What You Make Possible

TOMORROW
starts here.

Optical Transport (DWDM) Evolution and Developments

BRKOPT-2662

TOMORROW starts here.

Before We Start – Some Logistics

- We value your feedback - don't forget to complete your online session evaluations after each session & complete the Overall Conference Evaluation which will be available online
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- Please make use of the recycling bins provided
- Please remember to wear your badge at all times

- **And please ask questions when you have them, we are here for you**

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100,000,000,000

124,964,000,000

1,249,640,000

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100,000,000,000	Bits per second of client data are transmitted in 100G DWDM channel
124,964,000,000	Bits per second are actually transmitted over single wavelength
1,249,640,000	Bits per second can be corrected by 100G Transponder

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Today’s Session Outline

- DWDM technology refresh
- High speed transmission
- Optical layer evolution
- Optical control plane

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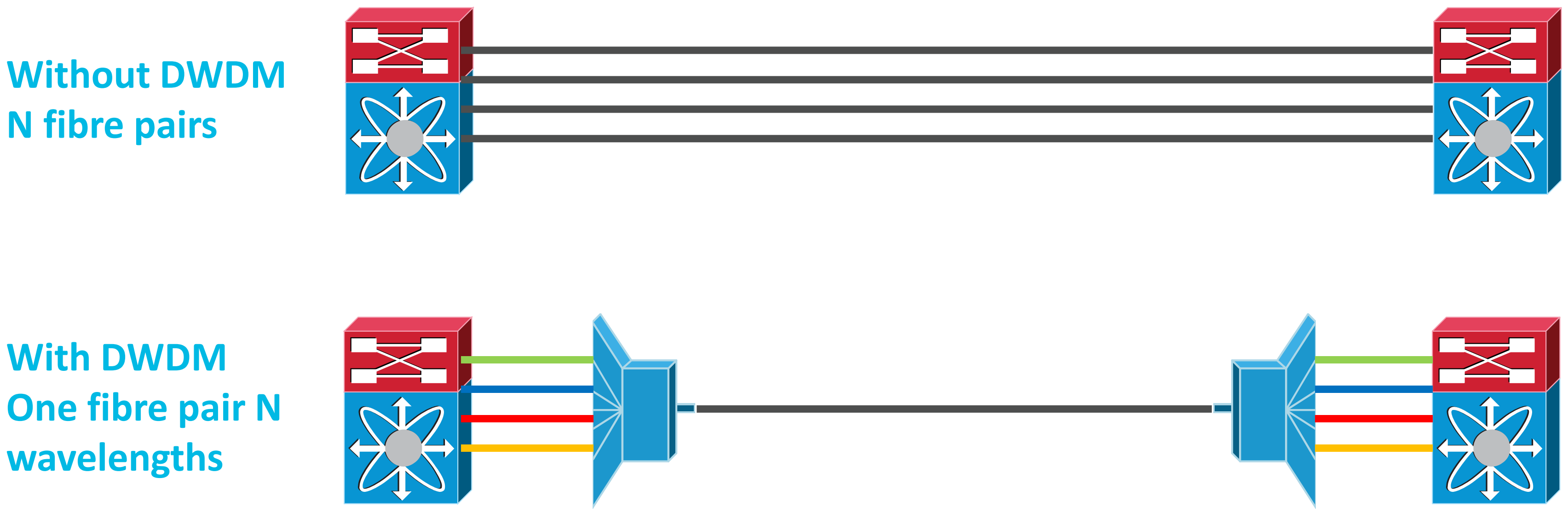
DWDM Technology Refresh

Why DWDM?

Increase transmission density

- Transport of bandwidths beyond available interface rates (10G, 40G, 100G) requires multiple channels.
- With standard interfaces, multiple channels requires multiple fibre pairs. Fibre is a scarce resource, and can be costly.
- DWDM allows multiple channels over a single fibre pair, and is often more cost effective than using multiple fibre pairs.



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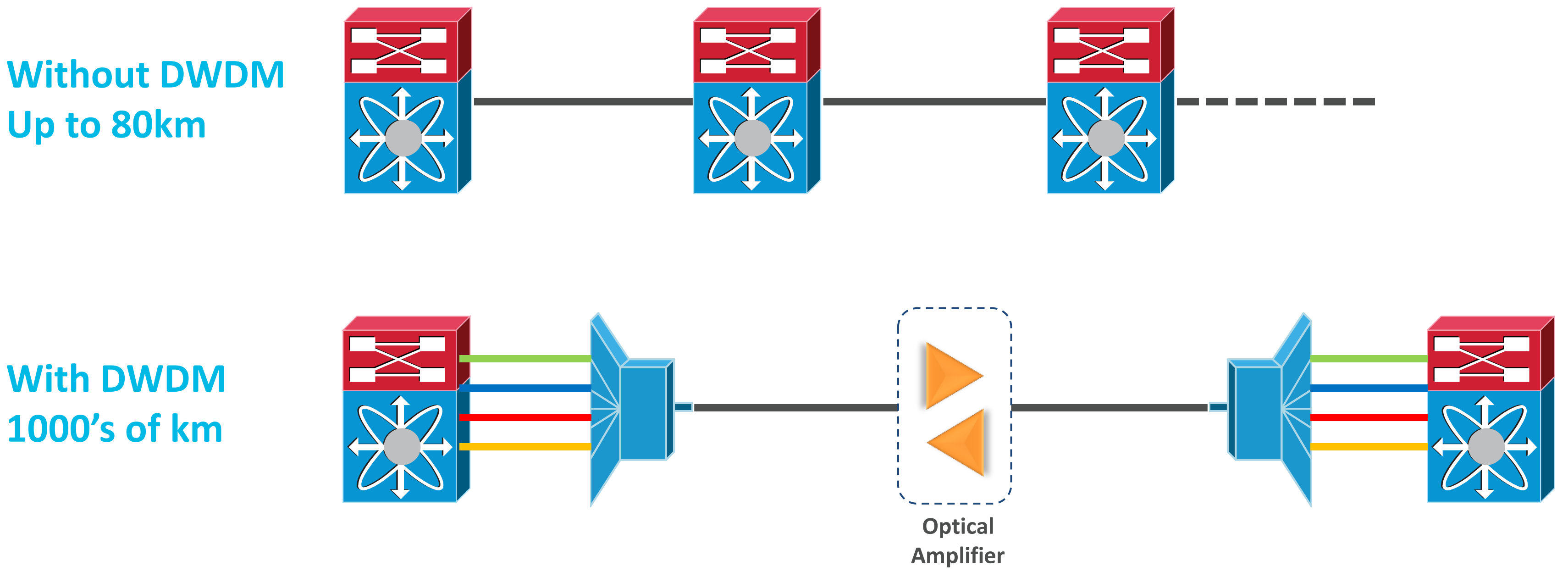
Why DWDM?

Solve distance limitations

- With standard interfaces, distance is limited to the reach of the specified interface (e.g. LX, EX, ZX – 10 km, 40 km, 80 km).
- Exceeding these distances requires regeneration of each channel (typically with router/switch interfaces).
- With DWDM, single span distances can reach 250 km.
- Amplified, multiple span DWDM distances can reach 1000’s of km, with no ‘electrical’ regeneration.



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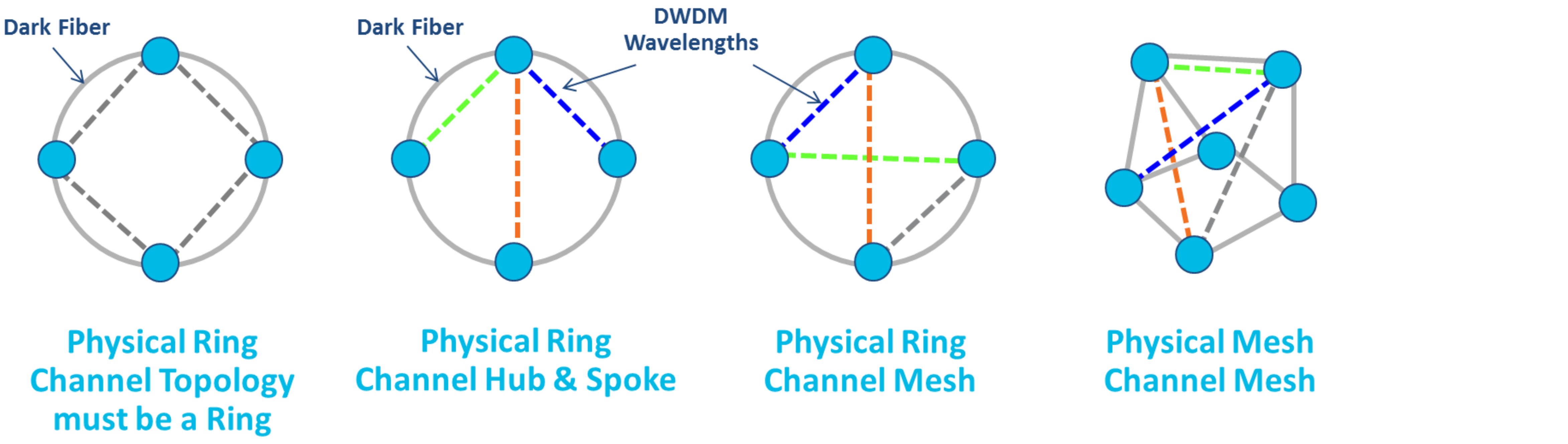
Why DWDM?

Topology flexibility

- With standard interfaces, the physical (layer 1) network topology is restricted to the fibre topology.
- Fibre is expensive, and availability is limited. Metro / regional fibre is most cost effectively deployed to multiple sites in a ring.
- DWDM, specifically ROADM, allows any L1 topology (hub and spoke, mesh) over any fibre topology – typically a ring.



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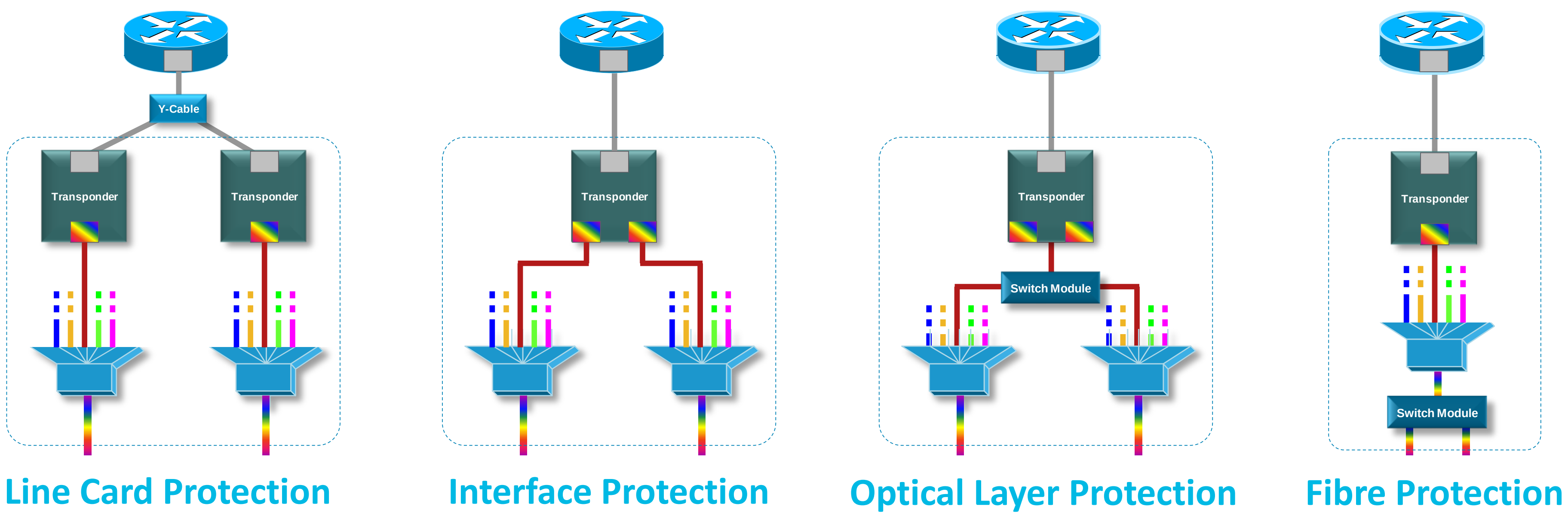
Why DWDM?

Service protection

- Without DWDM (or TDM), service protection must be provided by an upper layer protocol. This can be complicated and slow.
- DWDM provides the ability to protect individual channels at layer 1, with sub 50 ms switching times.
- Bandwidth is reserved, with no oversubscription or contention in a failure scenario.
- Multiple levels of resiliency are available, at varying cost points.



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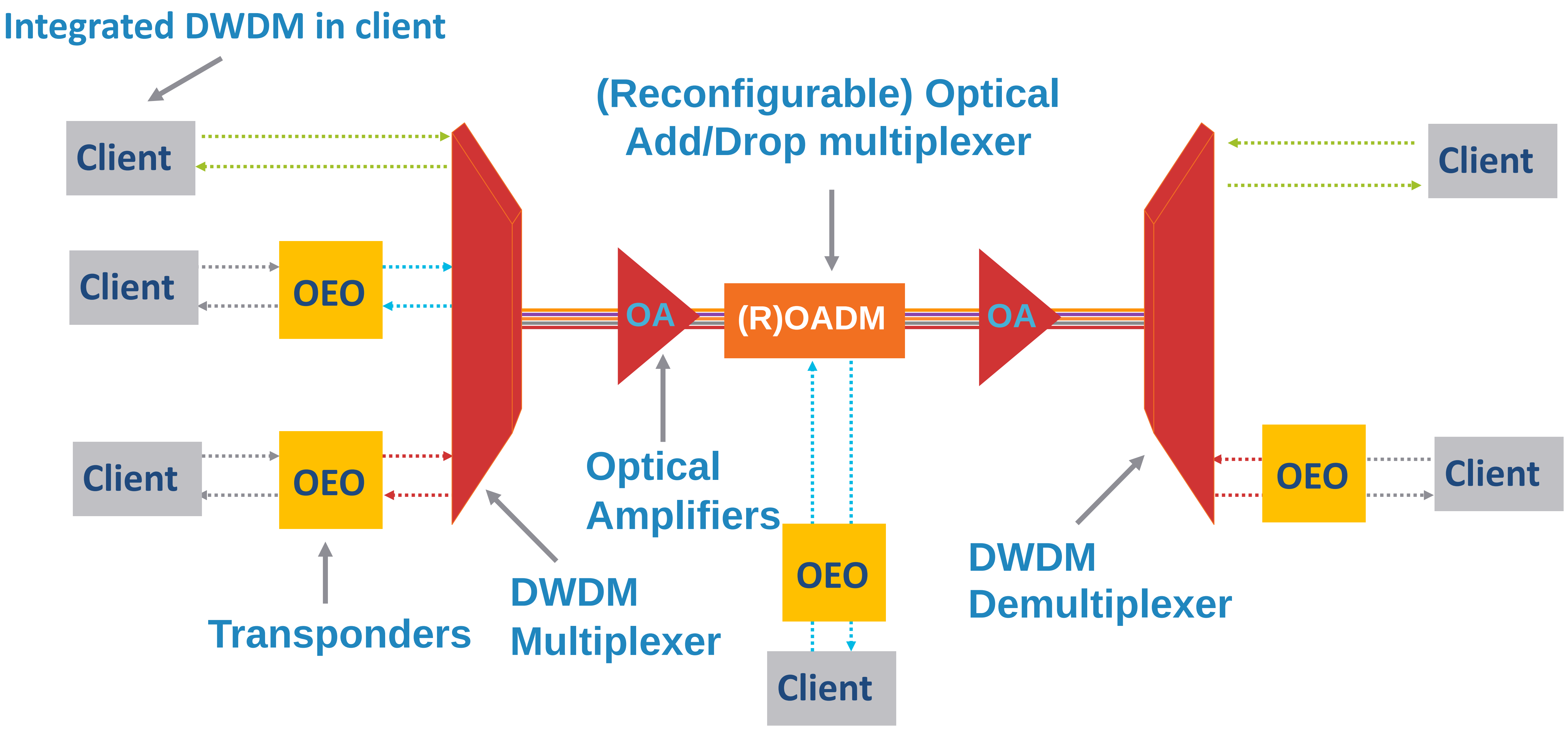
DWDM System – Typical Building Blocks



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Types of DWDM Systems

	Access	Metro / regional	Long Haul	Submarine
Reach	10-100 km	100-500 km	1000-4000 km	1000-10000 km
Nr of wavelength	4-16 (CWDM)	32-80	80-128	40-80
Fibre	Any SM fibre	Any SM fibre	Any SM fibre	Engineered
Bit rate per wavelength	10G	10G-100G	40G-100G	10-100G?
Amplifiers	None	EDFA	EDFA/Raman	EDFA/Raman
Reconfigurability	No	Ring	Ring / mesh	No

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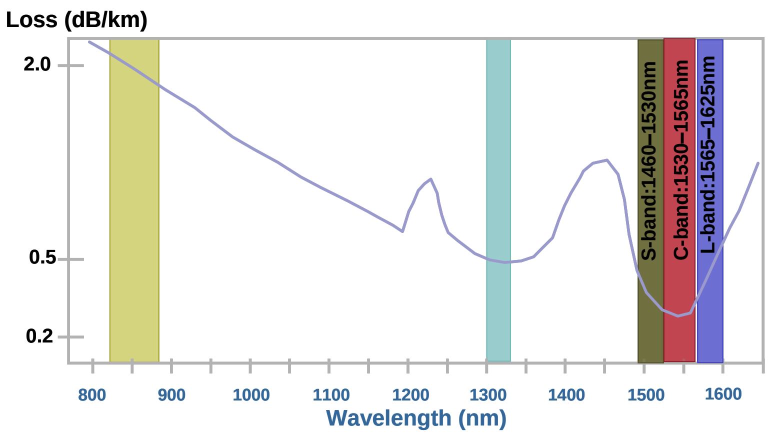
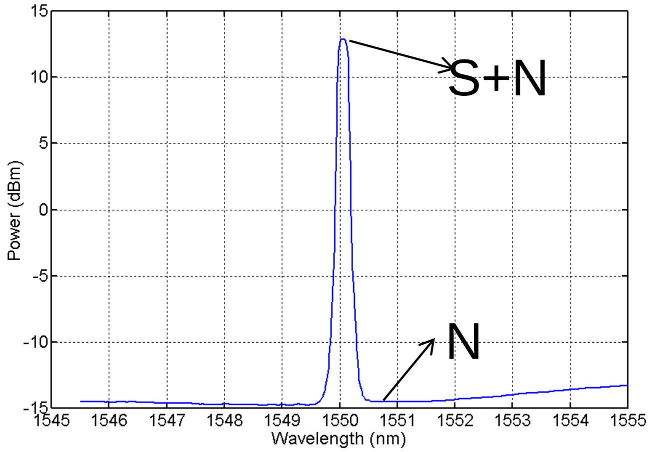
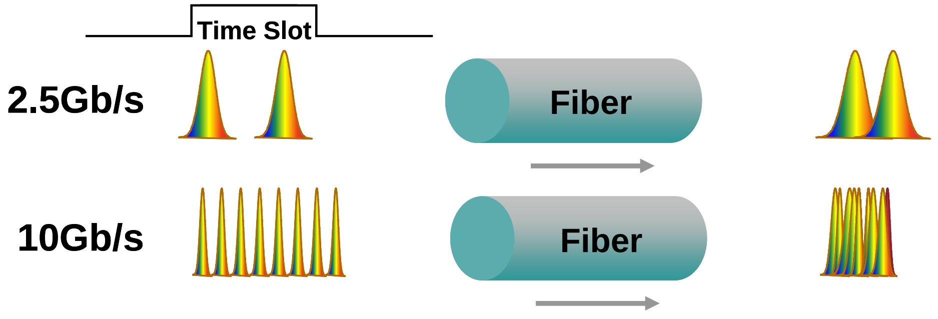
Optical Impairments

- Attenuation
  - Loss of signal strength
  - Limits transmission distance
  - **Optical amp compensates**
- Optical Signal to Noise Ratio (OSNR)
  - Noise introduced by optical amplifiers
  - Function of data rate — rule of thumb, 2X data rate = 3 dB higher OSNR
  - Limits number of amps hence distance
  - **Forward error correction and regeneration counter impact**
- Chromatic Dispersion (CD)
  - Amps allow greater distance leads to Distortion of pulses
  - Limits transmission distance
  - Inverse to the square of the data rates
  - **DCUs / TDC / Electronic Compensation**







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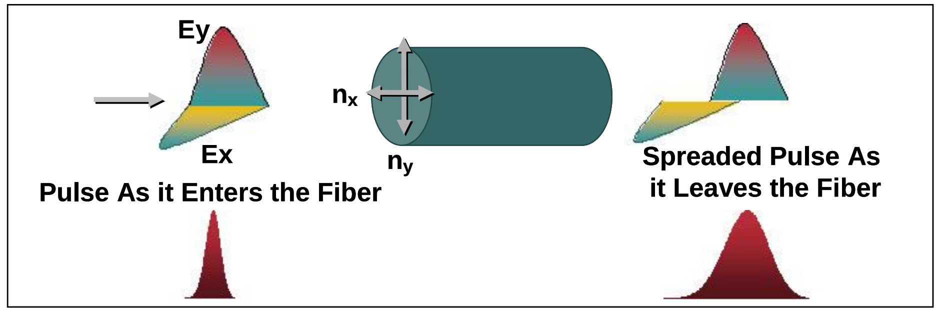
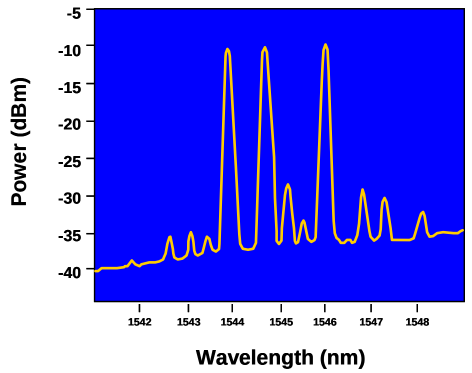
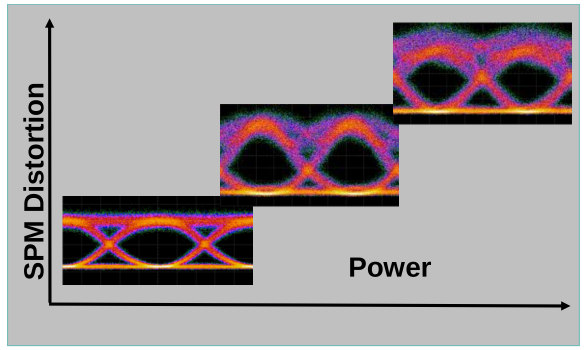
Optical Impairments

- Polarisation Mode Dispersion (PMD)
  - Caused by non-linearity of fibre geometry
  - Very disruptive at higher bit rates (> =10G)
  - **PMDC / Electronic or Regeneration to compensate**
- Four Wave Mixing (FWM)
  - Effects in multichannel systems
  - Effects for higher bit rates
  - **CD, unequal channel spacing, larger spacing**
- Self/Cross Phase Modulation (SPM, XPM)
  - Effected by high channel power
  - Effected by neighbour channels
  - **CD, reduce launch power, larger spacing**







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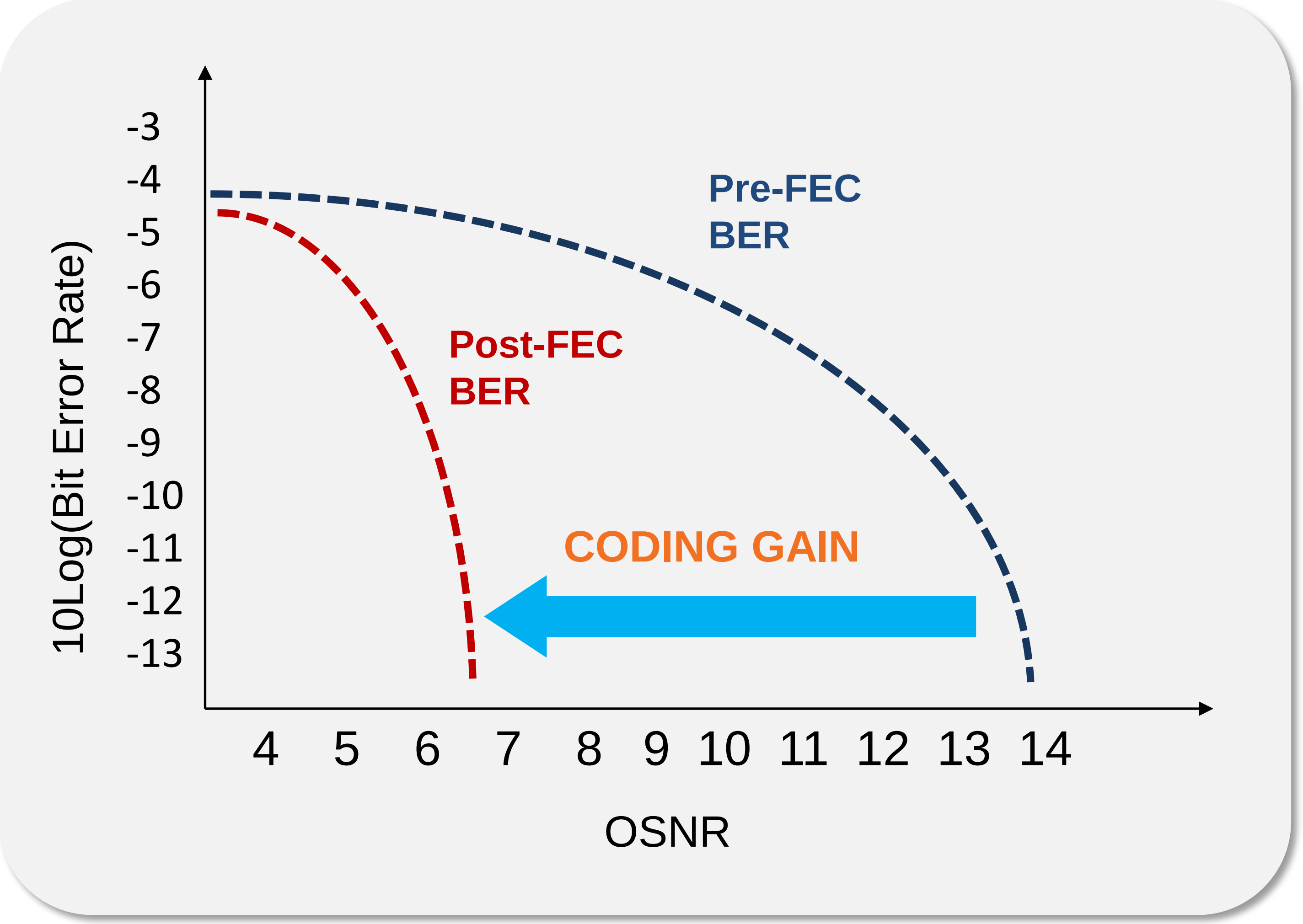
Compensate for Low OSNR using FEC

- FEC extends reach and design flexibility, at "silicon cost"
- G.709 standard improves OSNR tolerance by 6.2 dB (at 10^{-15} BER)
- Offers intrinsic performance monitoring (error statistics)
- Higher gains (8.4dB) possible by enhanced FEC (with same G.709 overhead)



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High Speed Transmission

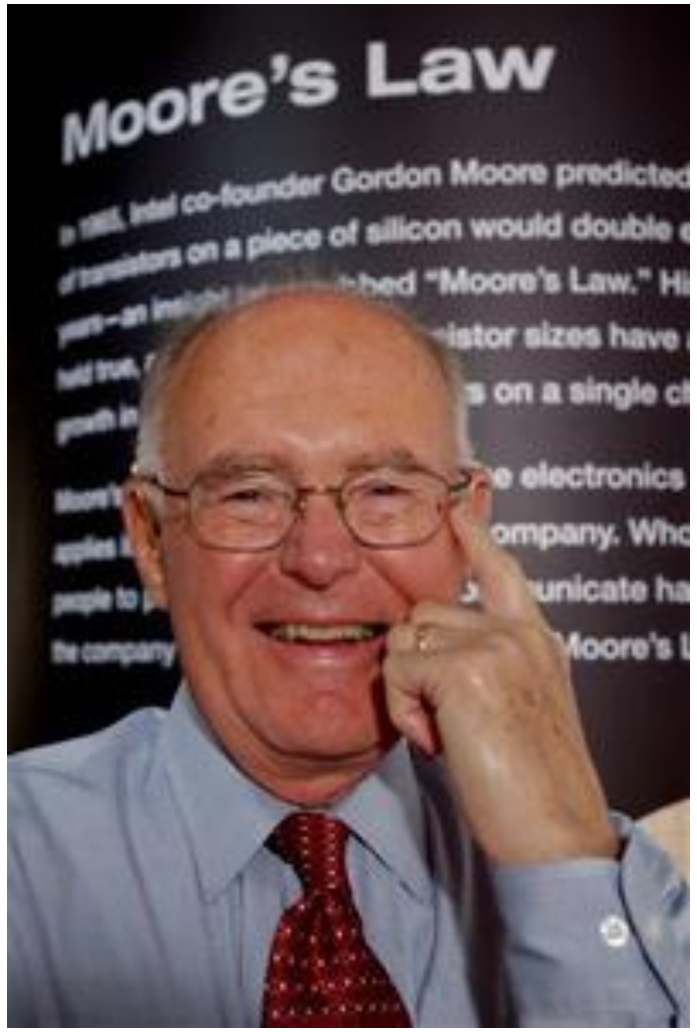
The ASICs Role in Networking

<u>Moore's Law still holds:</u>

- Driving down power, increasing density

  "The # of transistors on an IC doubles every 2 years" - Stated by George Moore, Intel founder, in 1965

- Many to 1 Integration – simplifies systems, enables alternate packaging
- ASICS used in many different networking applications
  - Digital Signal Processing for optics
  - NPU
  - Fabric
  - Phy & Framing for I/O sight.



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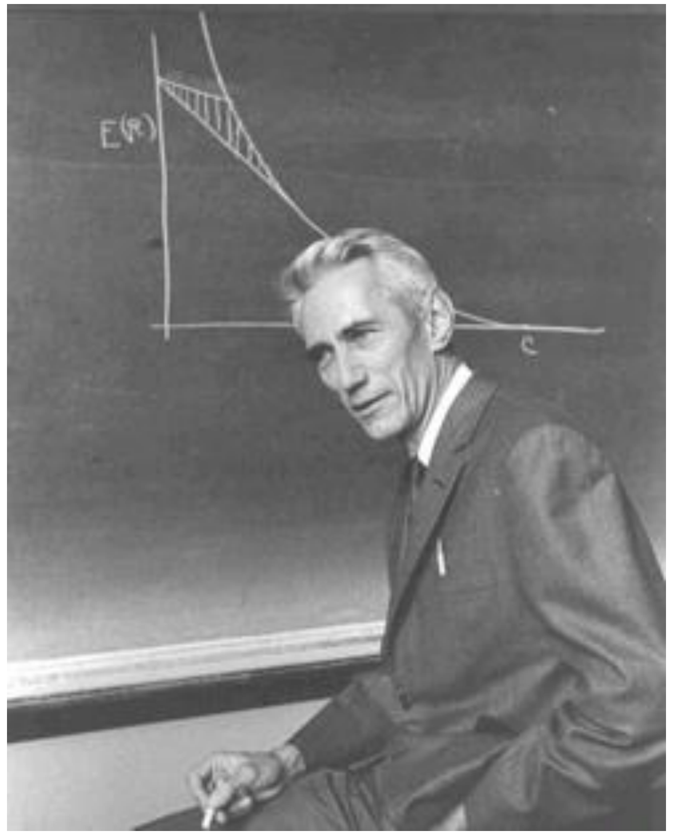
100G+ DWDM Optics Dilemma

- High performing 100G+ DWDM optics have another challenge beyond package density & Moore's Law
- Hybrid structure of the solution is a mix of ASIC technology and analog optical signalling technology
- Analog Optical technology follows Shannon's Limit
  - Summarised that each channel has a maximum low BER information rate or bandwidth
  - Bandwidth is limited by material, frequency, channel spacing, signal processing complexity, and signal to noise ratio, among other things



Claude Shannon pioneered information theory in a 1948 paper

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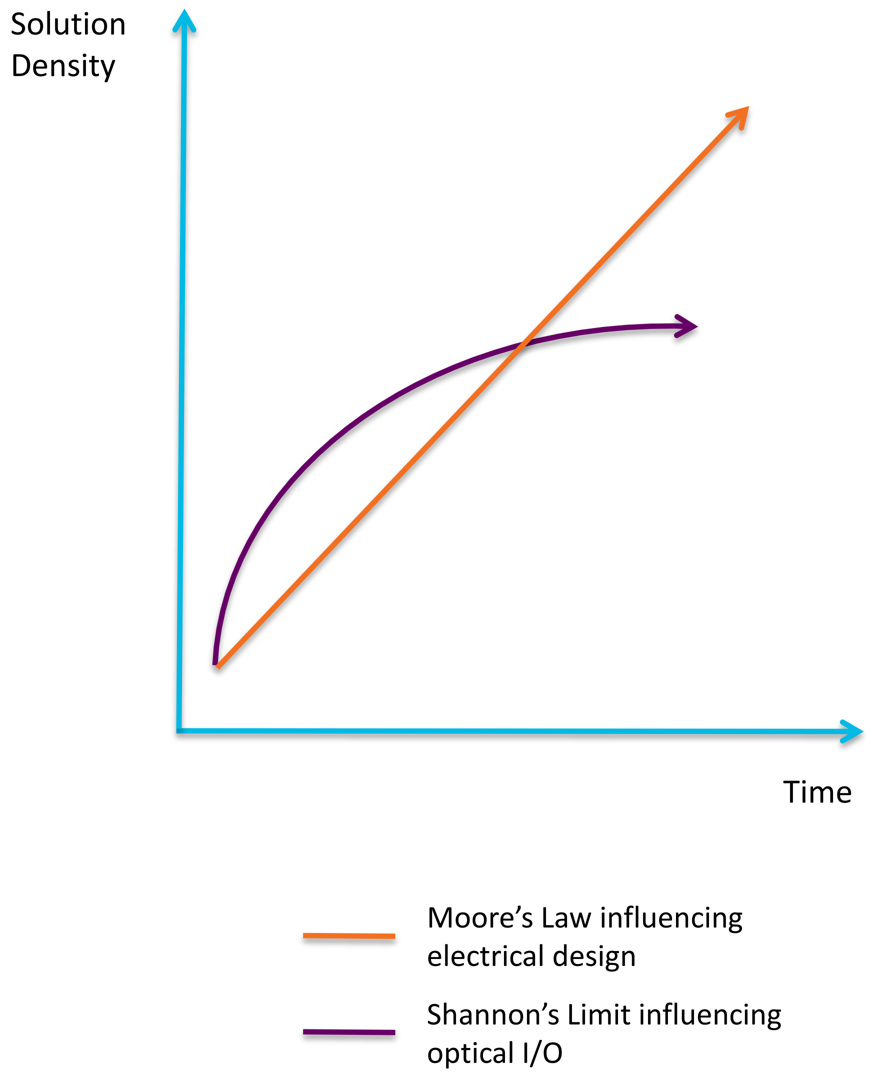
Moore vs. Shannon

What does it mean to us?

- In networking equipment we are approaching a point where board level processing will overtake the I/O section's ability to get the information off the board at a similar YoY density improvement
  - *New Approaches to System Design will emerge*
  - *Likely decoupling of DWDM I/O from L1/2/3 switching or routing function*
  - *New focus on "Optics Efficiency" from system design, network design, and bandwidth utilisation perspective*



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Speed Increase and Optical Impairments

As Bit Rate increases the optical impairments becomes more challenging

	100G vs. 10G	40G vs. 10G
OSNR Requirement	10 dB higher	6 dB higher
CD Tolerance	100 X less	16 X less
DGD Tolerance	10 X less	4 X less
PMD Limited Distance	100 X less	16 X less
Optical BW	10 X	4 X

Target: simplify 100G deployment in existing 10G DWDM systems

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How to Address the Challenge

Transmitter

- Decrease Speed – reduce $$
- Increase Modulation – Increase spectral efficiency
- Increase Optical efficiency – Increase spectral efficiency

Receiver

- Move from Direct Detection (Morse Code) to Coherent detection (Radio)
- Compensate for Optical impairments in Electrical Domain – reduce $$

Forward Error Correction (FEC)

- Move to Higher coding gain FECs – Increase reach

100Gig was first challenge – overcame with DP-QPSK (modulation) and new FECs

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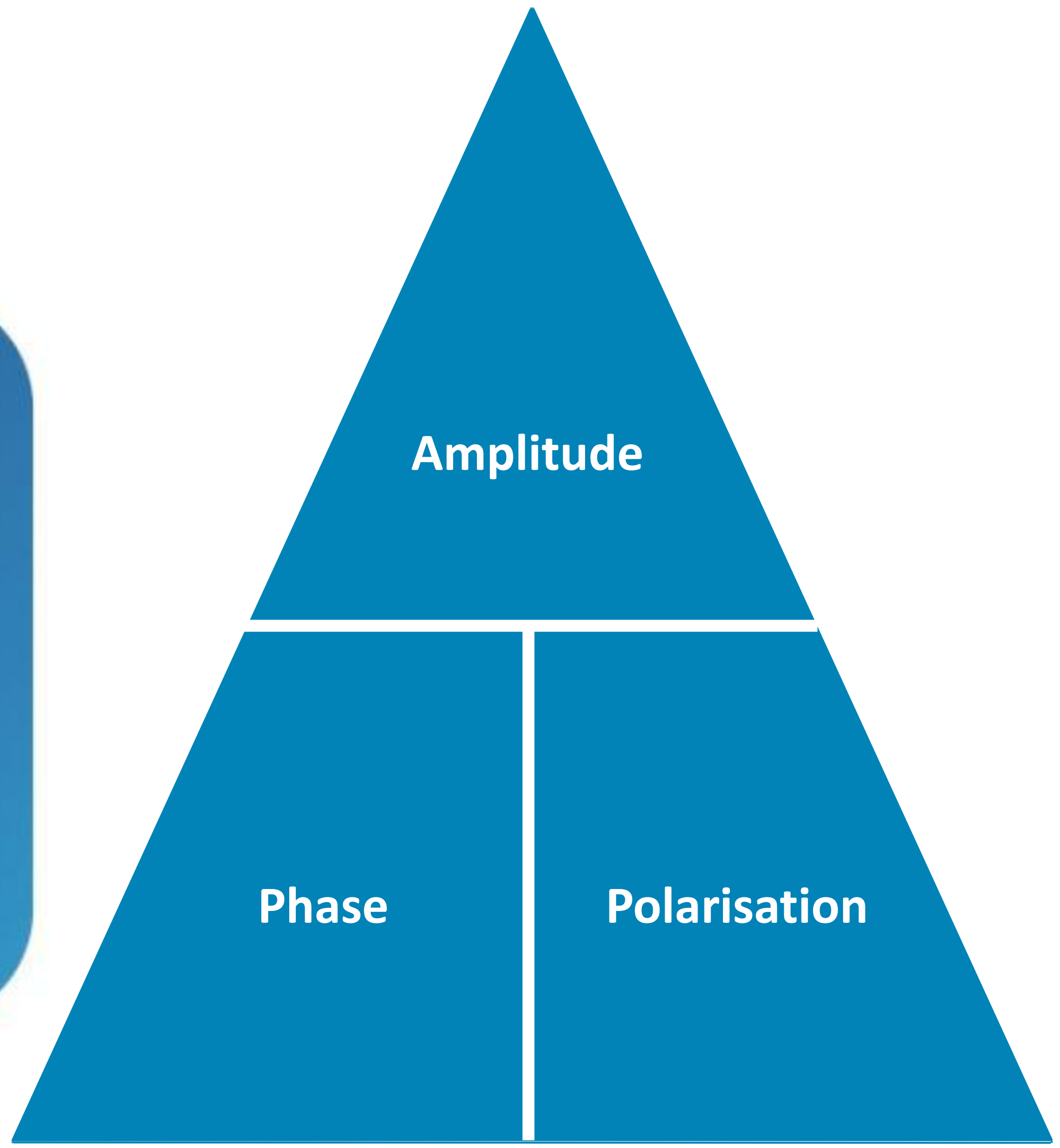
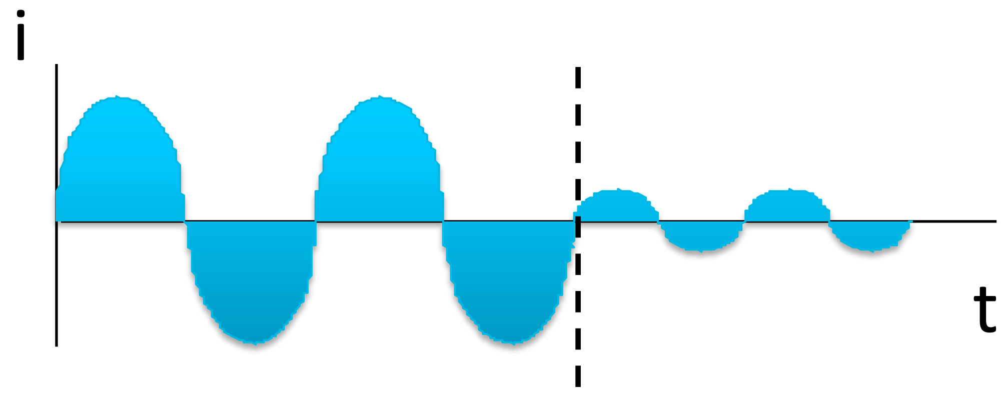
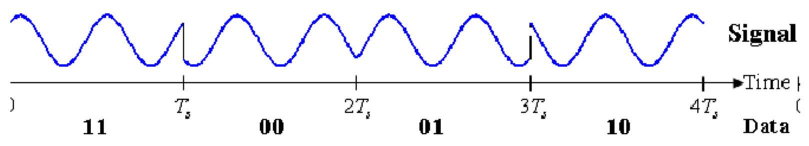
Modulation Schemes



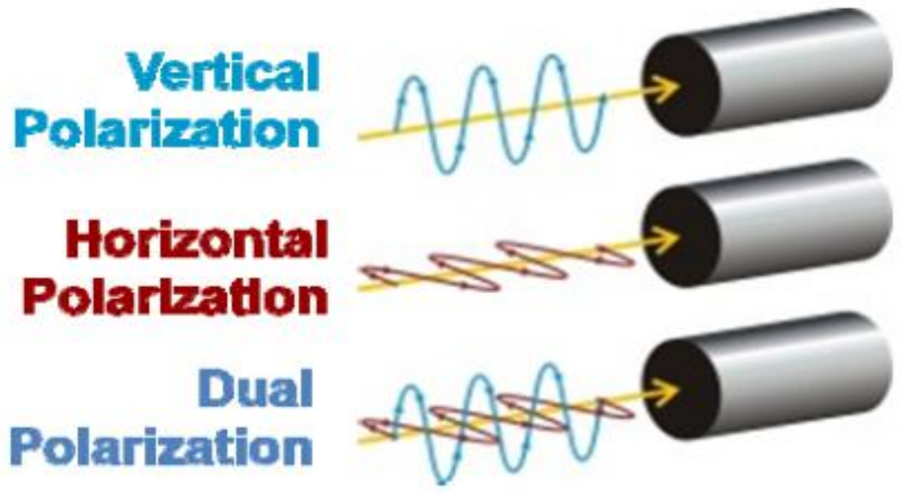
Amplitude:



Phase:



Polarisation:



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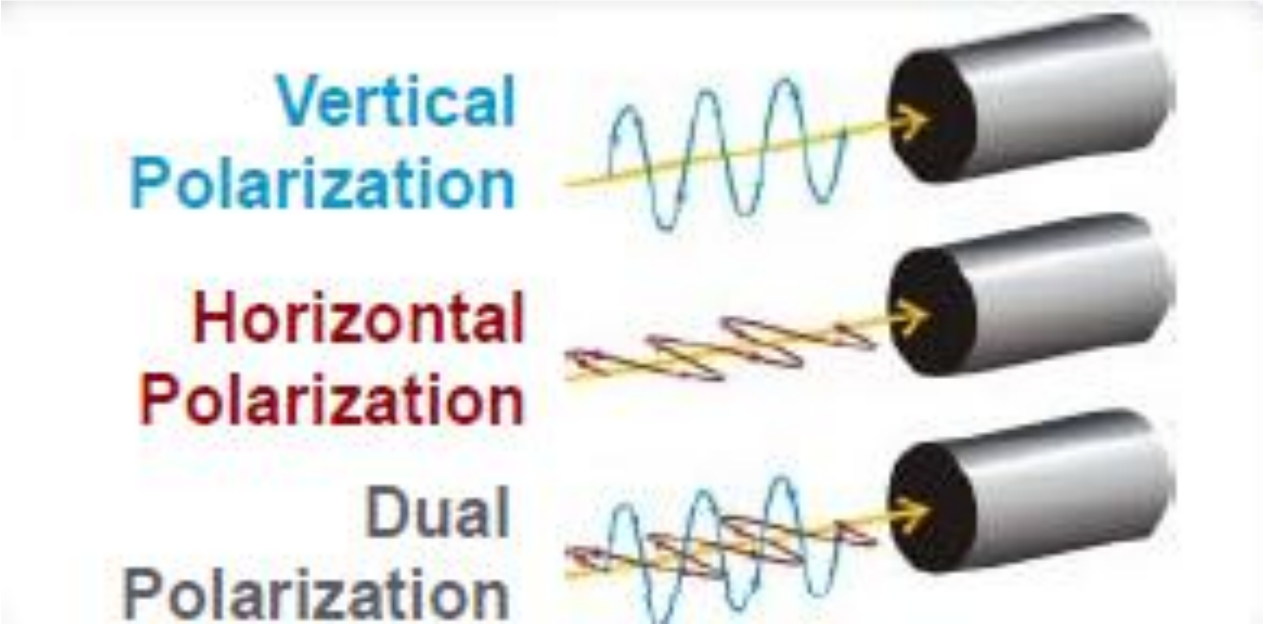
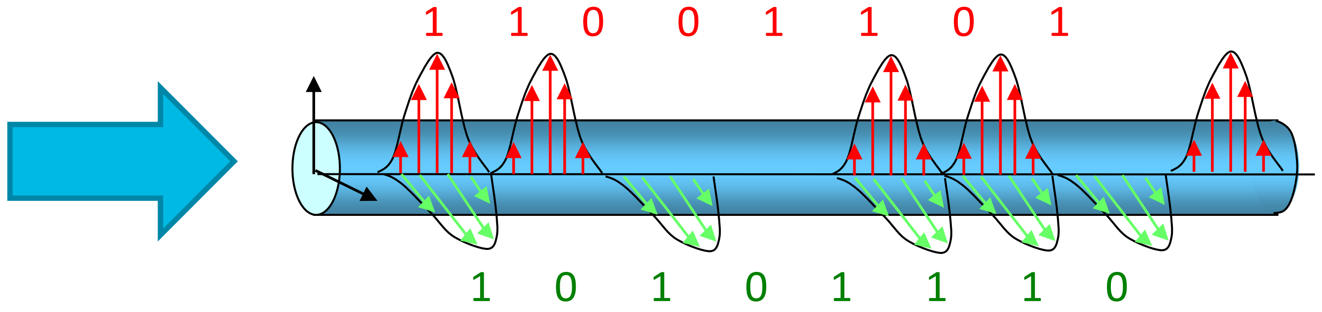
Modulation Schemes
Polarisation Multiplexing

- Polarisation multiplexing (Pol. Mux)
  Transmission of data on two orthogonal polarisations of the fibre





- PM-QPSK has ¼ the baud rate compared to ASK (4 bits of data in one pulse) and ½ of the baud rate of QPSK

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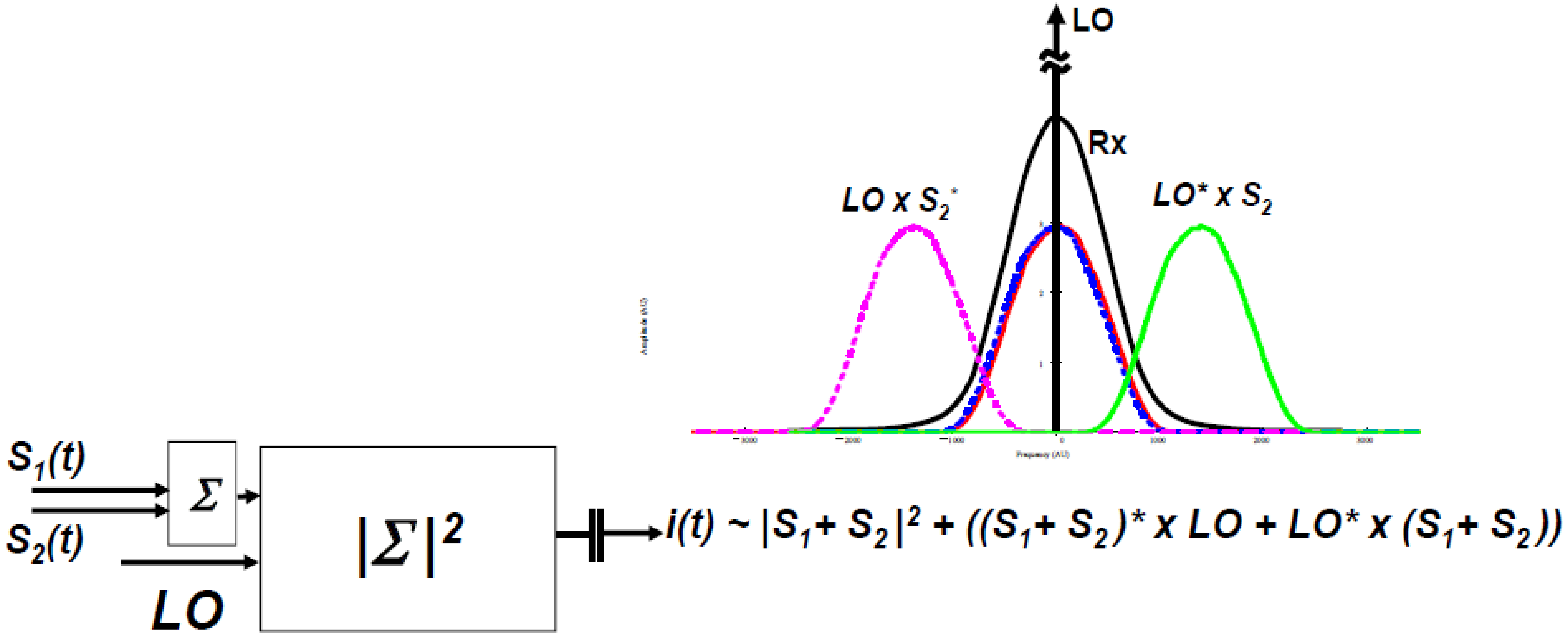
Coherent Detection

- Add local light source to the incoming signal
- When the frequency matches – the signal is stronger
- When the frequency mismatches – the signal is extinguished



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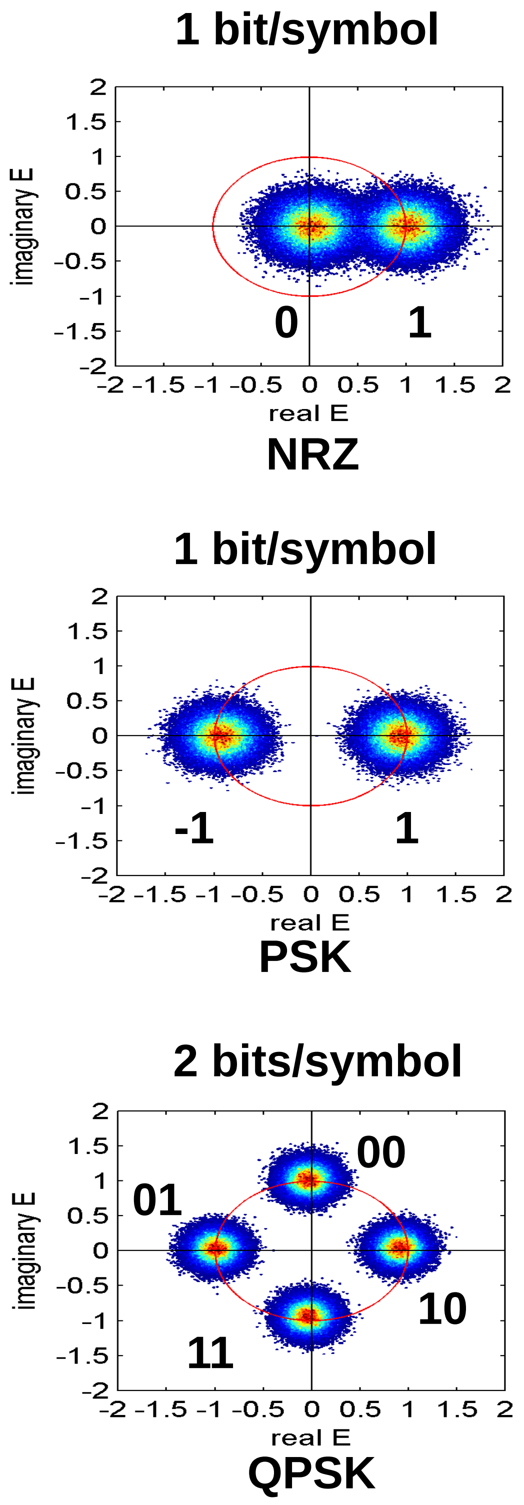
100G Transmission

The Transmitter

- Need to go slower
  - – Optical impairments are directly related to signalling rates
- Need to increase modulation efficiency
  - – Signalling speed decreases & Information Rate increases
  - – NRZ to ODB to (D)PSK to (D)QPSK
- Need to increase optical efficiency
  - – Split signal over two polarisations (PM – Mod Scheme)



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100G Transmission

The Receiver

- Higher data rates reduce tolerance transmission effects
  - Optical Compensation = $$$$$$
  - Electrical compensation = << $$
- Two Rx Design architectures:
  - Direct Detection - Morse Code
    - Convert Optical Energy to Electrical
      - Complex TX = Complex RX = $$$$
  - Coherent Detection – Radio / Wireless
    - Use Local Oscillator at RX to mix with incoming signal
      - Transmit signal / constellation preserved in electronics
      - Complexity moves to electronics = << $$

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100G Transmission

CP-DQPSK – 100G solution

- CP – DQPSK – Coherent Polarised Differential Quadrature Phase Shift Keying
- Advanced signal processing to address:
  – CD Compensation
  – PMD Mitigation
  – Single Channel Non-linear impairment mitigation

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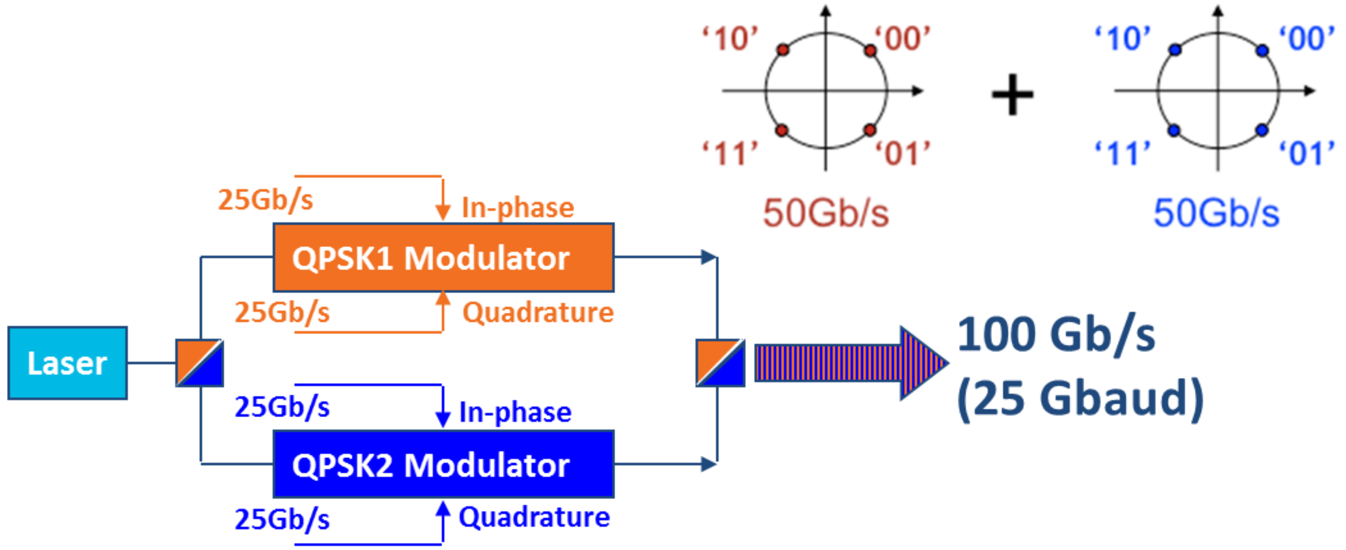
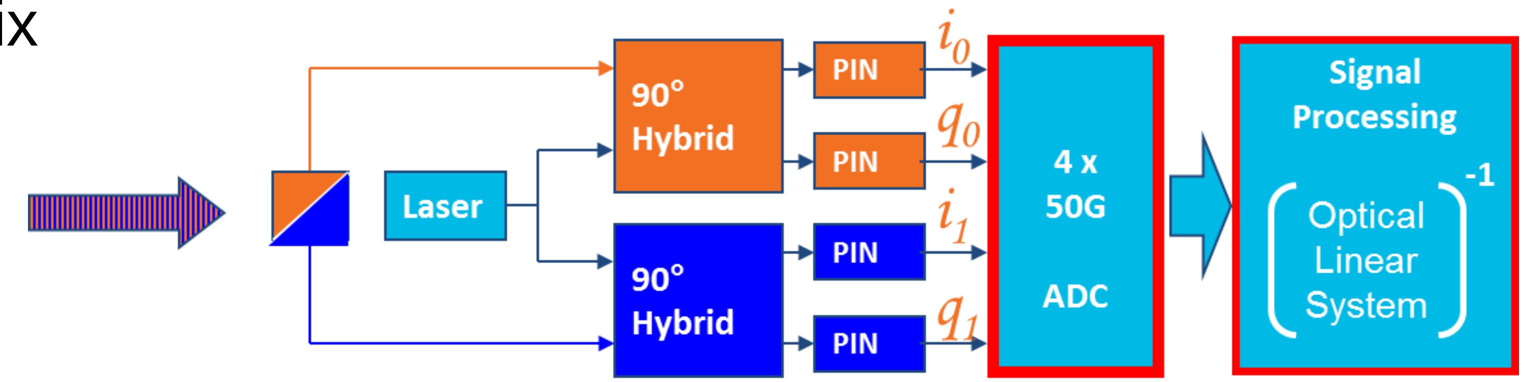
100G Transmission

CP-DQPSK – 100G solution

- RX Laser behaves as Local Oscillator to provide a Polarisation reference
- 90° Hybrid:
  - Converts Phase modulation in Amplitude modulation
  - Provides In-Phase and Quadrature information Φ (i0 , i1)
- Signal Processor:
  - Calculates the Inverse Optical System Matrix
  - Recovers Polarisation
  - Compensates CD and PMD electronically





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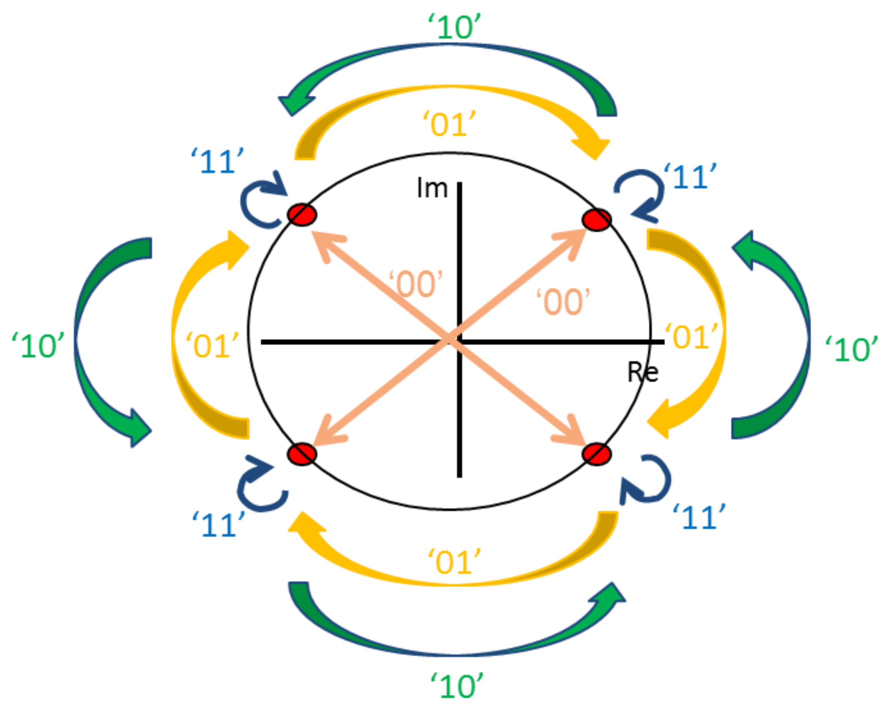
100G Transmission

CP-DQPSK – 100G solution

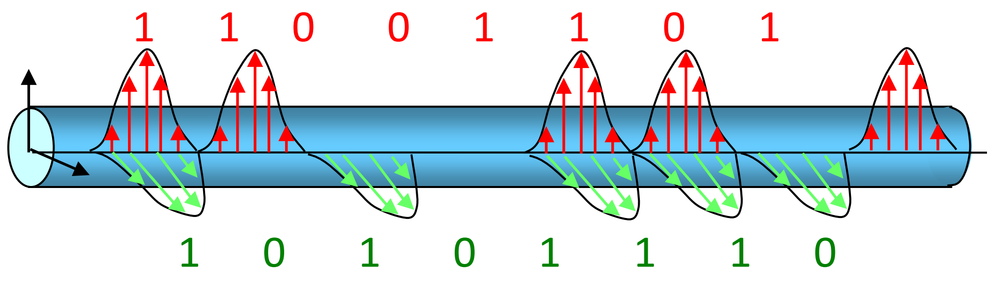
DQPSK

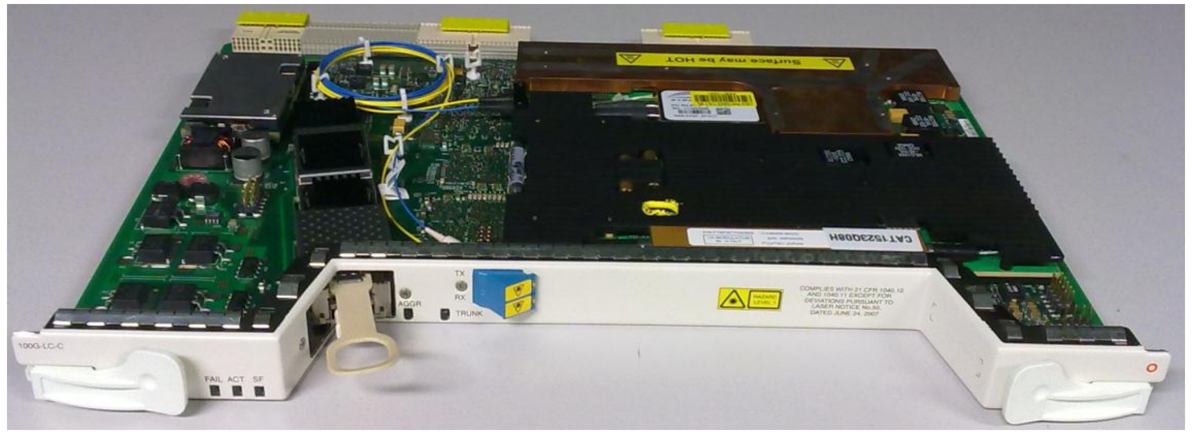


Coherent Detection Receiver

Polarisation Multiplexing

Electric field





100G Transponder

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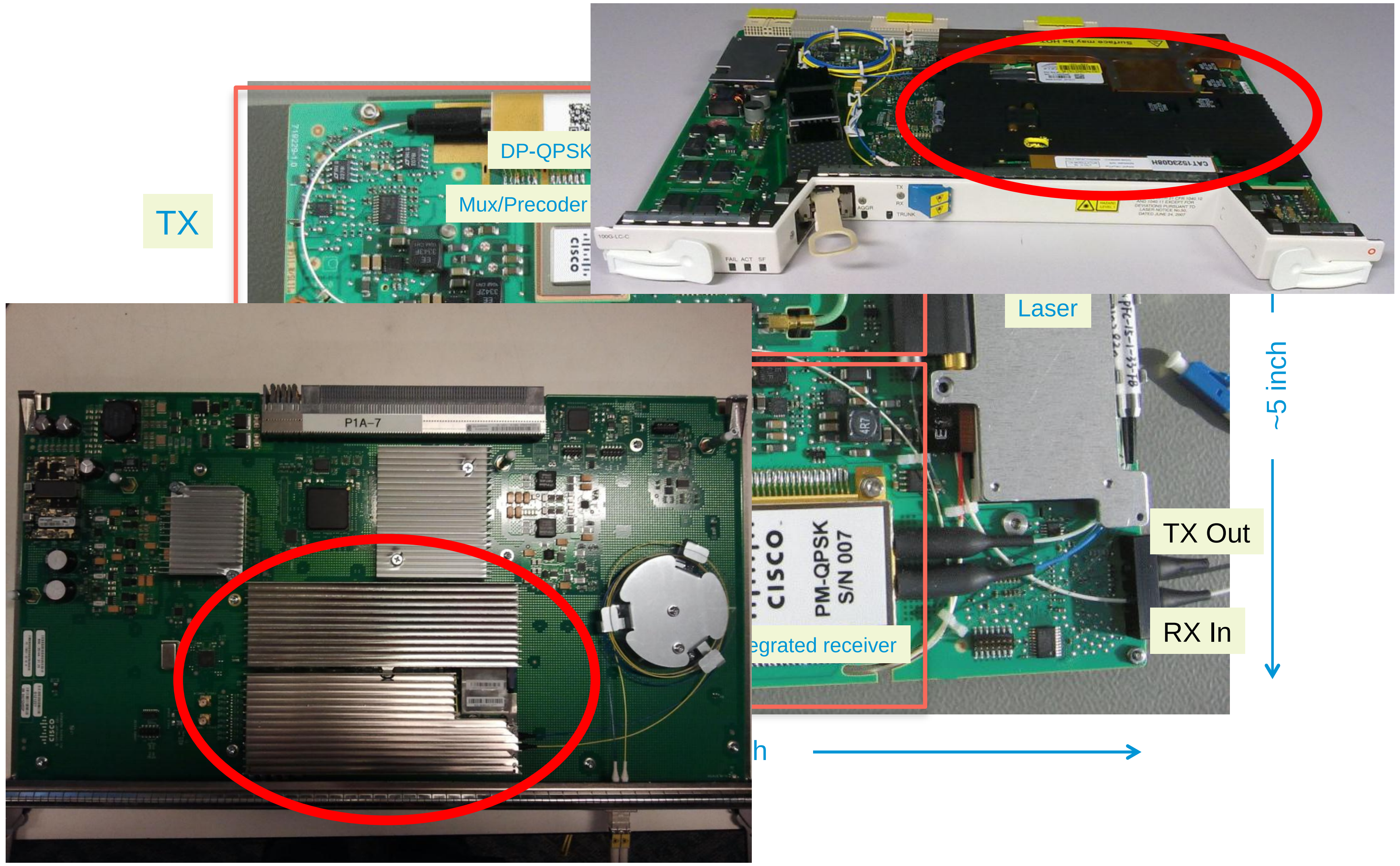
100G Transmission

CP-DQPSK – 100G solution



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100G Transmission

CP-DQPSK – 100G benefits

- Improved CD tolerance
  - Eliminates the need for DCUs
  - Simplifies Network Designs
  - Improves network Latency
- Improved PMD tolerance
  - Reduces the need for complex compensators
  - Allows high data rates over all fibre types
  - Reduces need of Fibre Characterisation
- Improved OSNR
  - Reduce need of Regeneration
  - Improve $$/Bit * Km

	100G (CP-DQPSK)
Optical BW (GHz)	50
FEC mode	EFEC (20% OH)
OSNR Requirement (dB)	7.5
CD Tolerance (ps/nm)	±70000
PMD Tolerance (ps)	>60 (DGD 180)
Latency (µs)	39

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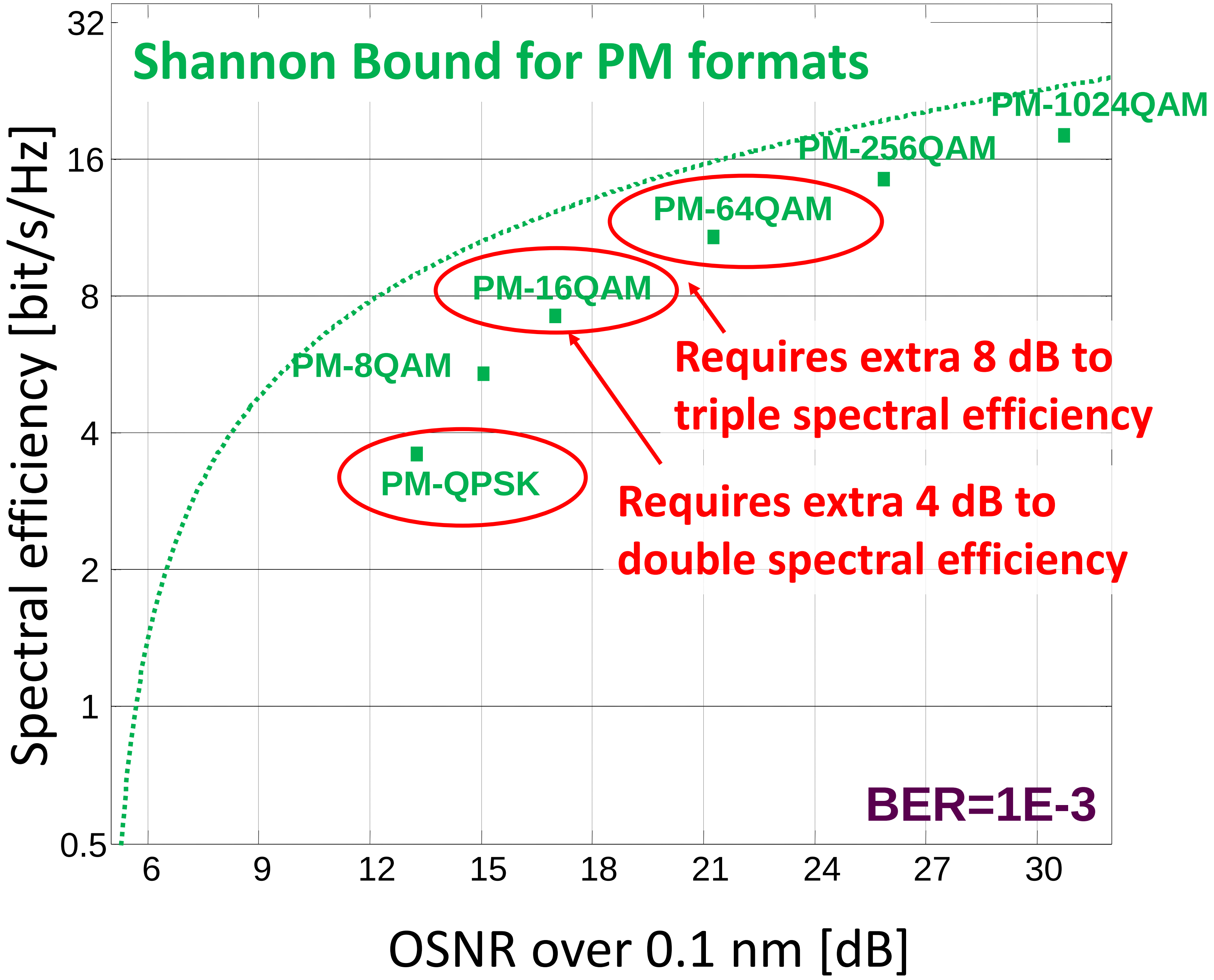
Todays Paradigm Can Only Last So Long

How OSNR change if we change modulation (for 111 Gb/s)

- **Approaching Shannon's Limit**
- PM-16QAM requires 4 dB more than PM-QPSK
- PM-64QAM requires 8 dB more than PM-QPSK
- PM-256QAM would require 13 dB more than PM-QPSK!
- **How will this operate in LH and ULH systems???**



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The Paradigm is Changing

- Must a channel really fit into 50 GHz spacing?
  - Or should it be gridless?
  - Should the BW be defined by the Data Rate?
- Is a single channel actually defined as a single Carrier??
  - Single carrier has multiple limitations
  - Can a single channel be made up of multi carriers?

In the end what we want is the:

best spectral efficiency at the best performance and price!

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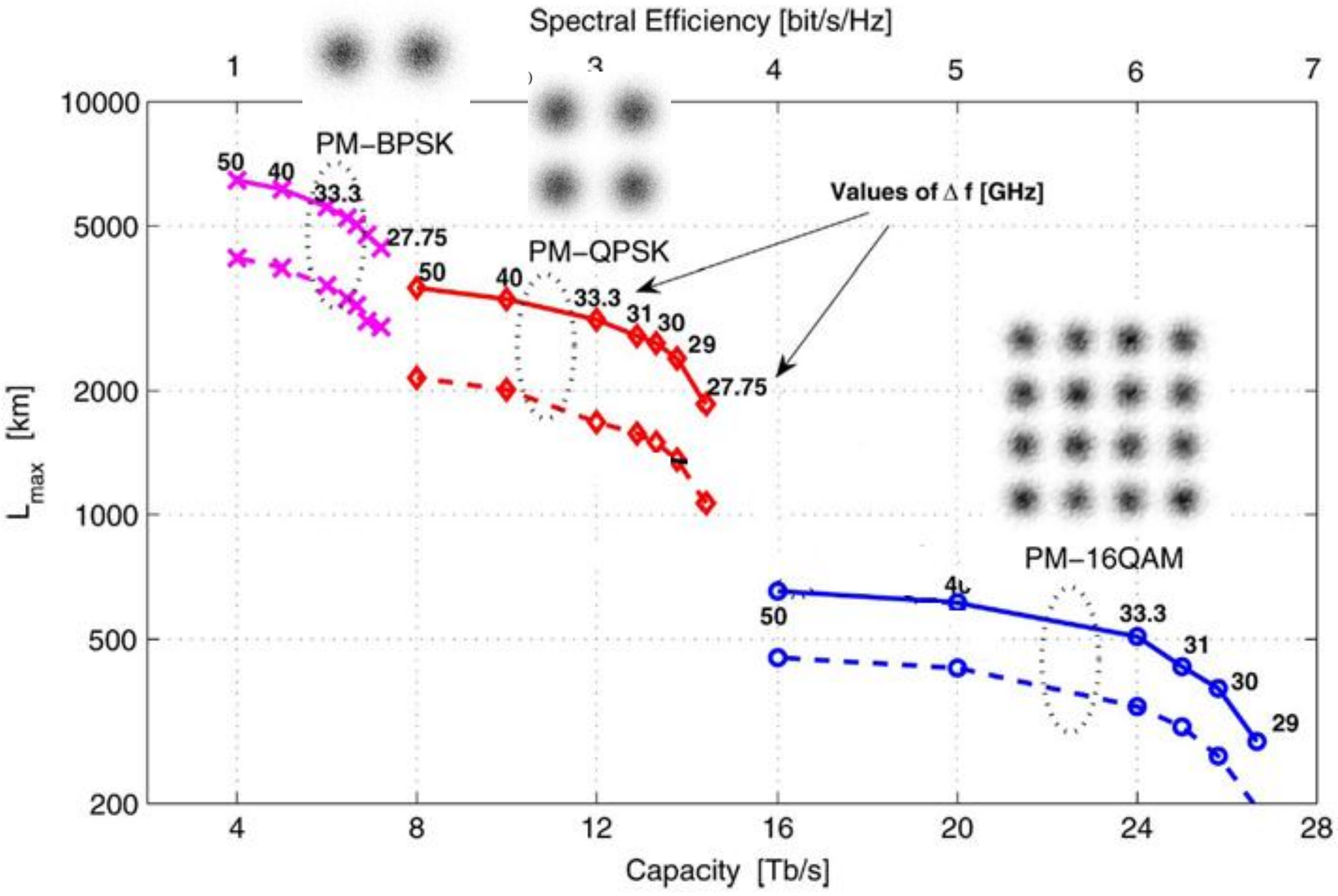
Trade off of Reach and Capacity

Variable modulation format and channel spacing



- Two types of fibres:
  - Solid lines is SMF
  - Dashed ELEAF
- no Raman amplification
- 90 km and 25 dB per span
- Symbol-rate 27.75 Gbaud
- BER 4E-3

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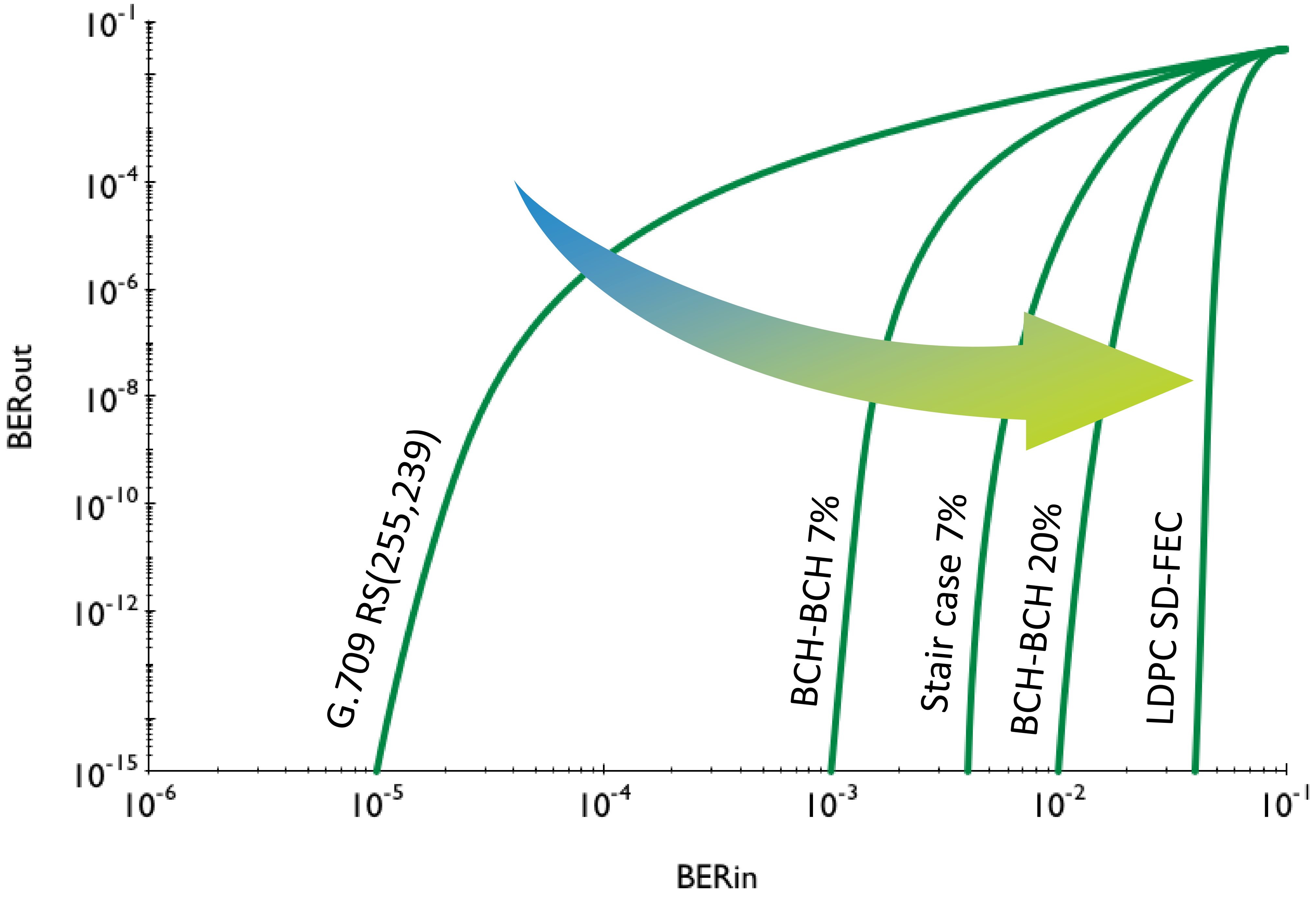
SD-FEC – Additional Performance Improvement
Different types of FEC and Performance



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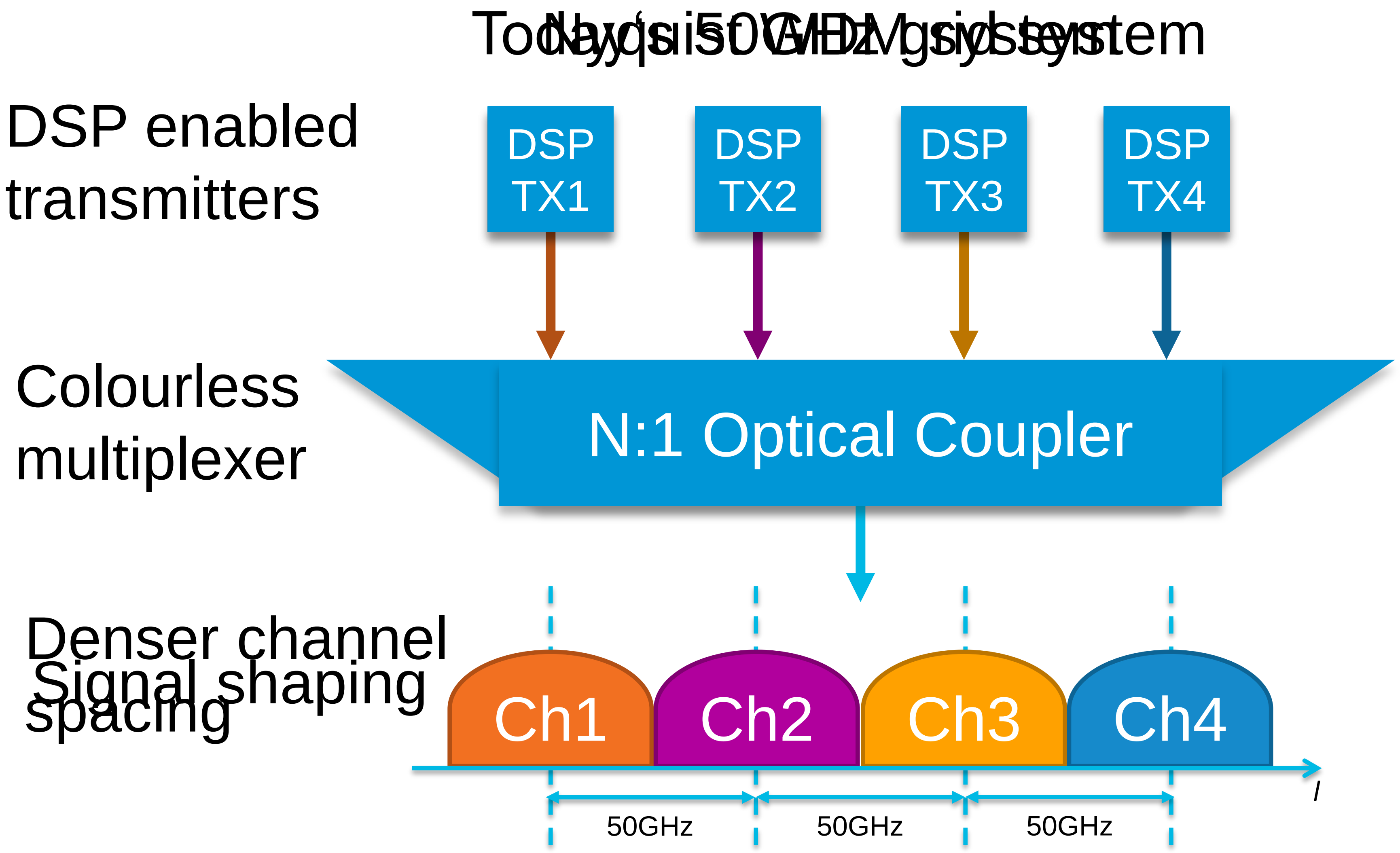
Introduction of Superchannels



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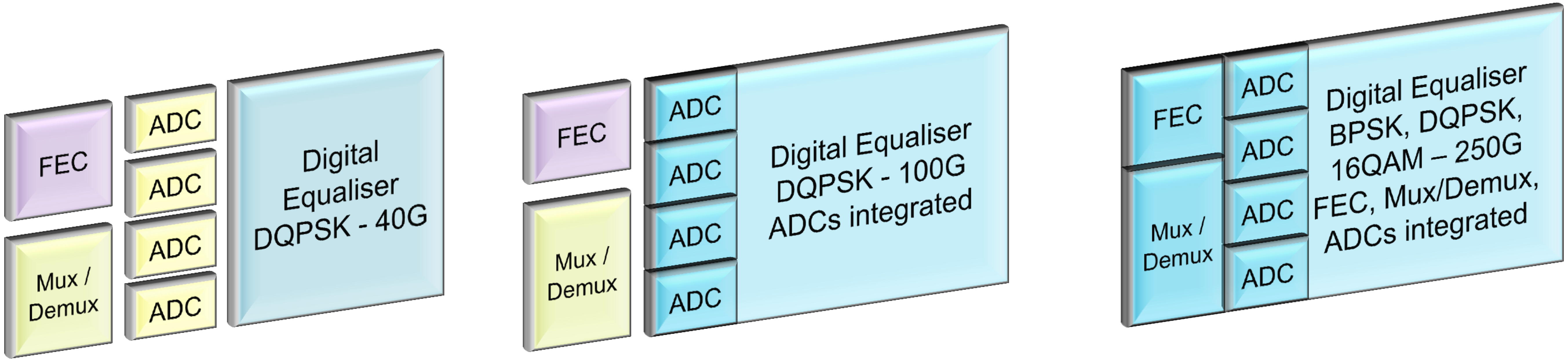
DSP Evolution – Many to 1 Integration

Enabling the Next Generation of Terabit Networks



40G DSP chip set
4-Bit ADC
DQPSK – 40G
Digital Equaliser
65 nm CMOS

100G DSP chipset
8-Bit ADC
DQPSK – 100G
Digital Equaliser
65 nm CMOS

250G DSP chipset
Digital Equaliser
Software Selectable Modulation
BPSK-50G, QPSK-100G, 16QAM-250G
TX / RX DSP, Soft Decision FEC
28 nm CMOS

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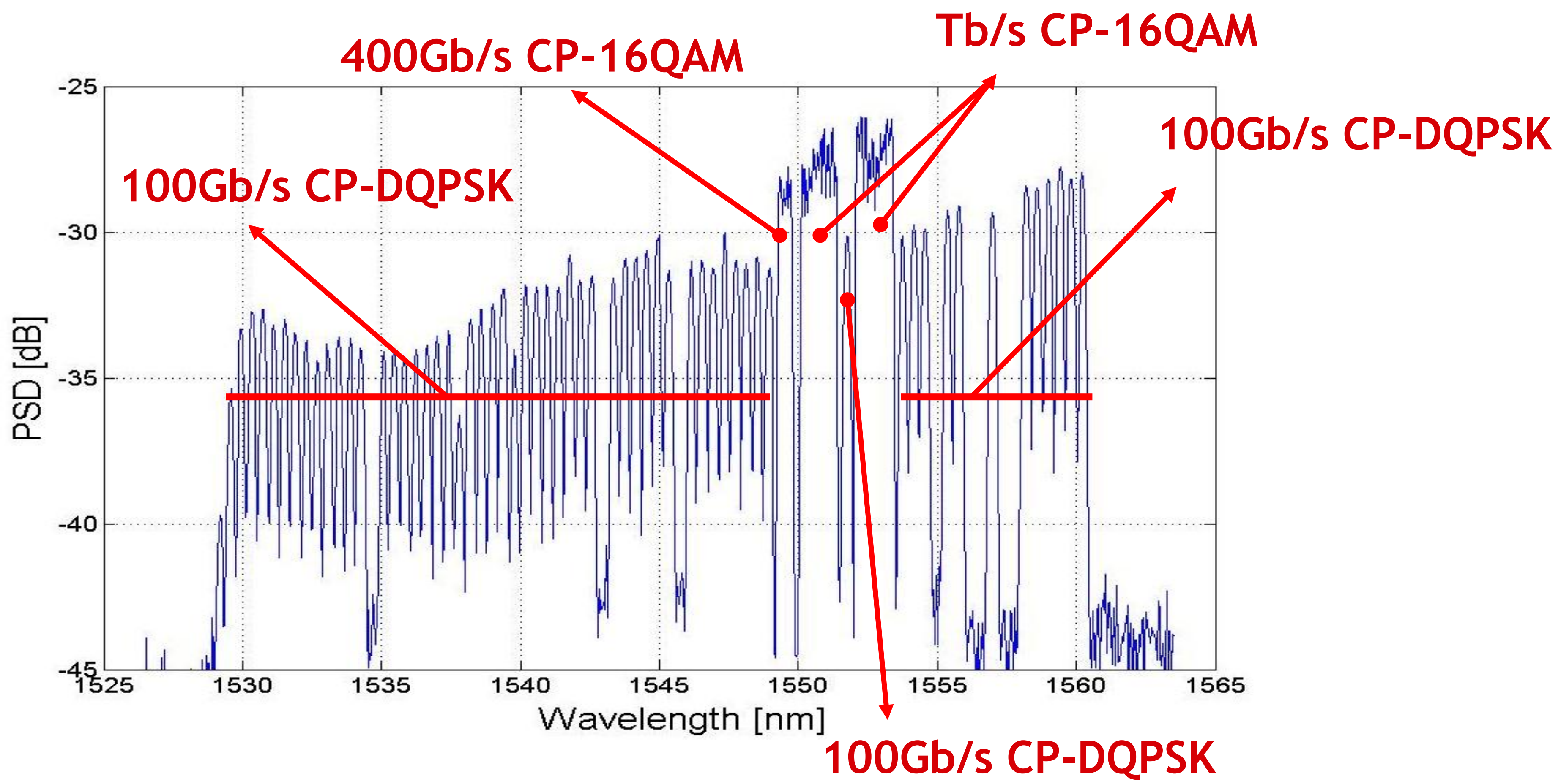
Superchannel Transmission Example

- 16QAM Modulation for Terabit and 400Gbit/s interfaces
- Flex Spectrum multiplexing Superchannels alongside today's 100Gbit/s



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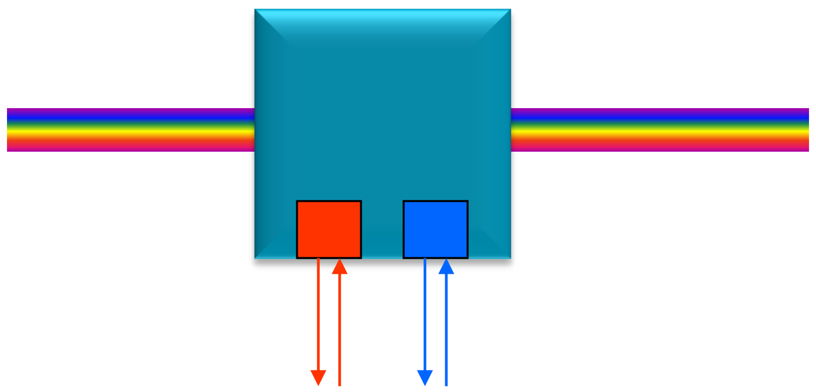
Cisco live!

Optical Layer Evolution

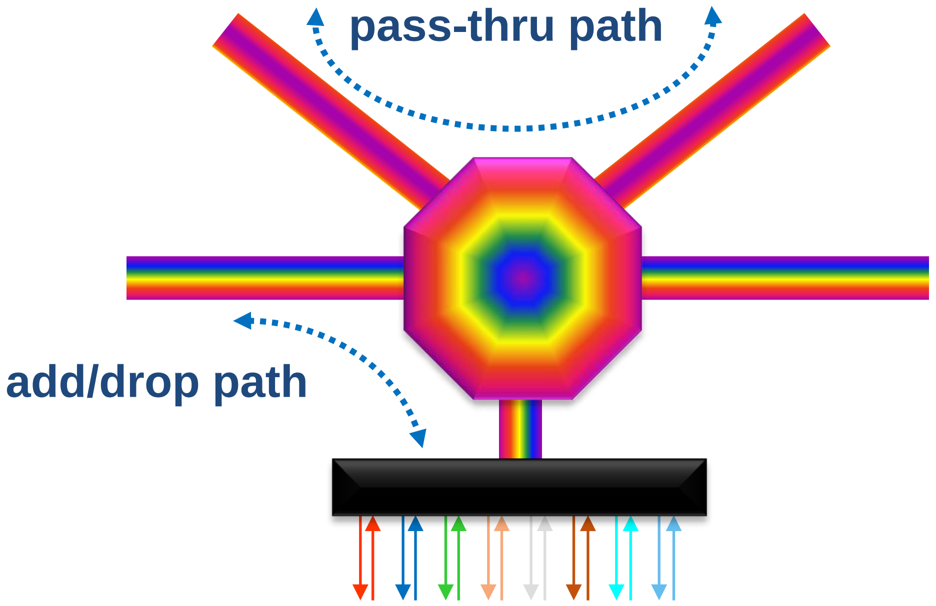
What is a ROADM?

A ROADM is a Wavelength Switch

Traditional OADM



Reconfigurable OADM



A fixed number of channels
A fixed set of channels

Physical Ring Only (2 Degree)

Any number of channels (0 to 40/80)
Any set of channels, directional

Physical Ring (2D) or Mesh (Multi-Degree)

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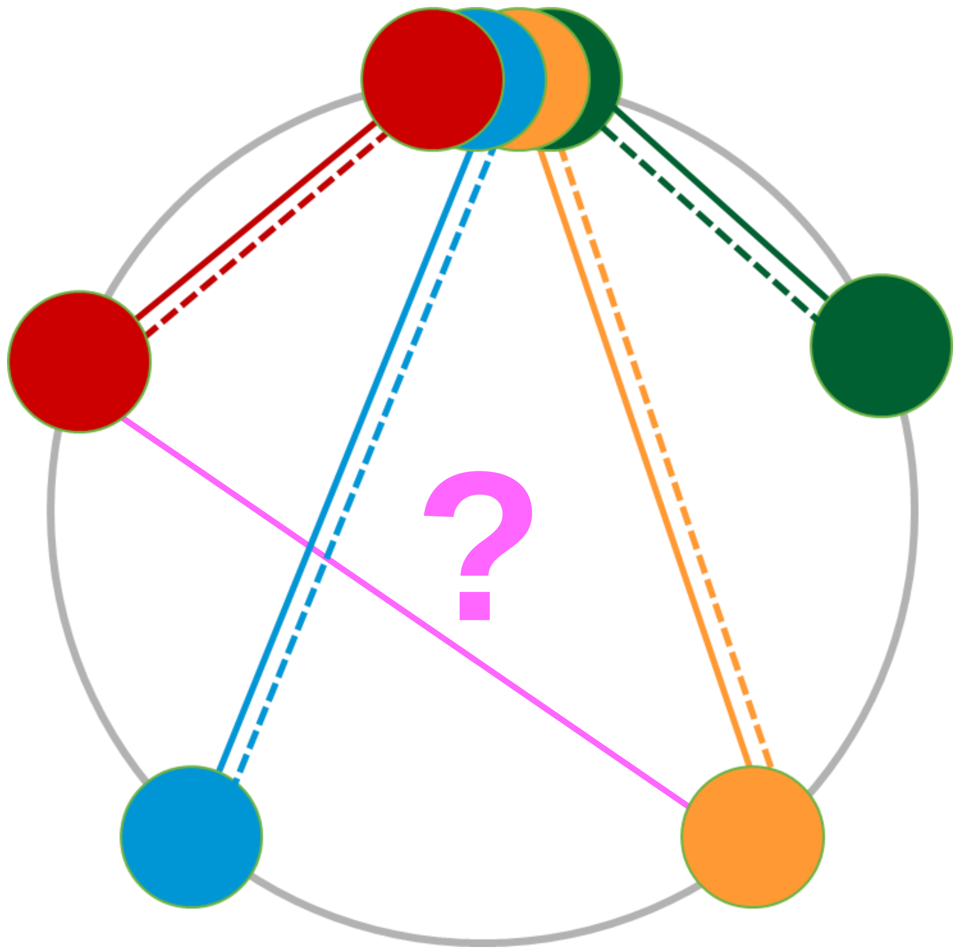
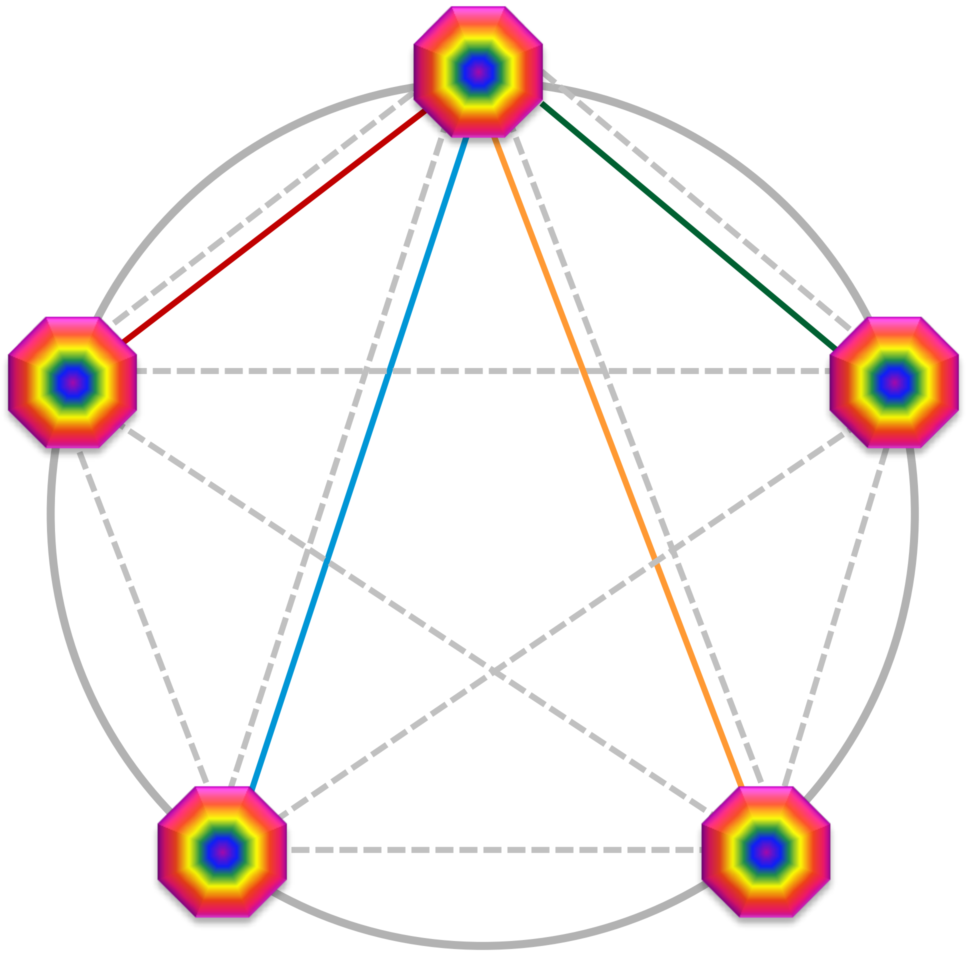
ROADM Network Flexibility

Simplifies Architecture, Planning, and Operations



Fixed or Banded Filter Architecture
Traffic Topology is Fixed
Difficult to Upgrade



ROADM Architecture
Traffic Topology is Fully Flexible (Any-to-Any)
Non-Disruptive Service Additions

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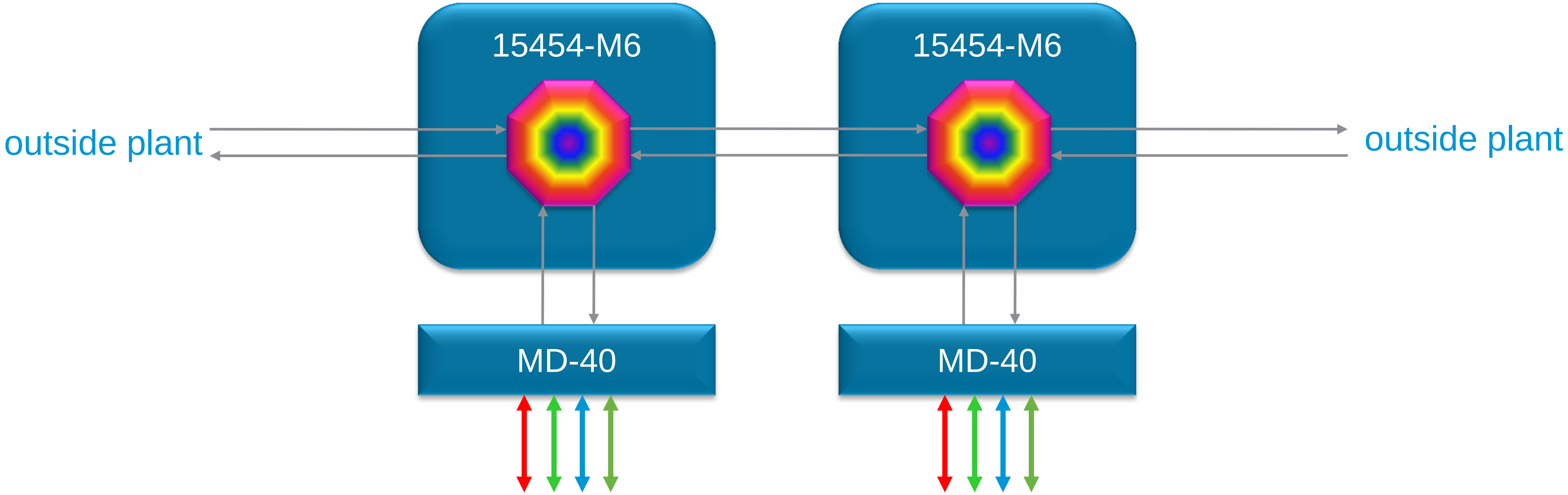
Cisco Two Degree ROADM Architecture

One or Two Degrees, Single or Dual shelf



- Total number of line cards for 40ch ROADM 2 Degree Optical Layer: 2
- Total number of internal cables for 40ch ROADM Optical Layer*: 6
- Total number of optical layer devices (line card + passive): 4

All amplifiers are internal to the ROADM

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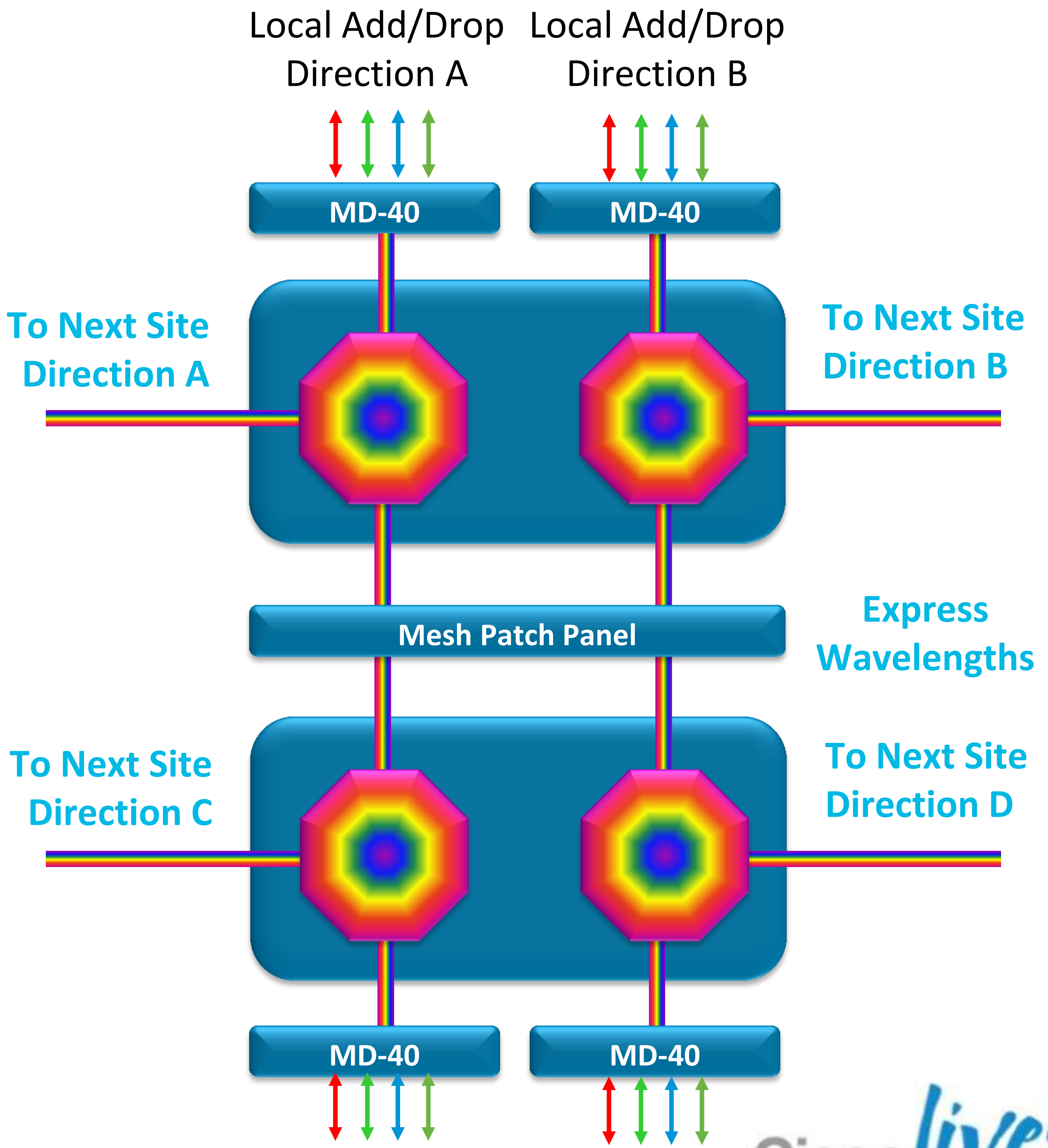
Cisco Multi-Degree ROADM Architecture

One to Four Degrees, One to Four shelves

- Total number of line cards for 40ch ROADM 4 Degree Optical Layer: 4
- Total number of internal cables for 40ch ROADM 4 Degree Optical Layer*: 8
- Total number of optical layer devices (line card + passive): 9

All amplifiers are internal to the ROADM



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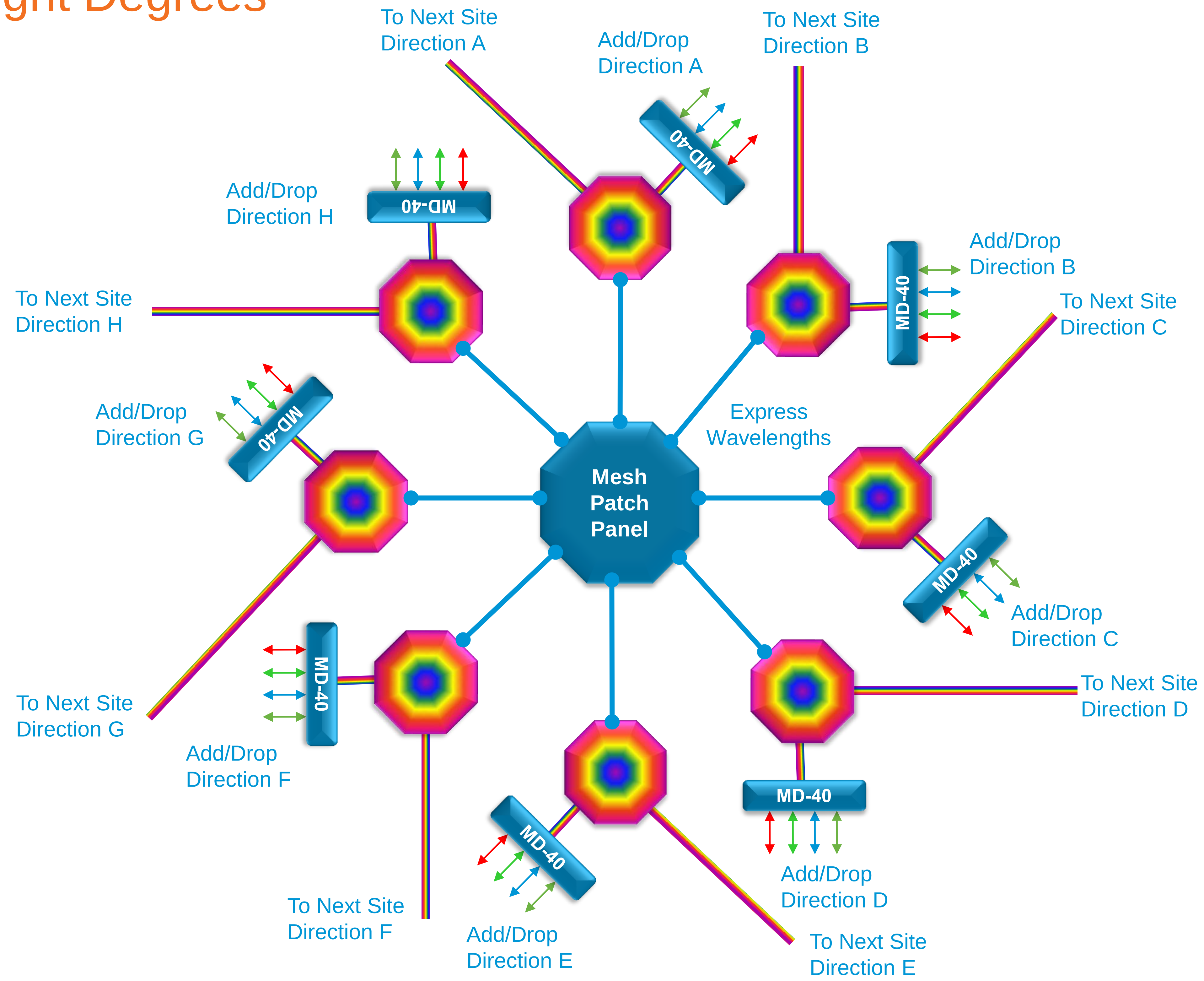
Cisco 80-WXC ROADM Architecture

One to Eight Degrees



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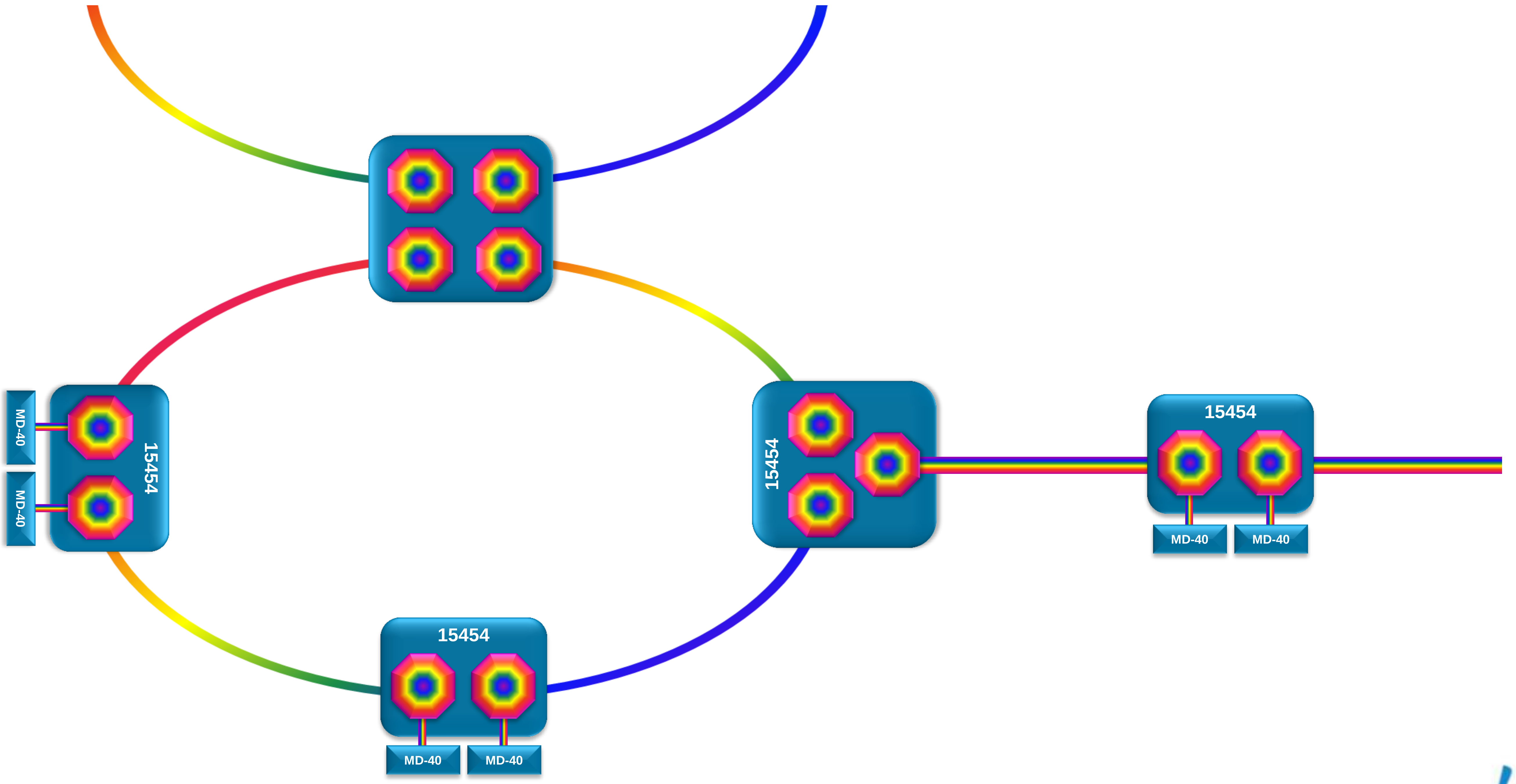
ROADM Network Architecture

One ROADM unit per Degree



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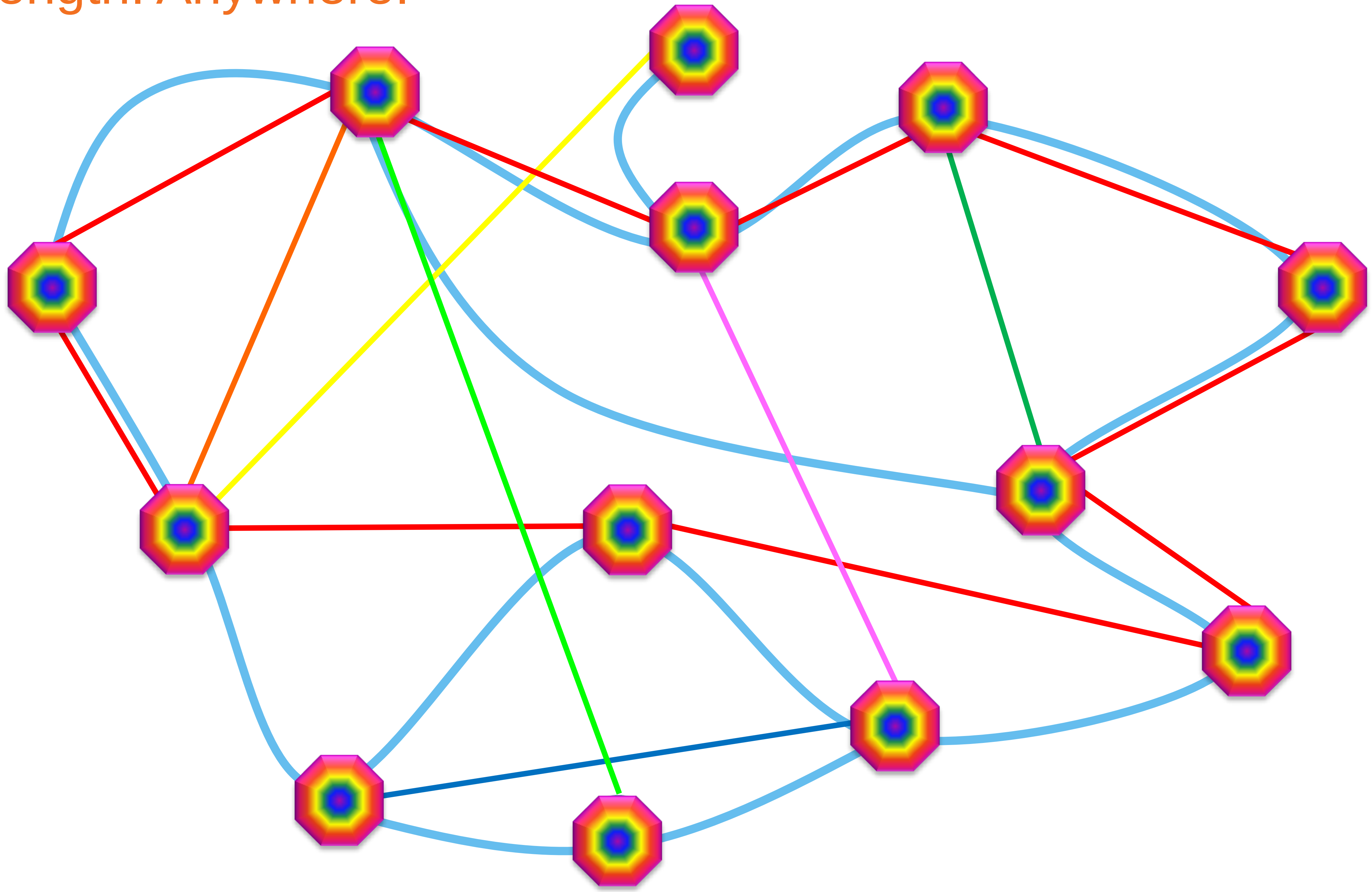
ROADM Brought Flexibility to DWDM Networks

Any Wavelength. Anywhere.



But it was a **static** flexibility. Classical ROADM have limitations.

Moves and changes required a truck roll.

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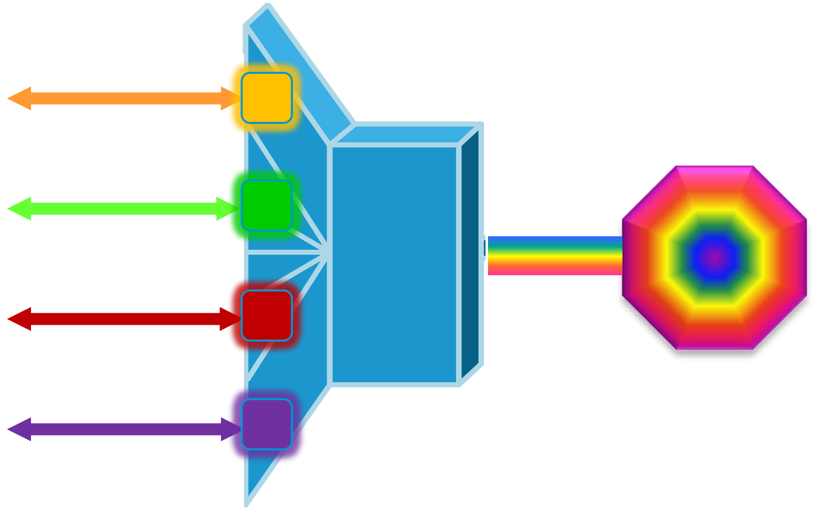
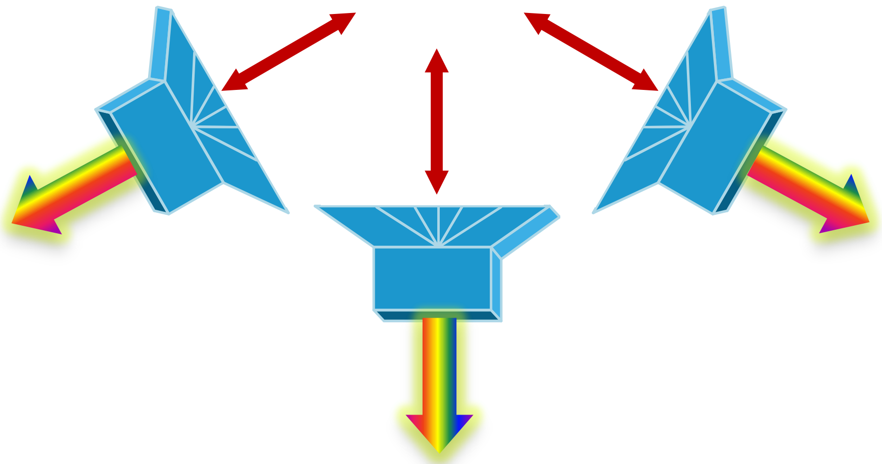
… because ROADM Ports were coloured and directional

Coloured Add/Drop
Fixed port frequency assignment
One unique frequency per port



Directional Add/Drop
Physical add/drop port is tied to a ROADM "degree"



Due to these restrictions, a change in **direction** or **frequency** of an optical circuit required a **physical change** (move interface to different port) at the endpoints.

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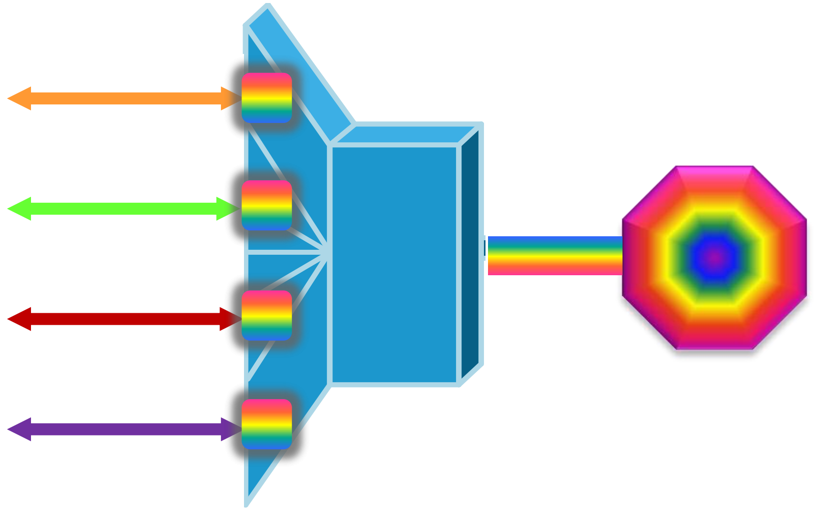
Animated slide

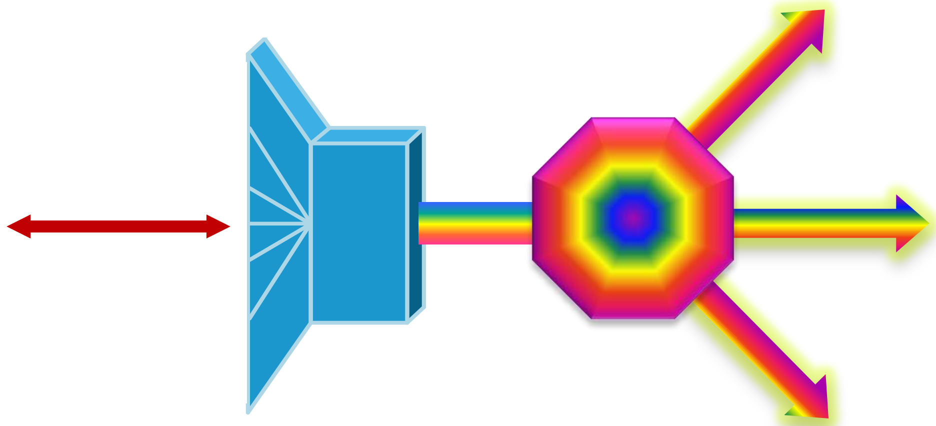
Colourless and Omni-directional Capabilities

Add Touchless flexibility, and hence Programmability, to ROADM networks

Colourless Add/Drop
No port-frequency assignment
Any frequency, any port



Omni-Directional Add/Drop
Add/Drop ports can be routed to/from any ROADM degree



With **Colourless** plus **Omni-Directional**, the frequency and direction of the signal can be changed, without requiring a change of ROADM add/drop port, therefore no truck rolls.

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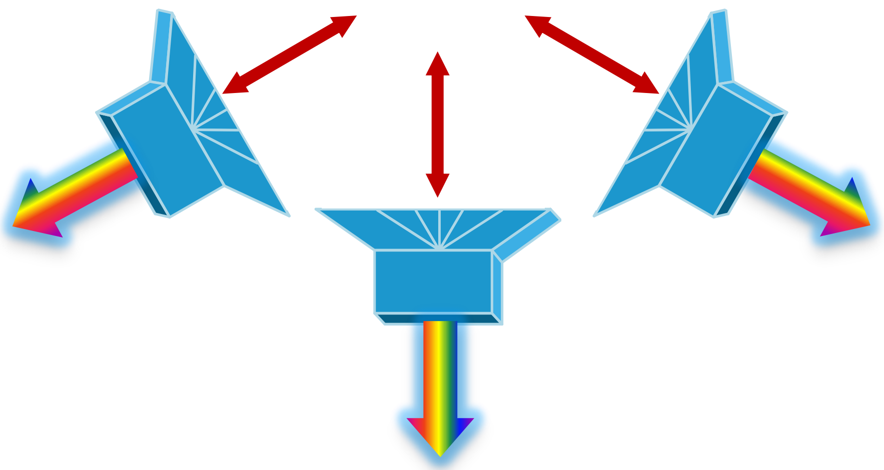
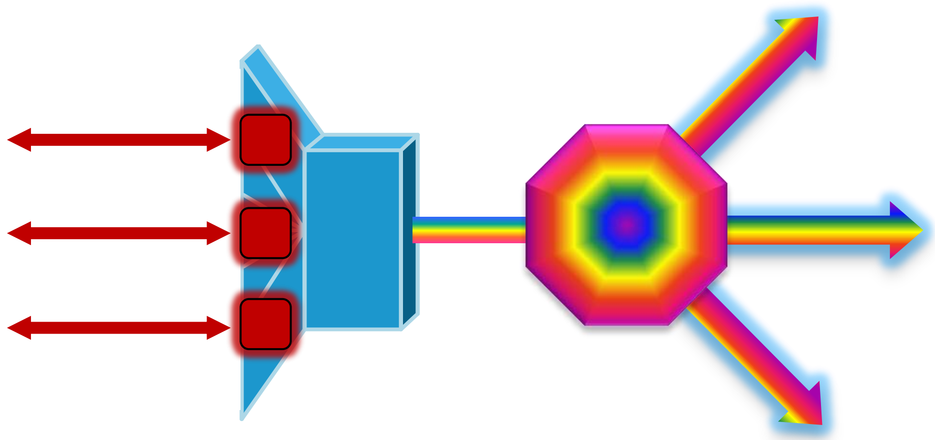
But…Colourless and Omni-directional introduce wavelength contention at the add/drop stage. Need a Contentionless architecture.

Directional Add/Drop ROADMs are by definition Contentionless



Contentionless allows multiple instances of the same frequency to add/drop from one unit.



With **Contentionless**, N instances of a given wavelength (where N = the number of line degrees in the ROADM node) can be add/dropped from a single device, eliminating any restrictions on dynamic wavelength provisioning.

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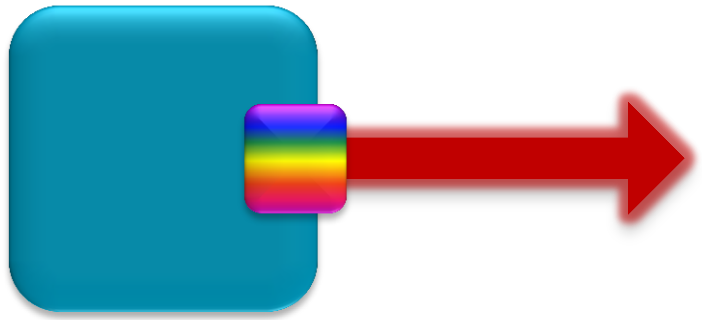
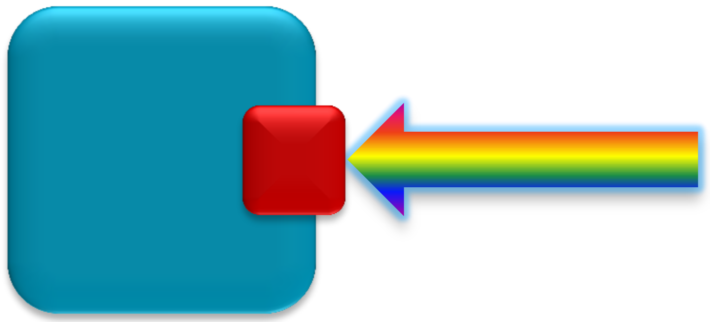
Tuneable lasers and coherent receivers are also key enablers of the NG ROADM

Transmitter can tune its laser's frequency to any channel in the ITU grid.



Receiver can select any channel from of a composite (unfiltered) signal.



Tuneable lasers work with colourless add/drop to enable touchless changes in the frequency of an optical signal. **Coherent receivers** simplify the construction of colourless and omni-directional ROADM nodes.

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Why we need NG ROADM

What is needed to scale the ROADM?

- Growing per-channel Bit Rate is expected to drive wider modulated wavelengths
- Flex-Spectrum capabilities required to be able to switch portions of the optical spectrum
- ROADM Ports are consumed by:
  - The Number of Line Degrees faced by the Node
  - The number of All-Optical interconnection happening @ Node
  - The need of increasing the Contentionless Add/Drop capacity of the Node

So need more ports to address the required scalability and flexibility

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Next Generation ROADM

Flex Spectrum – introduction

- Standard ROADM Nodes support wavelengths on the 50GHz ITU-T Grid
  - Bit Rates or Modulation Formats not fitting on the ITU-T grid cannot pass through the ROADM
- A Flex Spectrum ROADM removes ANY restrictions from the Channels Spacing and Modulation Format point of view
  - Possibility to mix very efficiently wavelengths with different Bit Rates on the same system
  - Allows scalability to higher per-channel Bit Rates
  - Allows maximum flexibility in controlling non-linear effects due to wavelengths interactions (XPM, FWM)
  - Allows support of Alien Multiplex Sections through the DWDM System

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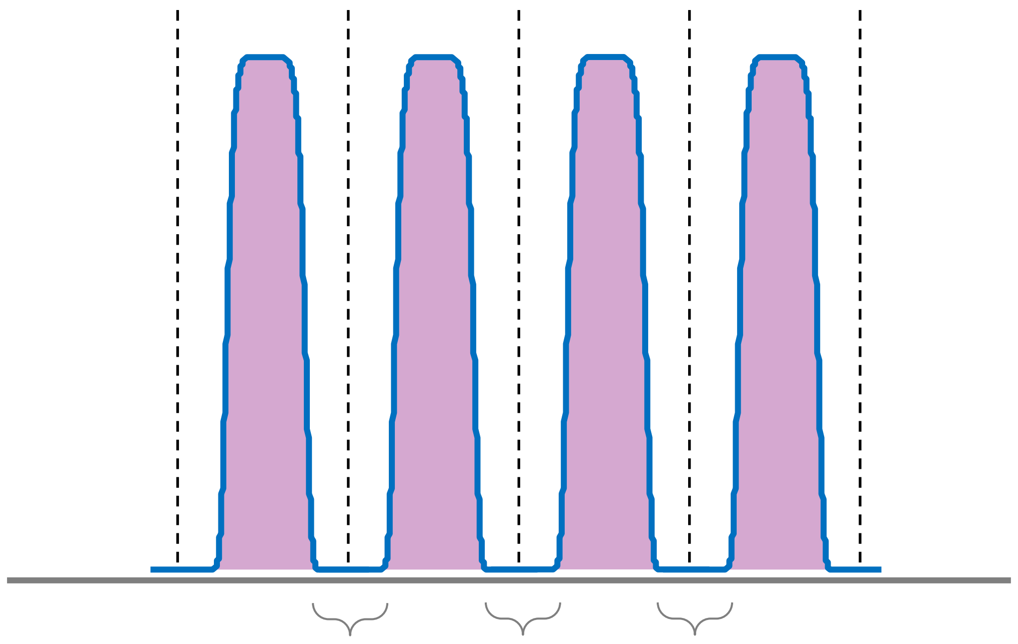
Next Generation ROADM

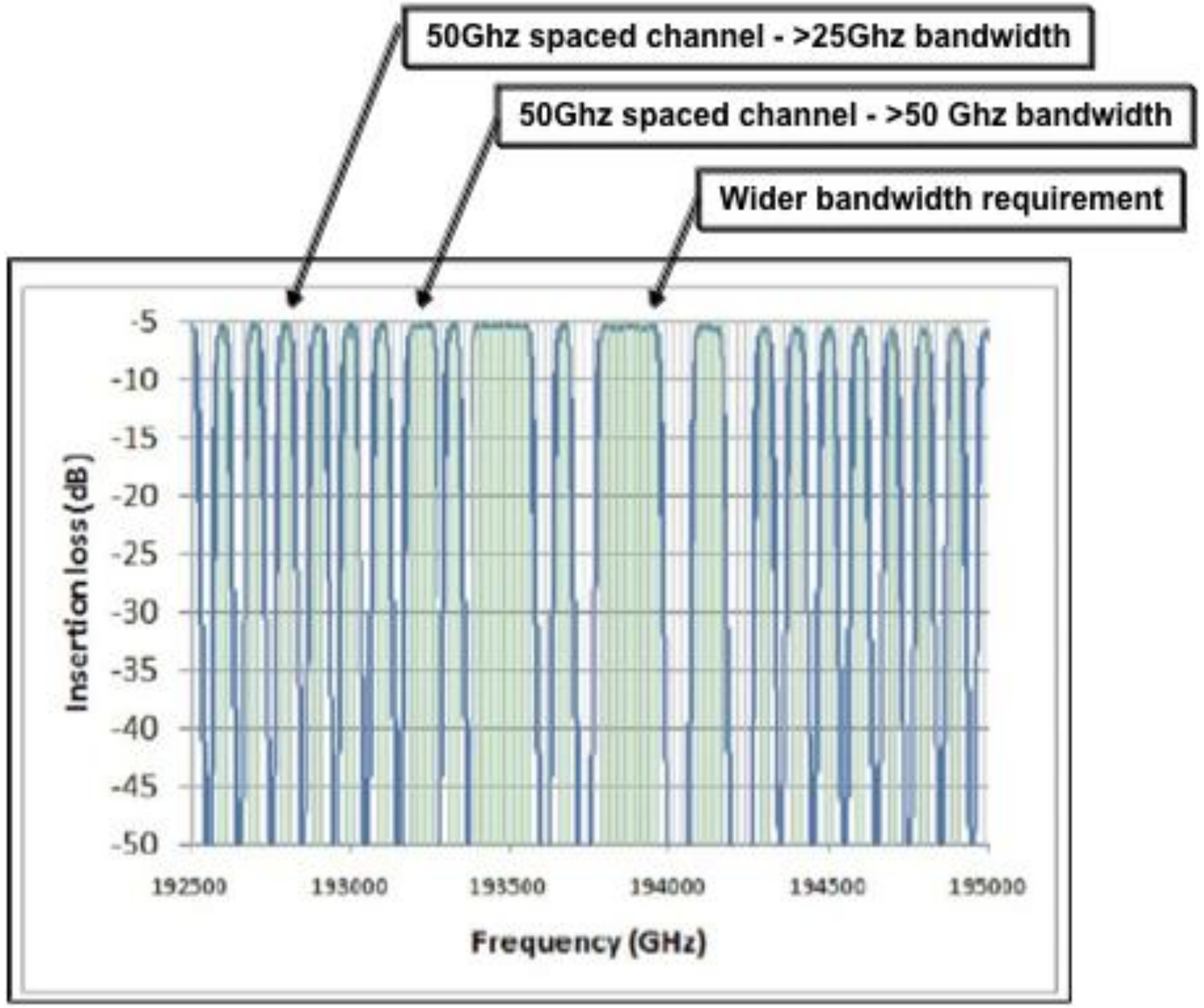
Flex Spectrum – minimise guardbands

50 GHz ITU Grid



Wasted Spectrum

4 x 100Gb/s in 200GHz
2 bits / sec / Hz



Reduction in wavelength spacing delivers 50% increase in capacity

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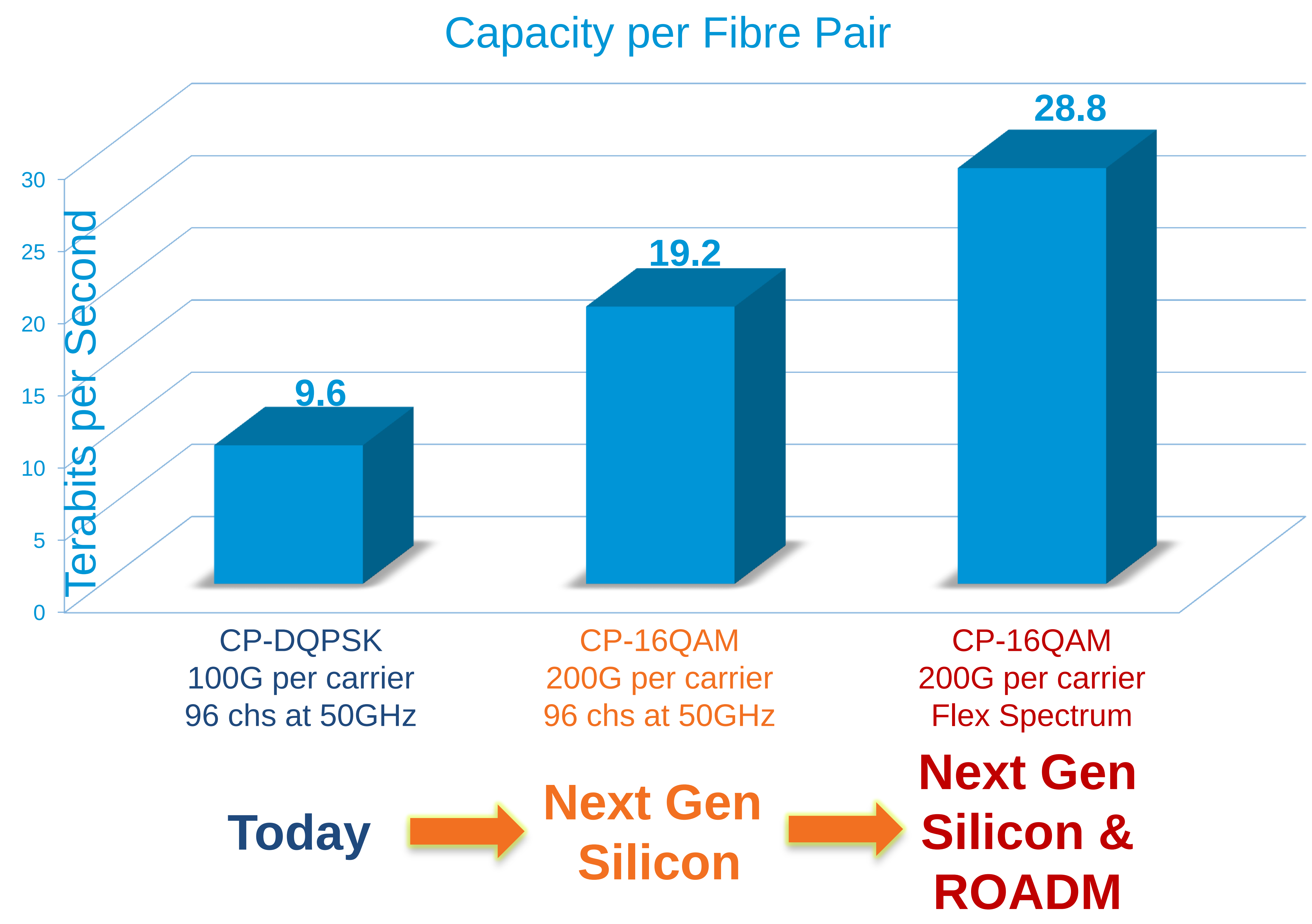
DWDM System Capacity



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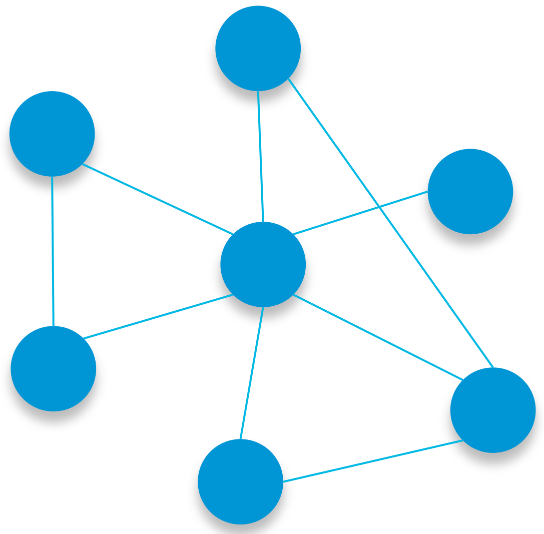
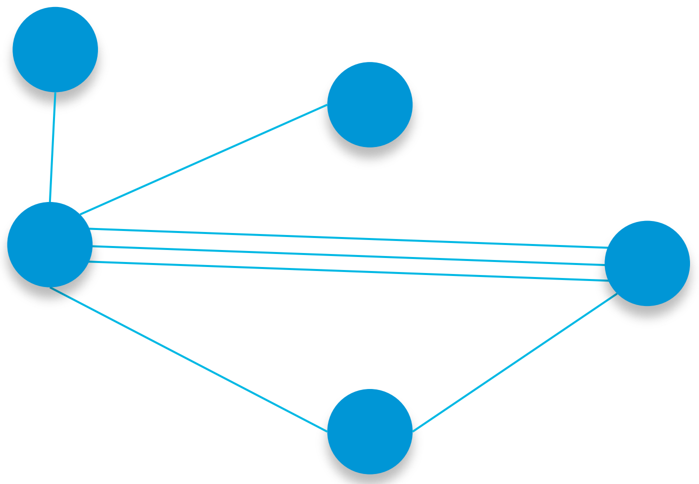
Next Generation ROADM

All-Optical mesh networks become more common

- More line degrees for increased mesh and site-to-site capacity





- More ports for contentionless add/drop

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  - The number of All-Optical interconnection happening @ Node
  - The need of increasing the Contentionless Add/Drop capacity of the Node

  So need more ports to address the required scalability and flexibility

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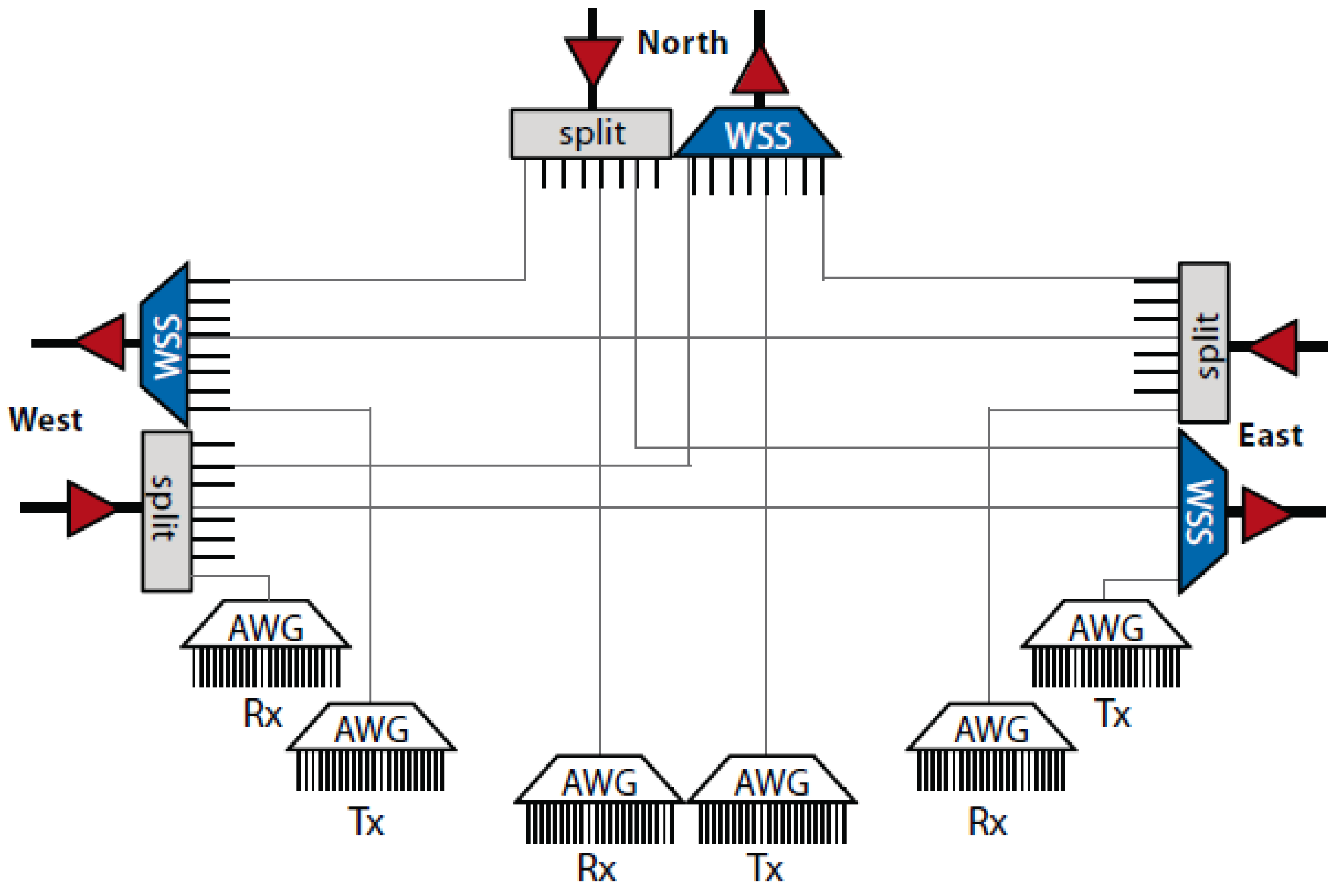
Legacy ROADM

"Broadcast and Select" Architecture

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



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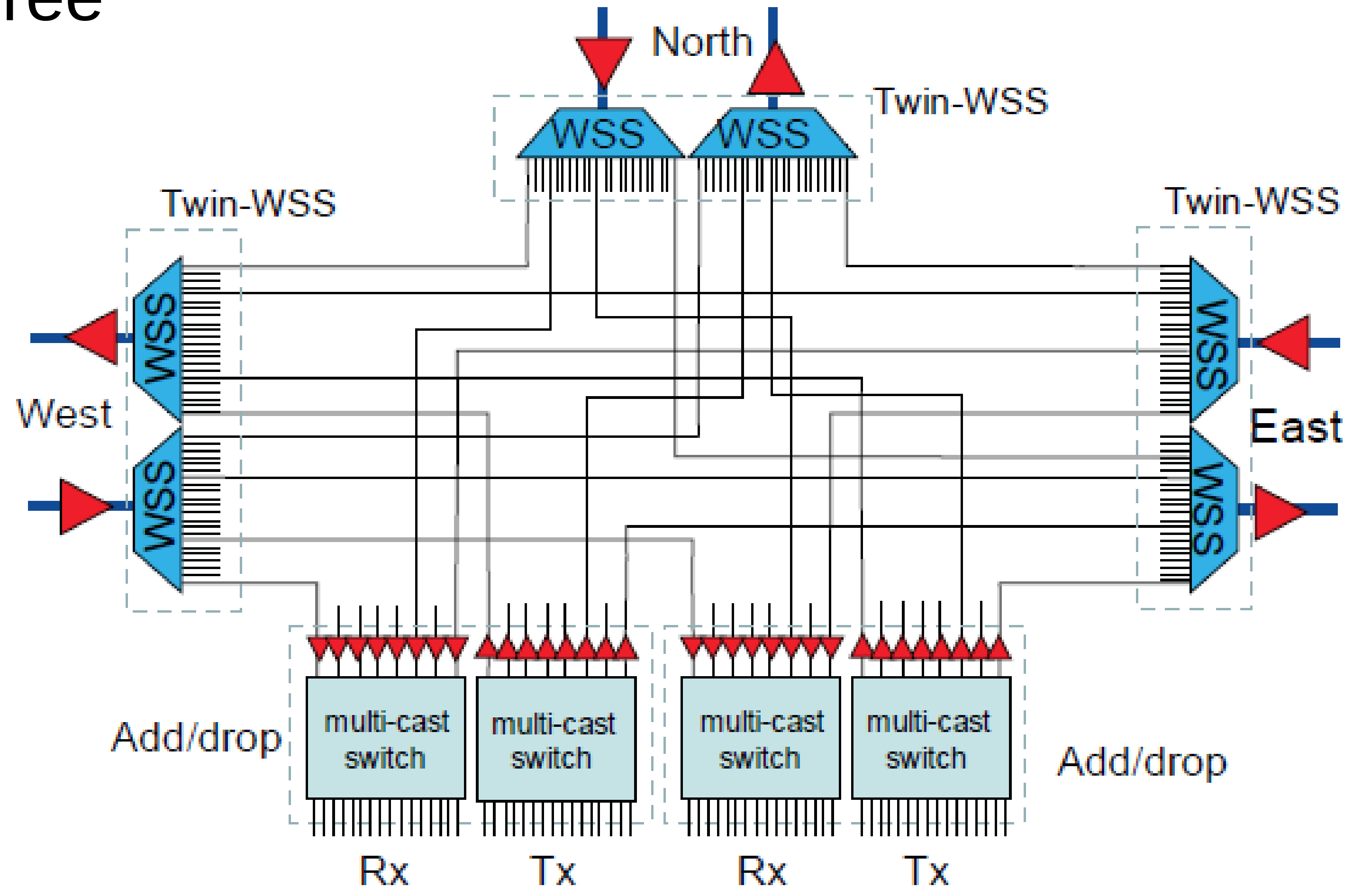
Next Generation ROADM

"Route and Select" Architecture

- Second WSS added at ingress of each degree
- Demux WSS 'routes' any combination of waves from COM-RX to any output port (drop and other degrees).
- Mux WSS 'selects' any combination of waves from its input ports (add and other degrees) to COM-TX.
- Channels are isolated by both the ingress and egress WSS, improving performance
- By eliminating the splitter, insertion loss is reduced, preserving channel OSNR
- Enables Omni-Directional and Colourless at large scale



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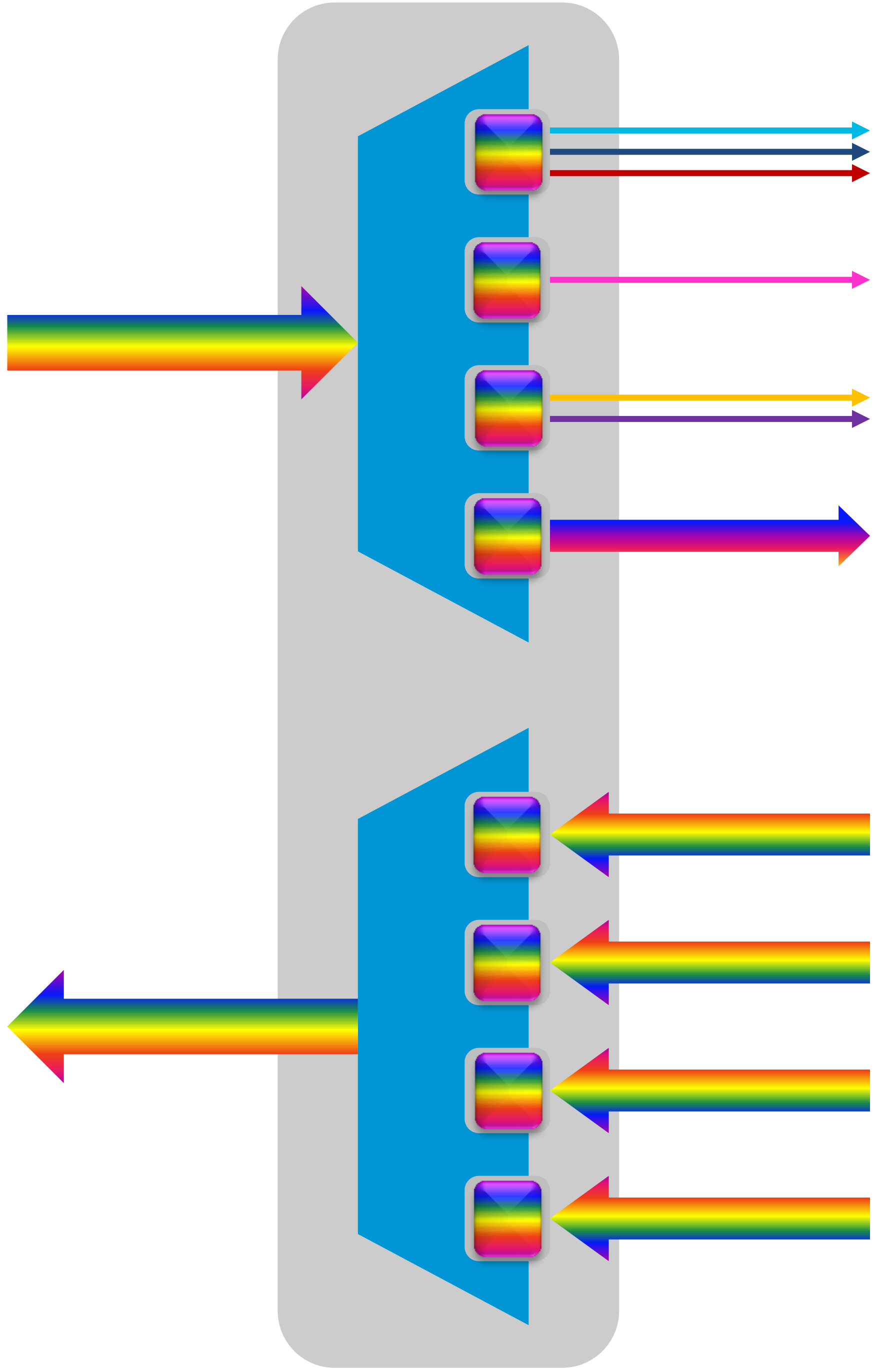
Next Generation ROADM

“Route and Select” Architecture

Route
and Demux

96 Unique Channels



Any (unique) wavelength combination to any port

Select
and Mux

96 Unique Channels

Any group of wavelengths up to the full spectrum

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Next Generation ROADM

16-WXC-FS: Card Overview

- The card shall be composed of two functional sections:
  - a mono-directional 1 x 16 WXC – De-Multiplexer Section
  - a mono-directional 16 x 1 WXC – Multiplexer Section
- Both sections shall be able to manage (on each port) up to 96 channels 50 GHz spaced
- The Multiplexer section can selectively send any wavelength combination coming from 16 input ports to a common (COM-TX) output port.
- The De-Multiplexer section can selectively send any wavelength combination coming from its common (COM-RX) input port to any of the 16 output ports.
- Two upgrade ports (UPG-TX and UPG-RX) are available for expansion to 32 degrees.
- Single or multiple OCM(s) shall be able to continuously read per channel power level from all the 36 (input and output) optical ports.
- Both OCM and WXC blocks can manage (on each port) a “Flex” Optical spectrum, consisting of a continuous arbitrary transfer function (attenuation vs. wavelength), specified by the user for each of the WXC ports.

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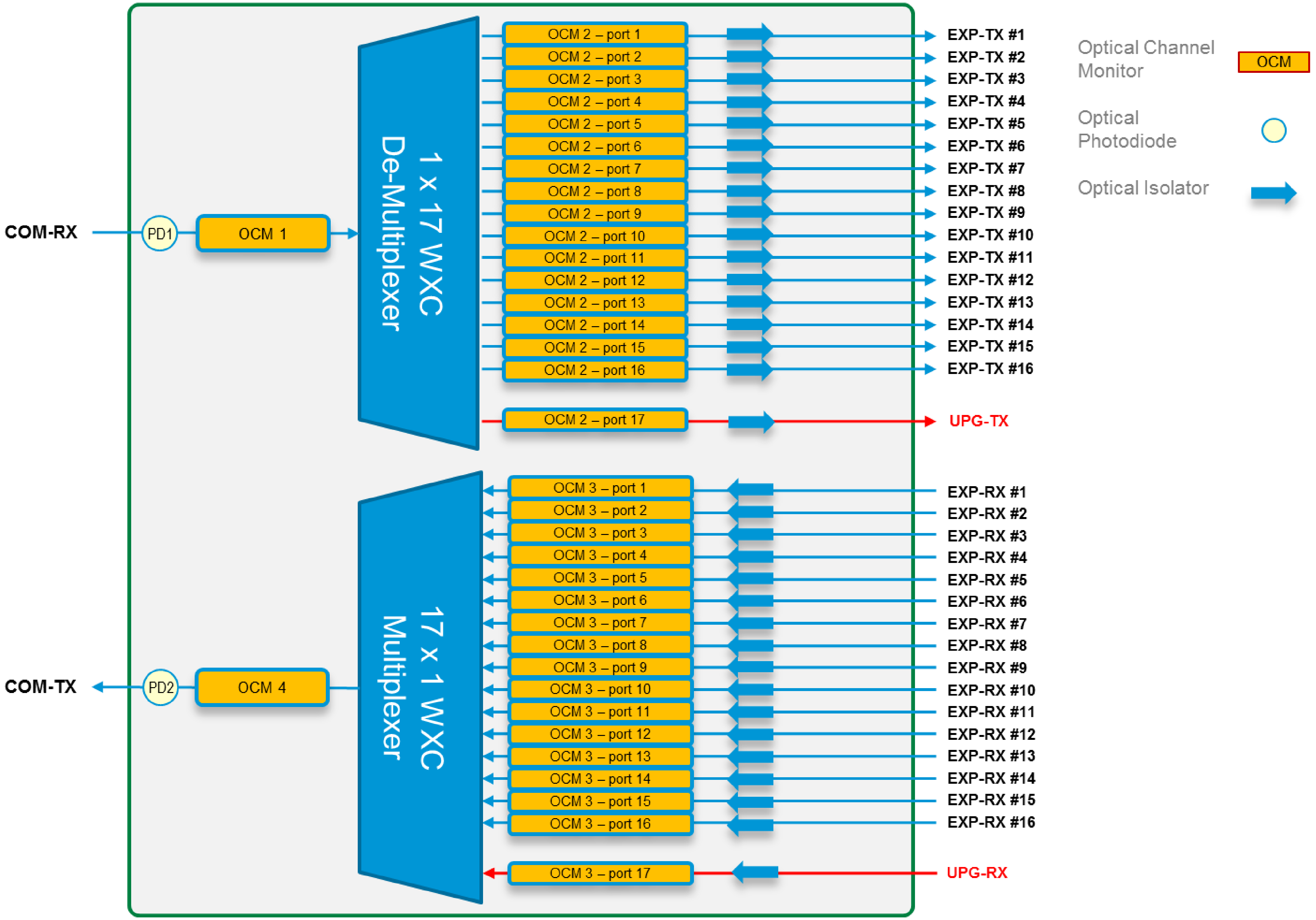
Next Generation ROADM

16-WXC-FS: Block Diagram



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Next Generation ROADM

Is it all what we need?

- Just Increasing the Capacity per Fibre by Increasing the Wavelength Bit Rate is not enough to Optimise Transport Cost
  - Higher Wavelength Bit Rate would require Higher OSNR
  - Higher OSNR would reduce the overall Unregenerated Distance…
  - …unless Modulation Format comes into play
  - Modulation Format has an impact on the number of Wavelengths per Fibre…
  - …hence on the overall Capacity per Fibre
- How do we make sure that we can have a net positive effect?
  - Need Optical Amplifiers with better OSNR!
  - Need to be able to support more wavelengths in the system

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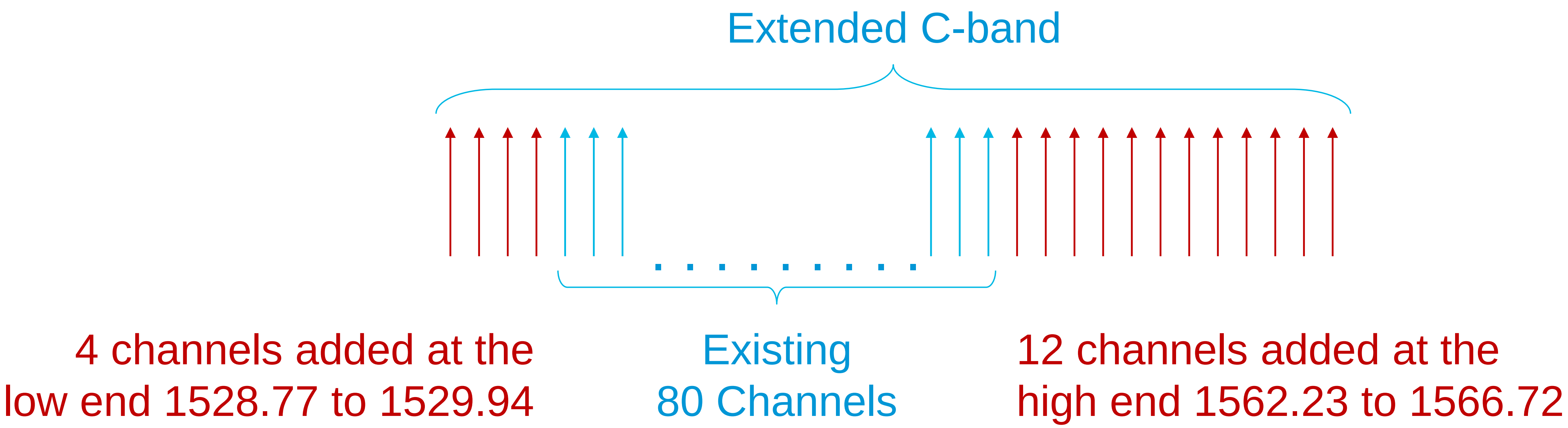
Next Generation Amplifiers

Increased number of channels

- Requires 96 channel Add/Drop and ROADM components
- Change from 80 to 96 channels in the C-Band at 50 GHz spacing



- Requires extended C-Band support on amplifiers
  - MAL-less EDFA
  - EDRA

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Next Generation Amplifiers

- Erbium Doped Fibre Amplifiers (EDFA) are generally used in DWDM Transport Networks to extend Unregenerated Distance between End Points in the Network
- Typical Optical Bandwidth of EDFA units allows to transport 80 wavelengths (50GHz spacing) in the C-band spectrum
- Raman amplification has been used to support very long spans
- **Can EDFA and Raman be jointly used to improve the number of wavelengths in the C-band and to provide better OSNR?**

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Next Generation Amplifiers

EDRA: Erbium Doper Raman Amplifier

- Integrating Raman and EDFA in a single card has already proven to be an effective solution to allow optimal balance between Distributed (Raman) and Concentrated (EDFA) amplification
- The goal is to provide a completely integrated Optical Amplifier solution which can include everything needed to face a single direction of the fibre:
  - Counter-Propagating Raman – Features variable power allowing to control the overall amount of Raman amplification for the specific Site Degree
  - Low-Noise Pre-Amplifier – True Variable Gain EDFA optimised to operated with the Counter-Propagating Raman
  - Optional Booster Amplifier – True Variable Gain EDFA 2 different versions of the unit will be made available for optimal Gain set point – Up to 96chs (50GHz spacing) supported

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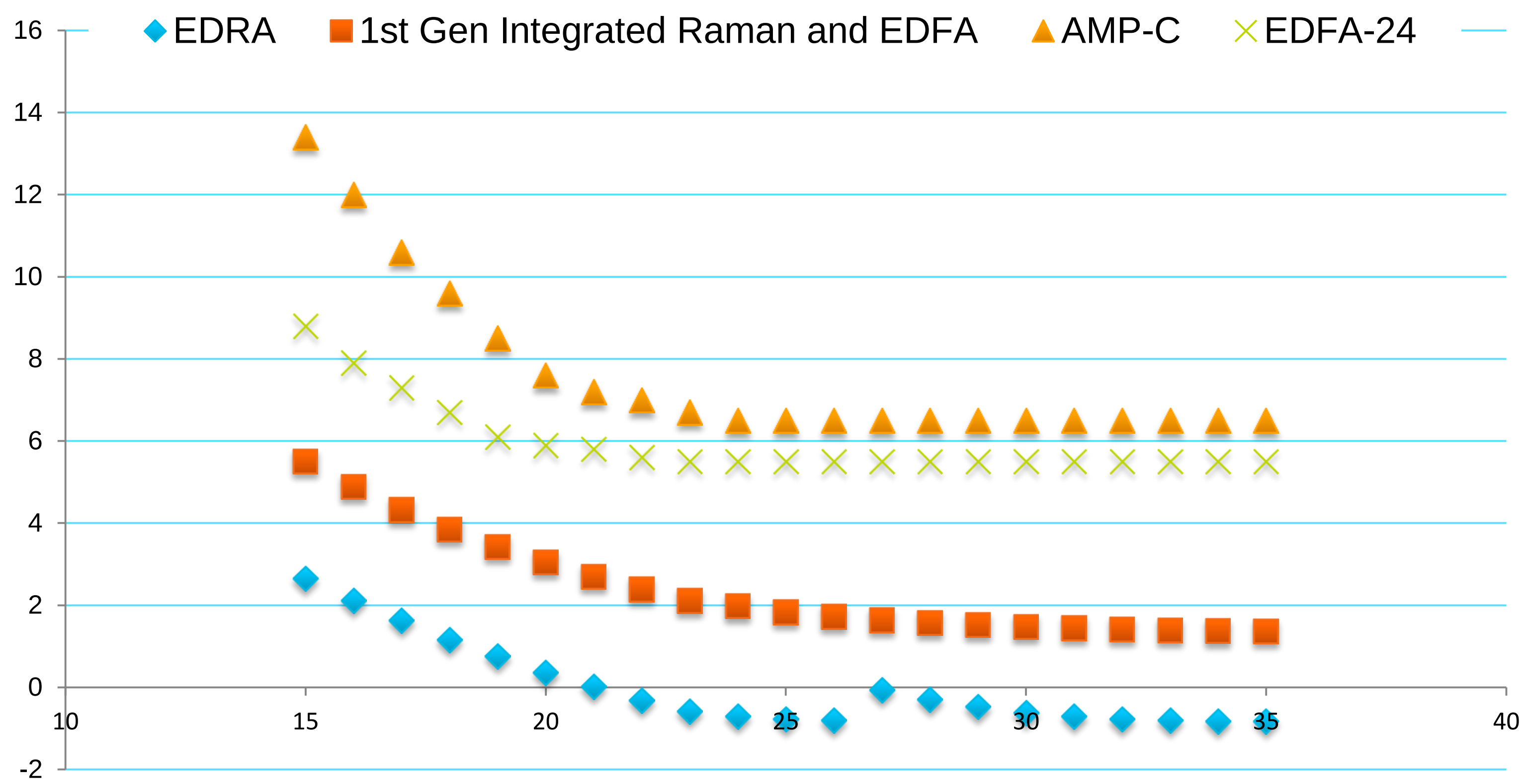
Next Generation Amplifiers

Amplification performance



- Coherent transmission offers new opportunities in optical amplification
- EDFA can be optimised to operate without CD compensation.
- Significant improvement are achieved when hybrid EDFA+Raman amplification scheme is used.

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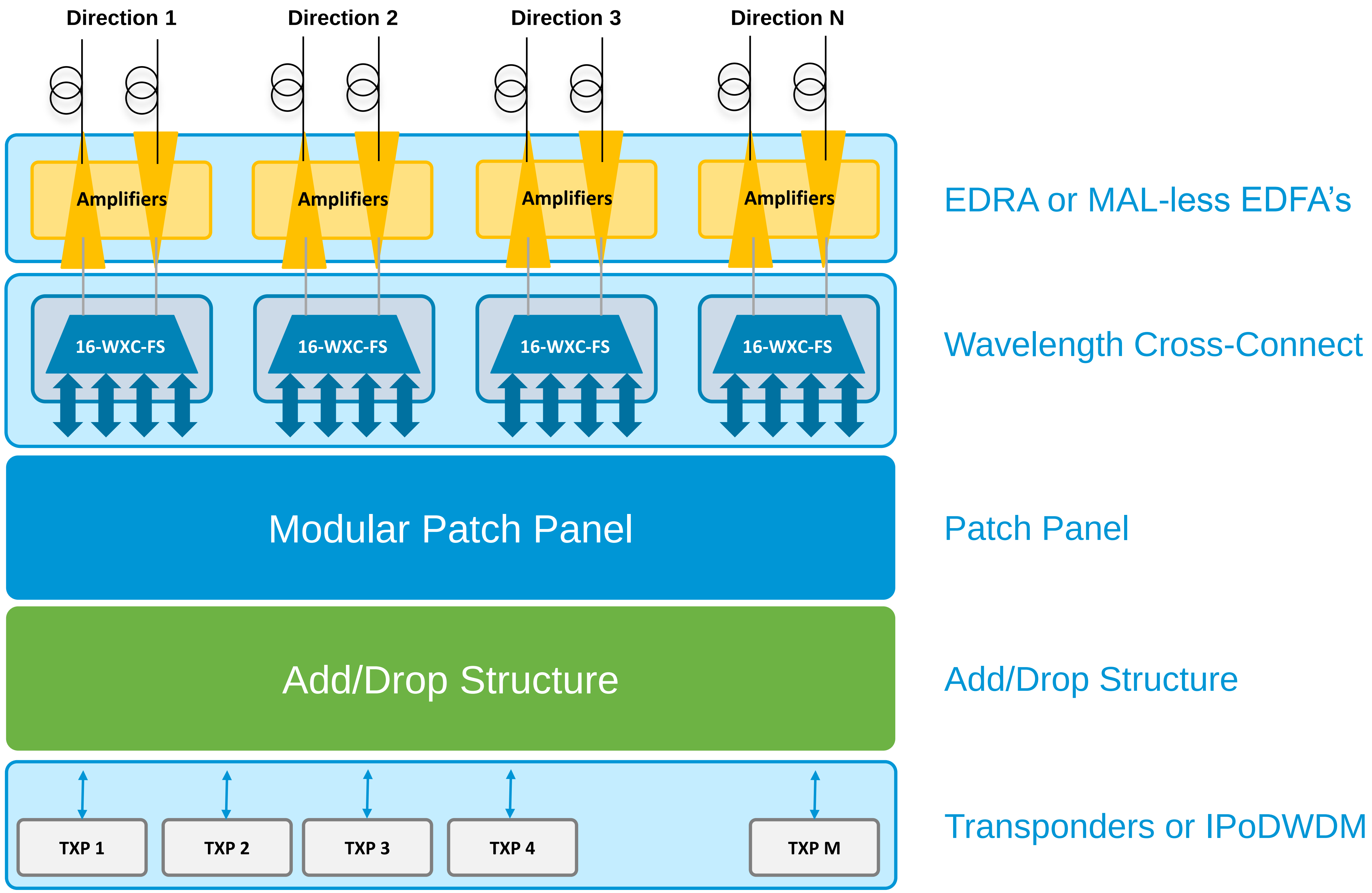
NG DWDM Architecture



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NG DWDM Architecture

Summary

Feature	Detail	Benefit
Next Generation Amplifiers		
Amplifier Integration (EDRA)	Combined EDFA + Raman single card	Simplicity, size
Increased Performance	High power plus optimal technology combination	Greater distances
Next Generation ROADM		
More Channels	80 → 96	More Capacity
More Ports	8 → 16 (32)	More degrees (mesh)
Flex Spectrum	50 GHz → 12.5 GHz spacing	More Capacity
Colourless/Omni/Contentionless	Optimised architecture	Touchless and programmability
Colourless	Any colour accepted on any mux port	
Omni-Directional	Any input signal on a mux can egress any degree	
Contentionless	Multiple inputs of same colour on same mux	

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Cisco live!

How NG DWDM can help you?

Problem

Bandwidth Growth

Solution

More network capacity

More Channels	Flex Spectrum
Extend the C-Band 50GHz	Spectrum Optimisation Future Proof

Problem

Unpredictable, dynamic traffic demands & tighter SLAs

Solution

Highly meshed, programmable networks

More Degrees	Touchless Operation
More highly meshed networks	Colourless Omni-directional Programmability

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Optical Control Plane

Animated slide

NG DWDM Capabilities

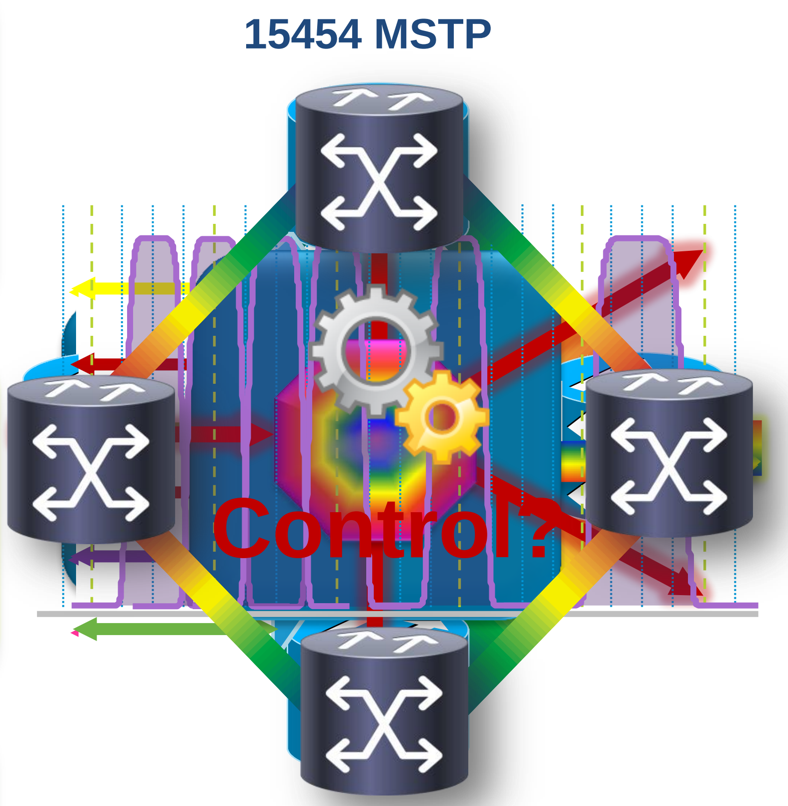
Complete Touchless optical layer

Complete Control in Software, No Physical Intervention Required

Omni-Directional – ROADM ports are not direction specific (re-route does not require fibre move)

Tunable Laser – Transmit laser can be provisioned to any frequency in the C-band (96 channels)

Colourless – ROADM ports are not frequency specific (re-tuned laser does not require fibre move)



Tunable Receiver – Coherent receiver can select one wavelength among a composite signal (no demux needed)

Flex Spectrum – Ability to provision the amount of spectrum allocated to wavelength(s) allowing for 400G and 1T channels.

Contention-less - Same frequency can be added/dropped from multiple ports on same device

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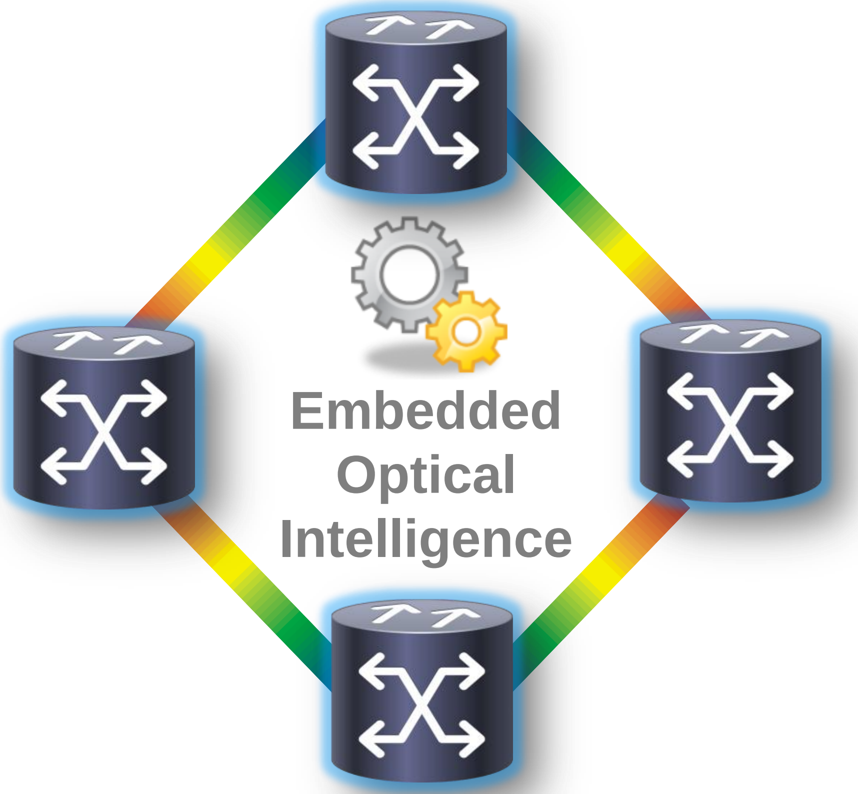
But this capability is of limited use without intelligence.

Intelligence to verify an feasibility of optical route through the network and for current state of the network instead of going into offline modeling process..

Intelligence to select most optimal optical path through network instead of shortest one.

Perform automatic channel rerouting and service restoration in case of multiple failures in mesh network.



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What is a Control Plane?

- An optical control plane is a set of algorithm, protocols and messages enabling a network to **automatically** do the following tasks:
  - –Network **topology** discovery including network changes
  - –Network **resource** discovery
  - –Traffic **provisioning**
  - –Traffic **restoration**
  - –Network **optimisation**

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Optical Control Plane for DWDM Networks

Problem

- Optical-layer transmission impairments are usually not considered when establishing a light-path in a transparent/translucent optical network
- Optical Channel is assumed to work by design
- Only pre-planned channels are guaranteed to work
- GMPLS (as is) is not sufficient to decide whether a proposed path is feasible in the photonic domain (no Optical Impairment Calculation)
- What is concept of optimality in term of Optical Path:
  - "Number of Hops"?
  - Optical Signal Quality?
  - Number of Regenerators?

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Optical Control Plane for DWDM Networks

Optical impairments impact

- if a wavelength exist, not necessarily its works!
  - Max distance constrained by signal degradation along the path
  - Wavelength selection constrained by effects on already active channels
- Optical signal degradation occurs in the network
  - Low OSNR on the path based on the optical interface characteristics
  - High non linear effect on the path based on link fibre type
  - High crosstalk on active adjacent optical channels

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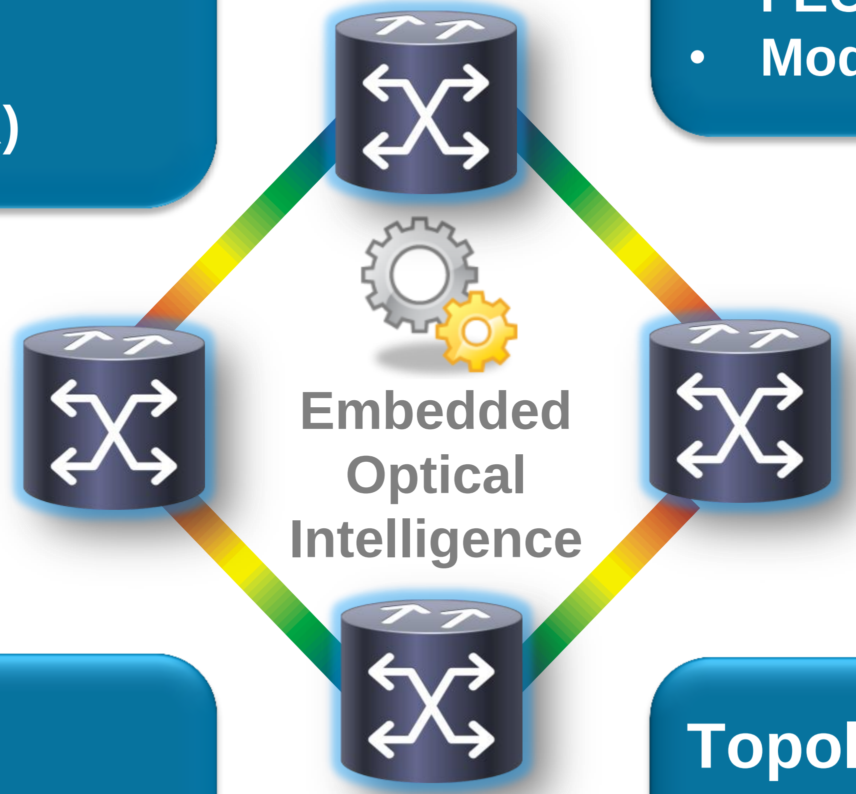
DWDM Aware Control Plane

Important optical parameters

Linear impairments:
- Power Loss
- Chromatic Dispersion (CD)
- Phase Modulation Distortion (PMD)
- Optical Signal to Noise Ratio (OSNR)

Interface Characteristics:
- Bit rate
- FEC
- Modulation format



Regenerators capability

Non linear Optical impairments:
- Self-Phase Modulation (SPM)
- Cross-Phase Modulation (XPM)
- Four-Wave Mixing (FWM)

Topology:
- Physical topology
- Lambda assignment
- Route choices (C-SPF)

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Wavelength Switched Optical Network

- Traditional control planes (MPLS-TE, ASON) assume a homogenous physical layer (regeneration everywhere, no L0 issues)
- WSON is defined in several IETF drafts, which add these key components to GMPLS
  - Routing and Wavelength Assignment
  - Distribution / collection of Channel Impairments, Path optical characteristics, other affected channels
- Optical impairment aware CP, Impairment calculation is distributed
  - Reasonable computation requirements on Network Elements
  - No heavy reliance on DCN bandwidth, delay, and availability
  - Centralised, but online computation certainly possible.

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WSON Impairment Aware CP

Control Plane Functions

- It is GMPLS control plane which is “DWDM aware”, i.e.:
  - LSP are wavelength and,
  - the control plane is aware of optical impairments
- enables Lambda setup on the fly – Zero pre planning
- enables Lambda re-routing, i.e. changing the optical path or the source/destination
- enables optical re-validation against current network configuration
- enables optical re-validation against a failure reparation or against re-routing

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WSON Impairment Aware CP

Information Required

- Need to have wavelength switching for each node (Switching Matrix).
  - It's a property of the node.
  - It is static (how the node is built)
- Need to know wavelength availability.
  - It's a property of the link.
  - It is dynamic (new advertisement every path established).
- Need to assess interface compatibility:
  - Two interface having the same wavelength may be different.
- Wavelength continuity vs. conversion capability.
  - GMPLS was assuming wavelength conversion available everywhere

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WSON Impairment Aware CP

Control Plane Based Functionality

- Client interface registration
  - – Alien wavelength (open network)
  - – Transponder (closed network)
  - – ITU-T interfaces
- Wavelength on demand
  - – Bandwidth addition between existing Source & Destination Nodes
- Optical restoration (NOT protection)
  - – Automatic Network failure reaction
  - – Multiple SLA options (Bronze 0+1, Super Bronze 0+1+R, Platinum 1+1, Super Platinum 1+1+R)

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WSON Impairment Aware CP

WSON Restoration Considerations

- WSON is a restoration mechanism rather than a protection mechanism
- Optical Protection guarantees < 50 msec protection and IPoDWDM guarantees < 15 msec protection. Since WSON is a restoration mechanism it does not guarantee sub 50 msec restoration.
- Network Planner should plan both protection and restoration together example 1+0+R or 1+1+R
- Resolve congested links in the event of fibre cut scenarios

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WSON Impairment Aware CP

Applications

- Rapid service setup
- Wholesale restorable wavelengths
  - 0+1+R (Super Bronze)
  - 1+1+R (Super Platinum)
- Wavelength rerouting
  - Change source / Change destination

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WSON Impairment Aware CP

Dynamic Optical Restoration

- What?
  - Dynamic Optical Restoration is a service provided by the DWDM layer to the client layer which enables the automatic re-routing of a failed optical circuit over a new route, triggered by a DWDM-layer event (no UNI required) or by the client (UNI required).
- Why?
  - By using the same optical interface for both working and protect modes, network capex can be dramatically reduced (50% savings vs. Y-cable), while its automated nature simplifies operations.
- How?
  - Colourless & Omni-Directional ROADMs combined with Tunable lasers allow the optical layer to re-route an optical circuit in a fully touch-less manner.
  - Embedded WSON intelligence enables the DWDM layer to dynamically validate the optical feasibility of the new route, ensuring success and eliminating dependence on an off-line design tool.

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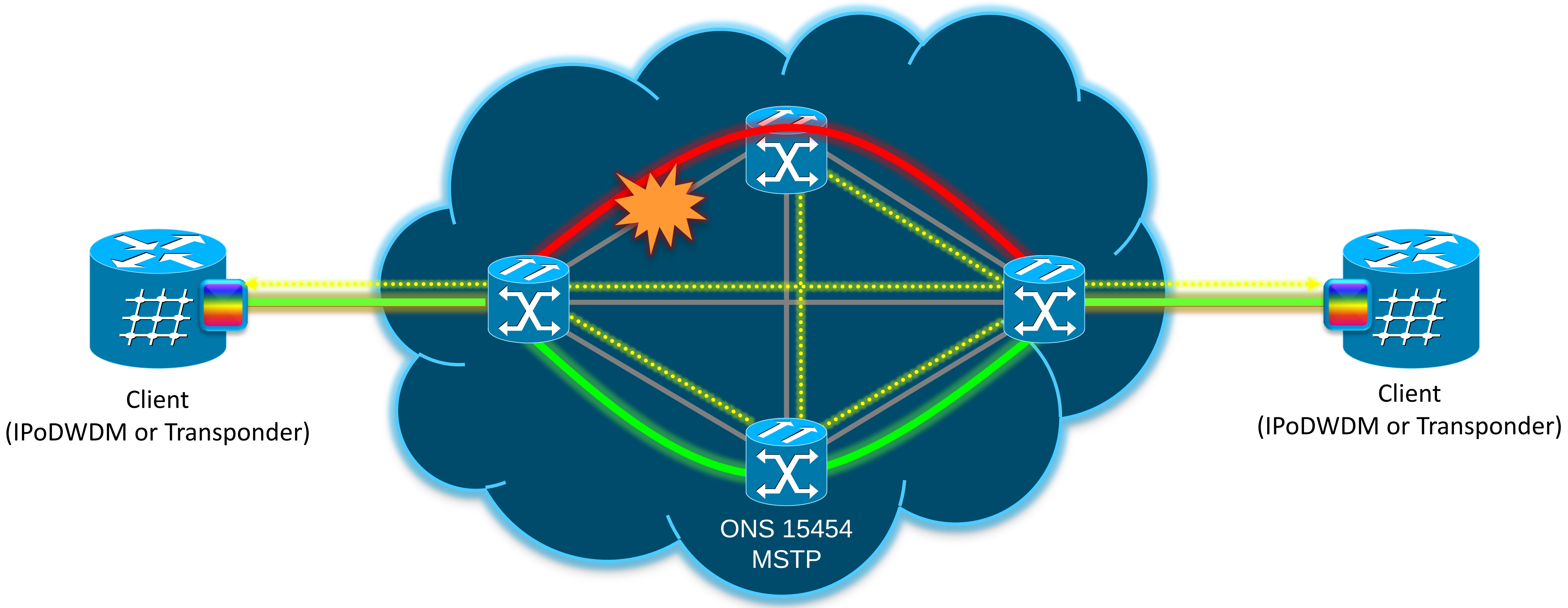
Dynamic Optical Restoration

Touchless Optical Layer + Embedded WSON Intelligence



Fibre Cut!

Embedded WSON intelligence locates and verifies a new path

Edge Nodes instruct client to re-tune its wavelength

Colourless, Omni-Directional ROADM switches the path

Service is brought back up with the **same Client and Optical interfaces**, zero touches

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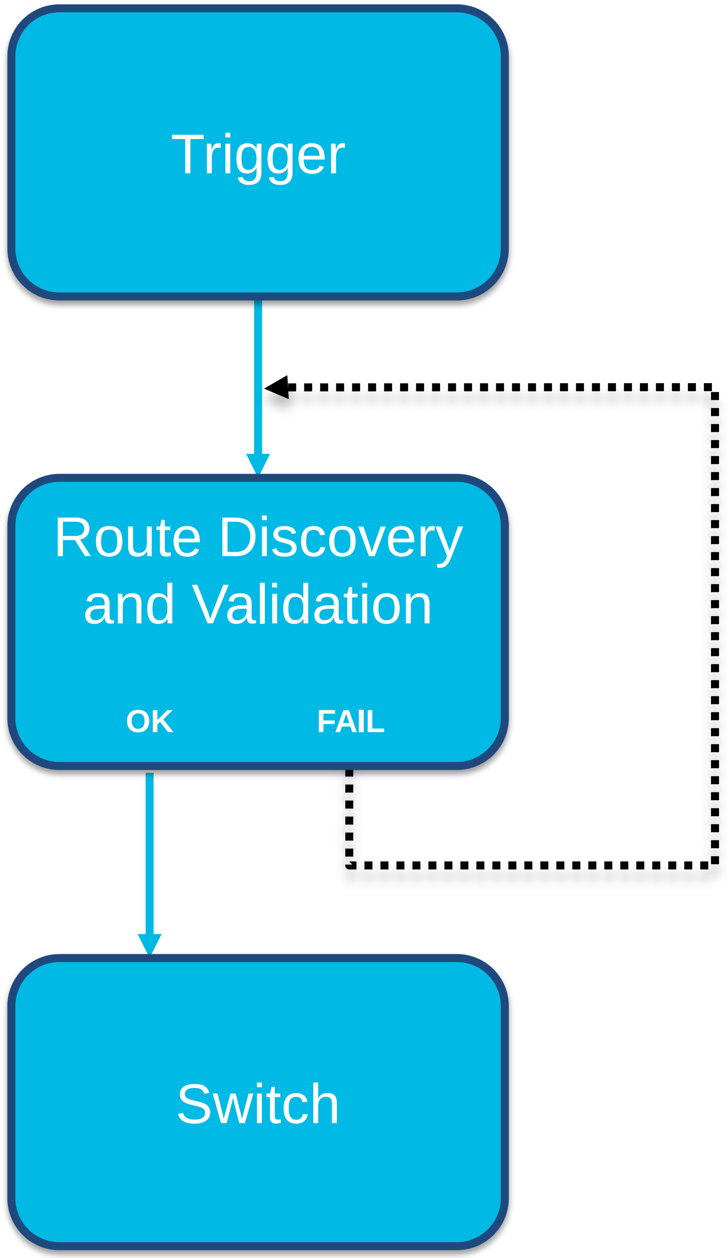
Dynamic Optical Restoration

Restoration Mechanism



Link Failure
Signal Failure

Constrained OSPF algorithm
First try original wavelength, then others
Relax other constraints (future)

Re-tune interface wavelength (if necessary)
Re-tune or provision VOAs and ROADM ports

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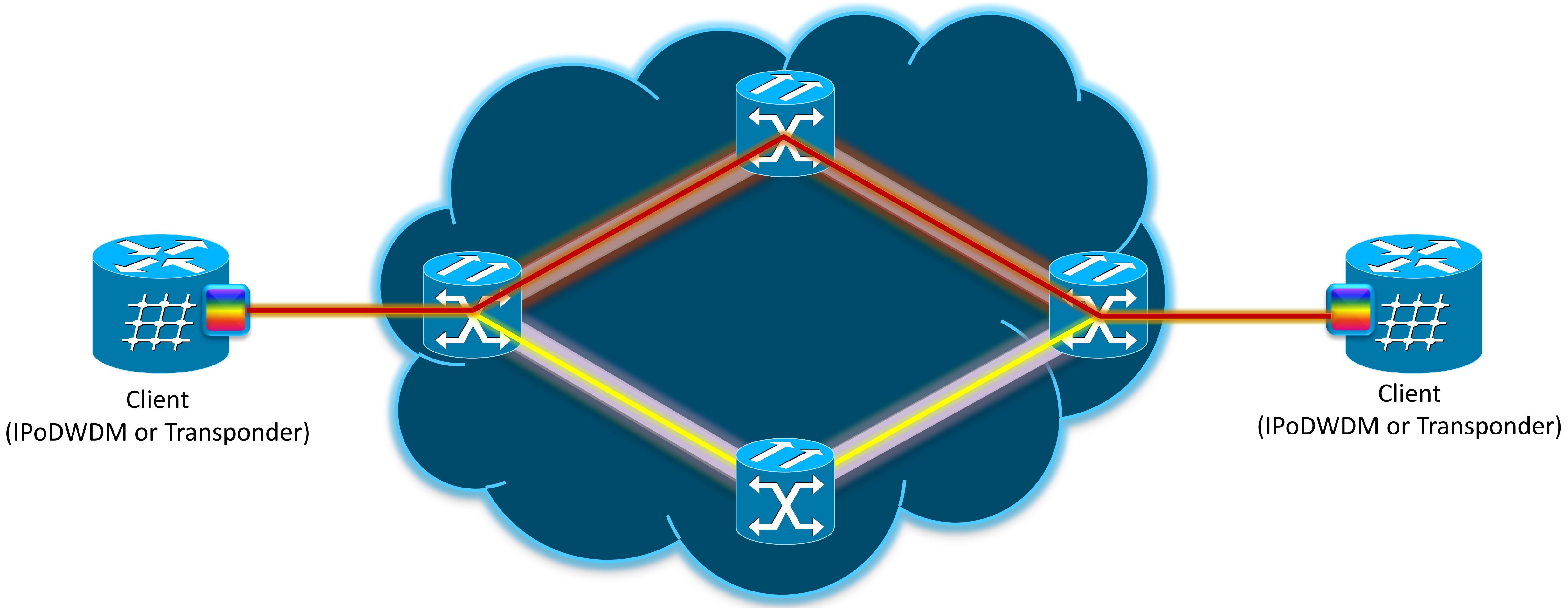
1+R Scenario #1: Restoration no Revert

Path Configuration: Restore no Revert



State: Traffic is on Main path

Change: Main path fails, traffic is lost

Behaviour: Restore path is calculated. Traffic moves to the Restore path

Behaviour: Main path is cancelled, Restore path becomes the new Main

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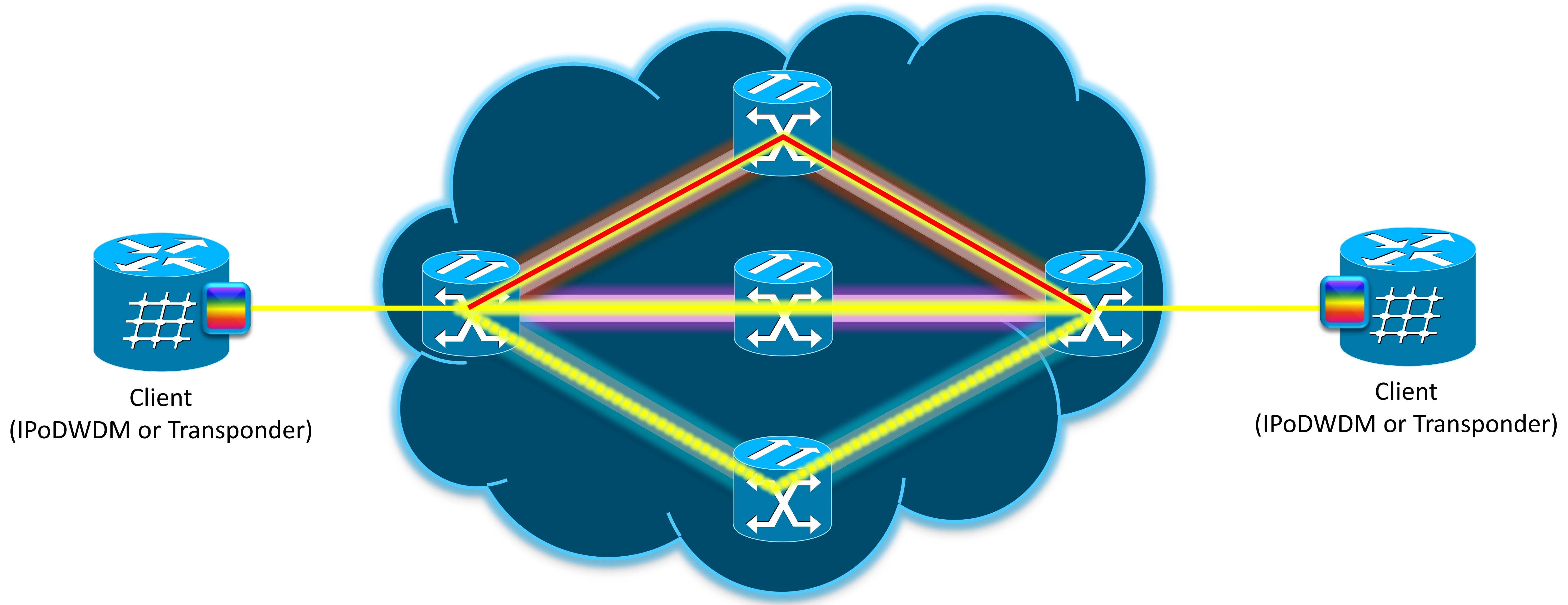
1+1+R Scenario #1: Working Failure

Path Configuration: Restore no Revert



State: Traffic is on Main Path / Working Trail

Change: Main Path / Working Trail fails, 1+1 switches traffic to Protect trail

Behaviour: Restore Path is calculated. Working Trail moves to Restore Path. Old Main path is cancelled. Restore path becomes new Main Path.

Subcase: If 1+1 is revertive, traffic is 1+1 switched back to new Main / Working

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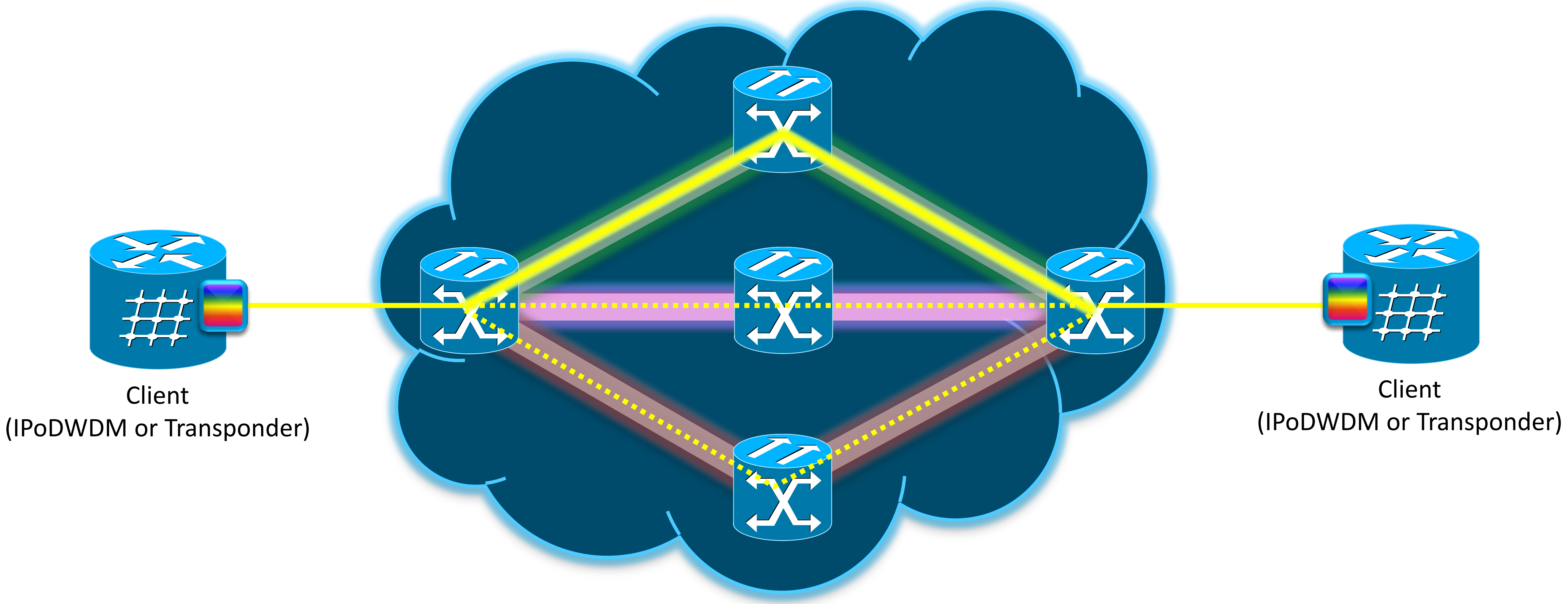
1+1+R Scenario #2: Protect Failure

Path Configuration: Restore no Revert



State: Traffic is on Main / Working path

Change: Protect path fails. (1+1 does not switch). Protect trail is unavailable.

Behaviour: Restore path is calculated. Protect Trail moves to Restore Path.
Restore path becomes new Protect Path. Old Protect path is cancelled.

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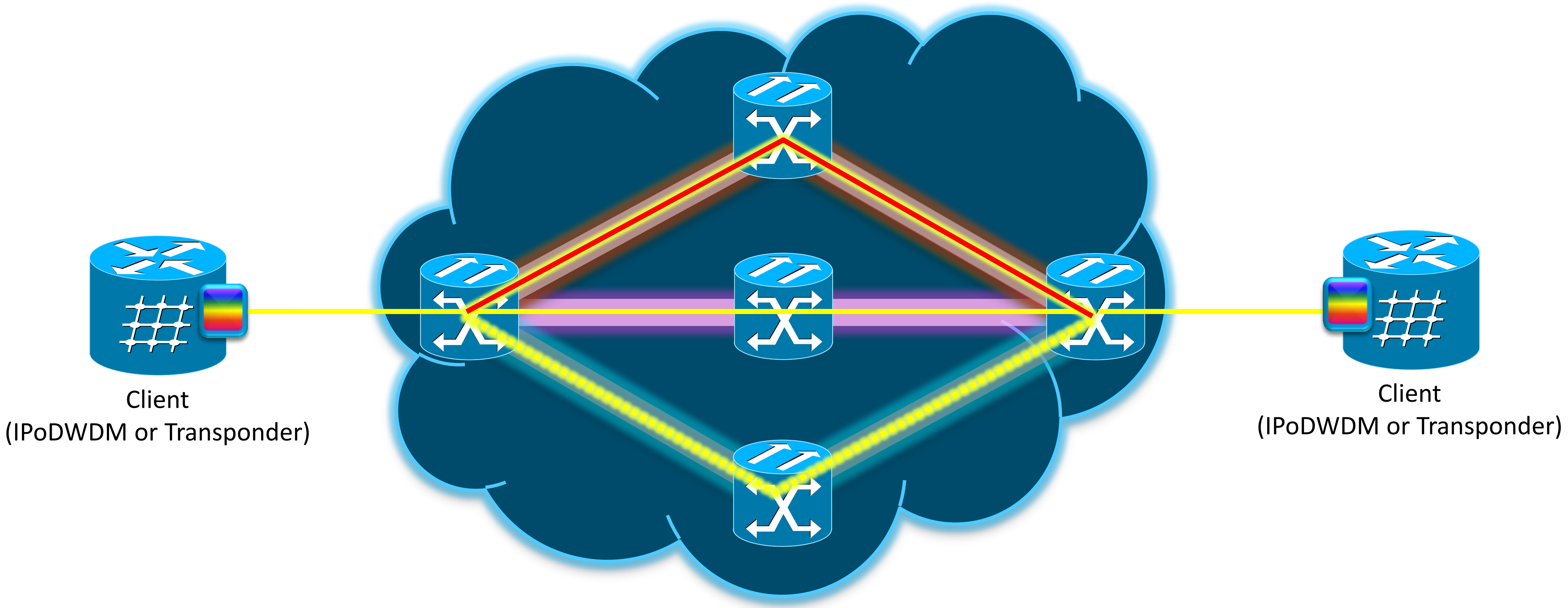
Animated slide

1+1+R Scenario #3: Working Failure

Path Configuration: Restore with Revert



State: Traffic is on Main Path / Working Trail

Change: Main Path / Working Trail fails, 1+1 switches traffic to Protect Trail.

Behaviour: Restore Path is calculated. Working Trail moves to Restore Path.

Behaviour: When Old Main path is recovered. Restore path is cancelled. Working Trail moves back to Main Path. Traffic remains on Protect Trail.

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WSON Impairment Aware CP

IP/MPLS Benefits with WSON Control Plane

- Add/Remove Bandwidth on demand on the same link
- 1+1+R Restoration capability
  - –Back to line rate
  - –Freeing up old working connection
  - –Flexibility to multiple failure
- Shared Risk link group (S-GMPLS)
- Network optimisation (along the time!)
  - –Move wavelengths to re-adjust bandwidth
  - –Keep the links

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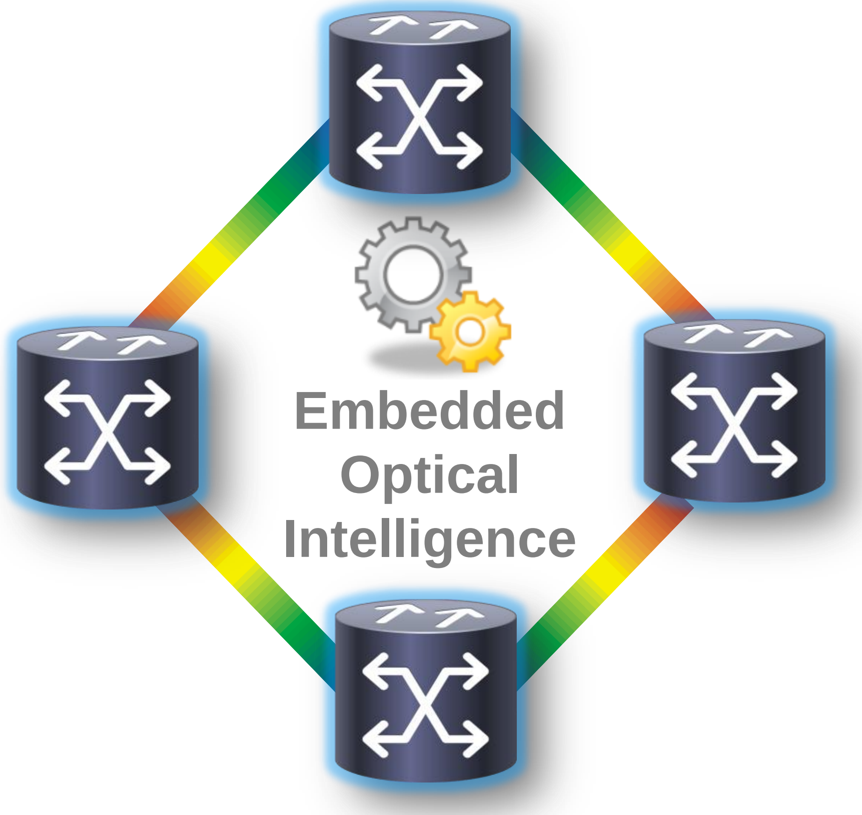
WSON Impairment Aware CP

Benefits of WSON enabled optical network

Ability to find an optically feasible route through the network and in for current state of the network.

The WSON Control Plane combines GMPLS signalling with knowledge of optical interface requirements and channel impairments, this enable dynamic restoration capabilities in optical network.

With the addition of a User Network Interface (UNI), upper layer protocols can request optical circuits



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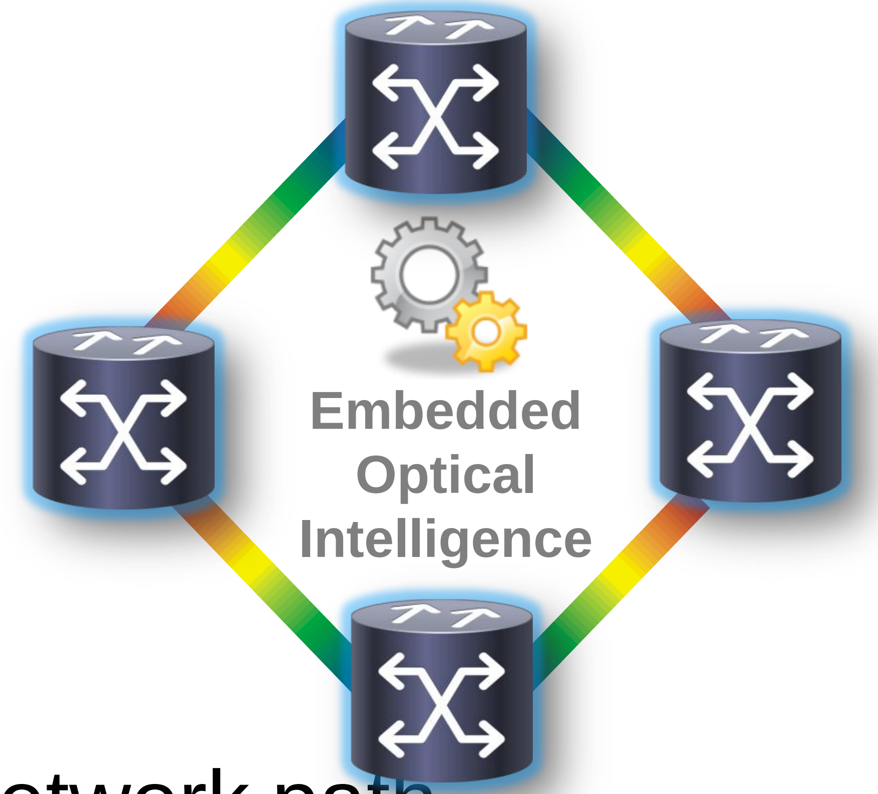
… so what can I do with this programmable, optical layer flexibility?

Instantly turn up a new optical circuit from pre-deployed DWDM interfaces:

- Manually …
  – via the DWDM provisioning system …
  – via the attached router's command line and GMPLS-UNI
- Automatically …
  – via embedded L3 path computation intelligence
  – via centralised SDN controller
- Remotely re-route an optical circuit across a new network path



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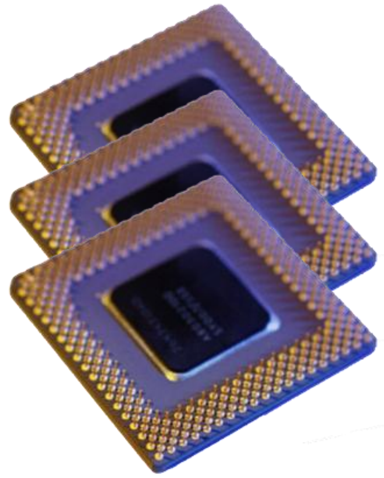
Closing / Summary

Animated slide

Optical Technology Evolution

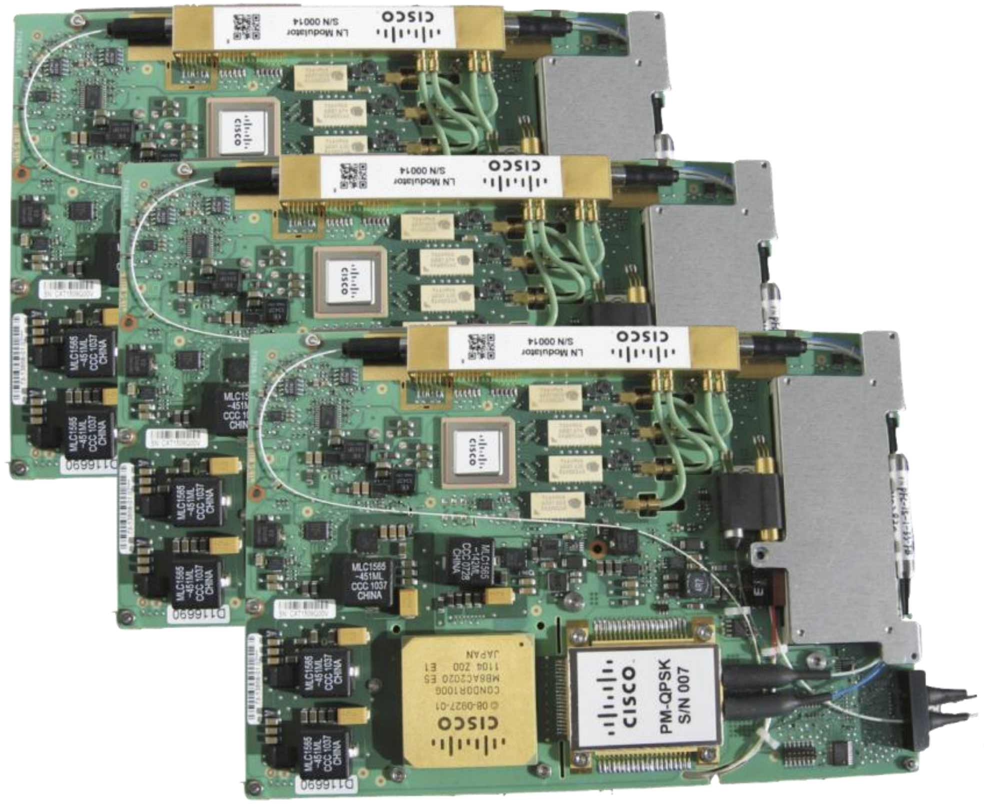
Where we are today?

NPU/Fabric



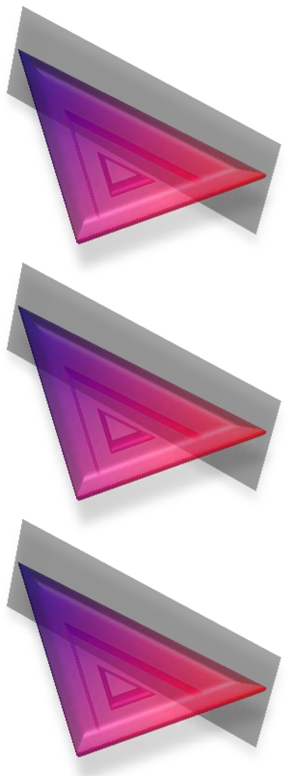
200G Fabric
200G NPU

Coherent Optics



Densest 100G Coherent Implementation

ROADM



40/80 Channels
Multi-Degree
Flexible Architecture

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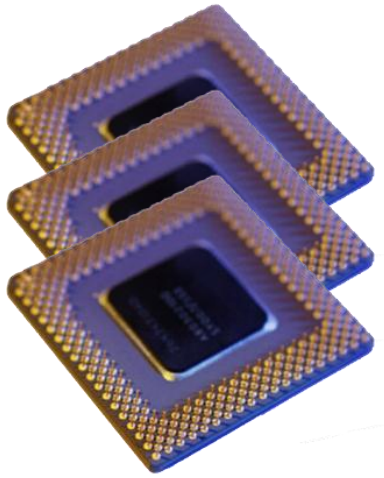
Optical Technology Evolution

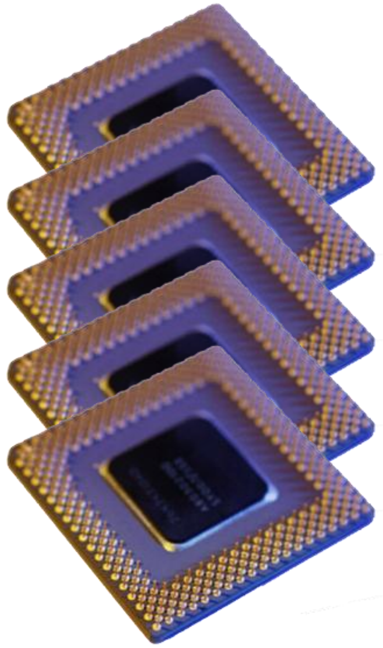
What to expect?

NPU/Fabric



Scale
I/O

Coherent
DSP

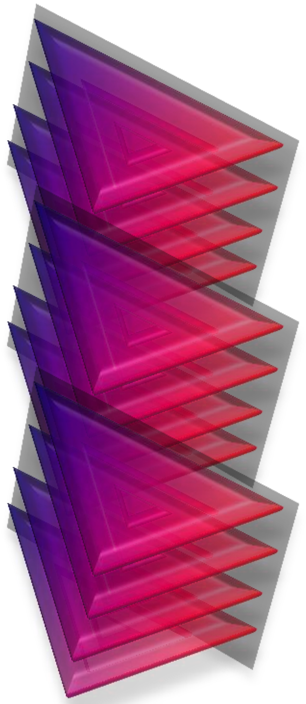


Multi-Modulation
Distance v Capacity

Pluggable
Optics

High density
interfaces

ROADM



Total Flexibility
Assemble SC
Broadcast SC
>24T In-Fibre

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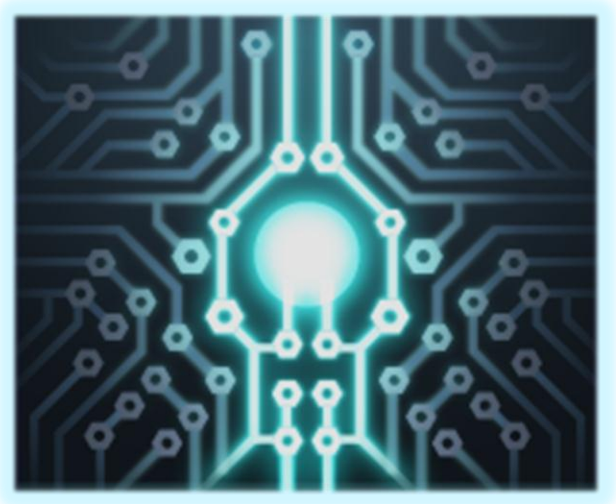
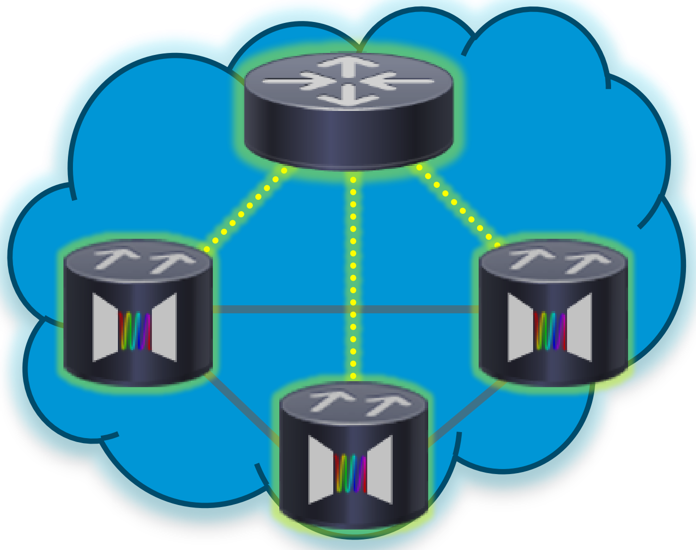
Cisco nLight Technology

Programmability, Convergence, and Scale



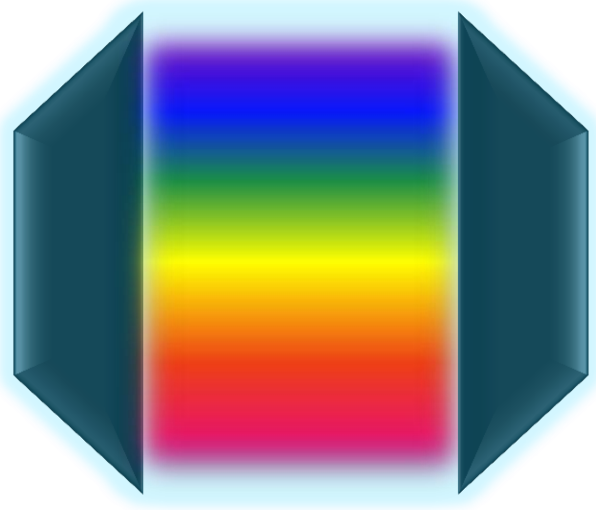
nLight Silicon

100G and Beyond
Adaptive Rate
High Performance



nLight Control Plane

Information Sharing
The Network is the Database
Automation to Optimisation



nLight ROADM

Complete Flexibility
No Manual Intervention
Massive Scale

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Q & A

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