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Let's go

The bridge to possible

The Journey to Routed Optical Networking

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Global MIG Specialists

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BRKOPT-2130

Agenda

- Innovations and Standards leading to Routed Optical Networking
- RON Architecture, Benefits and Building Blocks
- Full Services Convergence with RON
- RON Journey and Future Evolution

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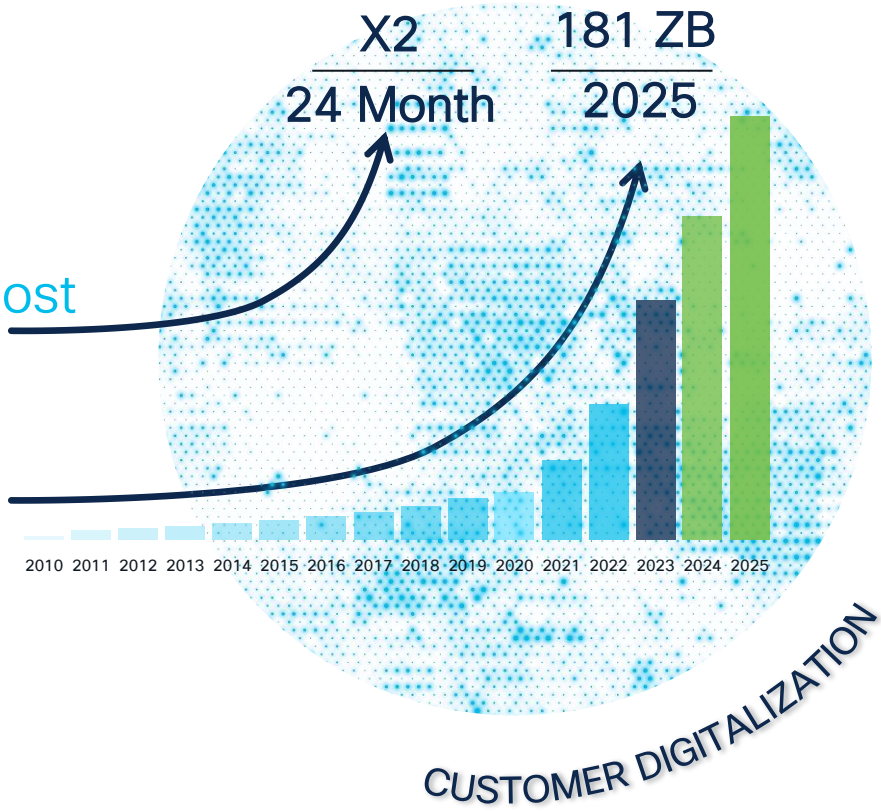
Innovations and Standards Leading to Routed Optical Networking

Data Growth

Consumption of Data is growing almost exponentially
50% per each year!

Creation of Data will grow
to 181 zettabytes in 2025!



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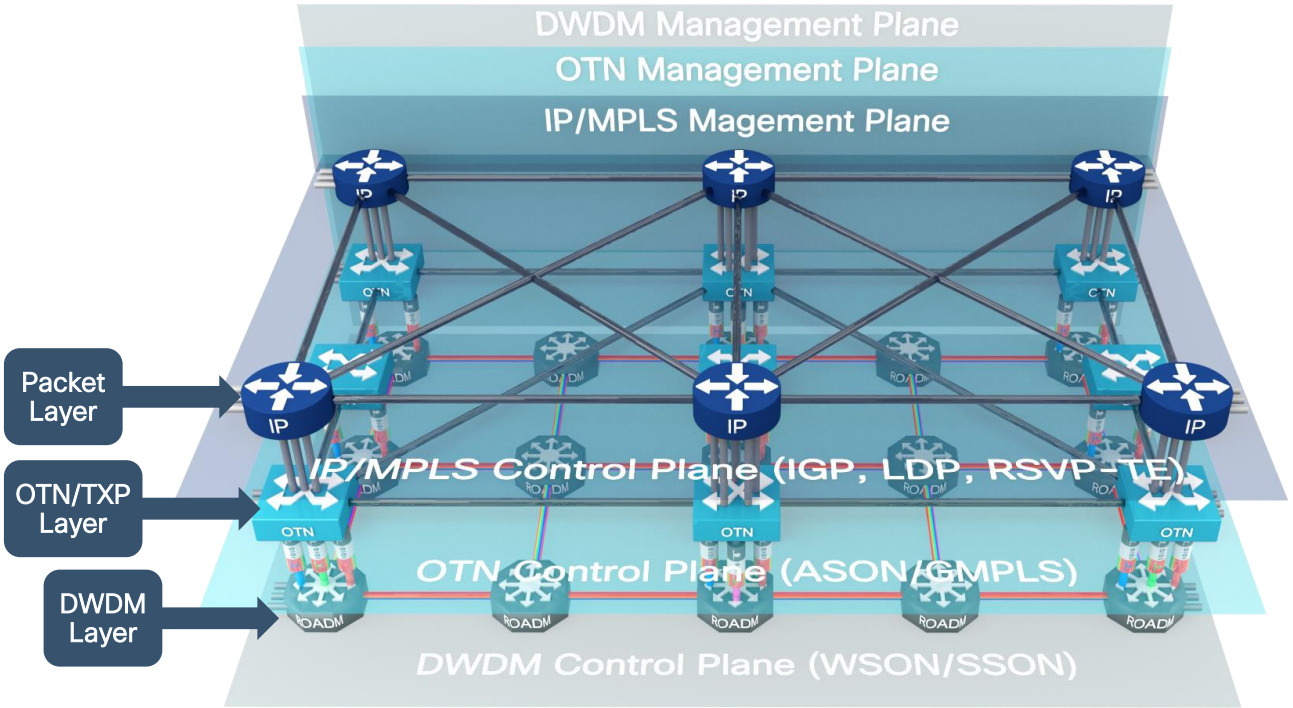
Complexity of Current Multi-Layer Networks



- 3 Different control Planes (each treated individually)
- 3 Management Platforms
- Huge amount of idle and/or duplicate capacity and redundant protection
- Separate teams/staff and skills to operate the networks.
- 90%+ of services at Packet Layer

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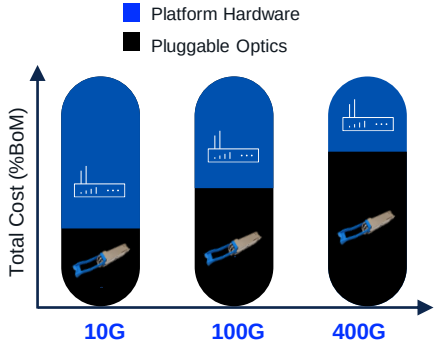
Shifts in Economics and Technologies

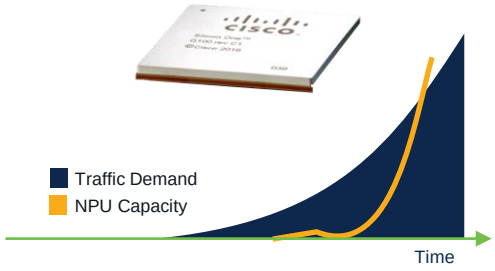
Optics and Routing

Shift in Economics



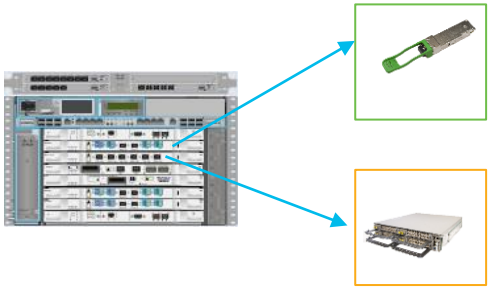
Routers are no longer the highest cost element in the network. Optics spent exceeding routers platform spent at 400G and beyond to the point where the cost contribution between Routing and Optical flipped.

Routing Scale Evolution



Innovation in Silicon leading to breakthroughs in higher ASIC/Silicon capacity (50 Tbps +) and hence overall lower cost/power per bit in Routing

Optical Systems Evolution



10s 100s 1,000s 10,000s

DCI Metro Long Haul Subsea

Innovation in Silicon Photonics with the emergence of DCO technology coupled with Optical disaggregation is leading to purpose build Optical solutions

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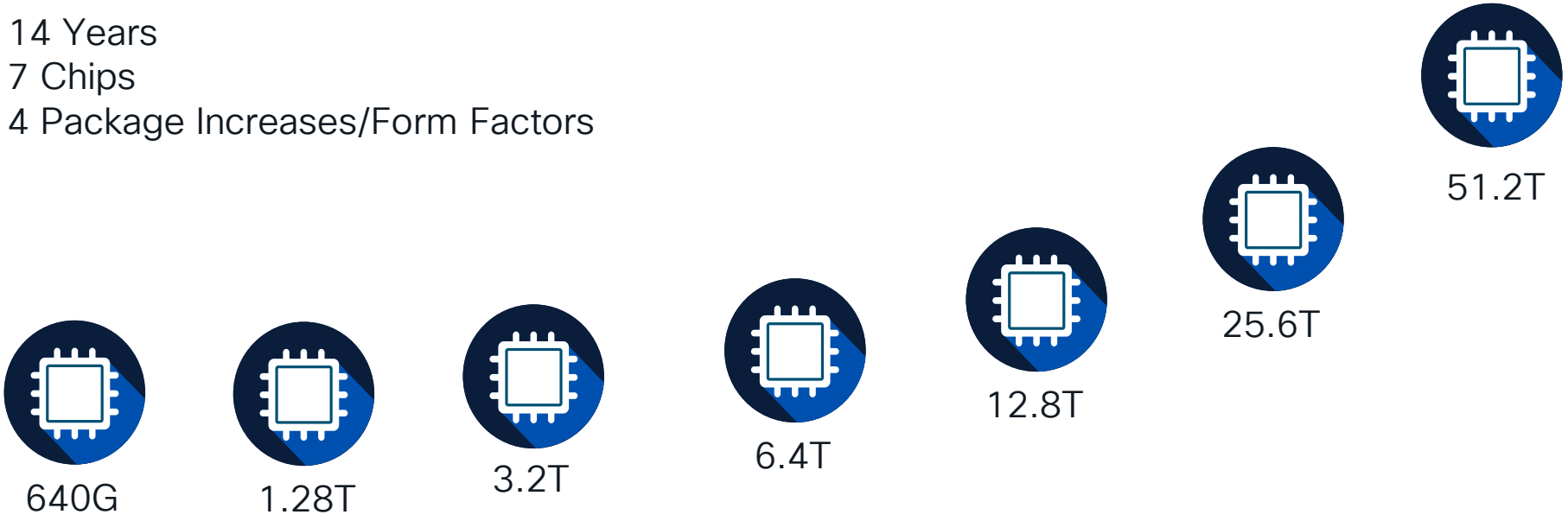
Innovation and Advancement in ASIC

2010 | 2012 | 2014 | 2016 | 2018 | 2020 | 2024

14 Years
7 Chips
4 Package Increases/Form Factors



Slides represent a combination of multiple chip families and architectures to provide historical context

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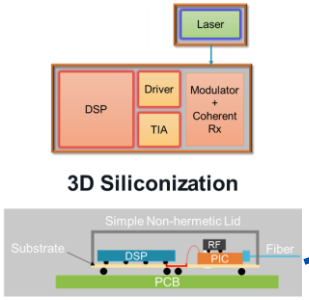
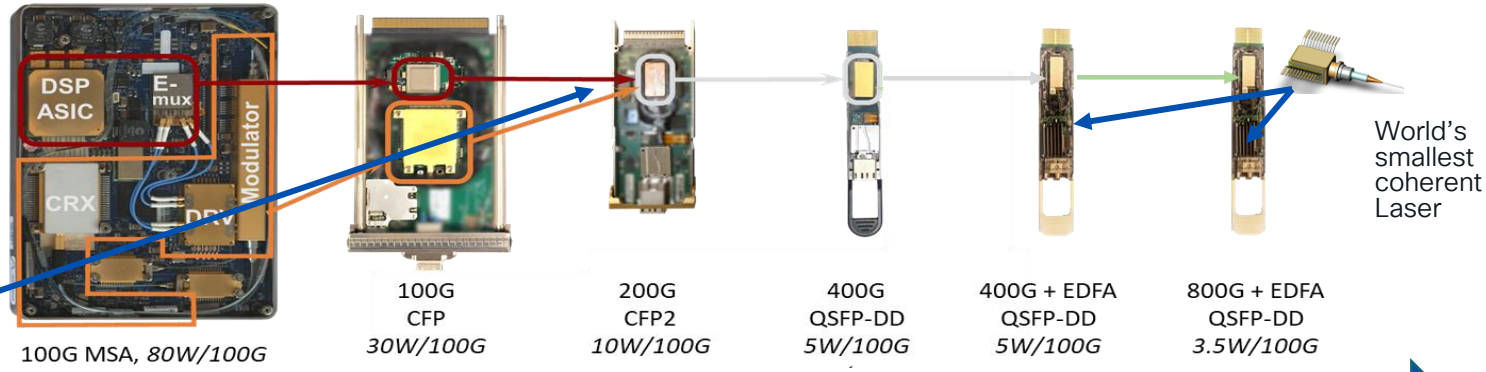
Innovation and Advancement in Silicon Photonics (SiPh & Digital Coherent Optics)





In-House:	DSP	+ SiPh Optics	+ OE-MCM	+ ASIC	+ Laser	100% Integration
QAM:	QPSK	QPSK	16QAM	16QAM	PCS	
CMOS:	40nm	28nm	16nm	7nm	4 nm	
Optics:	Discrete, InP, LiNbO3	SiPh	SiPh	SiPh	SiPh	

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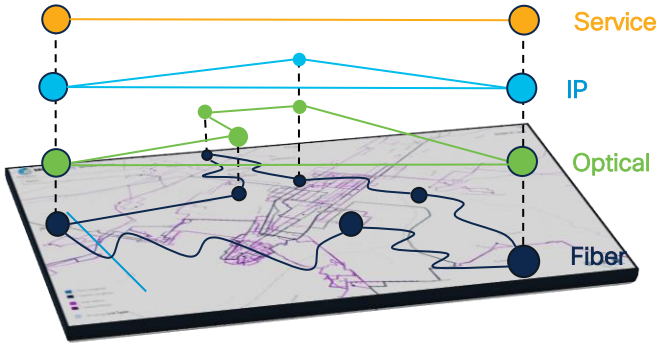
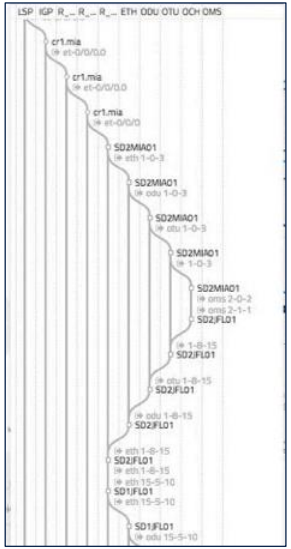
Innovation and Advancement in Automation and Visualization

Network Model – from service to fiber



Layered service view in Hierarchical Controller UI



Visualization of a protected private line service – zoom-out and zoom-in views

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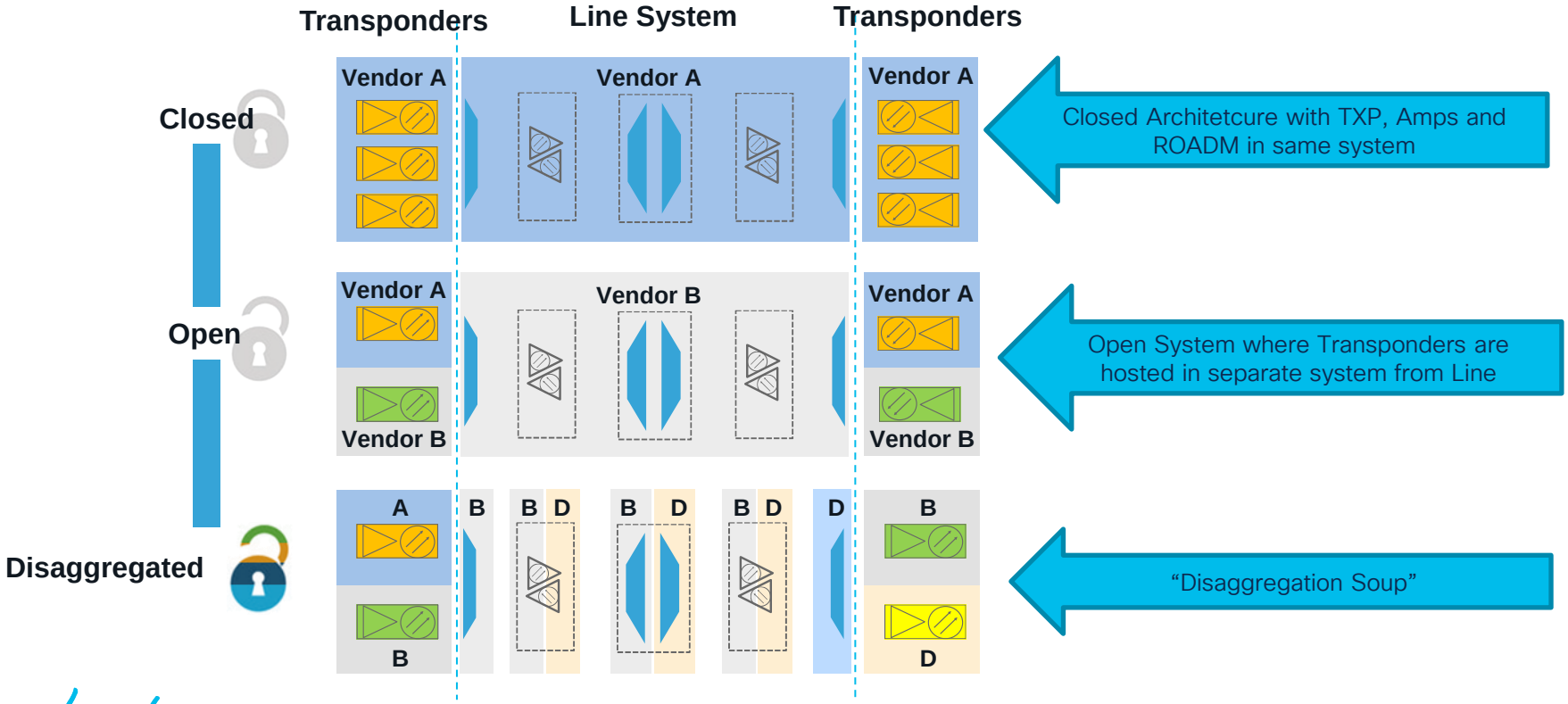
The Move Towards Disaggregation and Openness (away from closed)



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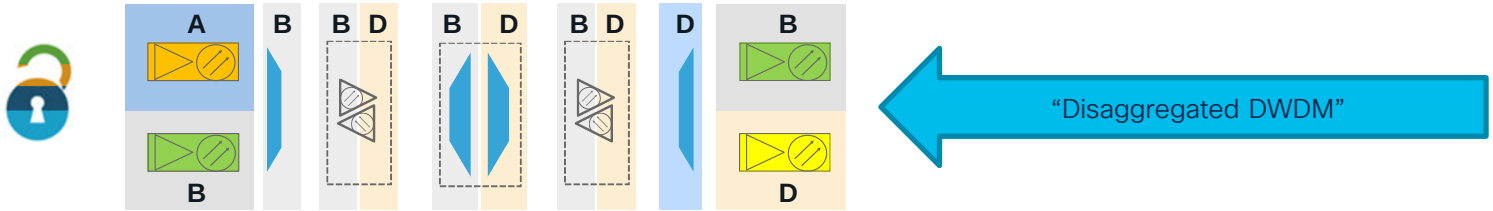
Open/Disaggregated Line System MSAs

- **OpenROADM** MSA (Multi-Source Agreement):
  - Targeting Metro/Edge applications
  - Driven by ATT with participation from many influential industry members
- **Telecom Infra Project** (TIP) Initiative:
  - (MSA) proposal for Point-to-Point Systems
  - Strong industry interest (GNPy for open source optical compute)
  - MANTRA

Disaggregated



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Main Standards Influencing DCOs

OpenZR+ MULTI-SOURCE AGREEMENT

- 400Gbps ZR+ pluggable DCO optics

Open ROADM

- Defined Network and component models
- 100 / 200 / 400Gbps Line Side DWDM Spec
- oSEC (Encryption) and OTN
- Architecture for Pluggable Optics Control / Management

OIF

- 400Gbps ZR pluggable DCO optics
- 800Gbps and Co-packaging Framework

TELECOM INFRA PROJECT

- Common OOPT, PSE – GNPY Compute for feasibility
- Disaggregated transponders – Phoenix

ITU

- First 100Gig DWDM Line Side Interop
- Defining 200 / 400Gbps DWDM Line Side interfaces
- Defining FEC for 200 / 400Gbps

IETF

- Defining SDN Architecture
- Defining Transport Models
- Defining Private Line Emulation

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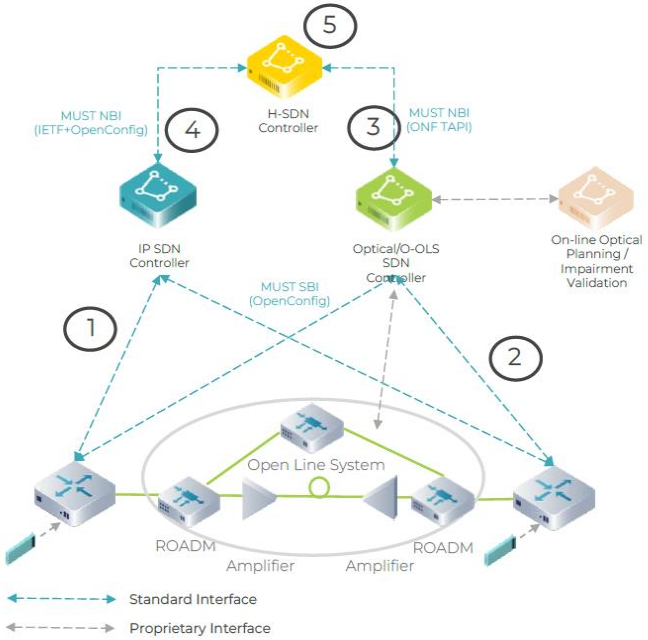
MANTRA Proposal 1 – Dual SBI management of DCO Routers



- **1 - IP SDN Controller SBI** – The IP SDN Controller is the **only entity configuring IPoWDM/ RON routers including coherent pluggable**
- **2- Optical/O-OLS SDN Controller SBI** – The Optical/O-OLS SDN Controller is granted with **read-only permissions**
- **3-The Optical/O-OLS SDN controller NBI** shall expose, path-computation (for OTSi services planning) and service provisioning services for OLS channel services (photonic layer)
- **4-The IP SDN Controller NBI** shall expose the optical line interface O-OLI configuration API.
- **5-The H-SDH Controller** shall be able to orchestrate the whole workflow.

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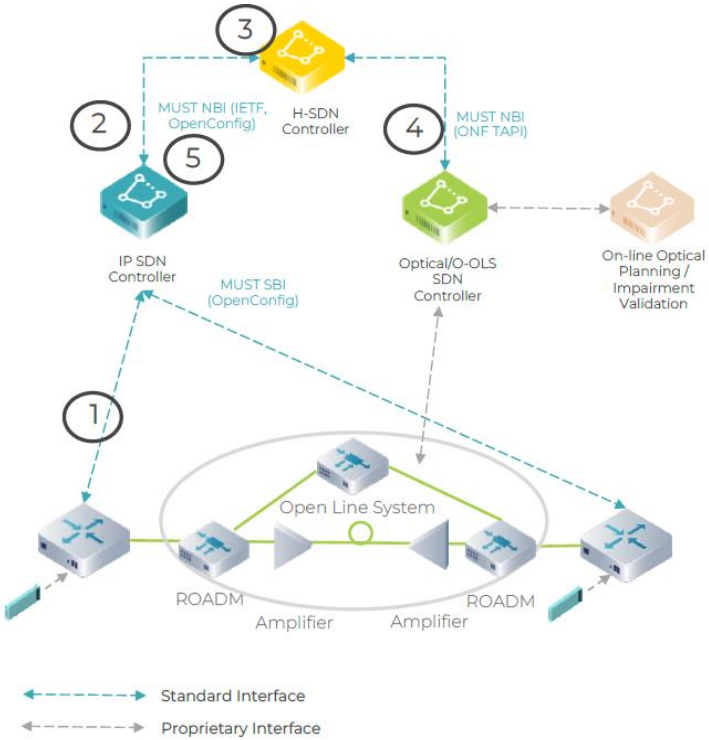
MANTRA Proposal 2 – Single SBI Management of DCO Routers



- **1-IP SDN Controller SBI**
  - O-OLI configuration - The IP SDN Controller is the only entity in configuring IPoWDM routers including coherent transceivers
- **2-IP SDN Controller NBI**
  - Device discovery
  - Performance monitoring
  - Fault management
- **3-The H-SDN SDN controller functions**
  - Multi-layer topology and service model – consolidation of the l3/L0 network and service model
  - Service provisioning - when a new multi-layer service needs to be provisioned the H-SDN Controller
- **4-Optical/O-OLS SDN Controller NBI**
  - Network Planning and Path computation:
  - O-OLS Service provisioning
- **5-The IP SDN Controller NBI: Expose the optical line interface O-OLI configuration API.**
  - O-OLI configuration

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Technology Trends and Innovation Summary

- Advances in SiPh @ 400G/800G lead to standardization of 400G DCO in a QDD-FF
  - Ex: 400G Open ZR+ MSA, OIF. Industry alignment on making 400G DCO Interop and evolving to 800G

- Innovation in Silicon leading to breakthroughs in higher per port router capacity and overall lower cost/power per bit (50 Tbps +).

- Optics $spent exceeding routers platform $spent at 400G and beyond to the point where the cost contribution between Routing and Optical flipped.

- Traditional Optical is becoming more expensive. DCOs integrated in routers becoming a game changer.

- Need for automation to streamline operations.
  - Ex: Advancement in Automation for IP+Optical coupled with the standardization for Higher Layer Controllers (TIP MENTRA/IETF) away from EMS based architectures.

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Routed Optical Networking Architecture, Benefits and Building Blocks

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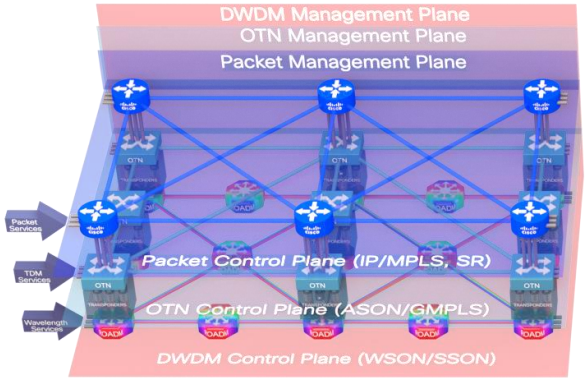
Routed Optical Networking Architecture



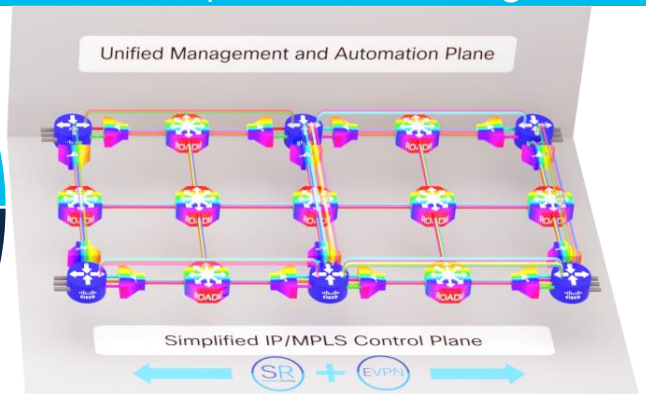
Today's Networks
3-4 Layered Architecture

Collapses 3 layers into 1

- 1 Switching Element
- 1 Control plane
- 1 Services layer

Single pane of glass

Internet for the Future
Routed Optical Networking



Route when you can and ROADM when you need to

RON is to Networking what EVs are to the Automotive industry as it redefines the way we build IP and Optical Networks by simplifying by providing a more sustainable way to build networks

3S' of RON :
Simplification, SavingsSustainability

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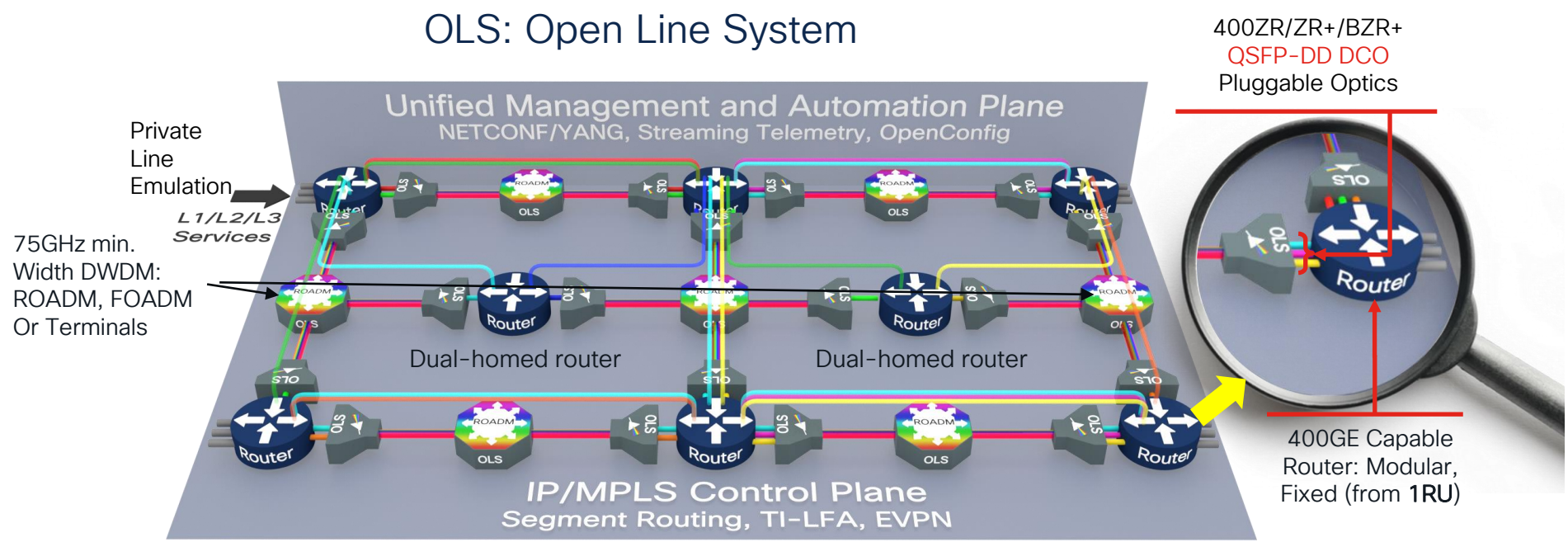
Routed Optical Networking Architectural Details



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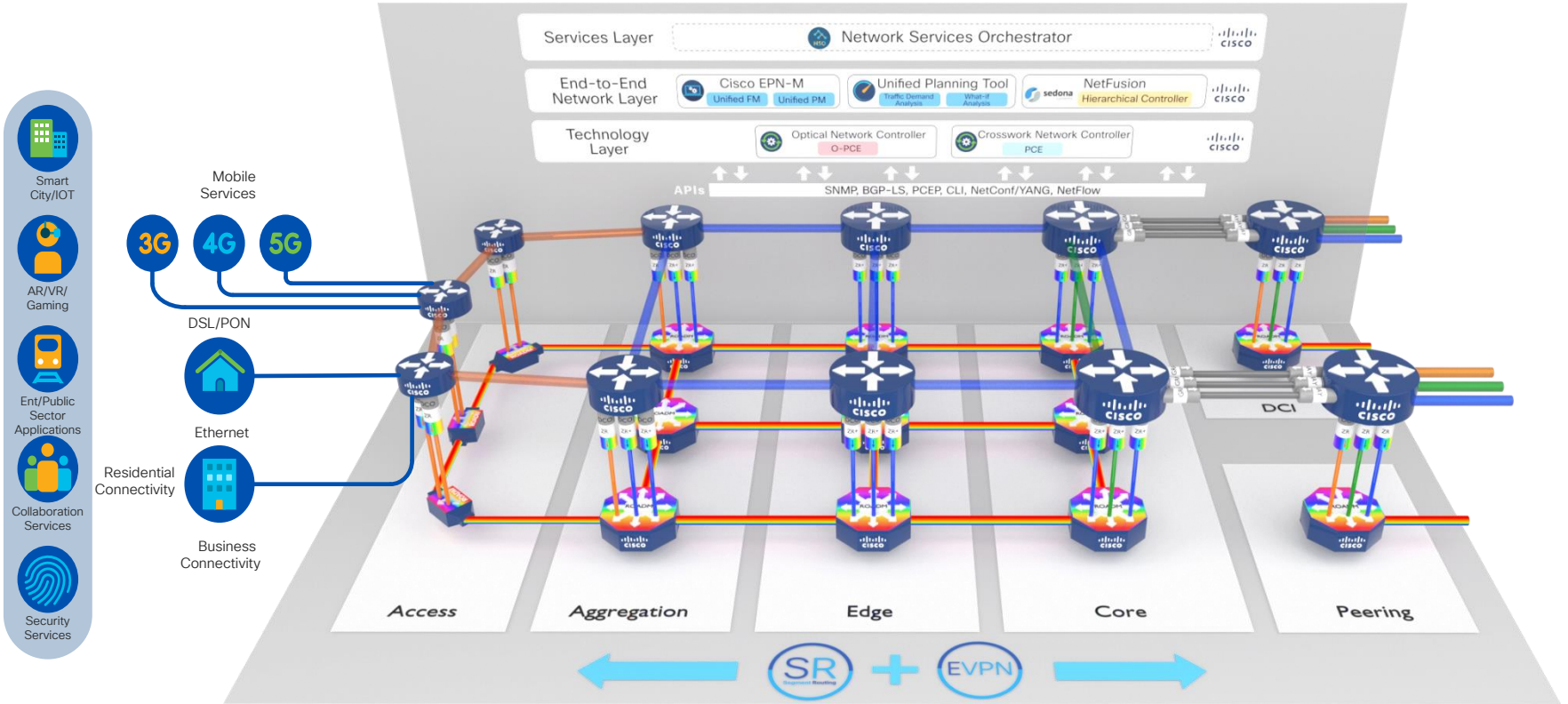
Routed Optical Networking – Applicability & Use Cases



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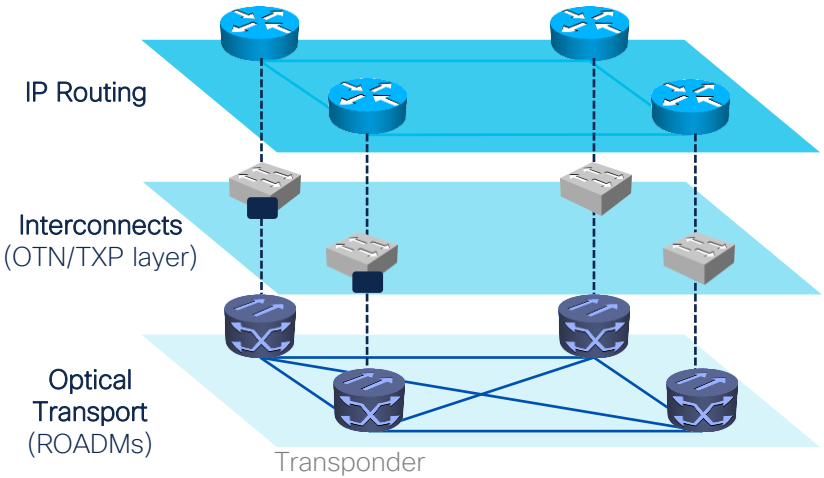
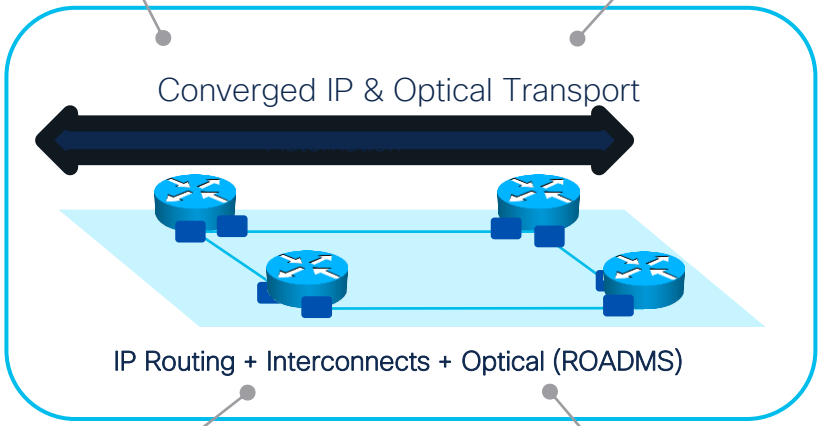
RON TCO Benefits – an ACG Research Findings

Traditional Layers in IP Transport Networks



Lower TCO with higher services agility incl PLE

Fewer platforms: easier to manage, more secure, more predictable

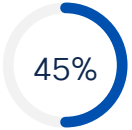


Reduced space and power requirements

Convergence: Simplification, savings & Faster time to market

CapEx Savings*

OpEx Savings*



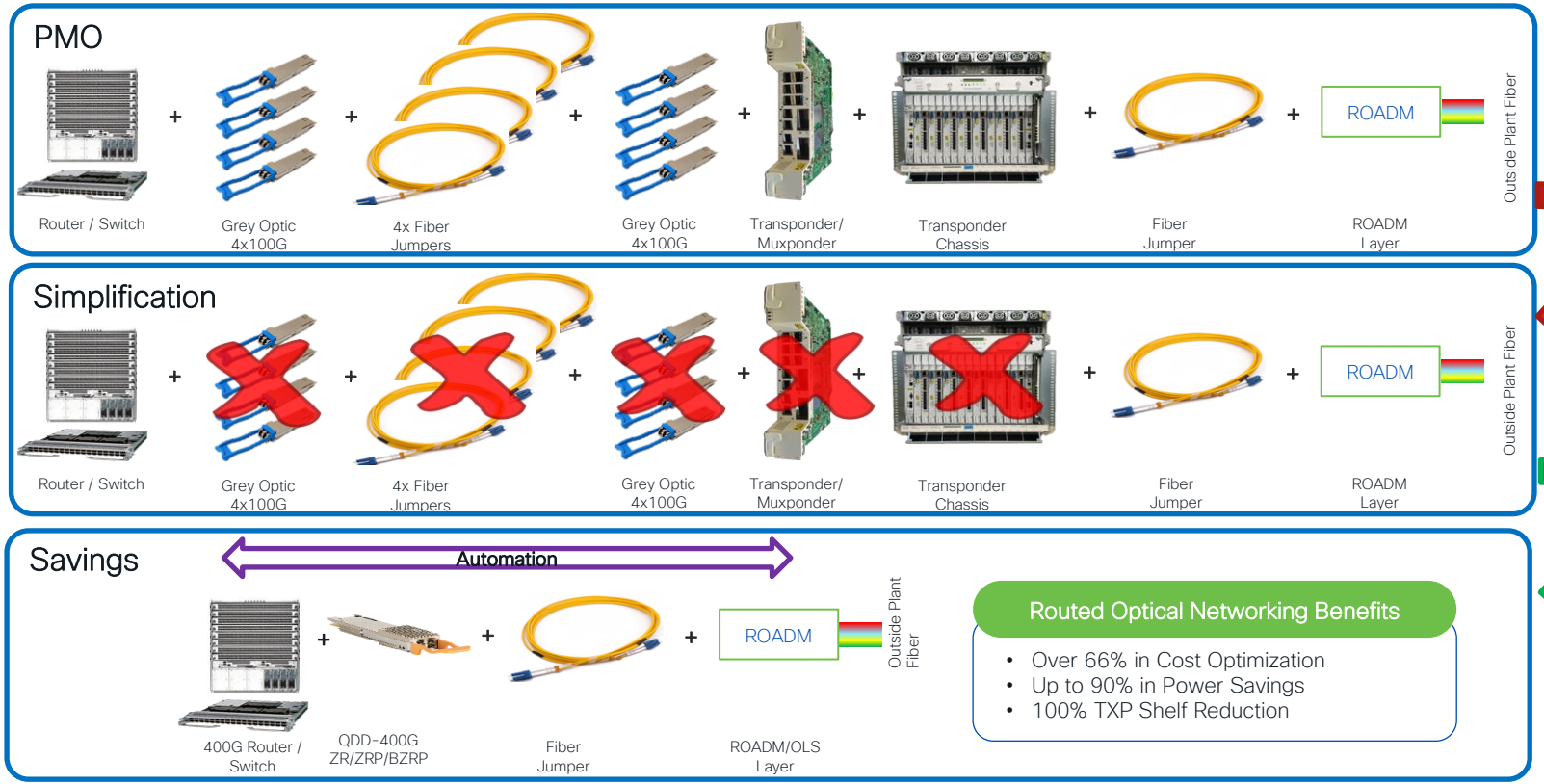
TCO Savings*

Power savings vs. transponders

*ACG Research

RON TCO Benefits – Cisco on Cisco

Sustainability



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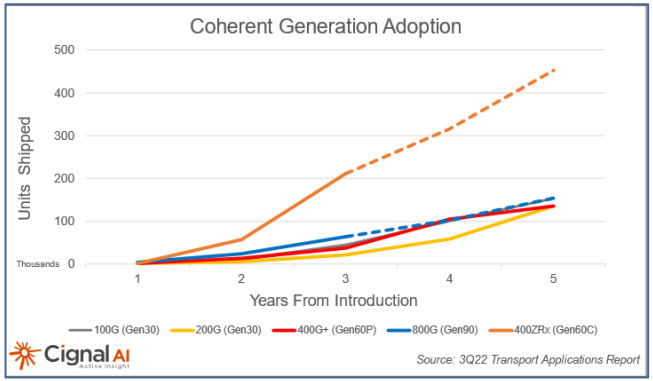
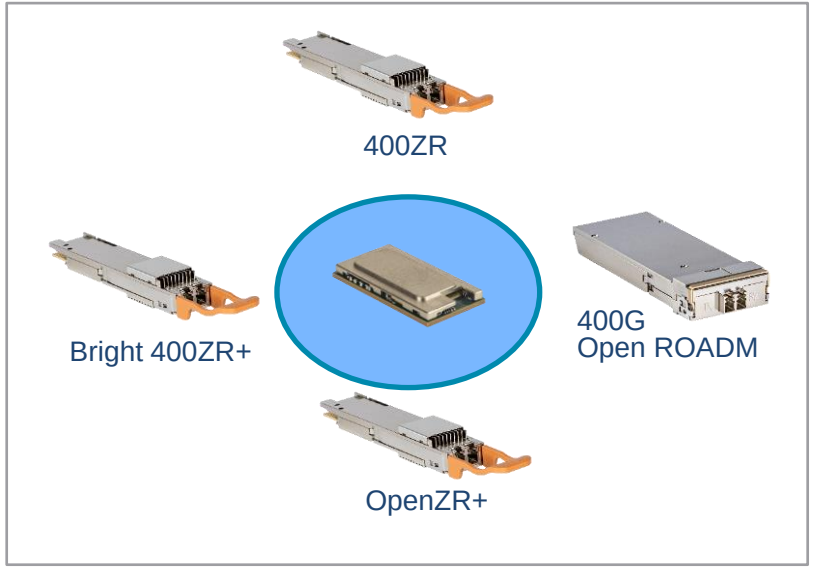
DCO Form Factors and MSA



- Significant market size



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400G QSDD Digital Coherent Optics Applications

ER1

Point to Point
Intra-data center, campus interconnect, core-to-edge router

Lowest Cost
Based on fixed laser with simple point-to-point connectivity

Short Reach
Up to **45KM** for unamplified at 13dB

ZR

Point to Point
Web, Data Center Interconnect, Non-SP/SP router interconnect

Low Cost
Lowest cost 400G DCO option for very simple designs

Short Reach
Up to **120KM** for P2P amplified links

ZR+

Data Centric
Web Scale, DC Interconnect, Non-SP/SP Router Interconnect

Cost Optimized
Essential power and features only to optimize for cost

Simple Features
Designed for open line systems that balance power levels; high-performance forward error correction
1000Kms Reach (400G)

Bright ZR+

Transport Centric
Service Providers, Routed Optical Networking

High TX Power
+1dbm for difficult spans; interop with brownfield transponder & legacy line systems

Advanced Features
TOF, OTN and L1 Encryption features; integrated optical amplifier
1500Km reach (400G)

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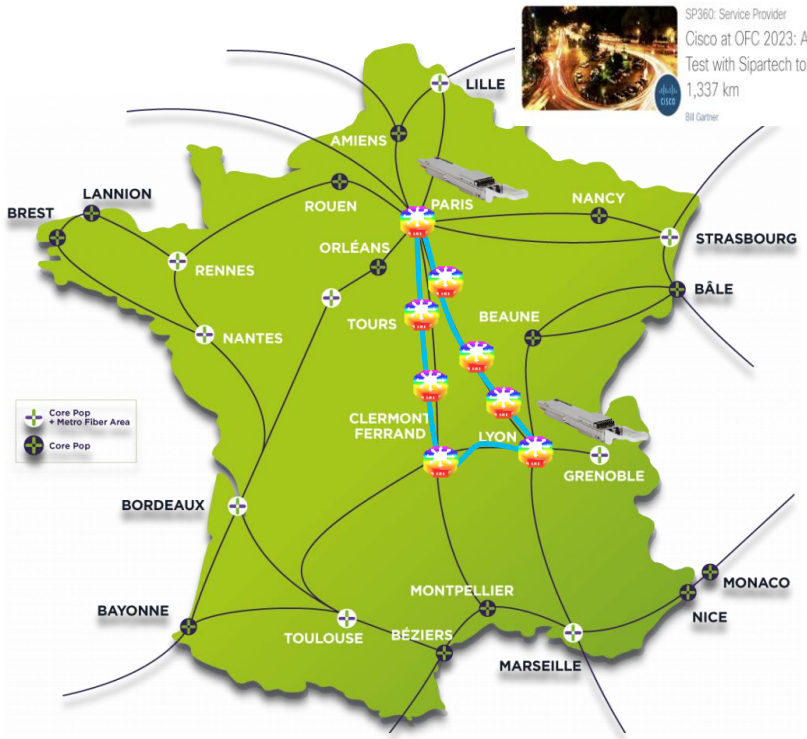
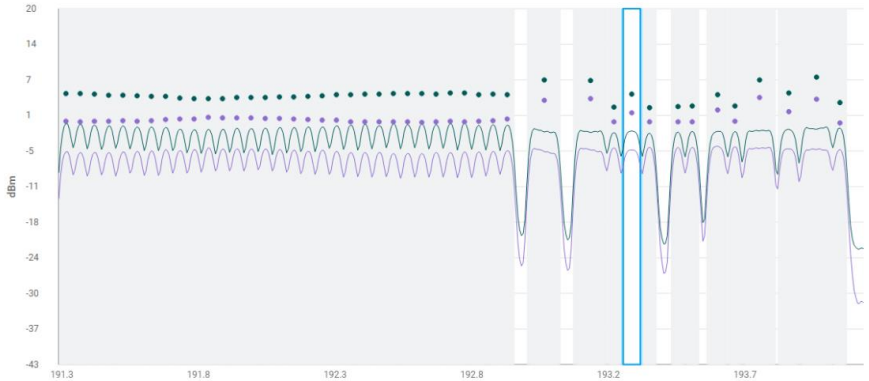
Sipartech Example : 400G BRZP 1337km



- Mixed SMF28 and E-LEAF fiber with 8 ROADM sites
- Alien λ over 3rd party CDC ROADM line system, plug and play!



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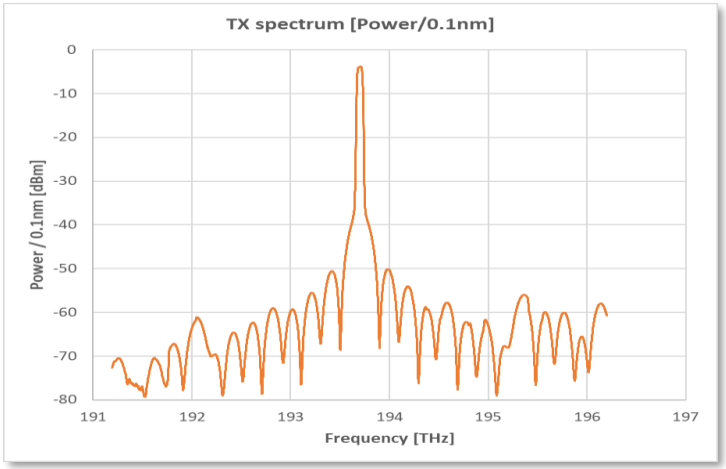
QDD 400ZR+ Pluggable for Any ROADM Networks

- **Applications:**
  - Seamless deployment in ROADM line systems (e.g., architectures w/ colorless multiplexing)
  - Transponder performance with Router deployment model and no faceplate density penalty
- **Key Features:**
  - 400G ZR+ QSFP-DD pluggable with up to **+1dBm TX Power**
    - Includes integrated TX EDFA and Tunable Optical Filter
    - High TX power in all operating modes
    - Enhances by about 12dB the un-amplified reach of ZR+
    - Increased OSNR performances in ROADM networks – OSNR tolerance : 22.1dB in om1nmW



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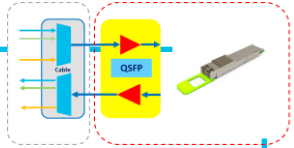
OLS Simplification w/ QSFP-DD Pluggable



Overview

- Bi-directional EDFA integrated into QDD
  - Up to 17dBm Output Power
  - 7dB to 25dB Gain Range for Booster EDFA
  - 2dB to 25dB Gain Range for Pre-amplifier
  - 2.4THz C-band range
- Supports up to 32 channel systems

Benefits

- No need of external WDM system for point-to-point applications
  - Everything embedded in the router
  - No need to manage/operate/upgrade/plan an external WDM system
  - Extremely simple to install and use without any need of optical expertise
- Various solutions with few channels (FLD4 FOADM up to 64ch Mux/Demux for 32x 400G point-to-point system

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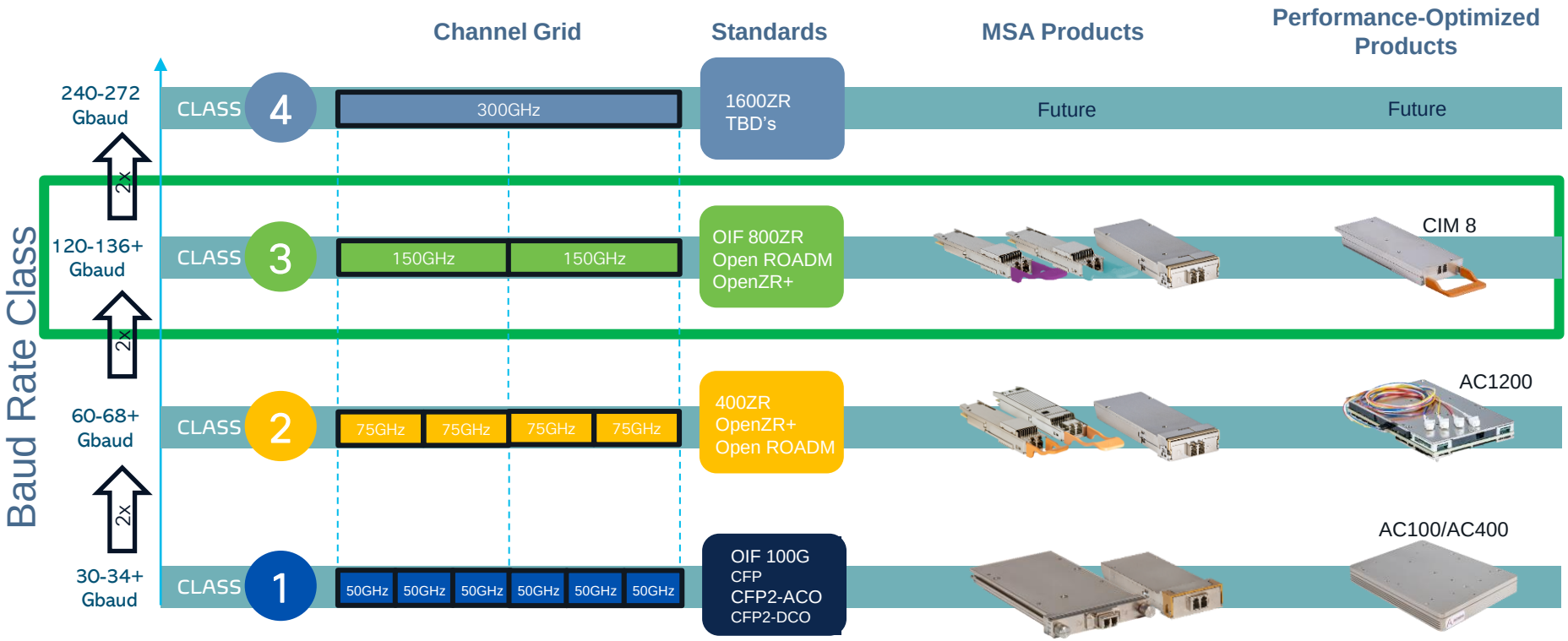
Coherent DCO Are Here To Stay !



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Coherent Transceivers Evolution

2021 | 2022 | 2023 | 2024 | 2025 | 2026

MSA Pluggables

400G(60GB+)
400ZR/ZR+ OpenROADM
BiDi

Bright 400ZR+

800G (120GB+)
800ZR/ZR+
400G LH

1.6T (240GB+)
1600LR/ZR/ZR+

DSPs

CMOS Node

ACACIA Greylock 400G ZR/Metro/LH

7nm

ACACIA Jannu 1.2T DCI/Metro/LH Single-core

5nm

ACACIA Delphi 800G ZR/ZR+

4nm

ACACIA NN-1 1.6T ZR/LR

2/3nm

ACACIA NN-2 2.4/1.6T DCI/Metro/LH

2nm

Performance Optimized

1.2T (138GB+)
C-band

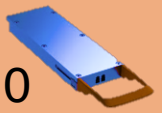
CIM 8

1.2T (138GB+)
L-band

CIM 8

2.4T (256GB+)

CIM10



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Performance vs Power Optimized Solutions

DSPs

400G, 64GB — 400ZR/ZR+ Greylock

1.2T, 140GB — 1.2T Multi-Haul Jannu

800G, 120GB — 800ZR/LR Delphi

1.6T, 106GB — 1.6T DR/FR/LR

7 nm | 5 nm & 4 nm | 3 nm

Modules

400ZR/ZR+

5nm 1.2T Jannu

1600 DR/FR/LR

400G Bright QDDZR+

800ZR/ZR+

400ZR++

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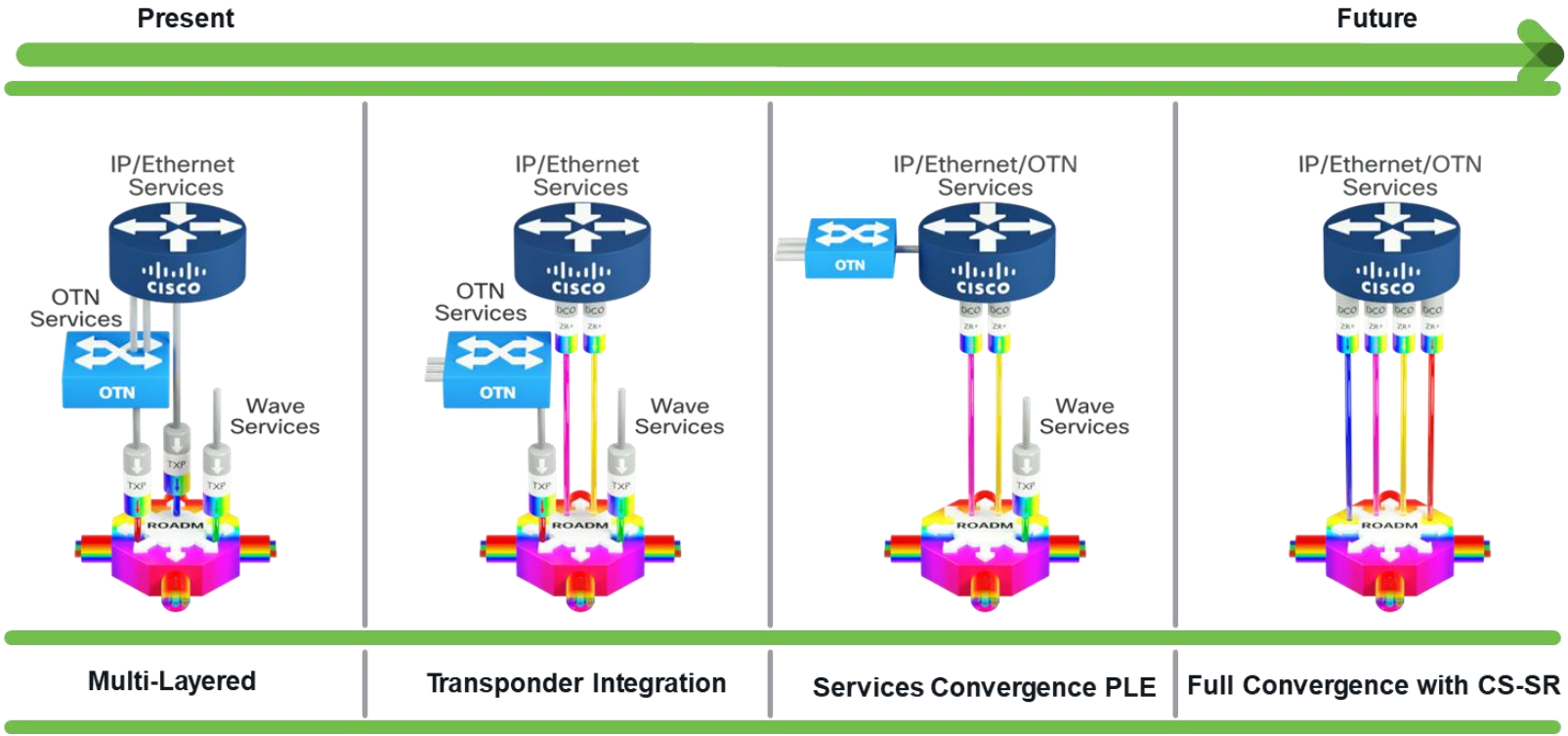
Full Services Convergence with RON

Routed Optical Networking Evolution



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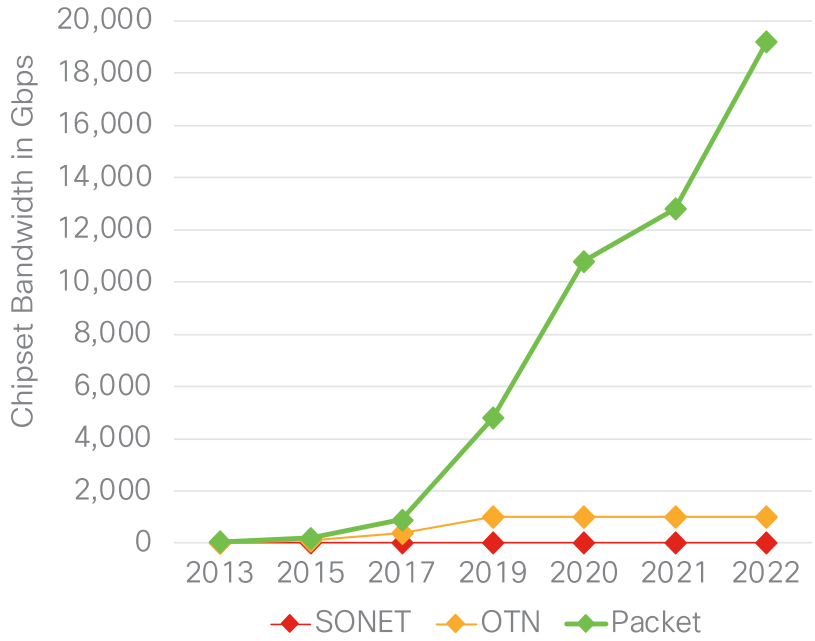
Why the need for a Converged Transport Architecture

- OTN chipset investment is already stalling now
- Pure packet chipsets show dramatic scale and power improvements
- Hence the need for a fully converged services (TDM/packet) architecture



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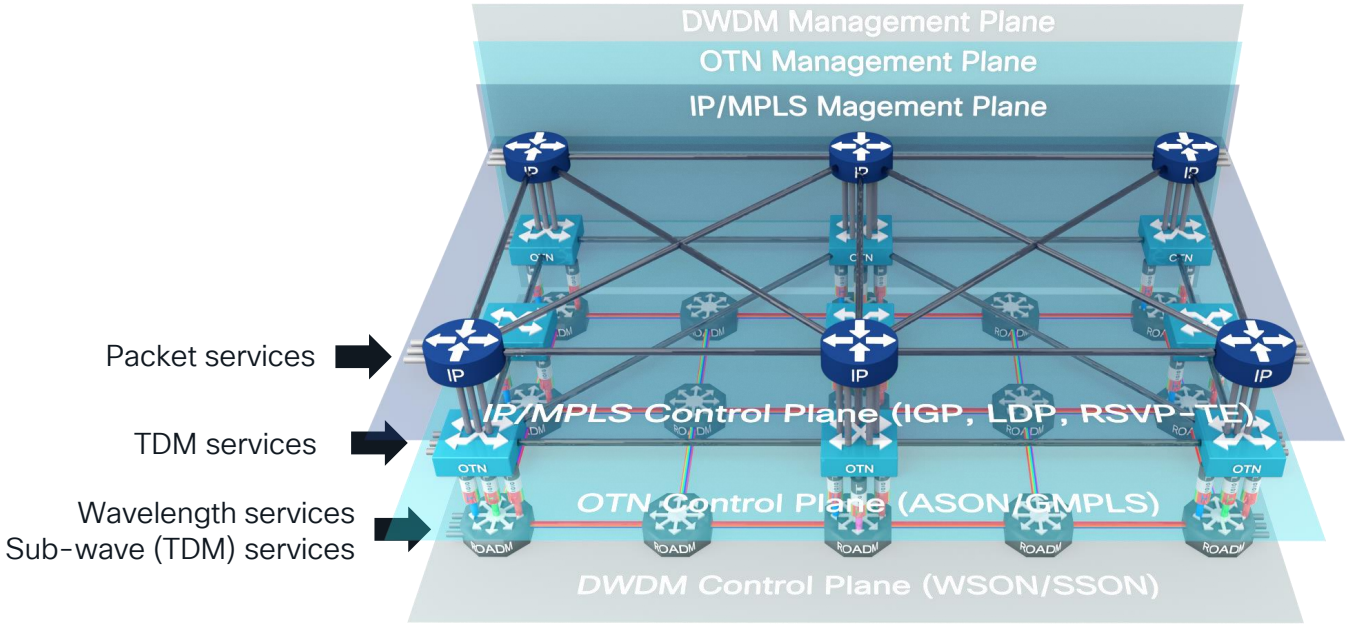
Services convergence

Today, most private line services run over dedicated transport networks



Justification:

- Transparency
- Non-Ethernet services
- Stringent SLAs
  - Bandwidth Reservation
  - Sub-50ms protection
  - Restoration (1+1+R)
- In-band OAM
- Clocking

What if a packet network could meet all these requirements?

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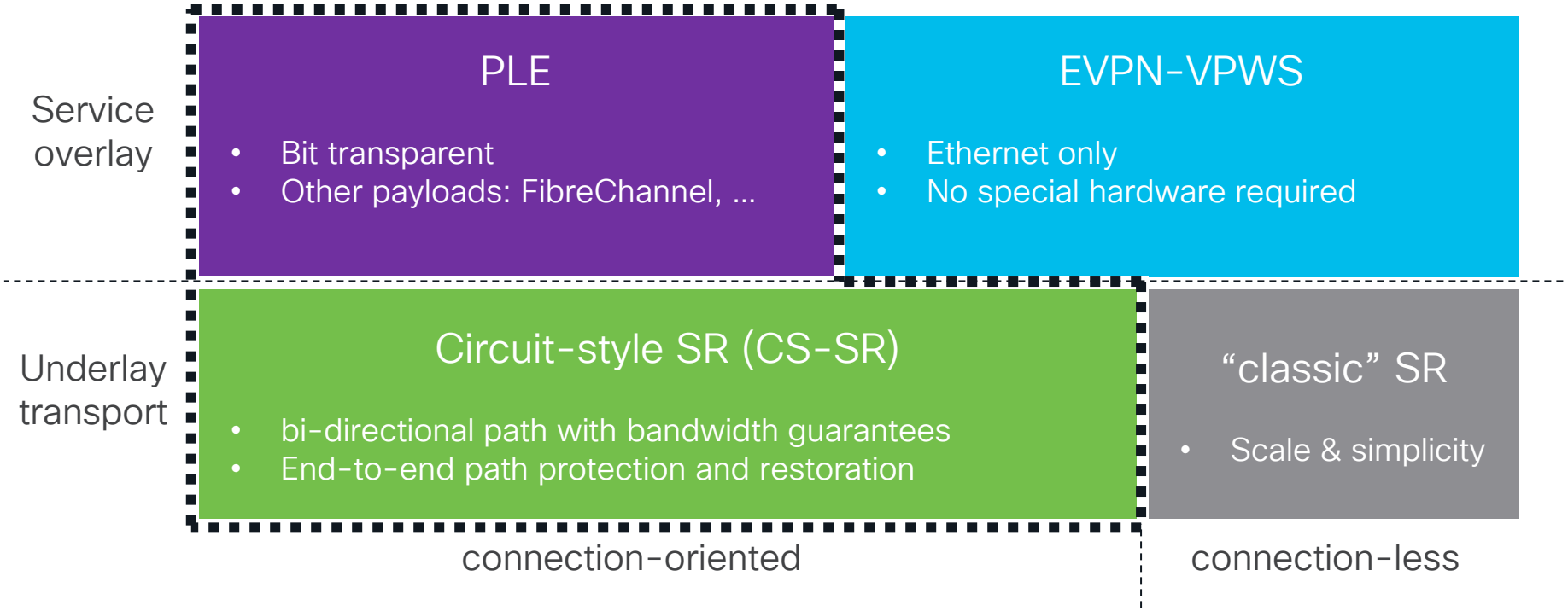
Introducing PLE and CS-SR



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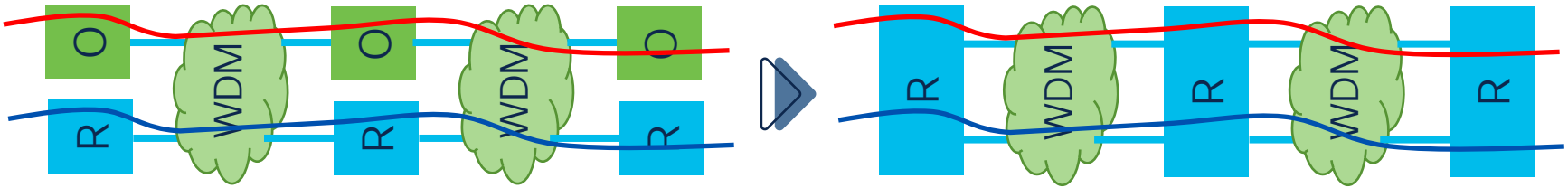
Value to Customers

- Removal of OTN switching or static muxes → OpEx savings
- Solution for cutomers trying to migrate away OTN
- Support for Fibre Channel
- Betting on the right ASIC horse → investments in OTN are low



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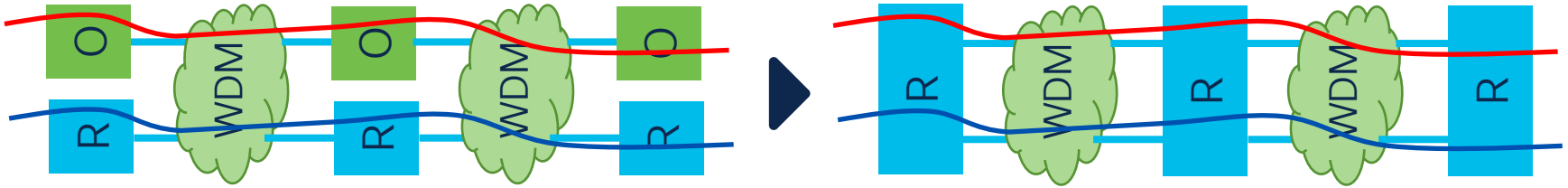
Does CS/PLE Enable CapEx Savings or ‘Just’ Operational Ones?

- **Less wavelengths for working traffic**: Same wavelength can be used for both types of traffic – reducing unused “siloed” capacity on working path
- **Reuse of working capacity:** When CS services don’t use their capacity, internet traffic can use it
- **Lower cost of protection**: Since IP traffic can flexibly use capacity, internet traffic can be preempted for CS/PLE traffic on the protection path



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OTN vs. CS-SR vs. PLE

Feature	OTN	CS-SR	PLE
Deterministic Bidirectional Routing	NMS / Optical Network Controller	Via PCE	Same as CS-SR
Guaranteed Bandwidth	Intrinsic / Flexible (via ODUFlex)	BW Booking CES/PW/PLE CAC	Same as CS-SR
1+1 APS (<50 ms)	1+1 / 1:1 APS	1:1 path protection (50 msec)	Same as CS-SR
1+1+R/1+R	Yes	Yes	Same as CS-SR
Multi-service	Yes	No	Yes (roadmap driven)
Bit Transparency	Yes	No	Yes
Specialized HW	Yes(*)	No	Yes: specific Adaptation Points (Pizza-box / MPA)
Statistical Multiplexing	No	Yes	Yes

(*) It requires an OTN box

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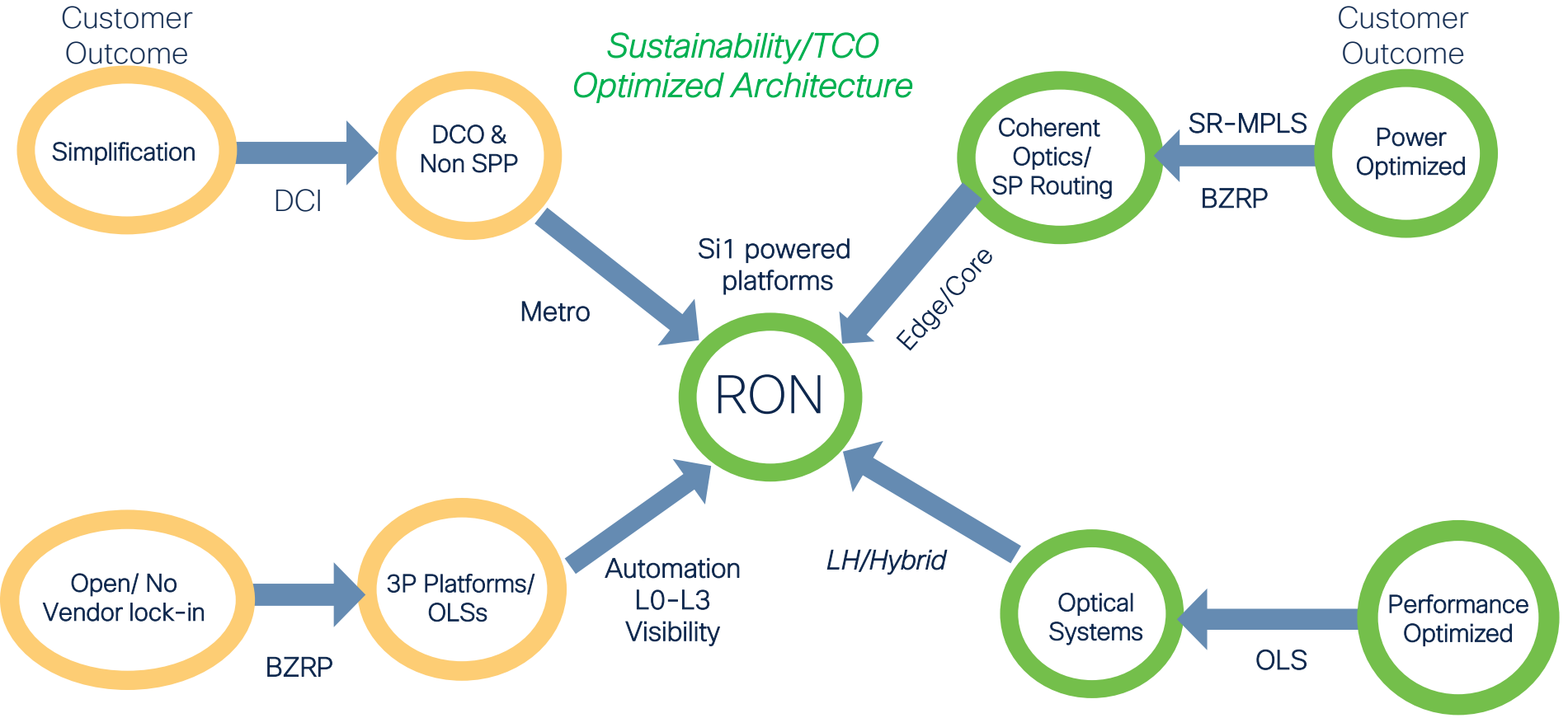
RON Journey and Future Evolution

RON Journey and Vision : “All Roads Lead to RON”



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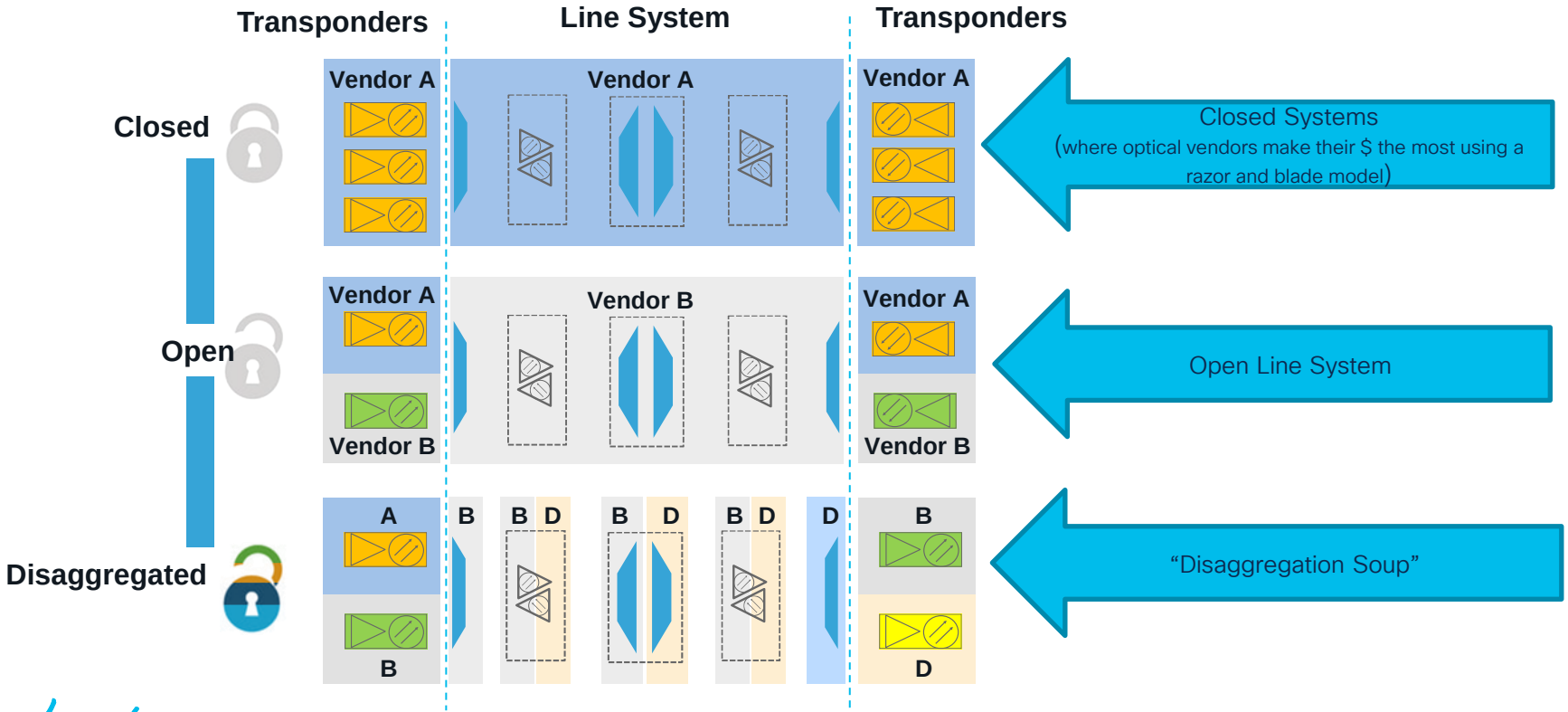
Open Line Systems and Open ZRP/ROADM MSA Interop



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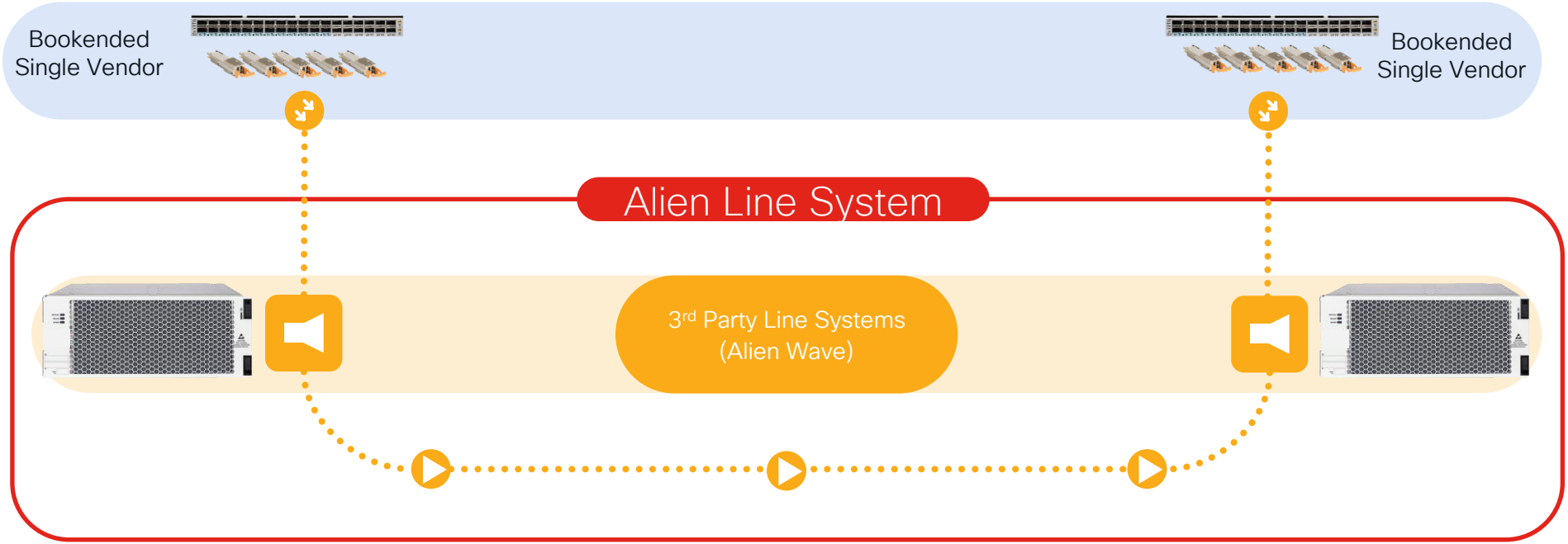
Disaggregation and Alien DCO



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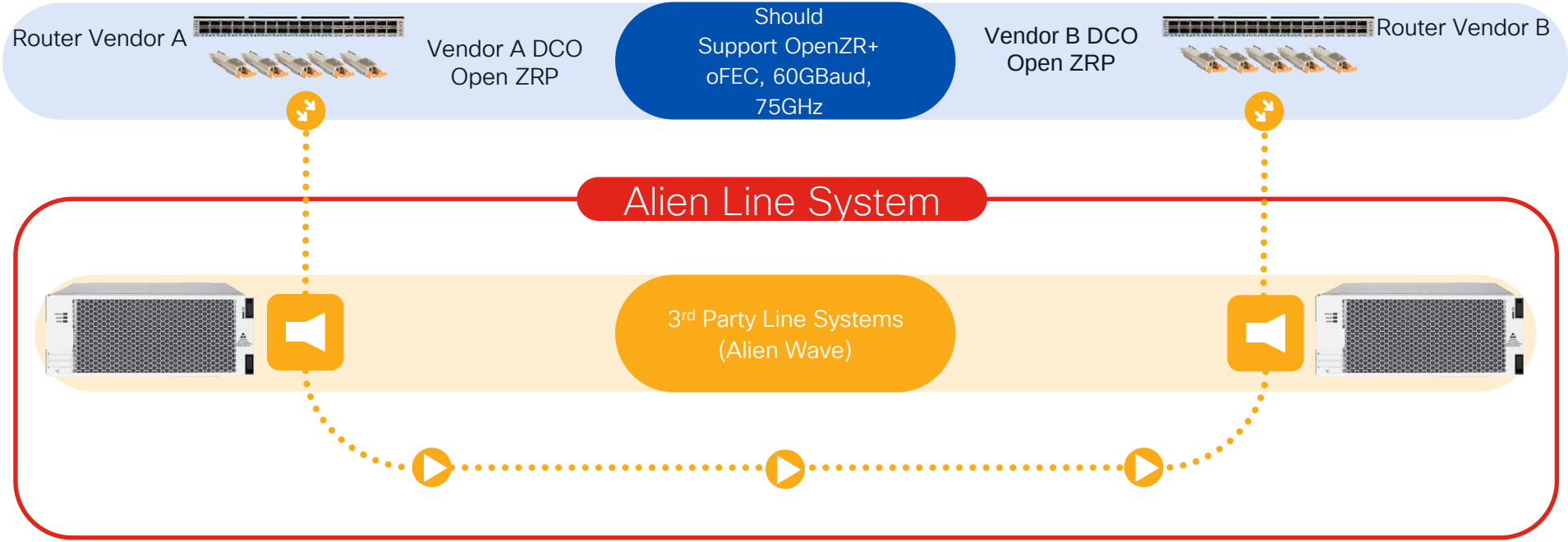
Disaggregation and DCO Vendor Interop



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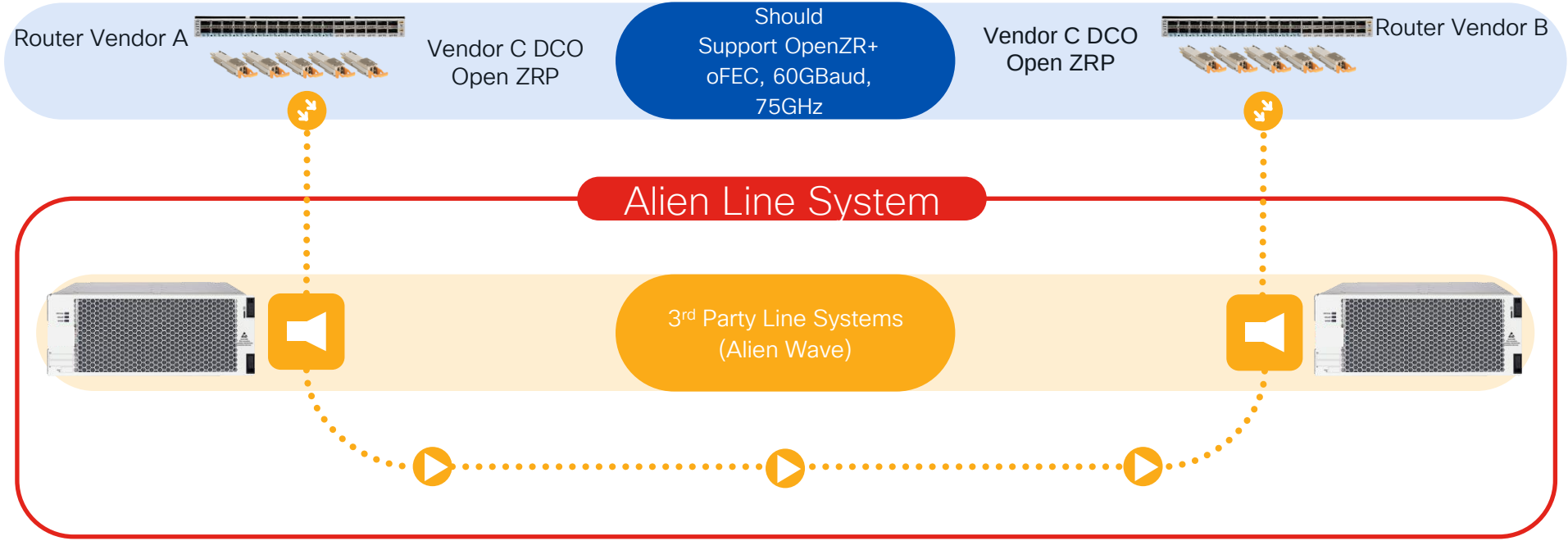
How about Disaggregated Host with DCO Vendor Interop ?



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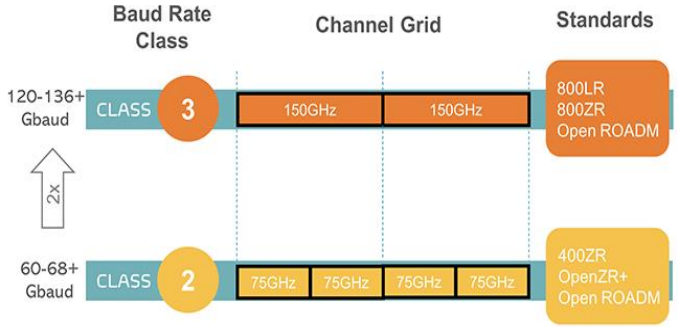
800G OIF & CMIS Standardization Update

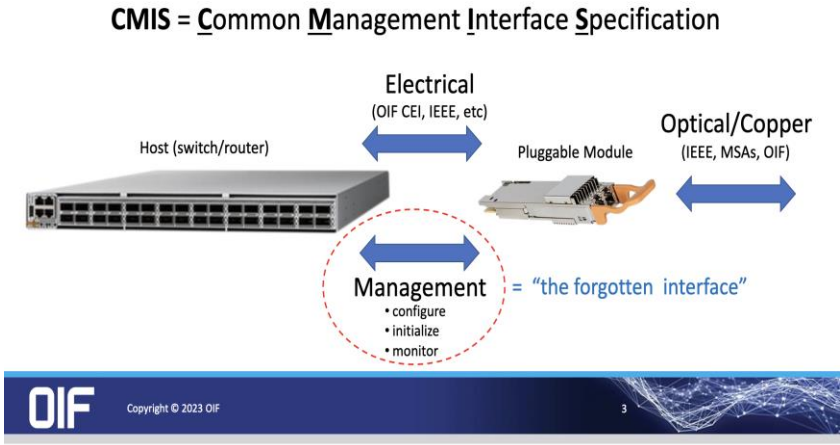
OIF

- At 800G, the industry has converged to 2x scaling of baud rate resulting in Class 3 ~120 Gbaud rates (2x60Gbaud). 800GE client support with channel spacing requirements double to 150GHz for 800G (2x75GHz)
- Advancements in both high-speed optical modulation and supporting components as well as high-speed 112G-per-electrical-lane(SerDes) capabilities are needed to enable 800G MSA pluggable in compact FF.



Common Management Information Service (CMIS).

- In addition to industry standardization efforts at the optical transmission and client traffic levels, there has been a concerted effort to ensure multi-vendor interoperability of the DCO module management interface through CMIS, defined in OIF.
- CMIS has been recently added a descriptor for **APPSEL code** (Application Select codes) to provision a DCO module which advertises a set of supported APPSEL codes and parameters that can be applied to the DCO module .



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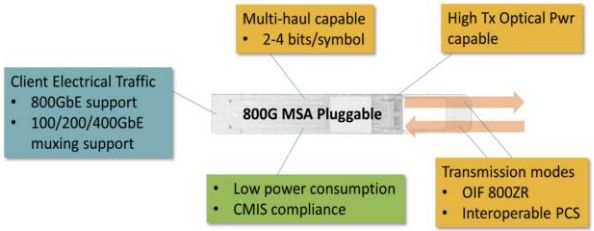
800G OpenROADM and OpenZR+ MSAs



- **Open ROADM(CFP2FF)** is defining enhanced performance modes that include an interoperable probability constellation shaping (PCS) implementation utilizing both **Ethernet and OTN framing** (400G QPSK, 800G 16QAM and 600G/800G PCS on the optical lineside)

- **OpenZR+(QDDFF)** is adopting from Open ROADM PCS for multi-haul approach for. This capability was standardized in Class 3 ~120Gbaud solutions and can be used for 800G metro/regional reaches **(Ethernet Clients)** and for multiple different standard modes at 400G and 600G to address a wide range of network requirements.

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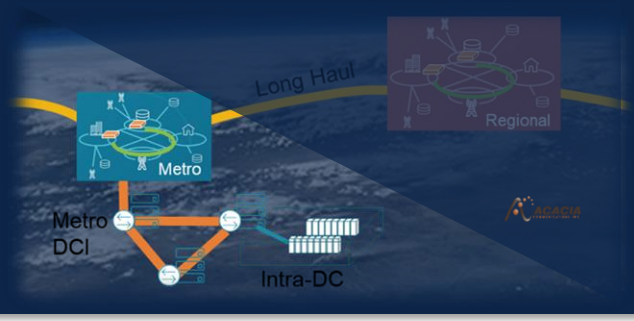
800G MSA Pluggable Coherent Modules

- 120+Gbaud Class 3
- Serdes: 112G PAM4 x8
- Bright variant (optional)
  - Build-in OA and TOF
  - >1dBm Tx output



Client Interface:
- 100GbE: 100GAUI-1/2
- 200GbE: 200GAUI-2/4
- 400GbE: 400GAUI-4/8
- 800GbE: 800GAUI-8

QSFP-DD800

Line interface:
- C-band Tunable
  - 800ZR
  - 800G PCS (130+Gbaud)
  - 600G PCS (118 & 130+GBaud)
- 800G LR1/ER1/ZR1 – Fixed λ

Client Interface:
- All above Ethernet
- OTN: FOLC 1.1/2

CFP2

Line interface: C-band Tunable
- 800G PCS (>130Gbaud)
- 600G PCS (>130GBaud)
- 400G PCS (>130GBaud)

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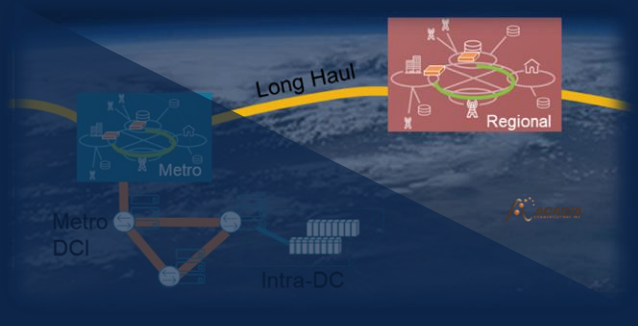
Long Haul 400G MSA Pluggable Coherent Modules

- Serdes: 56G PAM4 x8
- Bright day 1
  - Build-in OA and TOF
  - >1dBm Tx output



Client Interface:

- 100GbE: 100GAUI-2
- 200GbE: 400GAUI-4
- 400GbE: 800GAUI-8

- OTN: FOIC-1.2 (CFP2)

QSFP-DD

CFP2

Line interface (C-band Tunable)

- 400G PCS (96GBaud) for 112.5GHz spacing (2500km nominal)
- 400G PCS (85GBaud) for 100GHz spacing (2000km nominal)
- 400G PCS (69GBaud) for 75GHz spacing (1500km nominal)
- 400G QPSK
- OpenZR+ : 400G, 200G, 100G

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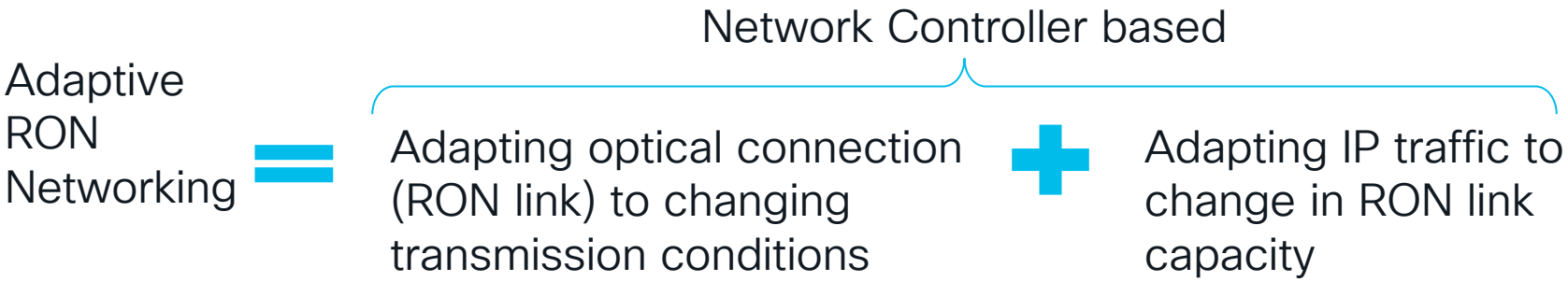
RON Evolution with Adaptive RON Networking



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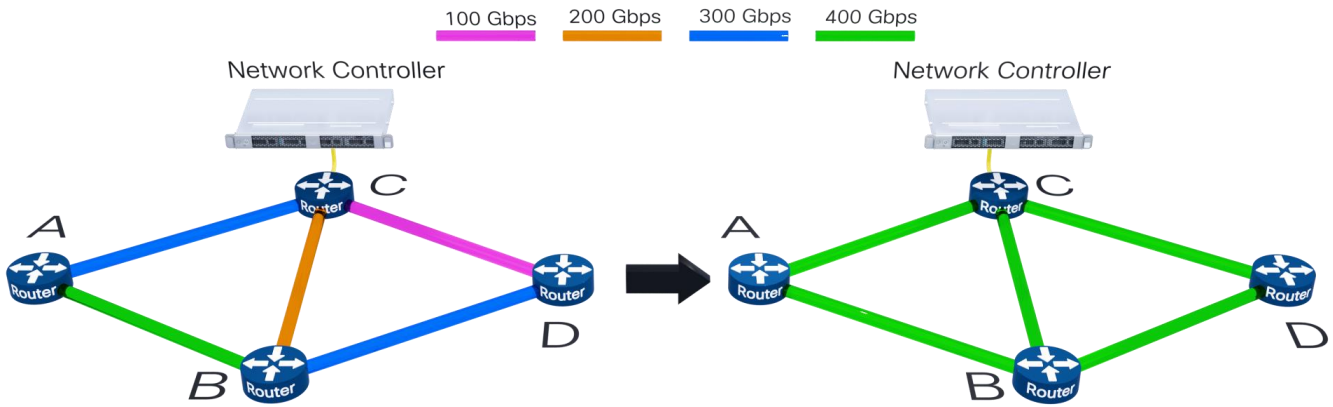
Adaptive Routed Optical Networking

Maximizing use of available optical capacity

1.3 Tbps total network capacity
(deployed day 1 for worst case EoL condition*)

Same network – 2 Tbps of total network capacity
(>50% more capacity under normal BoL conditions**)

Today's network → Adaptive Routed Optical Networking



For networks that rely on optical restoration, Adaptive Networking can recover a lot of network capacity

* EoL: End-of-Life
** BoL: Beginning of Life

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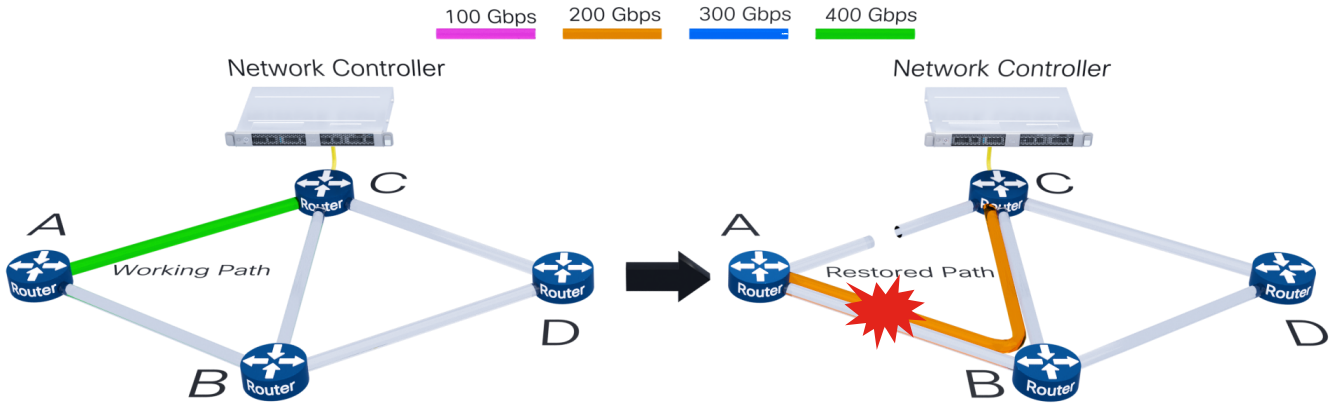
Adaptive Routed Optical Networking

Use Cases – Multilayer Restoration with capacity/spectrum adjustment



Dynamic capacity adjustments for optical restoration

- Upon an optical failure, optical channel is rerouted through a more challenging path. Original link capacity is no longer feasible
- Instead of failing to restore the link, capacity is adjusted based on new path conditions

OR

- Network controller adjusts **spectrum to allow more robust modulation and stay at the 400G level**.

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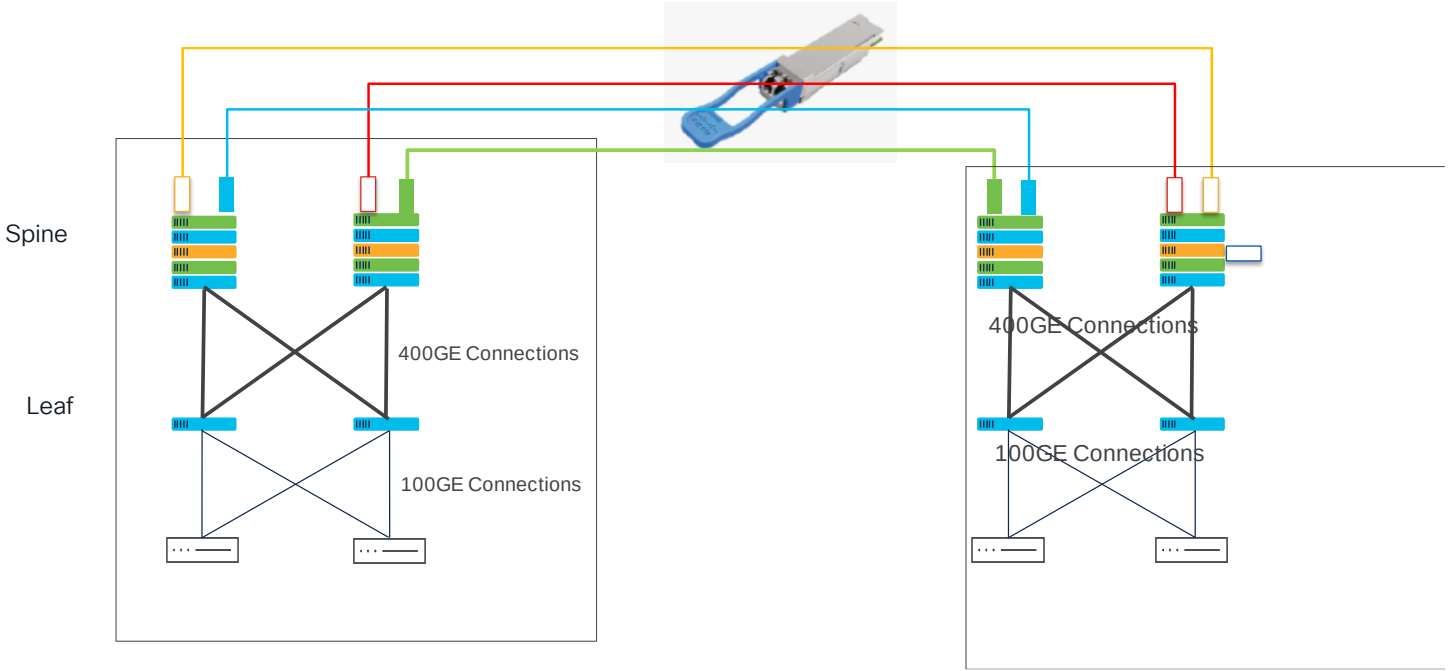
400G/800G ZR/P in Enterprise and DCI Space



- ZR for DCI transport optimization
- 400G/800G wavelength in point-to-point topologies
- AI consideration for ultra low latency latency
- Highly Cost effective as it simplifies further

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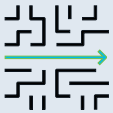
Routed Optical Networking Key Takeaways



Massive Network Simplification

- Integrated IP and Optical network with consistent topologies
- Simpler to engineer, add capacity and automate over a single pane of glass
- Advanced silicon and Silicon Photonics and platform architectures

Improved Network Sustainability & Efficiency

- More efficient use of wavelengths
- Removal of Redundancy in protection and restoration
- Statistical multiplexing
- More traffic aggregation leveraging routers

Full Services Convergence

- L1, L2, L3 services, including high-speed private lines
- Standards based Networking
- No vendor lock-in and ability to interop with other vendors

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Thank you
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