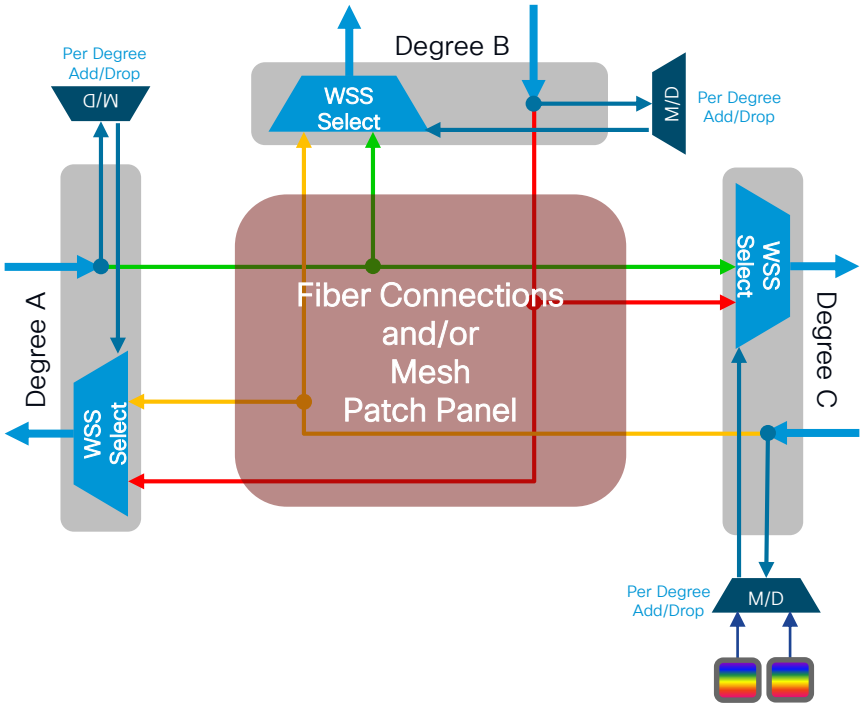
“Route and Select” Architecture



- Second WSS added at ingress of each degree
- Demux WSS ‘routes’ any combination of waves to any output port (drop and other degrees)
- Mux WSS ‘selects’ any combination of waves from its input ports (add and other degrees)
- By eliminating the splitter, insertion loss is reduced, preserving channel OSNR
- Enables Omni-Directional and Colorless at large scale

ROADM Types

“Broadcast and Select” Architecture



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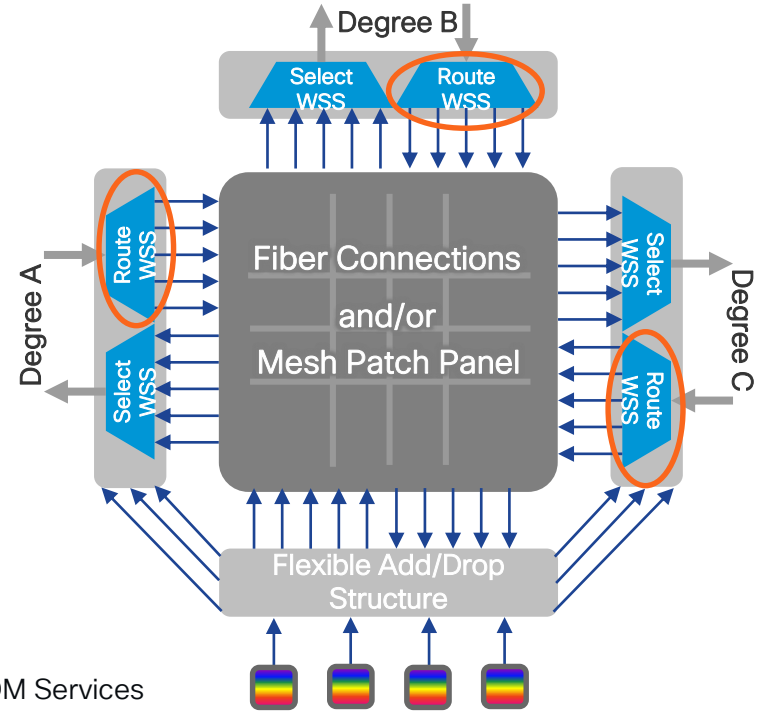
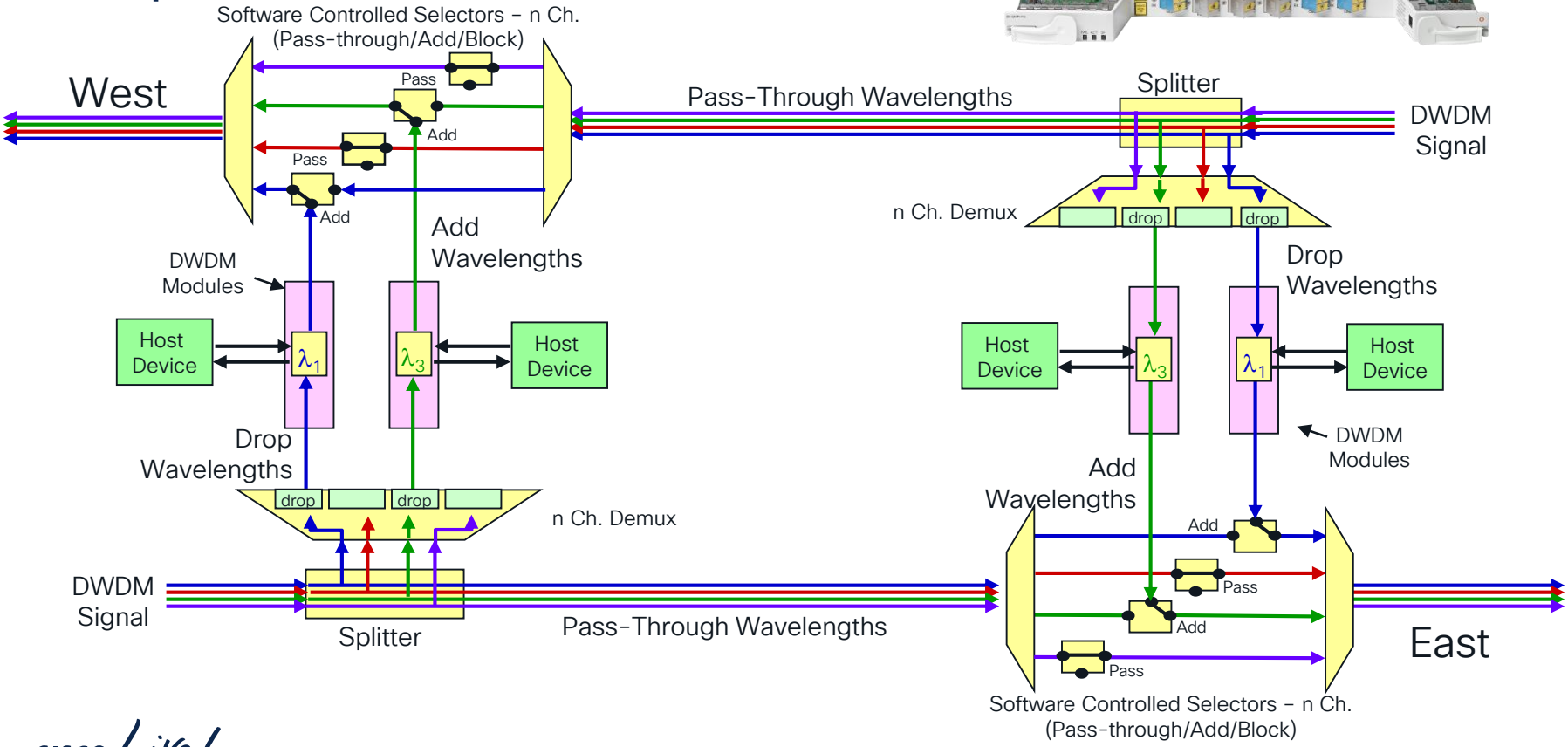
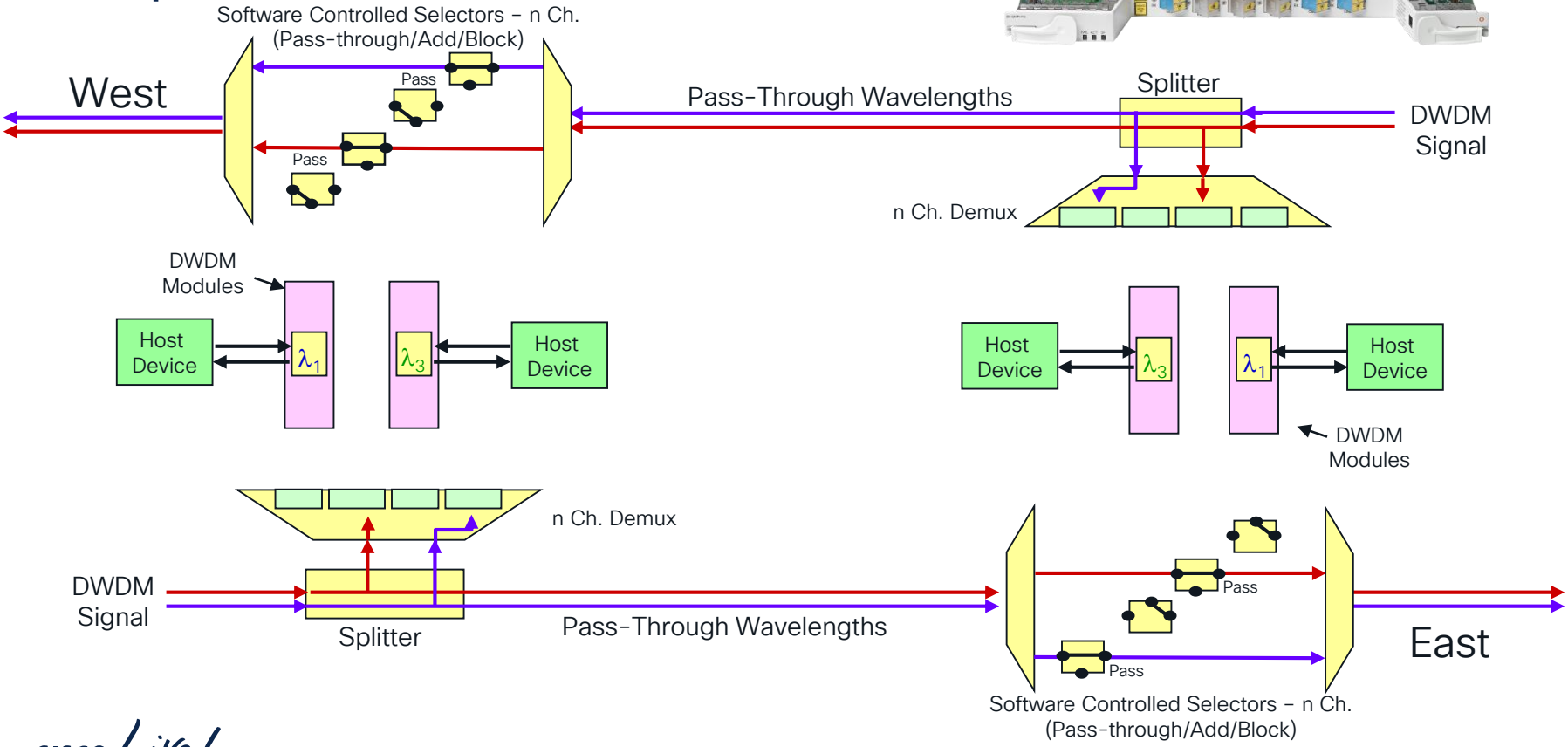


DWDM Services

Simple ROADM Architecture



Simple ROADM Architecture



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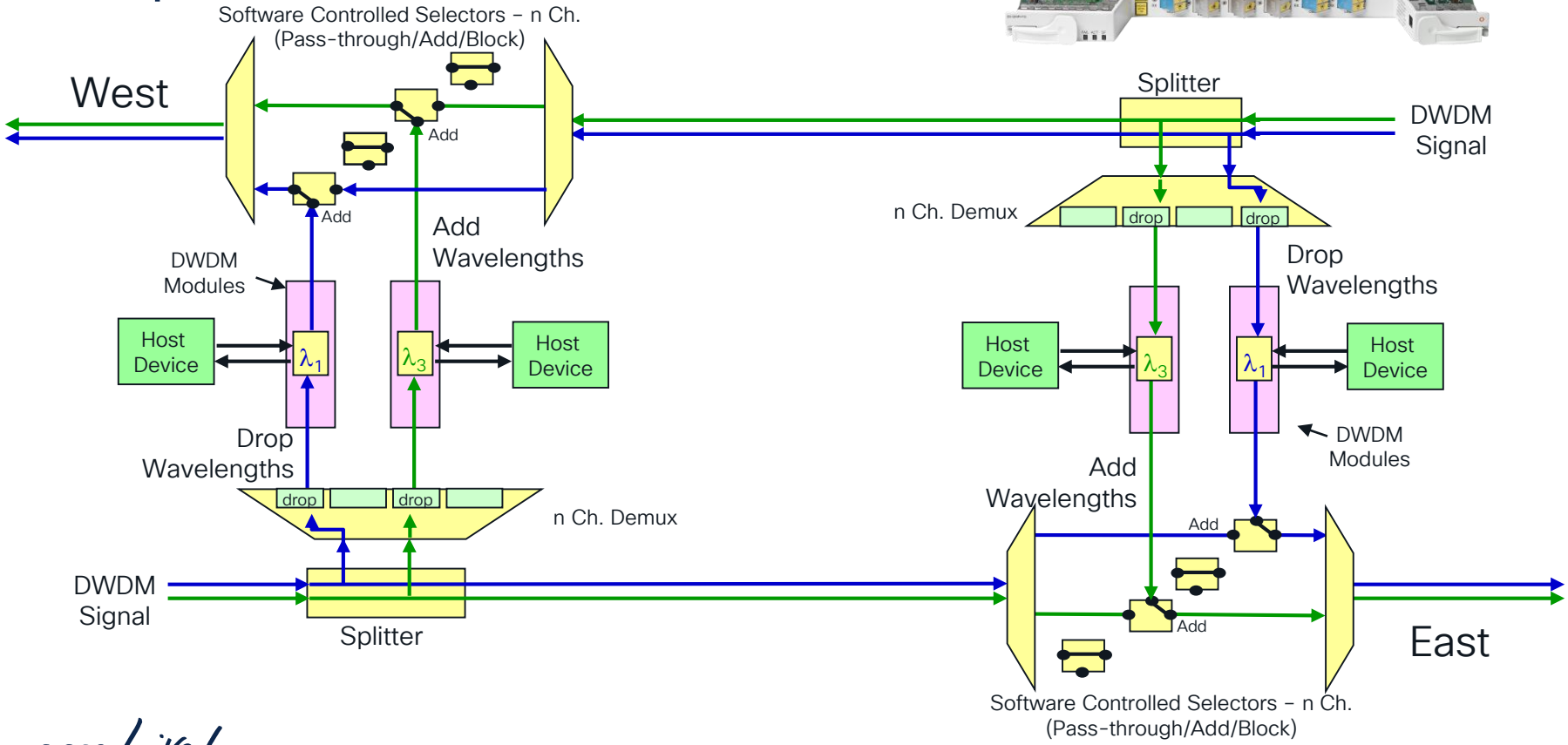

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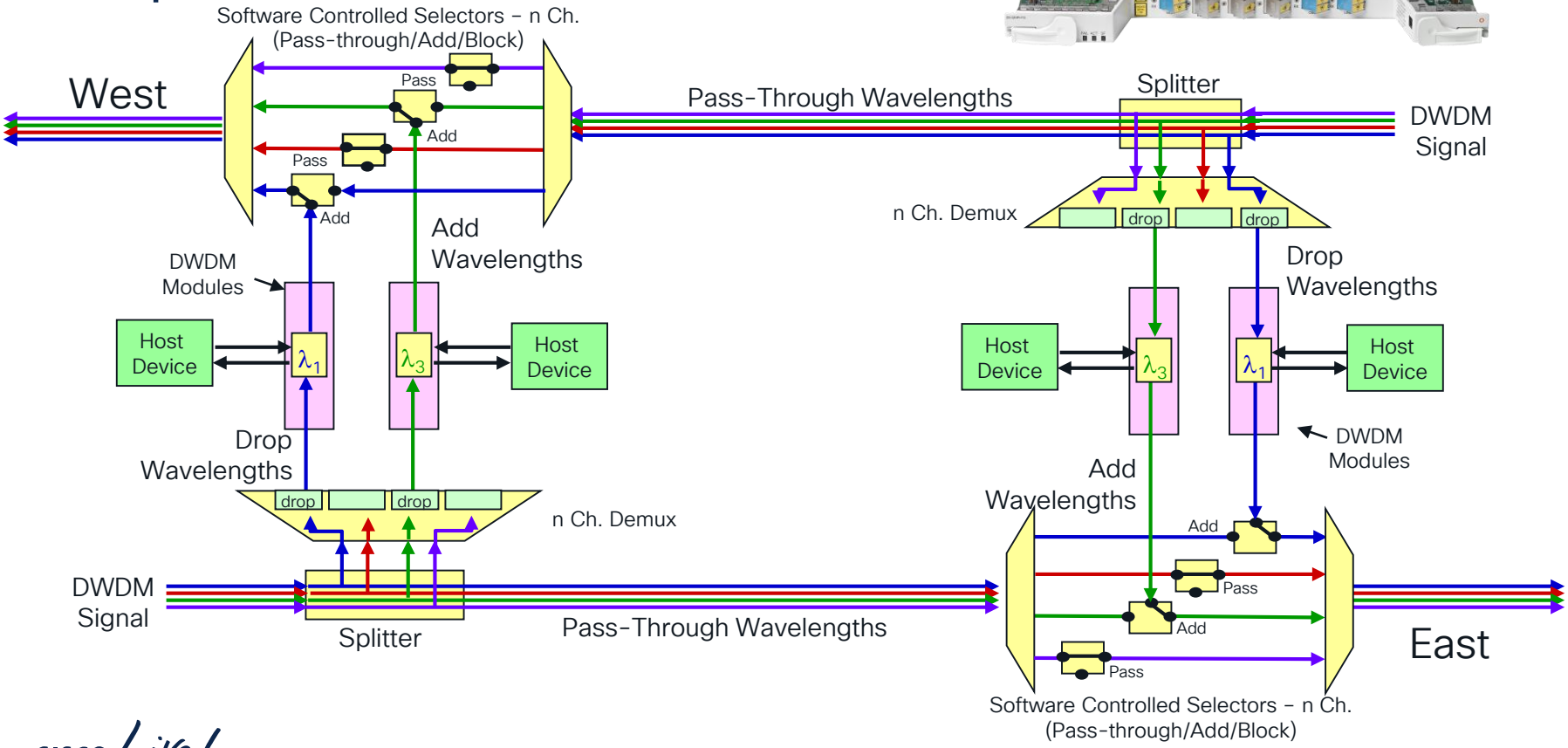
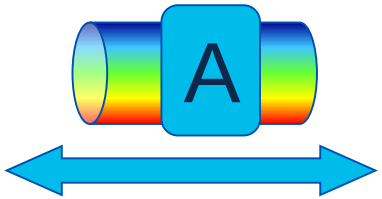
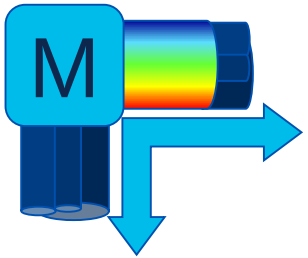


DWDM Services Types

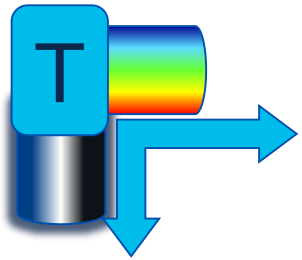
these terms are often interchanged, and many cards can support multiple



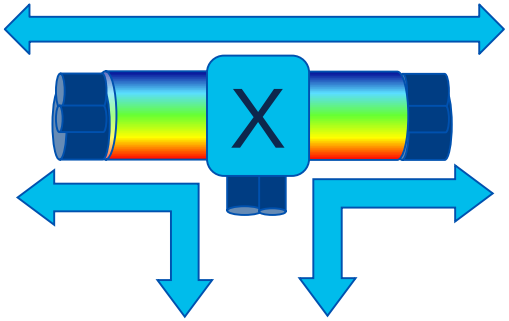
Alien: Foreign DWDM→Wavelength



Muxponder: Many→Wavelength



Transponder: One→Wavelength



Crossponder: Muxponder+

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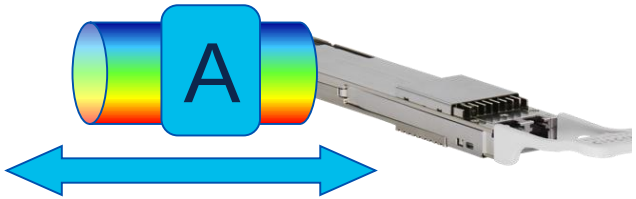
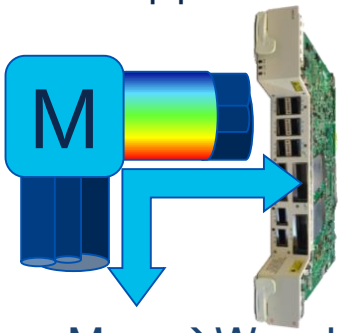
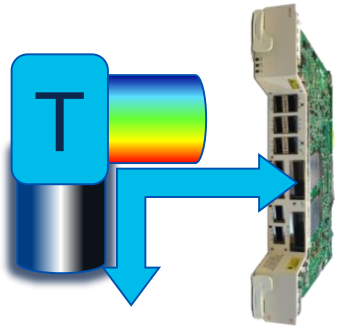


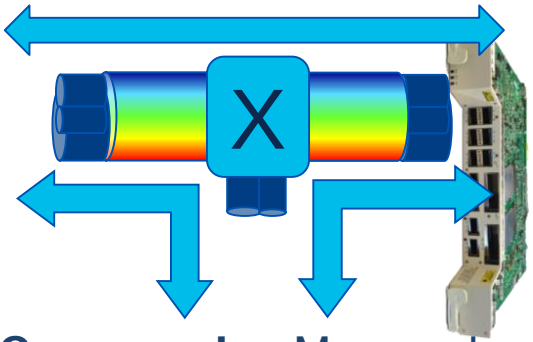
Alien: Foreign DWDM→Wavelength



Muxponder: Many→Wavelength



Transponder: One→Wavelength



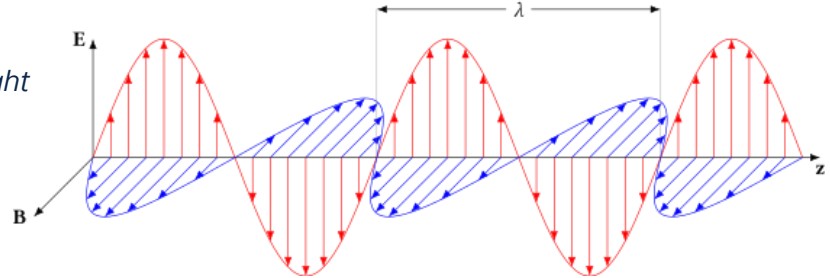
Crossponder: Muxponder+

Optical Modulation Brief

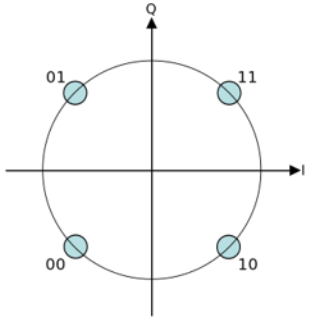
Modulation	Description	bps	Polarization Multiple	Total BW Multiple
OOK	On-off Keying	1	1	1
BPSK	Binary Phase Shift Keying	1	2	2
(D)QPSK	(Differential) Quadrature Phase Shift Keying	2	2	4
8-QAM	8-state Quadrature Amplitude Modulation	3	2	6
16-QAM	16-state Quadrature Amplitude Modulation	4	2	8
32-QAM	32-state Quadrature Amplitude Modulation	5	2	10
64-QAM	64-state Quadrature Amplitude Modulation	6	2	12

All of these can be and generally are polarization-multiplexed to double the symbol rate

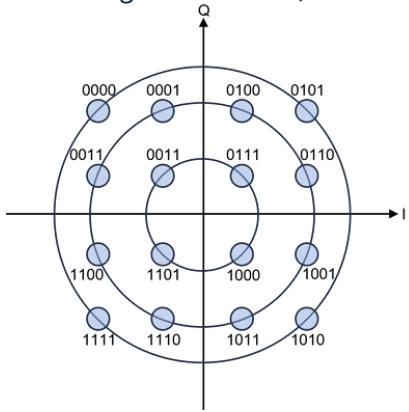
Transverse polarization of light



Constellation diagram of QSPK modulation



Constellation diagram of 16-QAM modulation

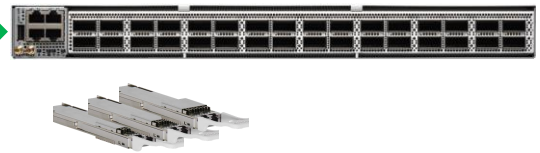


https://www.cisco.com/c/en/us/support/docs/optical-networking/routed-optical-networking/221071-understand-coherent-optical-modulation.html

DWDM Service Card Shelves vs. Native Routers

Cisco NCS 2015
14-RU
15x Service Slots
Up to 8.5Tbps
Up to 5,250W

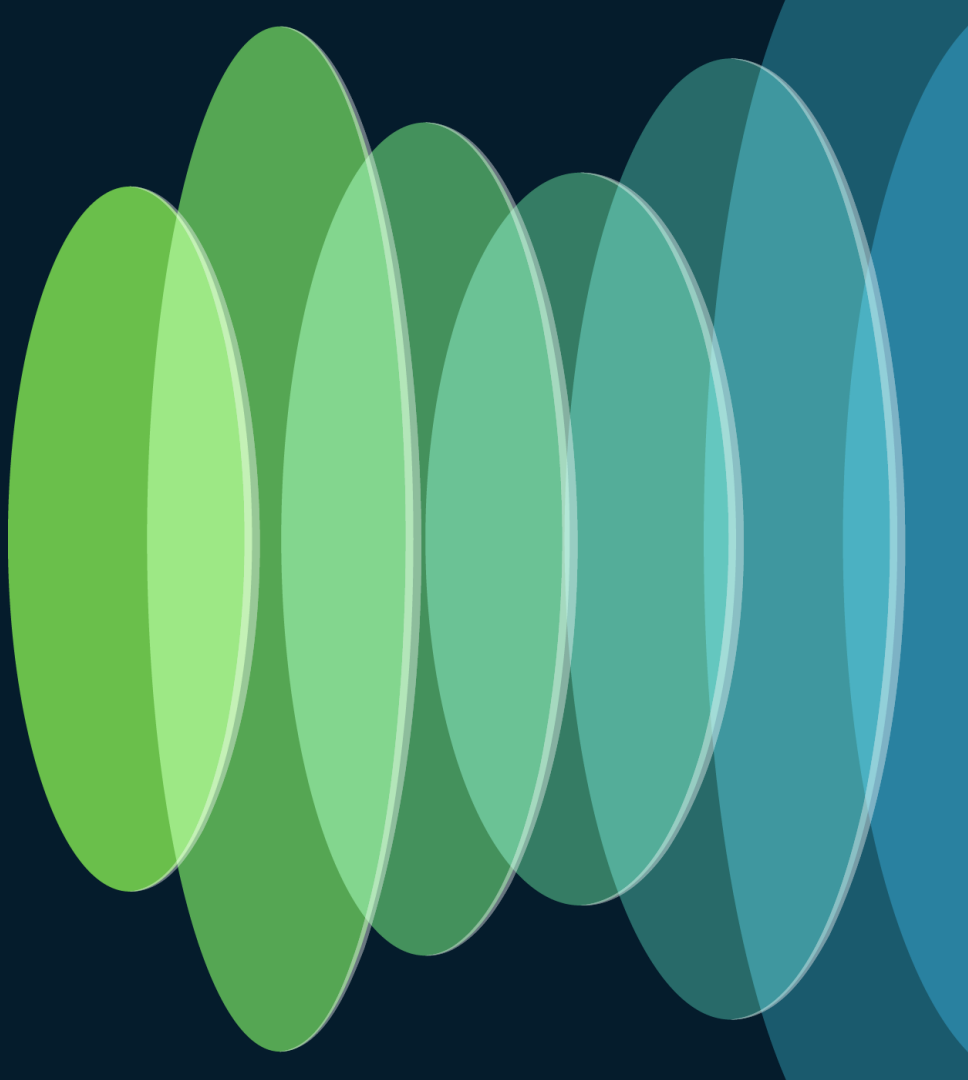
Cisco NCS 1014
2-RU
4x Service Slots
Up to 12.8Tbps
Up to 2,500W



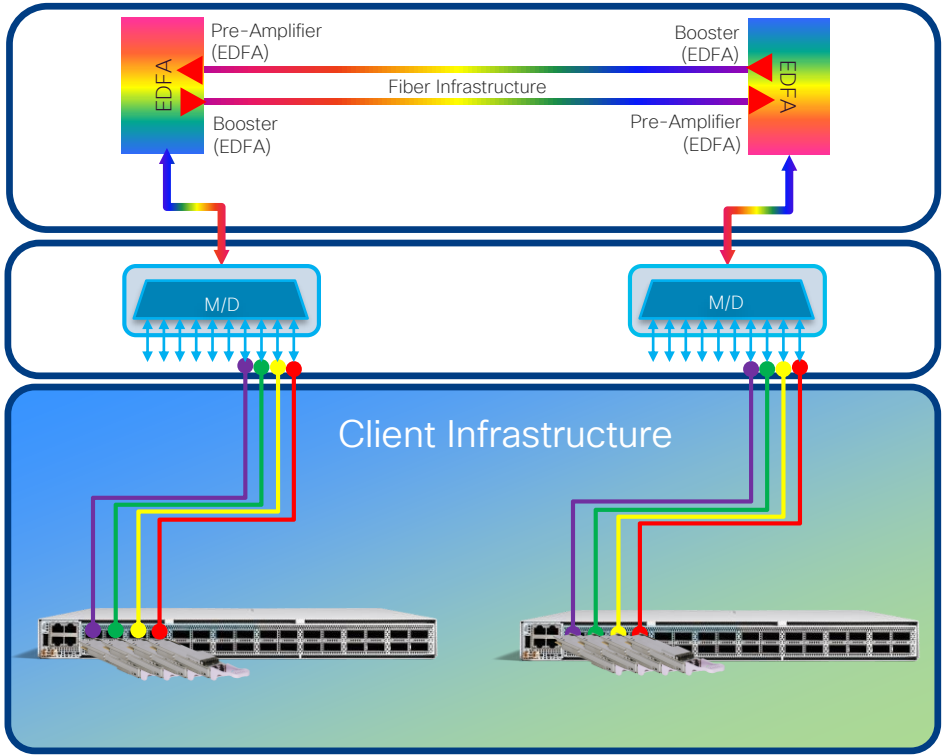
Cisco 8201-32FH
1-RU
32x 400Gbps
Up to 12.8Tbps
Up to 2,000W
fulfill

Add Pluggables as needed
Use 400G Coherent or Gray Optics

DWDM in Routers



DWDM Directly in Routers with simple Optical Line Systems



Optical Line System (as needed)

NCS 1001
Line Terminal/ILA

4, 48, 64-ch
Optical
Mux/Demux

- H2H (Hop-to-Hop) only (no Optimal Bypass)
- ZR @ 400G & ZR+ @ 100/200/300/400G
- Compact 1RU NCS1001 with EDFA and OTDR options

400G DCO's: Native DWDM Interfaces in Routers

400G-ZR

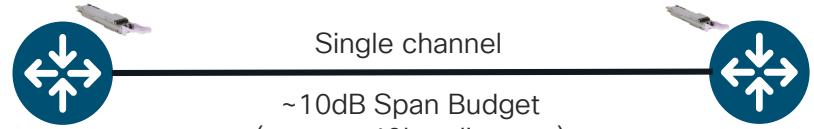
- Access to Metro Networks
- 400GE Client
- 400G Trunk
- Up to 120km
- TX Power -10dBm
- C-FEC

400G-ZR+

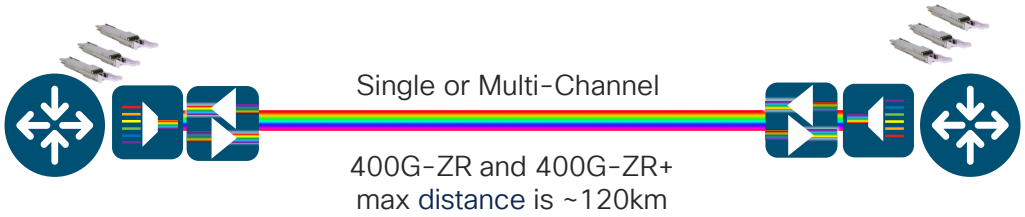
- Access to Long Haul Networks
- 100GE, 200GE, 400GE, n x100GE MXP Mode
- 100G, 200G, 300G, 400G Trunk Rates
- Up to 1,400km at 400G
  Longer distances at lower trunk rates
- TX Power -10dBm
- C-FEC and O-FEC
- TX Power +0dBm

400G-ZR+ Bright

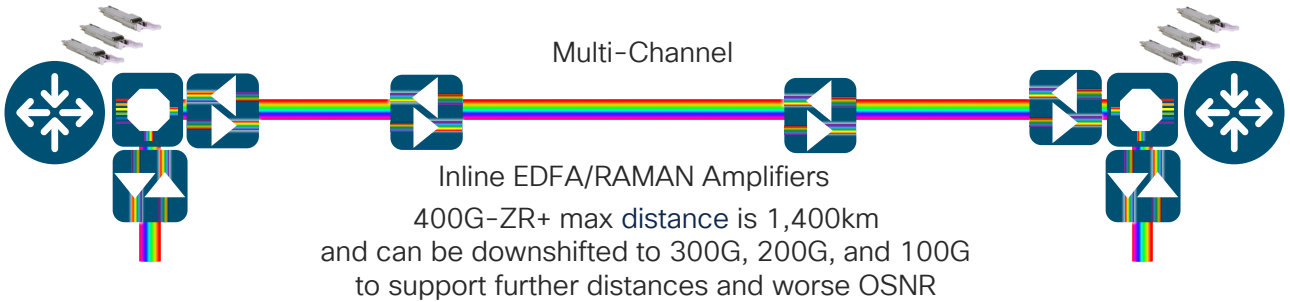
What's the Reach – ZR and ZR+



Unamplified, Dark Fiber

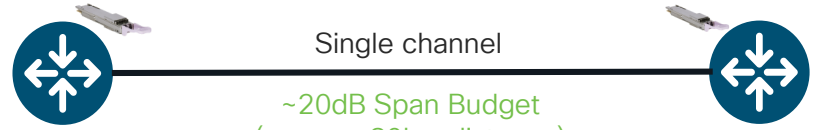


Amplified, Point-to-point DWDM



Full featured DWDM
(ROADMs, ILAs)

What's the Reach – including Bright ZR+

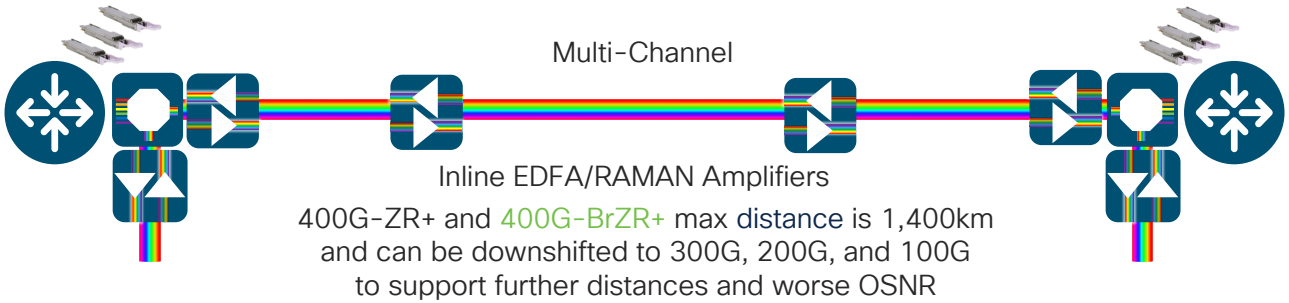


Unamplified, Dark Fiber

400G-BrZR+ supports up to 2x the loss and distance

Amplified, Point-to-point DWDM

400G-BrZR+ could require less amplification due to the increased TX Power

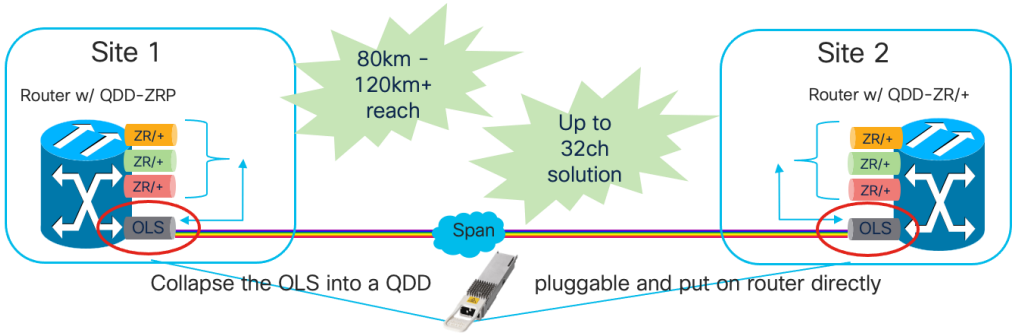


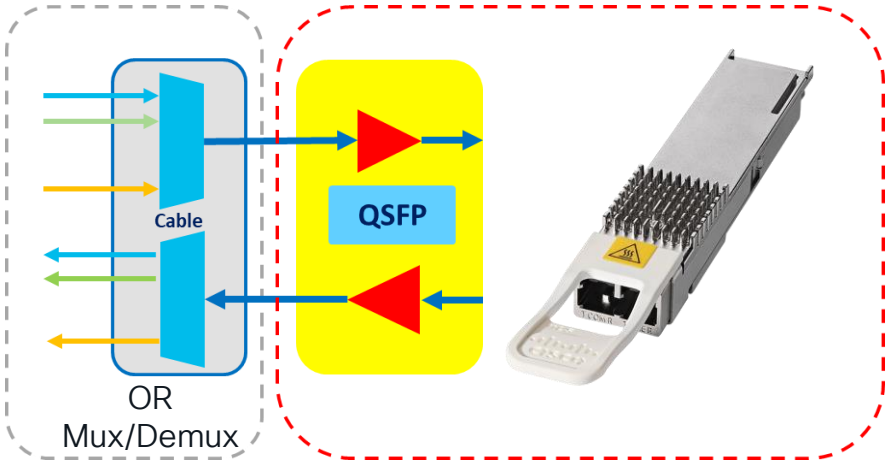
Full featured DWDM (ROADMs, ILAs)

400G-BrZR+ has 0.6dB of OSNR Improvement

QSFP-DD OLS: EDFA's Native to Routers

- Transforms separate EDFA system into a QDD Pluggable – continuing platform reduction options
- Extends the distance capabilities of ZR Pluggables further
  - Supports 4/8/16/32 channel systems
  - Colored or Colorless Add-Drop
  - Combines Booster and Preamplifiers – each with 17dBm output and up to 25 dB gain





Traditional vs. Coherent Deployments

Prior

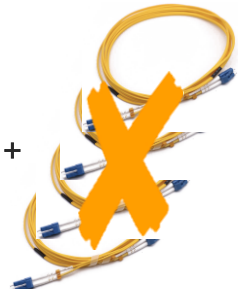
Router / Switch

+

4x 100G

Gray Pluggable

+



4x Fiber Jumpers

+

4x 100G

Gray Pluggable

+

Nx Muxponders

Transponder/ Muxponder

+

Optical Chassis

+

Fiber Jumper

+

ROADM

ROADM – OLS Layer

Outside Plant Fiber

Now

400G Capable Router / Switch

+

Consolidates transponder onto 400G pluggable

QDD-400G ZR/ZR+/BrZR +

+

Fiber Jumper

Reduces redundant client pluggable optic module spend on optical line system

Eliminates need for optical transponder / muxponder chassis spend

OLS

Outside Plant Fiber

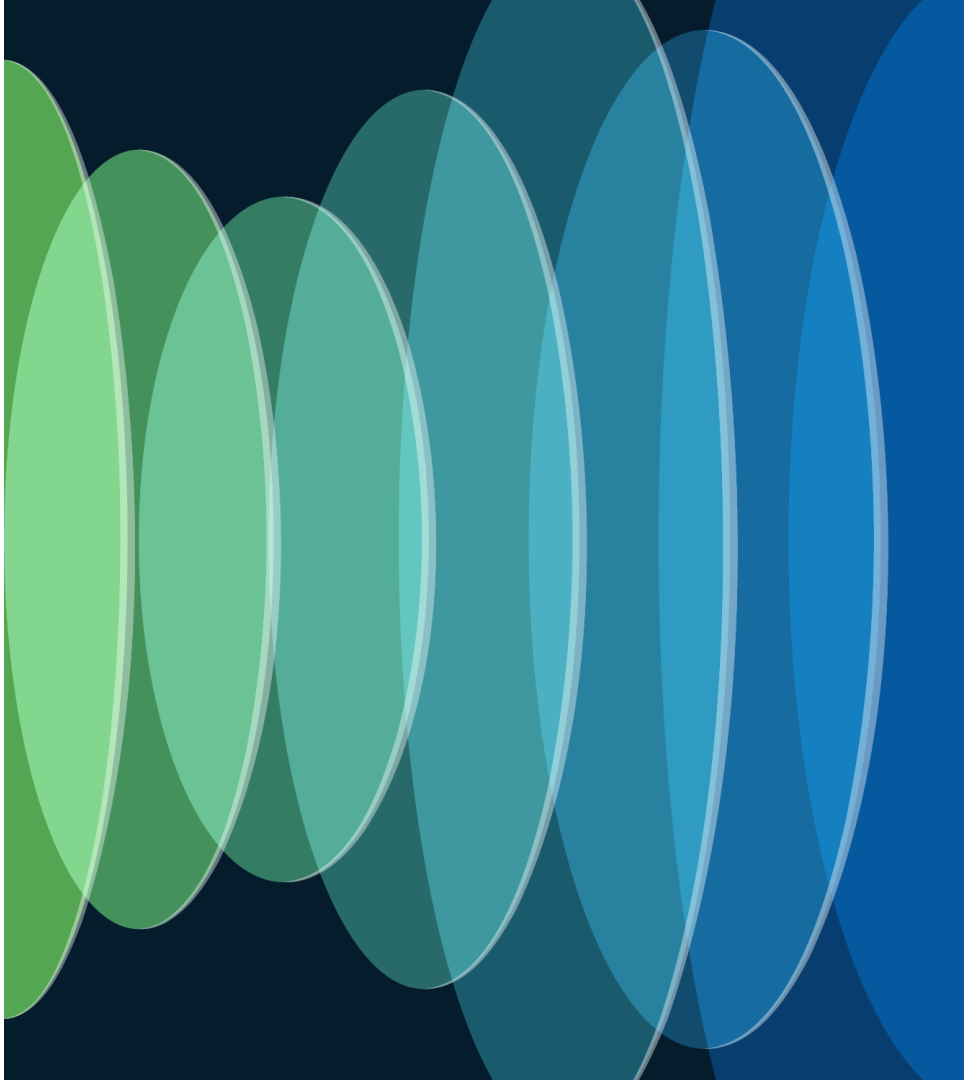
Latency
Service Separation
Traffic Engineering

ROADM or simpler OLS Layer

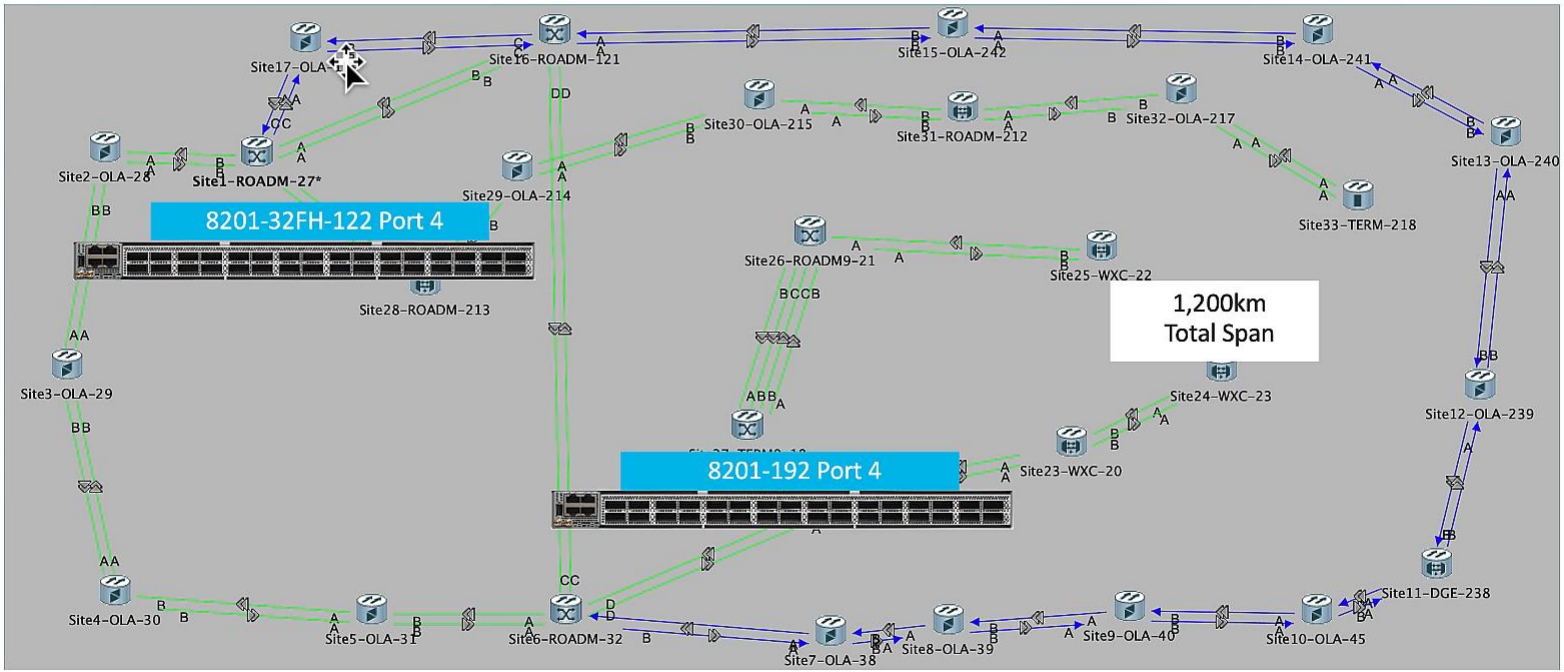
Comparison of Network Protection Mechanisms

Optical Protection Schemes				IP Protection
None – 1:1	1+1	1+1+R	PSM	
"Easily" done	< 50ms Electrical Switching (OTN)	N-x Optical Paths available for restoration	Fast Optical Switching	IP Protection is as fast as Optical Switching
Diverse Hardware and Paths	Diverse Paths could have diverse HW	No additional Optical Trunk (2)	Minimal Additional Hardware	All Paths are useable
<50% Link Utilization	+1 Optical Trunk/Card/HW	Requires Omni-directional, CDC HW	Loss of Light Switching prone to problems	Less Hardware
No or little IP Layer Interaction	Failback is not coordinated with IP Layer	Failback is not coordinated with IP Layer	Failback is not coordinated with IP Layer	New Skillset within IP
	Only 2-paths for redundancy	Multi-path support if available	Only 2-paths for redundancy	
	Additional Power, real estate, and costs			

Demo Time!



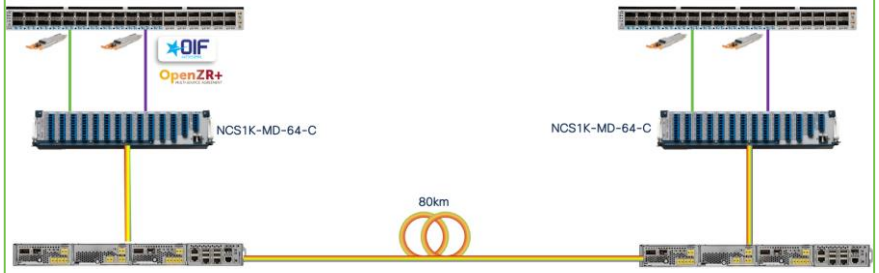
Cisco Network Topology – BrightZR+ @ 400G – 1,200km Path



Summary

- DWDM is not any harder than IP Networks
- DWDM is not going away
- Industry advances DWDM Interfaces in Routers
- Like-for-Like and additional functionalities are available
- Don’t be afraid to get started

Optical Networking Simplification



- Lower CapEx and OpEx
- Quicker time-to-market
- Improved Troubleshooting

Good links

https://www.cisco.com/c/en/us/td/docs/optical/15000r5_0/planning/guide/r50engpl/r50appc.html

https://www.cisco.com/c/en/us/products/collateral/routed-optical-networking/routed-optical-networking-wp.html

https://www.ciscolive.com/on-demand/on-demand-library.html?search=dailey#/session/1707505548618001pxaU

https://www.ciscolive.com/c/dam/r/ciscolive/us/docs/2020/pdf/DGTL-BRKOPT-2007.pdf

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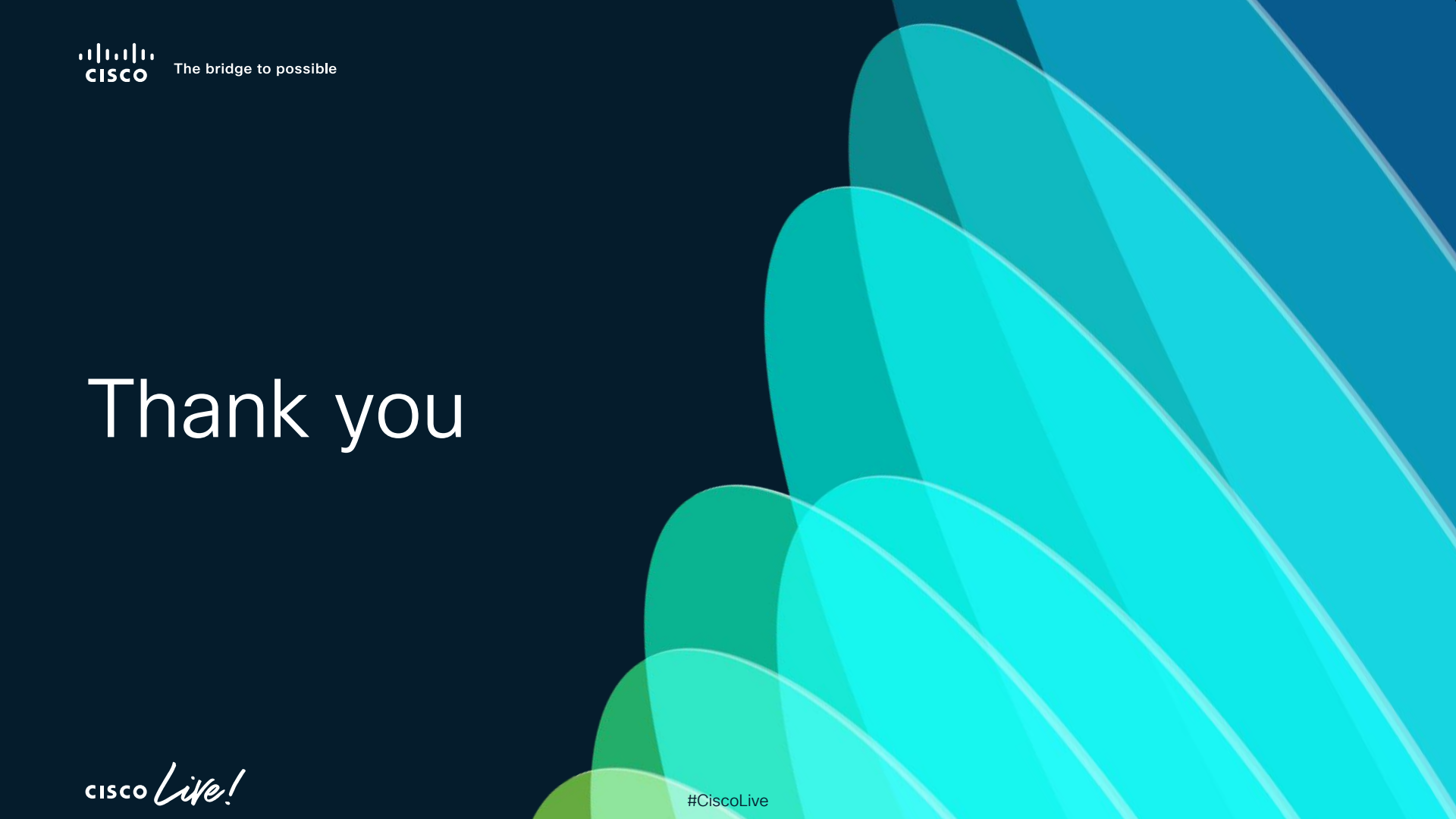
Contact us at: Brad Riapoloy, brriapol@cisco.com
Kent Dailey, kedailey@cisco.com


The bridge to possible
Thank you
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