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Designing Routed Optical Networking

IP/MPLS Routing Layer Considerations

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BRKSPG-2029

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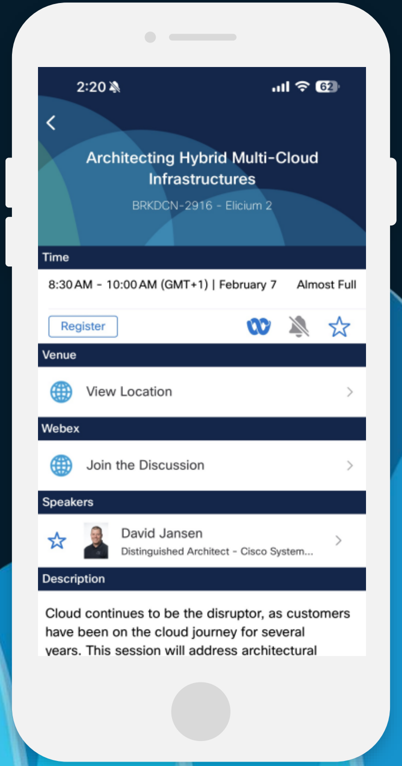


Acknowledgements

- This session was co-authored by:
  David Smith, Distinguished Solutions Engineer
  Cisco Americas Service Provider

Agenda

- Introduction
  - Traditional multi-layer switching
  - Routed Optical Networking (a.k.a. RON)
  - Digital Coherent Optics (DCO) pluggable transceivers
- IP/MPLS routing layer considerations
  - Topology & bandwidth
  - Service convergence
  - Protection, restoration & SRLGs
  - Final considerations
- Summary

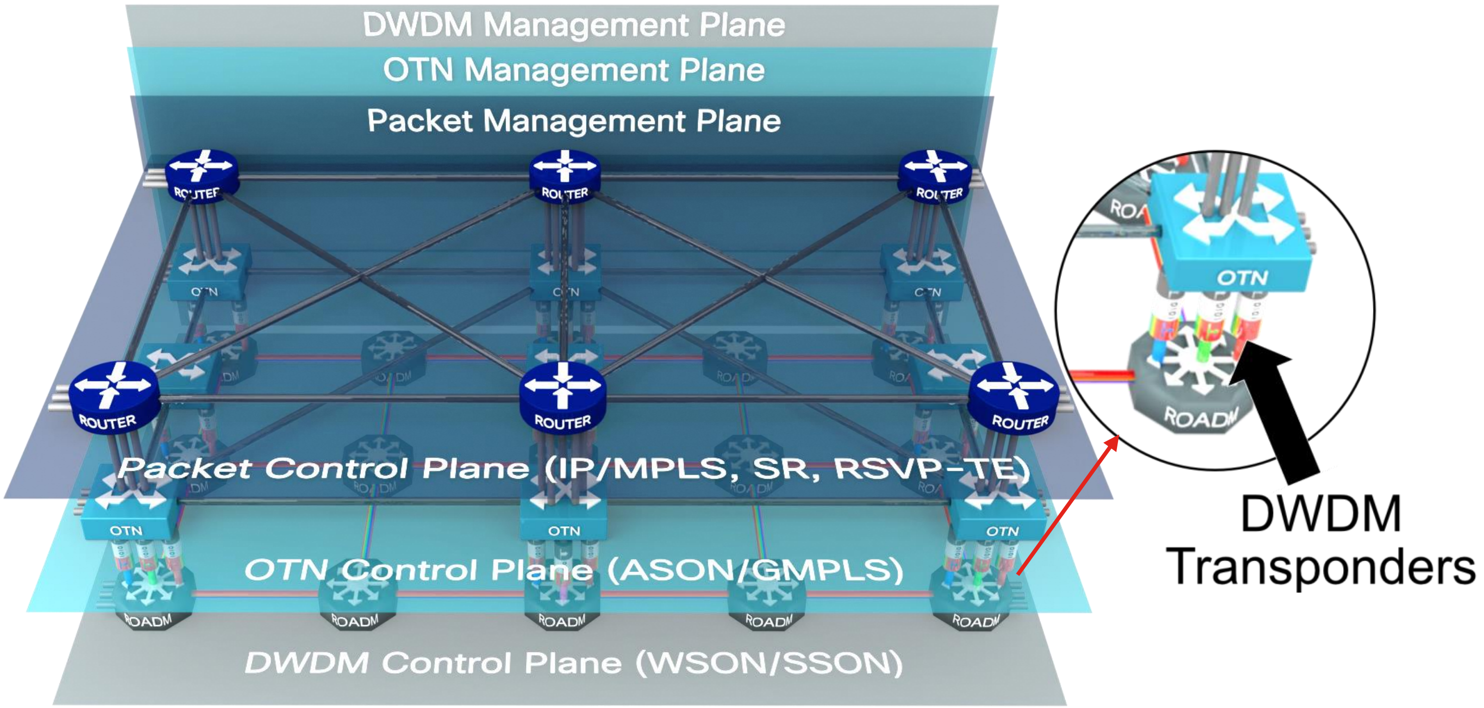
Problem statement

Challenges with traditional layered network architectures

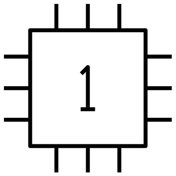
- High costs
- Complexity
- Increasing power and space
- Time to changes and upgrades
- Technology debt

Complexity of traditional network architecture

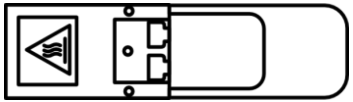
is breaking the economics



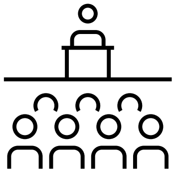
Technology innovations



Multi Tbps Routing Silicon



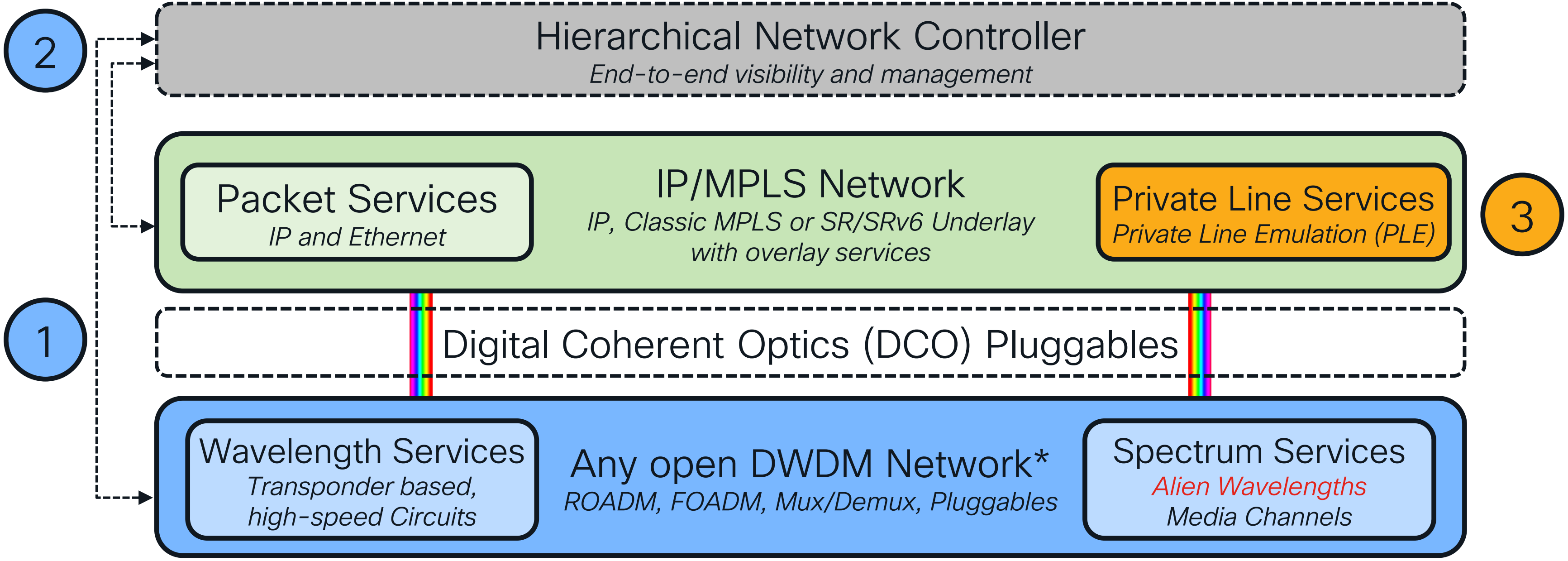
Digital Coherent Optics



Open Specifications

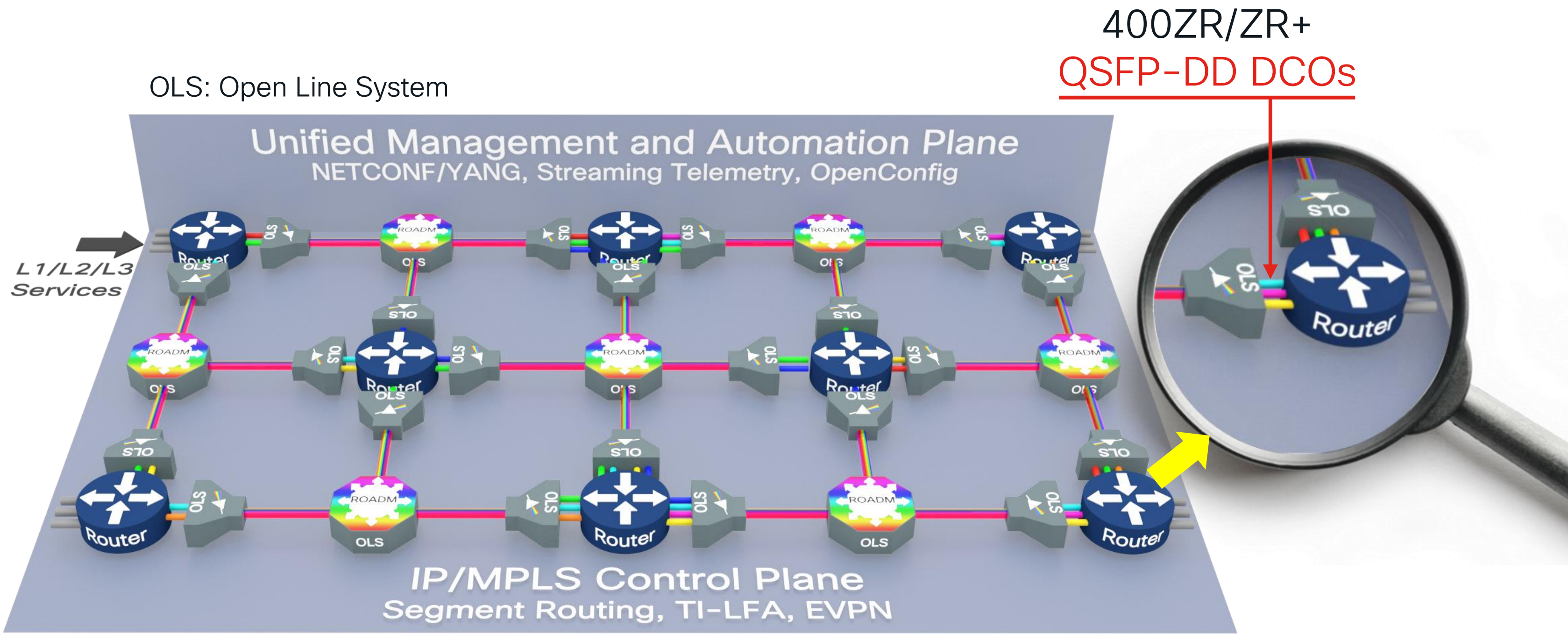
Automation and Controllers

3 steps to Routed Optical Networking



Note: * Any DWDM network that meets intended DCO specifications and performance/reach goals

Routed Optical Networking



Network simplicity, advanced SLAs and lower costs

Value of Routed Optical Networking

Massive Network Simplification

- Integrated network with consistent topologies
- Simpler to engineer, add capacity and automate
- Simpler yet superior silicon and platform architectures

Improved Network Efficiency

- More efficient use of wavelengths
  - *Statistical multiplexing*
  - *More traffic aggregation leveraging routers*
  - *Global traffic optimization (optional)*
- Reduced Power and space requirements

Full Services Convergence

- L1, L2, L3 services, including high-speed private lines
- Optimal traffic forwarding
- Transport SLAs and beyond (latency, security, disjointness)

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Digital Coherent Optics

What is Digital Coherent Optics - DCO

400Gbps
QSFP-DD DCO

Pluggable transceivers with the same coherent optics technology used by latest DWDM transponders and built-in optical DSP

Optimized to be **compact, power efficient** and **compatible** with any type of host (routers, switches, transport)

The value of pluggable DCO transceivers

Transport cost reduction

High-speed Access/Aggregation

Power/Space/Cooling cost reduction

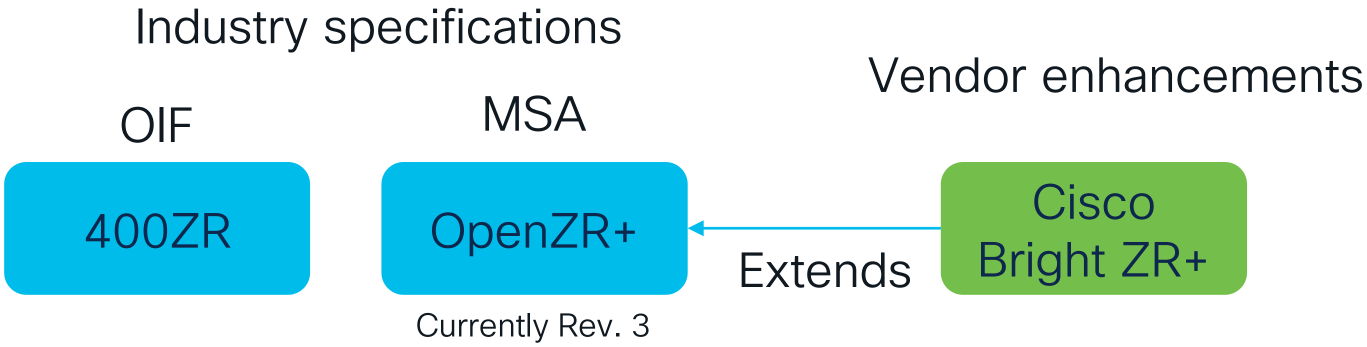
Improve resiliency/OAM

Dark fiber or
or
DWDM applications

DCO

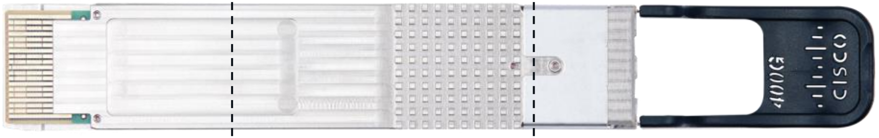
As physics of high-speed optical links become more challenging,
DCO will become a common requirement for inter site connectivity

400Gbps DCO Standards



Anatomy of pluggable DCOs

DCO Standard: OIF 400ZR



Logical Channels
4 x 100GE or
1 x 400GE

Media Channel
400Gbps only

Optical Channel
ITU DWDM Wavelength
and related paramenters

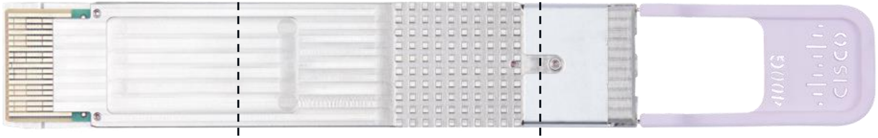
Same as a “gray” transceiver

100GE	400GE
100GE	
100GE	
100GE	

Breakout mode

Anatomy of pluggable DCOs (Cont.d)

DCO Specification: OpenZR+ and Bright ZR+
(Ethernet mode)



Logical Channels
N x 100GE or
1x400GE

Media Channel
100 Gbps,
200 Gbps,
300 Gbps or
400 Gbps

Optical Channel
ITU DWDM Wavelength
and related parameters

Same as
a “gray”
transceiver

100GE ⋮ 100GE	400GE

“Breakout“ mode

Transmit Power
OpenZR+: -10dBm
Cisco Bright ZR+: 1dBm

Note: When Media Channel is < 400Gbps, the host interface works in Nx100Gbps mode

400Gbps pluggable DCOs configurations

Reference

	400ZR	OpenZR+, Bright ZR+ (Cisco)
Clients (Logical Channels)	1x400, 4x100	1x400, 4x100, 3x100, 2x100, 1x100
Trunk Speed (Media Channel)	400 Gbps	400, 300, 200 or 100 Gbps
Frequency	C-Band, 196.1 To 191.3 THz	C-Band, 196.1 To 191.3 THz
FEC	cFEC (concatenated FEC)	oFEC (OpenROADM FEC), cFEC
Modulation	16QAM	16QAM, 8QAM or QPSK
DAC-Rate	1x1 (no oversampling)	1x1.25 (oFEC w/ oversampling) or 1x1 (cFEC)
Chromatic Dispersion (CD)	-2400 to +2400	-160000 to +160000
Transmitted (Tx) Power	Based on the module capability	Based on the module capability

Example: QDD-400G-ZRP-S configuration values

Reference

TXP/MXP*	Client	Trunk	Modulation	FEC	DAC Rate
400G-TXP	1 Client, 400G speed	1 trunk, 400G speed	16 QAM	oFEC	1x1.25
400G-TXP	1 Client, 400G speed	1 trunk, 400G speed	16 QAM	oFEC	1x1
400G-TXP	1 Client, 400G speed	1 trunk, 400G speed	16 QAM	cFEC	1x1
4x100G- MXP	4 clients, 100G speed	1 trunk, 400G speed	16 QAM	oFEC	1x1.25
4x100G-MXP	4 Client, 100G speed	1 trunk, 400G speed	16 QAM	oFEC	1x1
4x100G- MXP	4 clients, 100G speed	1 trunk, 400G speed	16 QAM	cFEC	1x1
3x100G-MXP	3 clients, 100G speed	1 trunk, 400G speed	8 QAM	oFEC	1x1.25
3x100G-MXP	3 Client, 100G speed	1 trunk, 400G speed	8 QAM	oFEC	1x1
2x100G-MXP	2 clients, 100G speed	1 trunk, 200G speed	QPSK	oFEC	1x1.50
2x100G-MXP	2 Client, 100G speed	1 trunk, 400G speed	QPSK	oFEC	1x1
2x100G-MXP	2 Client, 100G speed	1 trunk, 400G speed	16 QAM	oFEC	1x1.25
1x100G-MXP	1 client, 100G speed	1 trunk, 100G speed	QPSK	oFEC	1x1.50

Source: http://cs.co/9003psXLH (for (Cisco IOS-XR 7.11.x)

*Note: TXP: Transponder, MXP: Muxponder

DCO performance management (PM)

Reference

Optics PM

PM Parameters	Description
CD	Chromatic dispersion
DGD	Differential group delay
LBC	Laser bias current in mA
FREQ-OFF	Low signal frequency offset in Mhz
OPR	Optical power RX in uW or dbm
OPT	Optical power TX in uW or dbm
OSNR	Optical signal-to-noise ratio in dB
PCR	Polarization change rate
PDL	Polarization dependent loss
RX-SIG	Receiving signal power uW or dbm
SNR	Signal-to-noise ratio
SOPMD	Second order polarization mode dispersion

Coherent DSP PM

PM Parameters	Description
Q	Q factor
Q-margin	Q margin
EC-BITS	Error corrected bits
PostFEC BER	Post forward error correction bit error rate
PreFEC BER	Pre forward error correction bit error rate
UC-WORDS	Uncorrected words

Pluggable DCO transceivers provide detailed visibility of optical transport performance and fiber quality directly to the router (or host).

Reference

Sample PM counters output for optics

```
RP/0/RP1/CPU0:Ravello-51#sh controllers optics 0/0/2/2 pm current 30-sec optic$
Thu Dec 22 13:38:27.415 CET

Optics in the current interval [13:38:00 - 13:38:27 Thu Dec 22 2022]

Optics current bucket type : Valid
                MIN       AVG       MAX      Operational      Configured      TCA   Operational      Configured      TCA
                                             Threshold(min)   Threshold(min)  (min) Threshold(max)   Threshold(max)  (max)
LBC[mA ]      : 73        73        73        0                 NA              NO    131              NA              NO
OPT[dBm]      : -11.44    -11.44    -11.44    -15.09            NA              NO    0.00             NA              NO
OPR[dBm]      : -7.41     -7.37     -7.33     -30.00            NA              NO    8.00             NA              NO
CD[ps/nm]     : -928      -927      -926      -160000           NA              NO    160000           NA              NO
DGD[ps ]      : 2.00      2.46      3.00      0.00              NA              NO    80.00            NA              NO
SOPMD[ps^2]   : 21.00     44.96     70.00     0.00              NA              NO    2000.00          NA              NO
OSNR[dB]      : 31.20     31.35     31.50     0.00              NA              NO    40.00            NA              NO
PDL[dB]       : 1.00      1.07      1.10      0.00              NA              NO    7.00             NA              NO
PCR[rad/s]    : 0.00      0.00      0.00      0.00              NA              NO    2500000.00       NA              NO
RX_SIG[dBm]   : -7.95     -7.93     -7.90     -30.00            NA              NO    1.00             NA              NO
FREQ_OFF[Mhz]: -919      -908      -896      -3600             NA              NO    3600             NA              NO
SNR[dB]       : 18.00     18.21     18.50     7.00              NA              NO    100.00           NA              NO

Last clearing of "show controllers OPTICS" counters never

```

Sample PM counters output for DSP

Reference

```
RP/0/RP1/CPU0:Ravello-51#show controllers  coherentDSP 0/0/2/2 pm current 30-sec fec
Thu Dec 22 13:46:38.918 CET

g709 FEC in the current interval [13:46:30 - 13:46:38 Thu Dec 22 2022]

FEC current bucket type : Valid
    EC-BITS   : 0                    Threshold : 111484000000          TCA(enable)  : YES
    UC-WORDS  : 0                    Threshold : 5                     TCA(enable)  : YES

                                    MIN       AVG       MAX      Threshold      TCA      Threshold     TCA
                                                                   (min)     (enable)     (max)     (enable)
PreFEC BER                  :    7.3E-04   7.3E-04   7.3E-04      0E-15        NO         0E-15        NO
PostFEC BER                 :      0E-15     0E-15     0E-15      0E-15        NO         0E-15        NO
Q[dB]                       :      10.00     10.00     10.00       0.00        NO          0.00        NO
Q_Margin[dB]                :       3.70      3.70      3.70       0.00        NO          0.00        NO

Last clearing of "show controllers OTU" counters never
```

Key take aways for DCOs

- Pluggable DCOs will eventually become the norm
  - It's very cost effective for most applications (cheaper than DWDM transponders)
  - Excellent optical performance
  - Improved visibility into optical layer
- From the router's perspective, DCO has two parts:
  - Ethernet layer: business as usual. Eg. 400GE or 4x100GE breakout
  - Optical channel: Look-and-feel of a transponder, but sitting in the router. Gives you full visibility of the optical layer.

Moving forward, as a network professional you will need to learn how to operate these pluggable DCOs.

IP/MPLS Routing Layer Considerations

Building Routed Optical Networking's IP/MPLS Layer

3 questions we need to answer to build the IP/MPLS layer for Routed Optical Networking:

1. Does the router support the DCO transceivers? ✔

   Cisco Transceiver Compatibility Matrix: https://tmgmatrix.cisco.com/

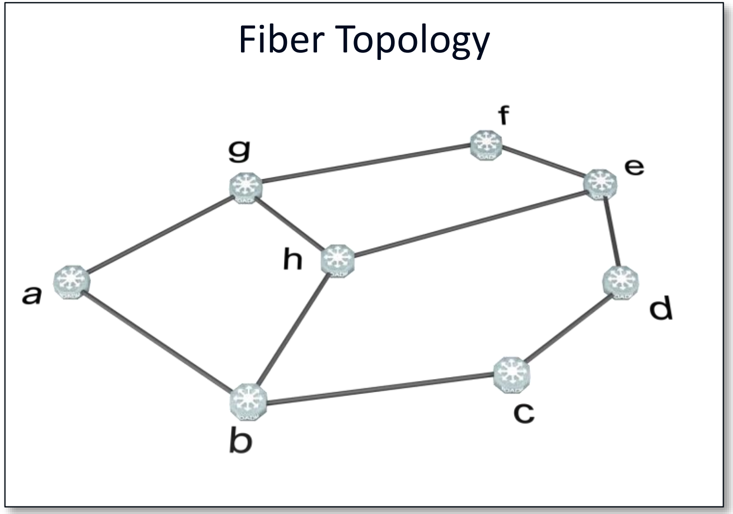
2. Do I need to change the IP control plane? ✔

   No. But you should consider the opportunity to modernize the IP/MPLS network control and services planes with SR/SRv6.

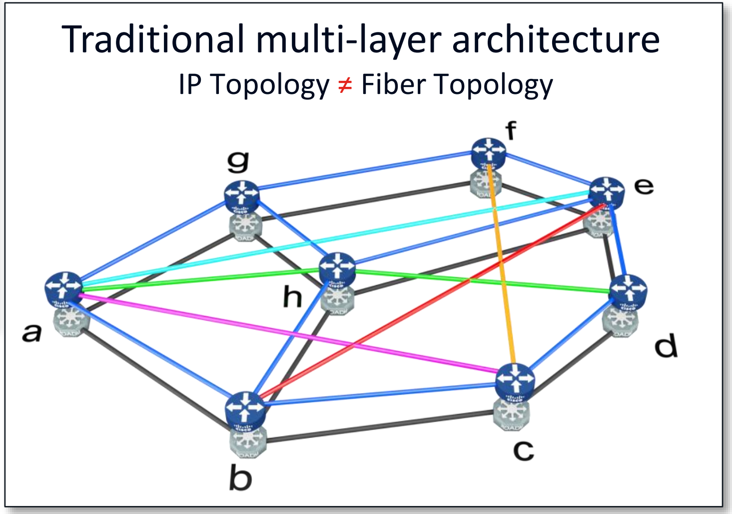
3. What services can I run on top of the network? ✔

   All **L2** and **L3** services the IP/MPLS network is designed for, **plus L1 private line services** services if you adopt Private Line Emulation.

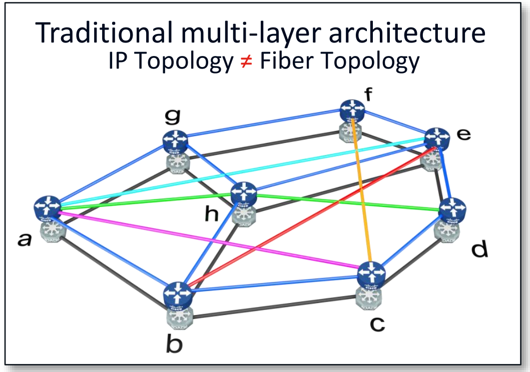
Network topology considerations



Network topology considerations

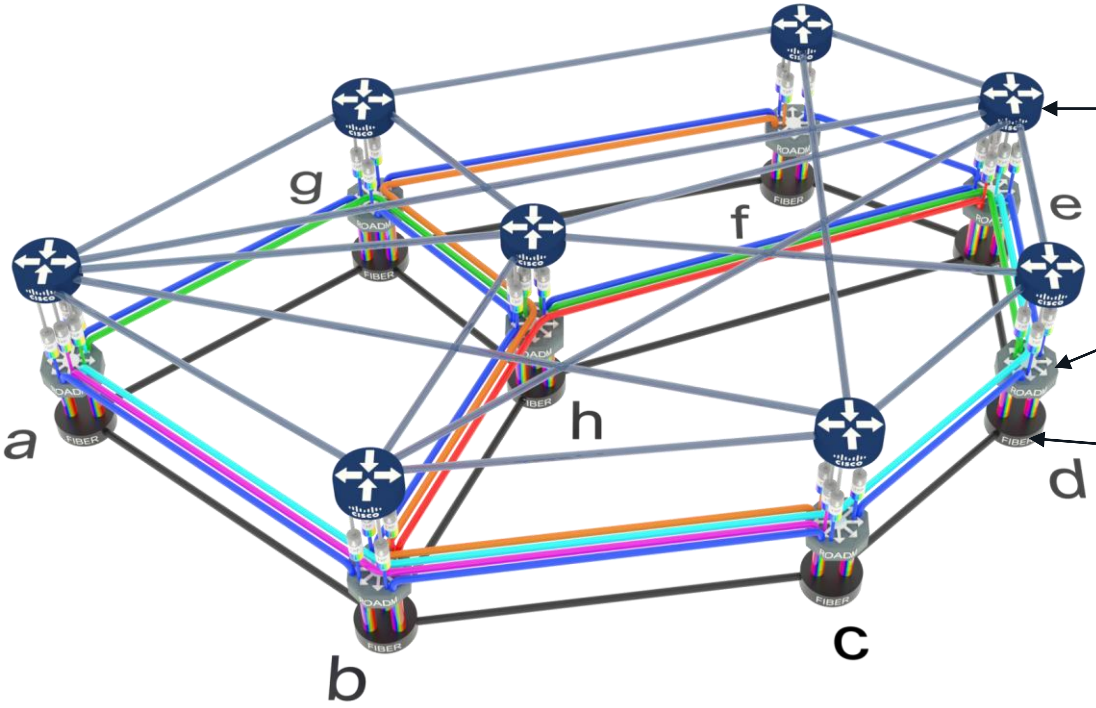


Network topology considerations



- Despite a shared Fiber topology, a traditional architecture has two (2) distinct topologies for the IP and Optical layers given its complex mesh of wavelengths

Things are always more complicated....



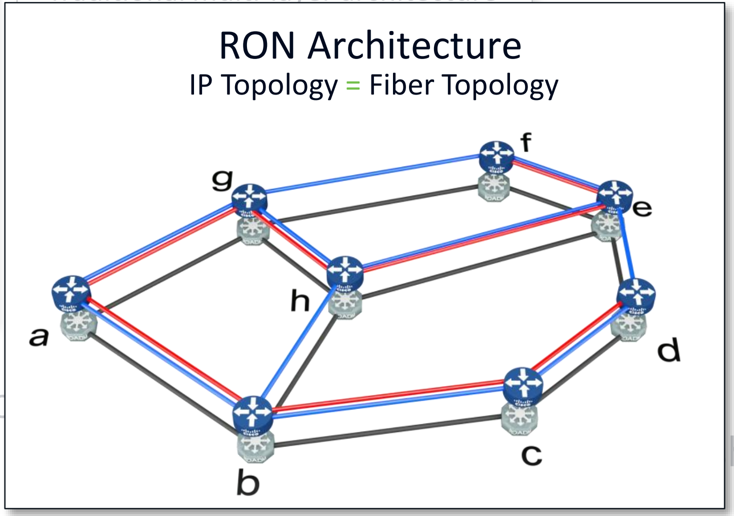
IP Topology
Links/Adjacencies

ROADM Topology
Wavelegth paths

Fiber Topology
All the way to ducts

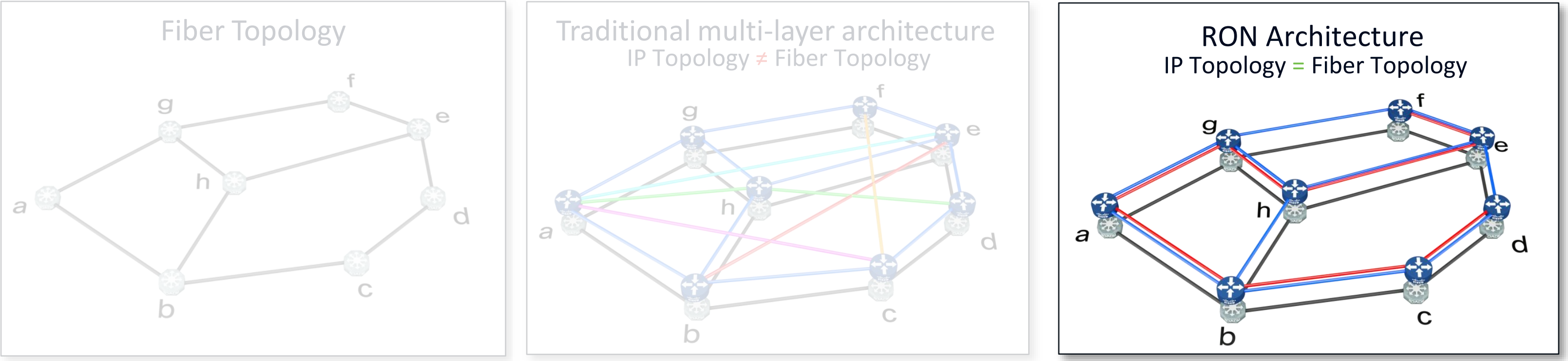
Network topology considerations

Traditional multi-layer architecture



- Despite a shared Fiber to… two (2) distinct topologies for the IP and… h of wavelengths

Network topology considerations

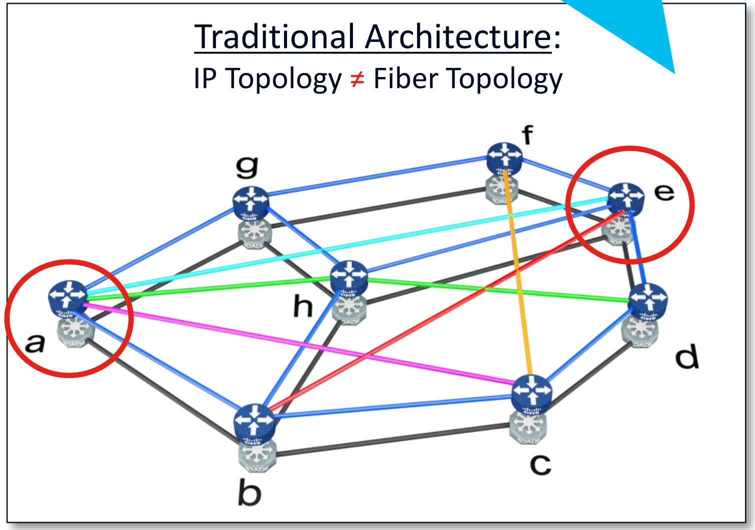


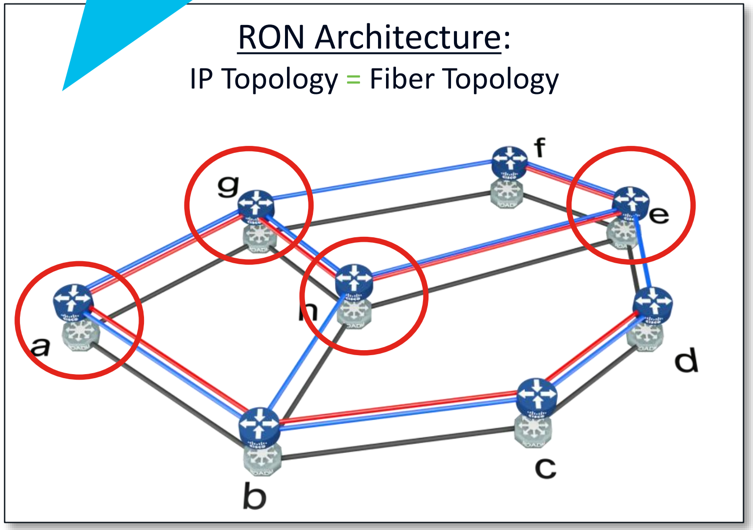
- Despite a shared Fiber topology, a traditional architecture has two (2) distinct topologies for the IP and Optical layers given its complex mesh of wavelengths
- RON architecture aims at making **optical and IP topologies congruent** which enables:
  - Optimal traffic forwarding for applications, content and Internet peers
  - Higher utilization of network assets, wavelengths and higher bit-rate wavelengths given their shorter distances. Routers have direct visibility of optical performance.

IP/MPLS topology scale

One (1) IP hop between Routers A and E

Three (3) IP hops between Routers A and E

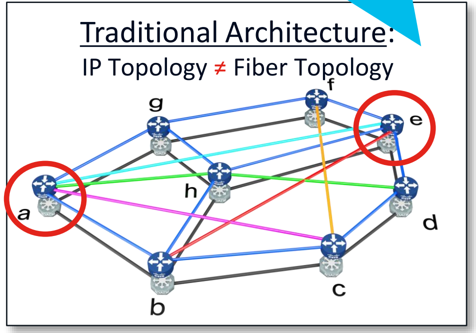




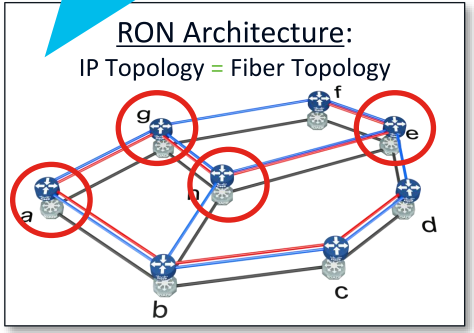
IP/MPLS topology scale

- Traffic forwarding in the RON architecture *may* incur a higher IP hop count and *may* require more IP ports.
- However, ***this does not imply that more IP routers*** are required

One (1) IP hop between Routers A and E



Three (3) IP hops between Routers A and E



- If more routers are required with RON:
  - Typically affects only sites with local traffic interest; Not intermediate sites with only Regens/ILAs
  - IGP scale may or may not be affected (i.e., LSDB); Depends on current node count & scale limits
- Managing IGP scale is nothing new as multiple well-known techniques are available:
  - Unified MPLS / Seamless MPLS using BGP labeled unicast
  - Converged SDN Transport design using SR-PCE
  - Multi-area/domain design using SRv6 route summarization
- Regardless, more IP traffic switching, and aggregation is by design given the cost & efficiency benefits

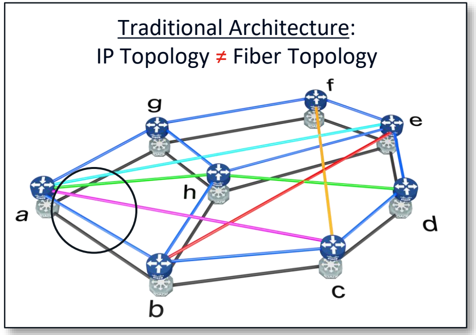
IP/MPLS network capacity expansion

Capacity Expansion	Traditional Architecture	RON Architecture	Notes
Potential touch points	IP ports, TXP/MXPs, regens, fiber pairs (or L-band)	IP ports, regens, fiber pairs (or L-band)	RON's use of DCOs eliminates need for TXP/MXPs
Risk of wavelength blocking (more fiber pairs / L-band)	Higher	Lower	RON has lower risk due to less # of wavelengths
Risk of more regens or lower bit rate	Higher	Lower	RON has lower risk of more DWDM regenerators due to shorter wavelength distances

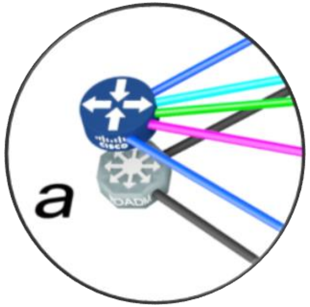
- Must also consider if ROADM has spare degrees (not factored into the above)
- Routed Optical Networking design makes more efficient use of available fiber and deployed capacity leveraging IP for traffic aggregation and helping delaying expansions

Note: Routed Optical Networking capacity expansions, i.e., adding new links, can be done added in-service.

IP/MPLS network capacity utilization



- Traditional Architecture

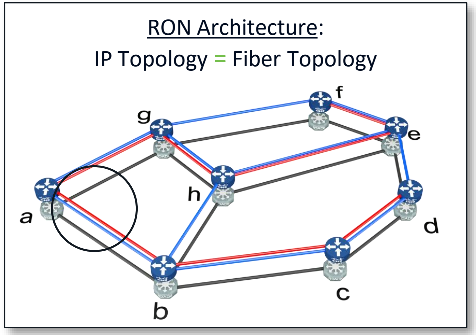


- Uses more wavelengths per fiber span
- Uses less traffic aggregation
- Results in lower IP port/wavelength utilization
- Results in lower IP port/wavelength bit rates (due to longer distances)

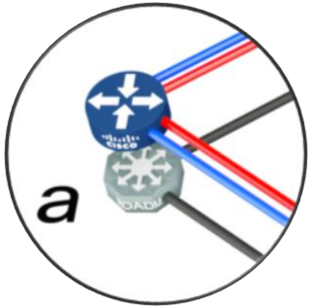
  - Traditional architecture splits traffic onto dedicated IP ports and wavelengths toward distant routers (based on destination)

- Leads to:
  - Underutilization of wavelengths (scarce network assets) and IP router ports
  - Over-investment in the physical infrastructure
  - Higher cost per bit

IP/MPLS Network Utilization



- Routed Optical Networking design



  - Typically uses less wavelengths
  - Uses IP for traffic aggregation to *fill the wavelengths*
  - Results in higher IP port/wavelength utilization
  - Results in higher IP port/wavelength bit rates (due to shorter distances)

- Routed Optical Networking design goal is to aggregate traffic onto fewer IP ports/wavelengths on a given node to
  - Drives higher utilization of network assets
  - Increases network efficiency which leads to a lower cost per bit
- Traffic Engineering (TE) is not required
  - However, use of TE and a Centralized (SDN) Controller can drive utilization even higher

Key routing technologies in Routed Optical Networking IP/MPLS layer

- IGP of choice (IS-IS, OSPF), BGP-LU (labeled unicast) for large scale
- MP-BGP (services) and BGP-LS (topology)
- DiffServ QoS

"Business as usual"

- YANG model-driven programmability & telemetry
- Segment Routing (SR), TI-LFA, ODN and SR-TE (Traffic Engineering)
- Centralized (SDN) Controller with PCE (Path Computation Engine)
- PLE (Private Line Emulation)

"Value-added"

Optional – introduce them as needed and at your own pace

Routed Optical Networking *can* leverage SDN architecture for network optimization. New service capabilities are also available with PLE.

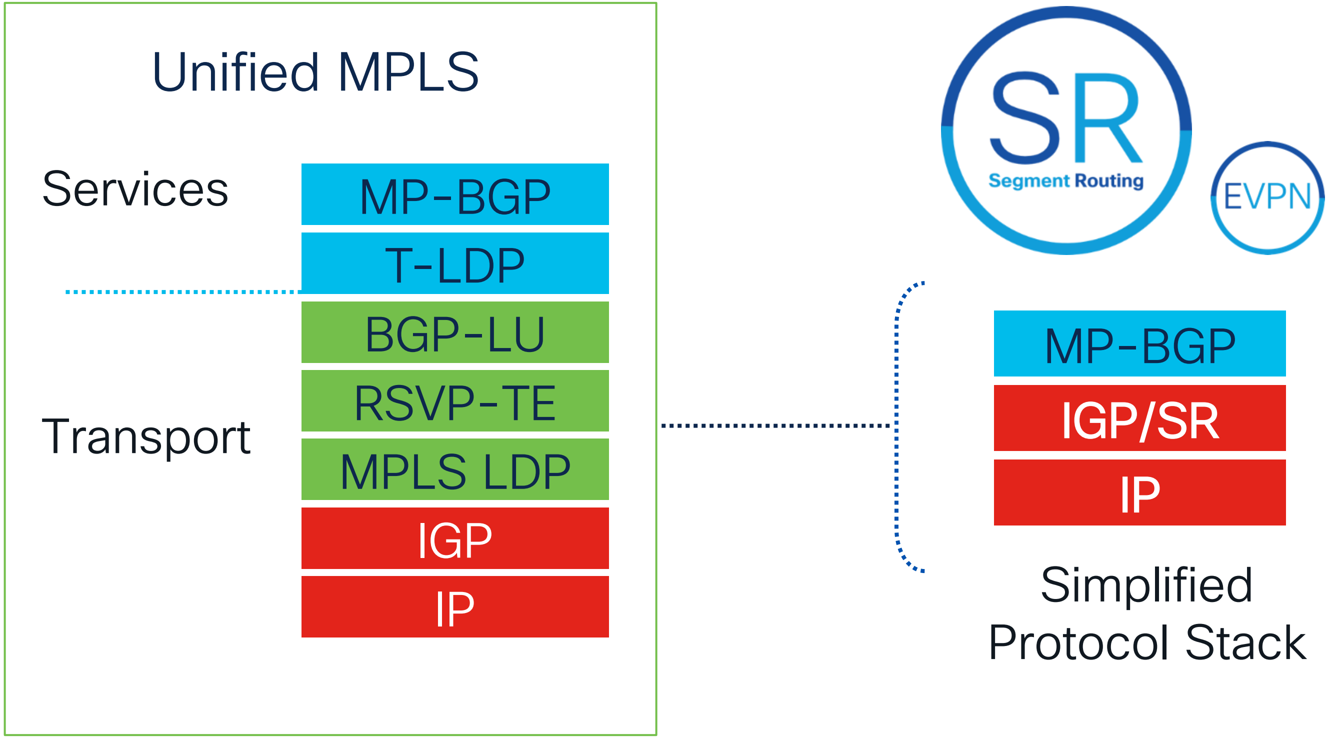
Routed Optical Networking and Segment Routing

- Segment Routing (SR) *is not* mandatory for Routed Optical Networking. Classic IP/MPLS can be used as well.
- However, Segment Routing can provide *many benefits* when deployed for Routed Optical Networking:
  - Better solution for the traffic optimization problem
  - Adds transport-like service capabilites to packet networks
  - Better scale properties while keeping the network simple
  - Super fast (<50ms) protection over any network topology with TI-LFA
- Both SR MPLS and SRv6 are supported
  - Each option has its own set of benefits (see later slides)

Segment Routing (SR) at a glance

- A programmatic IP source-routing architecture that provides the optimal balance between distributed intelligence and centralized control
- Network simplification
  - Reduces control plane protocols (no LDP, no RSVP-TE)
  - Delivery of all network services (IP, MPLS, Ethernet, Private Line, Wave) over IP
  - Automatic <50 ms protection (topology independent), automated traffic steering
- Very scalable
  - Reduces core network state (no RSVP-TE tunnels required for TE/FRR)
  - Enables route summarization between domains/areas (SRv6), On-Demand BGP Next-hops (ODN)
- Advanced capabilities
  - Advanced TE (flow-based, ECMP-aware, multi-domain, disjointness, circuit-style)
  - Network slicing, service chaining, data plane monitoring, delay performance monitoring

Segment Routing = Network Simplification
Does more with less



Segment Routing IPv6 extended benefits

Segment Routing IPv6 makes networking even simpler. It's just IP routing!

- Maximum scale
- Simple and efficient
- Services rich
- Operational simplicity
- Seamless deployment

Reference

SRv6 unique benefits

- Eliminates numerous **legacy protocols** including LDP, RSVP-TE, BGP-LU, and MPLS OAM
- **Maximizes** network **scale** – enables IP route summarization between areas/domains unlike MPLS
- **End-to-end** applicability including WAN, Metro, xHaul, DC, Far/Near Edge, IoT, etc.
- Enables tight **application interaction** with the network, i.e., application-driven network programmability as well as service function chaining
- Optimal **ECMP** load balancing (no sub-optimal MPLS label hashing)
- Provides more **QoS** markings for packet classification and drop profiles (6-bits versus 3-bits)
- **Seamless deployment** with classic IPv6 nodes
  - For example, if no TE, Flex Algo or FRR, then core routers only need to support IPv6, and SRv6 is not required
- Optimal **MTU efficiency** with micro-segment (uSID)
- **Better NPU forwarding** pipeline resource allocation (ECMP-FEC, FEC, EEDB)
- **Better FIB scaling** – no ip2mpls, mpls2mpls, and mpls2ip entries

"SRv6 allows for huge simplification and enables IPv6 to be self-sufficient. It also provides ultra-scale and end-to-end policy with IP summarization, stateless network programming, and native compression supporting a complete handset-to-server solution." – Clarence Filsfils, Cisco Fellow

Segment Routing – Forwarding Plane

- Ingress edge router encodes forwarding instructions in packet headers
- Encoding is based on an ordered list of Segment IDs (one or more SIDs)
  - SR-MPLS uses MPLS labels as SIDs (RFC 8660)
  - SRv6 uses SRv6 segment routing header (RFC 8754)
- SIDs are distributed using IGP, MP-BGP and/or PCEP
- The rest of the SR network forwards packets based on the encoded instructions (i.e., SID-list). Ex. IGP shortest path, explicit paths, TE policies
- Different types of SIDs are available and may be combined in a SID-list:
  - https://www.iana.org/assignments/segment-routing/segment-routing.xhtml
  - SRv6 with uSID (micro-SID) is the *state-of-the art*

Segment Routing – Forwarding Examples

Reference

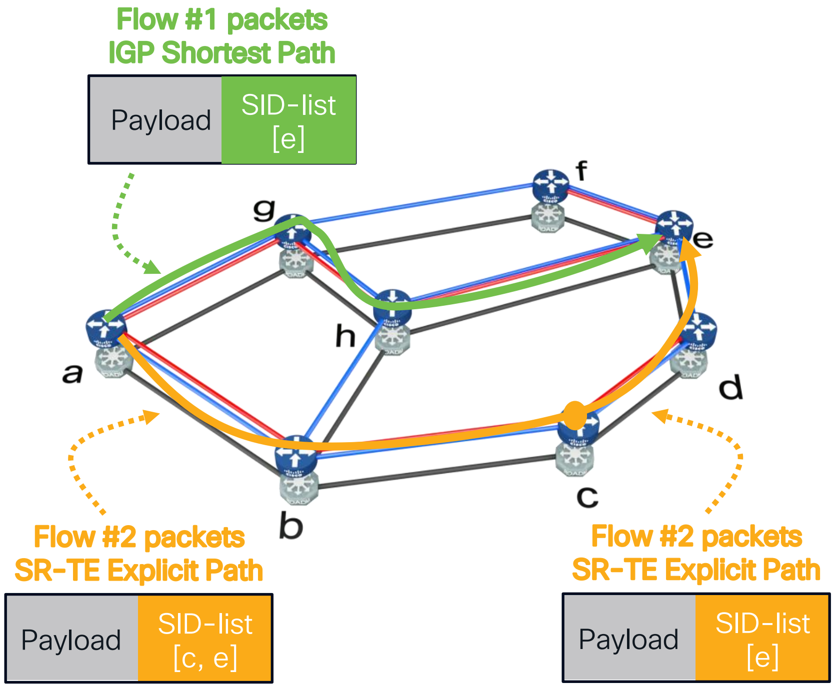
1. Router A encodes Flow #1 to use IGP shortest path (default behavior)

   SID List = <e>

2. Router A encodes Flow #2 to use an explicit path (SR-TE) via Router C

   SID List = <c, e>

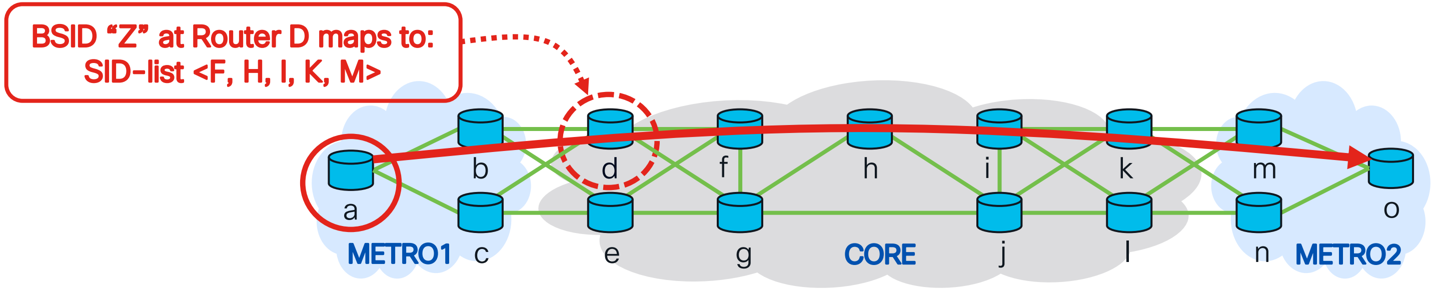
- Note, no stateful core tunnels required for the SR-TE explicit path used for Flow #2



* Assumes all link IGP metrics equal

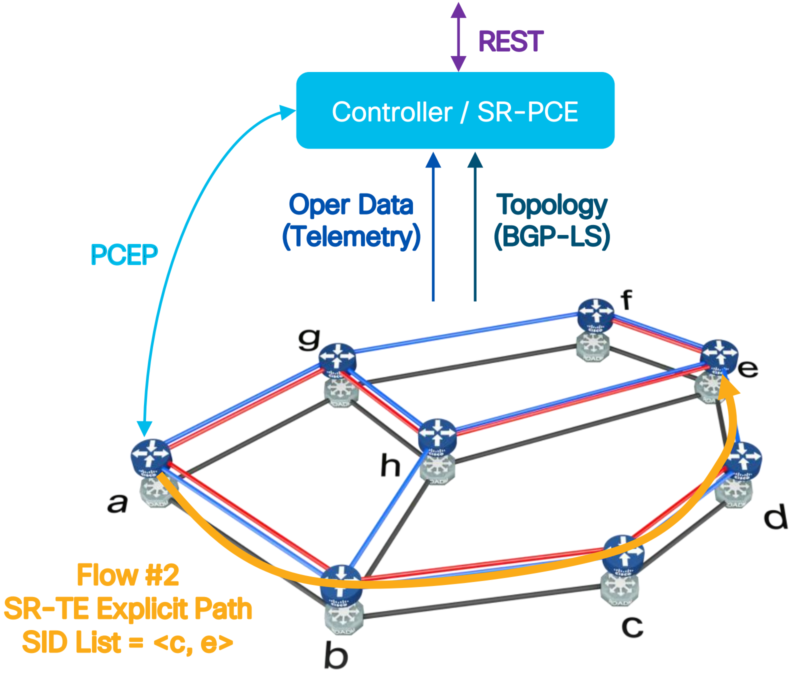
Maximum Segment Depth (MSD)

	MPLS SID-list	SRv6 uSID-list
NCS 5700	12	26



- An SR explicit path is constrained by the maximum number of SIDs a router can impose onto a packet (i.e., MSD)
- SR-PCE can determine the MSD capability of a router via IGP, BGP and PCEP
- Techniques are available to resolve MSD constraints, e.g., using Binding SIDs (BSID)
- BSID may be pre-programmed or automatically injected into the network by a PCE
  - Example without BSID: SID-list imposed at Router A is **<D, F, H, I, K, M, O>**
  - Example with BSID: SID-list imposed at Router A is **<D, Z, O>**

SR PCE (Path Computational Element)



- Head-end (e.g., edge) router either computes explicit path itself or requests explicit path from a central (SDN) controller / SR-PCE
- Controller is ONLY required when local head-end computation is not possible:
  - Multi-area/domain explicit path routing
  - Explicit path routing with BW reservations
- Central controller enables:
  - Better network utilization given global topology view
  - Faster network-wide convergence of explicit paths to target optimum on failure
  - Better PCE performance using modern compute HW

Services Convergence

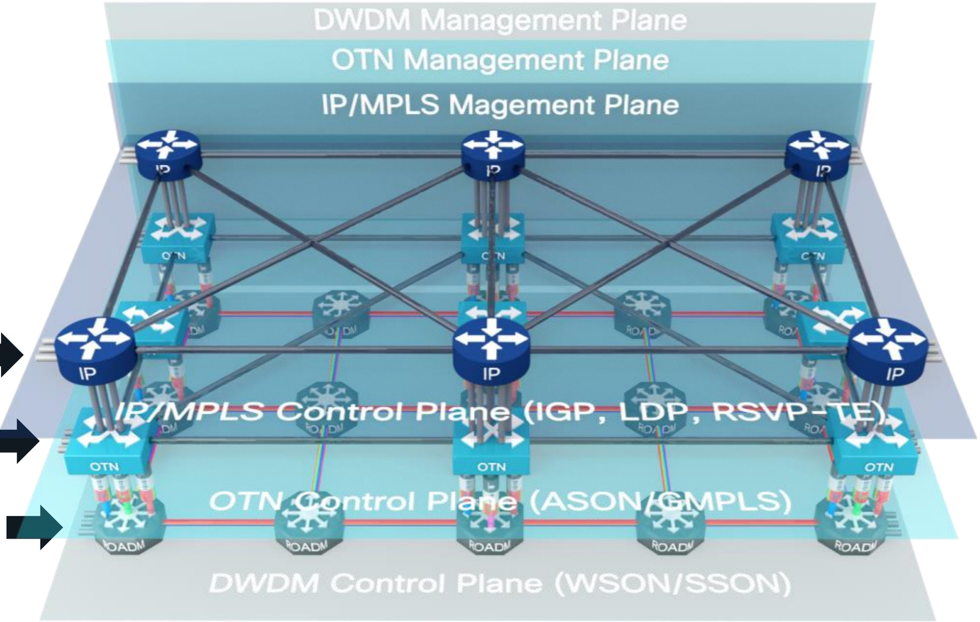
Services convergence

Today, most private line services run over dedicated transport networks

Packet services

TDM services

Wavelength services
Sub-wave (TDM) services



Justification:

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

What if a packet network could meet all these requirements?

Converging services

Reference

<table>
<tr><th>Network Services</th><th colspan="2">Traditional architecture</th><th colspan="2">RON Architecture</th></tr>
<tr><th></th><th>Services Switching</th><th>Services Control Plane</th><th>Services Switching</th><th>Services Control Plane</th></tr>
<tr><td>Internet
(DIA)</td><td rowspan="3">IP/MPLS</td><td rowspan="3">MP-BGP
T-LDP
RSVP-TE
VPWS
VPLS</td><td rowspan="5">IP/MPLS</td><td rowspan="5">MP-BGP
EVPN
PLE</td></tr>
<tr><td>MPLS
(IP VPN)</td></tr>
<tr><td>Ethernet
(E-LAN, E-Line, E-Tree)</td></tr>
<tr><td>Private Line
(ODU0, ODU1, ODU2)</td><td>OTN Switching</td><td>GMPLS</td></tr>
<tr><td>Wavelength
(e.g., ODU4)</td><td>ROADM</td><td>WSON/SSON</td></tr>
</table>

- MP-BGP and SR enable a converged IP/MPLS network to support various services and SLAs
- PLE (Private Line Emulation) enables IP packetization of Private Line and Wavelength Services

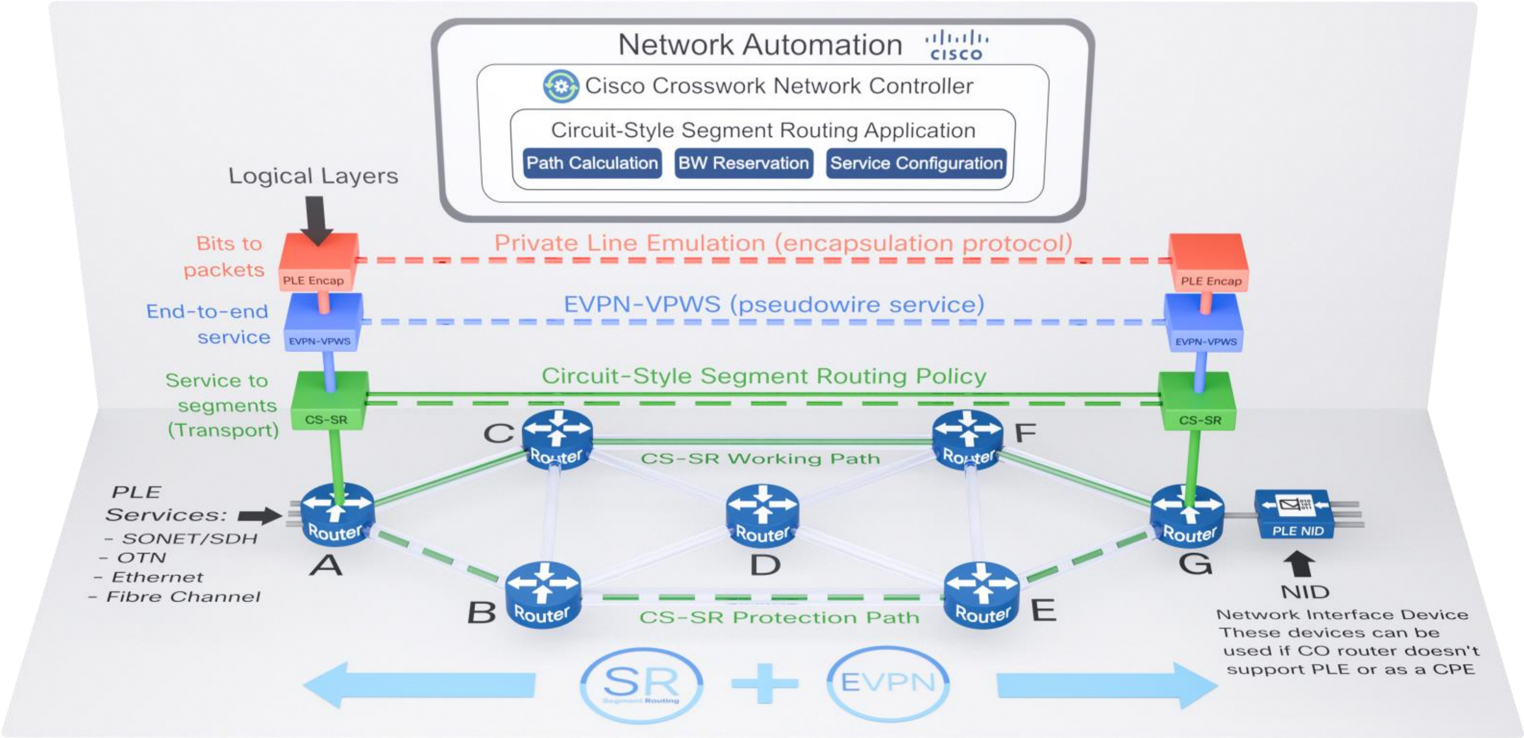
MP-BGP: Unified Service Overlay Control Plane

Reference

Services	MP-BGP Address Family	AFI	SAFI	Notes
Internet (DIA)	IPv4 unicast	1	1	
	IPv6 unicast	2	1	
	IPv6 labeled unicast	2	4	IPv6 service over MPLS-based IPv4 network
MPLS (IP VPN)	IPv4 VPN unicast	1	128	
	IPv6 VPN unicast	2	128	
Ethernet	EVPN (E-LAN)	25	70	
	EVPN-VPWS (E-Line)	25	70	Adds EVPN extended community L2 attributes
	EVPN (E-Tree)	25	70	Adds E-Tree extended community
Private Line	EVPN-VPWS (PLE)	25	70	Adds PLE Attribute; Requires circuit-style TE
Wavelength	EVPN-VPWS (PLE)	25	70	Adds PLE Attribute; Requires circuit-style TE

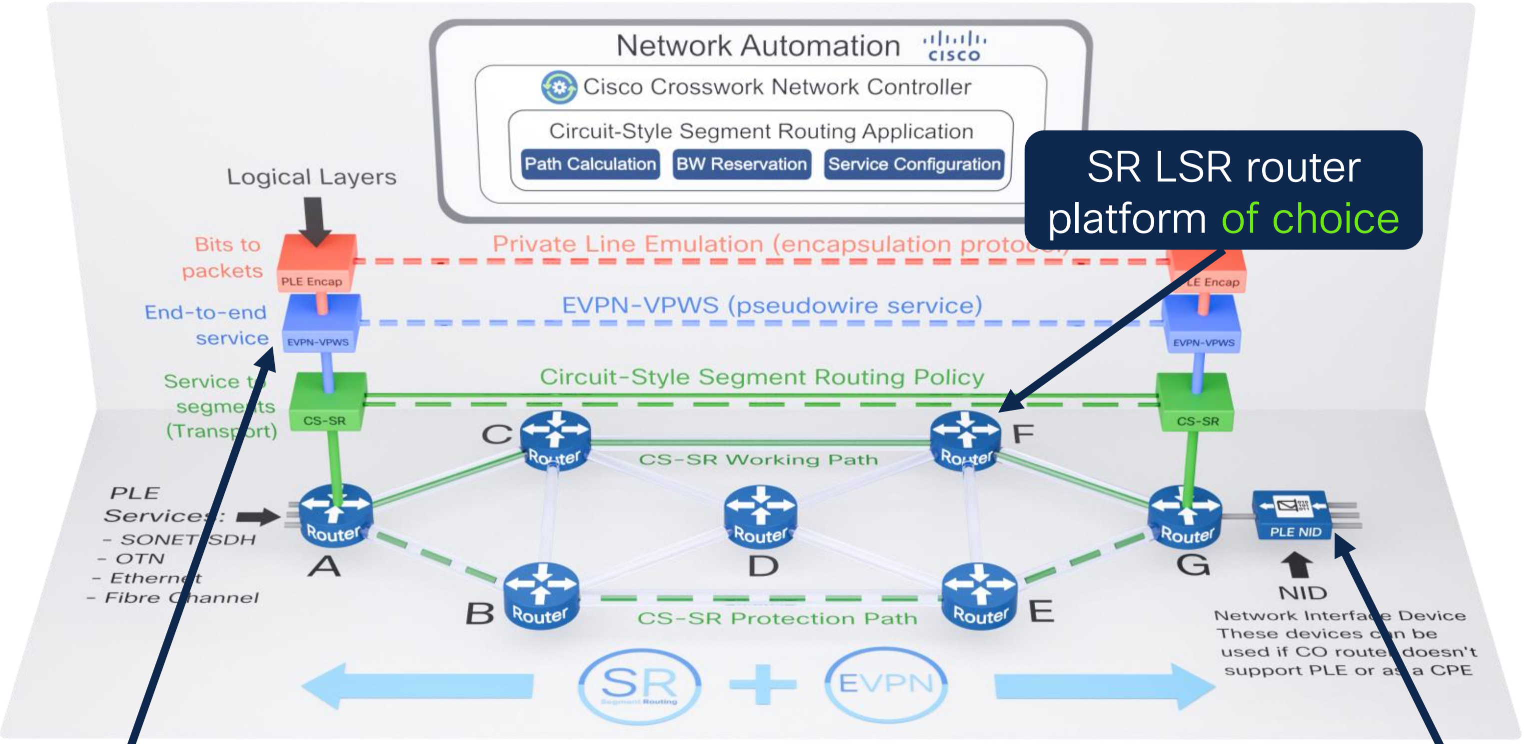
- Only PLE is new with the RON architecture

Private Line Emulation (PLE) Architecture



*PLE enables **bit transparent, transport oriented services** with **high SLAs** natively **over IP/MPLS**. It supports SONET/SDH, OTN, Ethernet and Fibre-Channel clients.*

Private Line Emulation (PLE) Architecture



SR LSR router platform of choice

Simple, flat and scalable SR + EVPN control plane

Pay as you grow investment in CO

PLE payload types

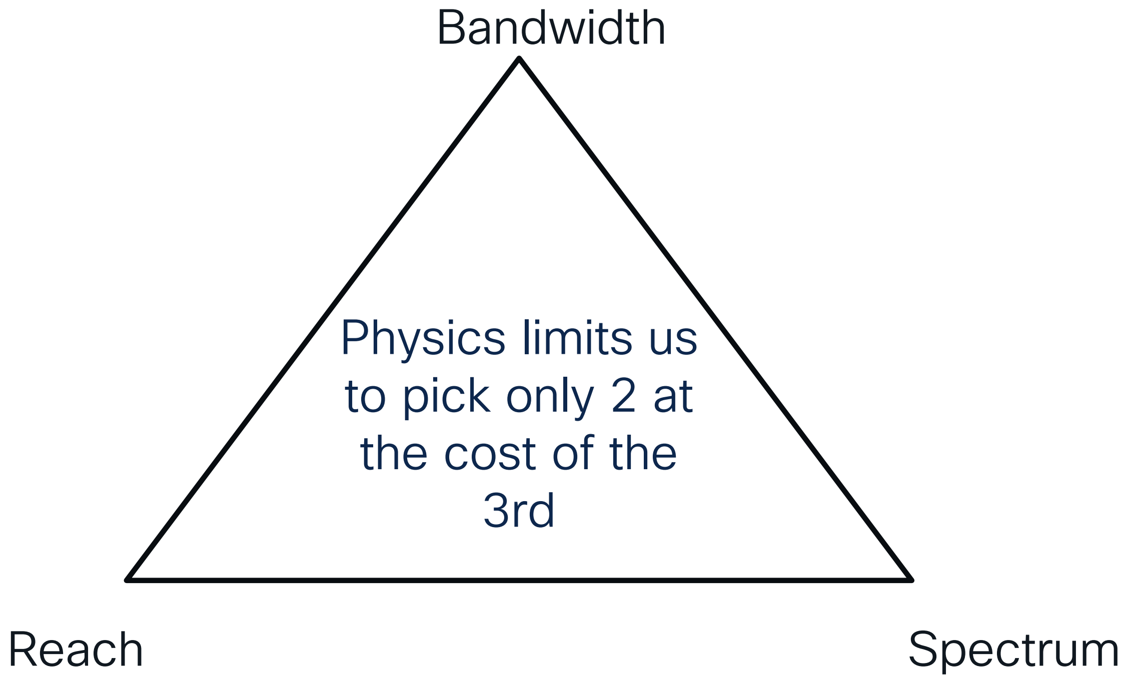
Reference

	SONET/SDH	OTN	Ethernet	Fibre Channel
1Gbps		ODU0	1GE	FC100
	OC48/STM16	ODU1		FC200
				FC400
				FC800
	OC192/STM64	ODU2/ODU2e	10GE	
				FC1600
				FC3200
100Gbps		ODU4	100GE	

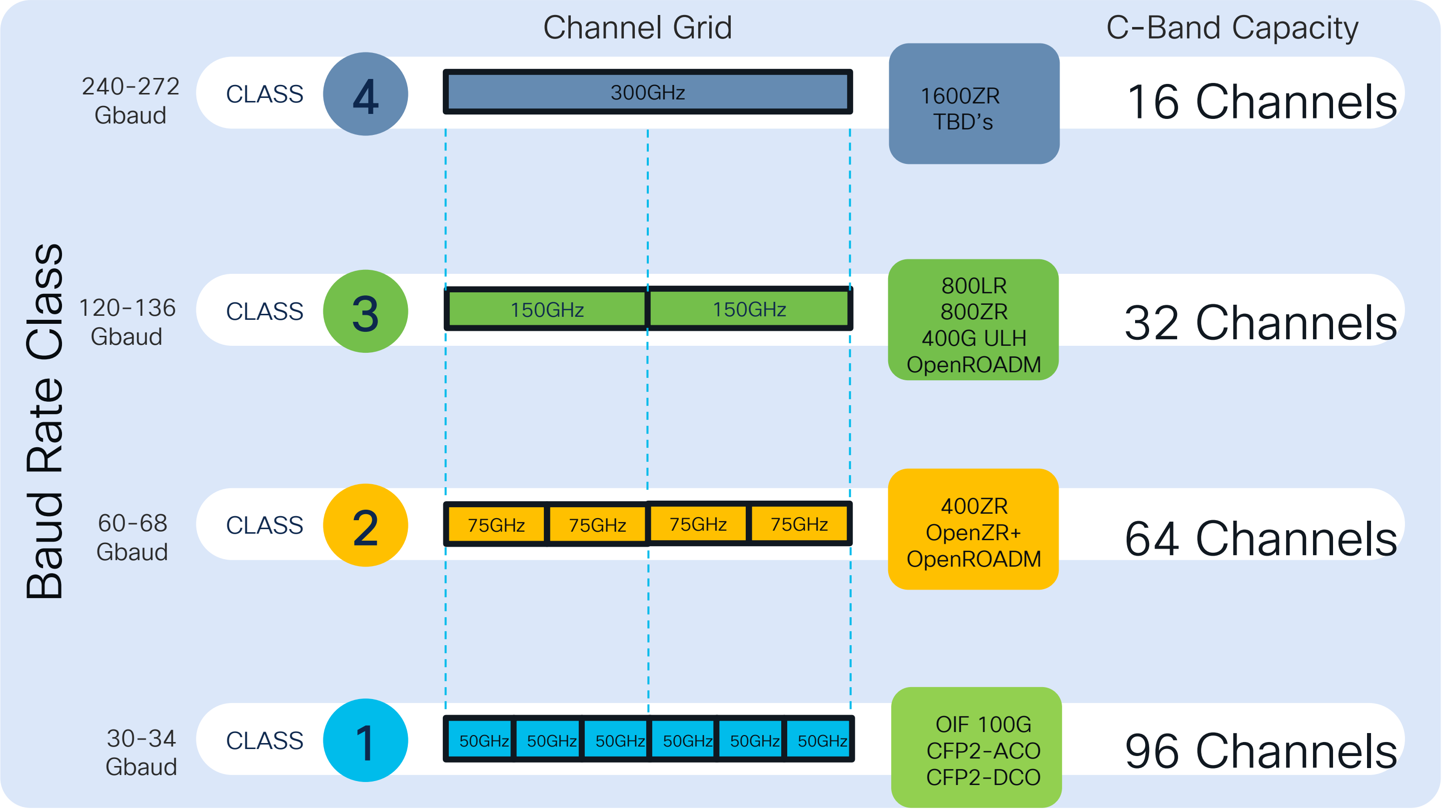
Future

Protection and restoration considerations

First things first...



Digital Coherent Optics evolution



Practical implications

- Many networks designed with optical protection and restoration had plenty of wavelenghts available with excellent reach. *Unfortunately, those things were true in the 100G era and are no longer a given.*
  - Ex. From 96x100G to 32x800G over C-Band (66% less channels)
  - Meshed wavelength connectivity will be more challenging
  - Protection and restoration counts on spare wavelengths that may not be available
- If we want to keep the number of wavelenghts in the fiber at higher bandwidths, distance will be limitted
- As speed increases, we get less wavelenghts no matter what… but if we want to reach the same distances at higher speed, spectrum will be even more sacrificed and we end up with *even less wavelenghts*

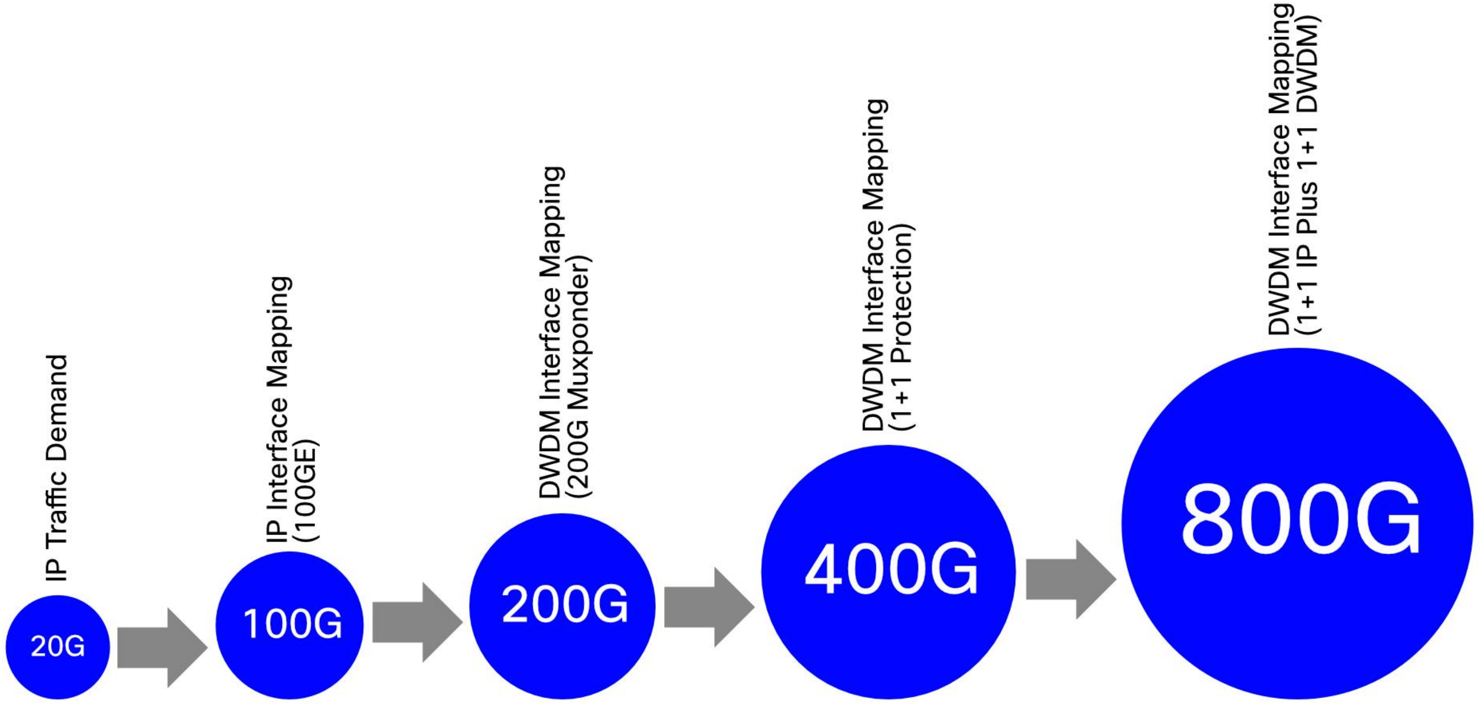
Network Protection Mechanisms

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			

Protection & Restoration for RON

- A Routed Optical Networking design provides the same protection and restoration capabilities and beyond - all at the IP/MPLS layer
- Network operators have a choice to continue using optical layer protection or restoration for the DCO links, noting the implications and potential caveats:
  - Deploying protection and/or restoration at both layers multiplies network capacity requirements - inefficient and potentially higher cost per bit
  - Competing protection mechanisms require hold-over times, which may increase the protection time of the upper network layer (IP/MPLS in this case)

Network inneficiences
The snowball effect



Beware of the n*(n-1)/2 problem

Max. number of routers – 75GHz channel spacing, C-Band only

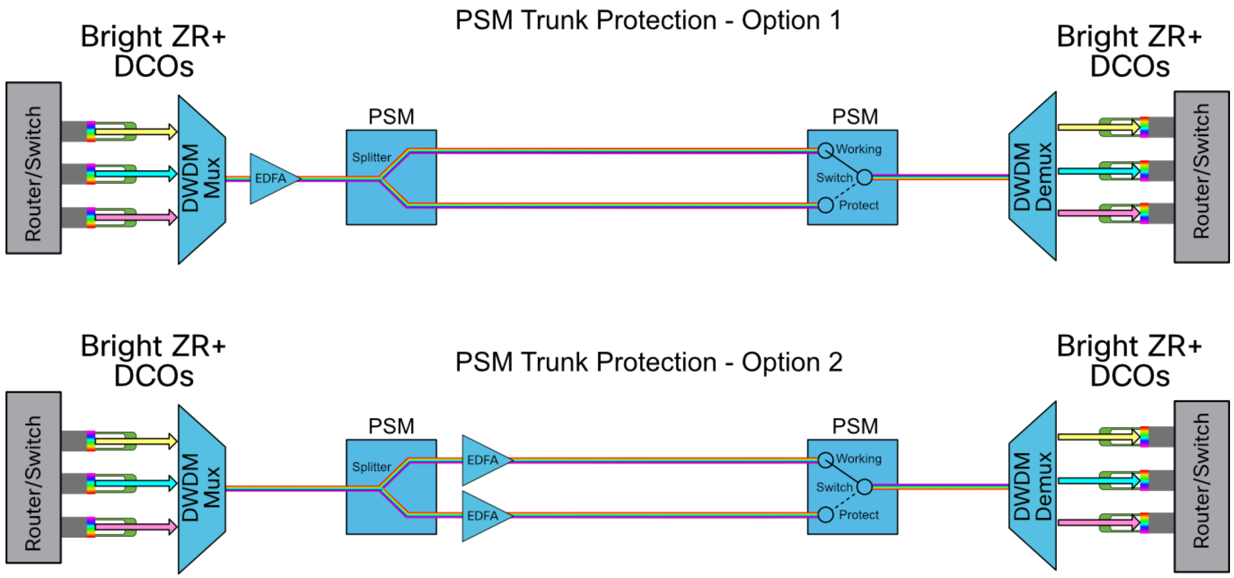
N of nodes	Wavelengths Single link	Wavelengths Dual links
2	1	2
3	3	6
4	6	12
5	10	20
6	15	30
7	21	42
8	28	56
9	36	-
10	45	-
11	55	-

Beware of the n*(n-1)/2 problem

Max. number of routers – 150GHz channel spacing, C-Band only

N of nodes	Wavelengths Single link	Wavelengths Dual links
2	1	2
3	3	6
4	6	12
5	10	20
6	15	30
7	21	~~42~~
8	28	~~56~~
~~9~~	~~36~~	–
~~10~~	~~45~~	–
~~11~~	~~55~~	–

Protection Switch Module options – DCO



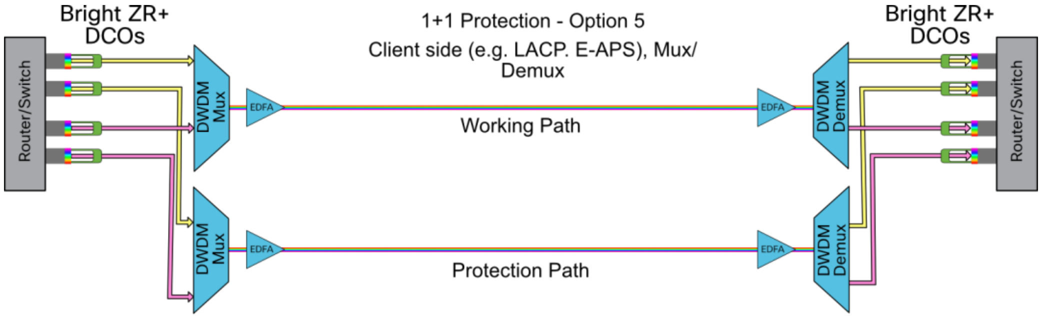
Routing layer considerations:

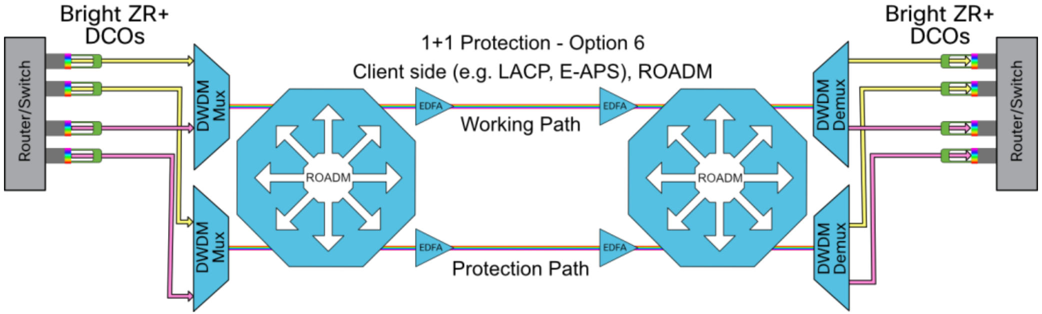
- Router with DCO must support hold-over to avoid generating alarms under LOS for the few msec hit due to PSM switching process and DSP re-alignment. *As a result, routing layer hit will be higher than the PSM sub-50ms switching time.*

1+1 vs 1:1

- RFC 7347 definitions (text cut for brevity):
- 1+1 Architecture: In the 1+1 architecture, the protection transport entity is associated with a working transport entity. The ***normal traffic is permanently bridged onto both the working transport entity and the protection transport*** entity at the source endpoint of the protected domain.
- 1:1 Architecture: In the 1:1 architecture, the protection transport entity is associated with a working transport entity. When the working transport entity is determined to be impaired, the ***normal traffic MUST be transferred from the working to the protection transport entity at both the source and sink endpoints of the protected domain***. *(n.a. Requires network signaling)*

1+1 Protection applicable to DCO

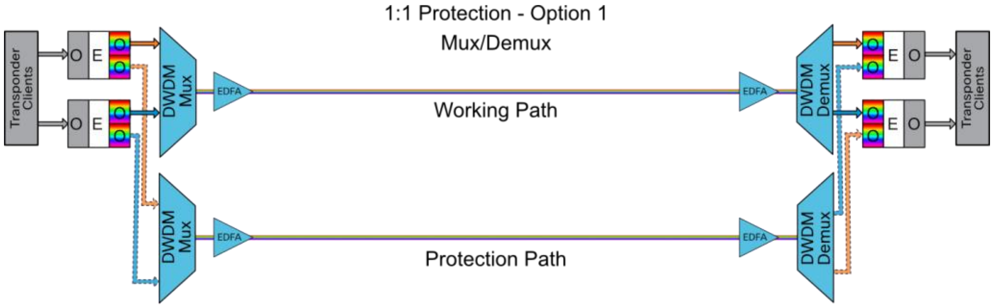


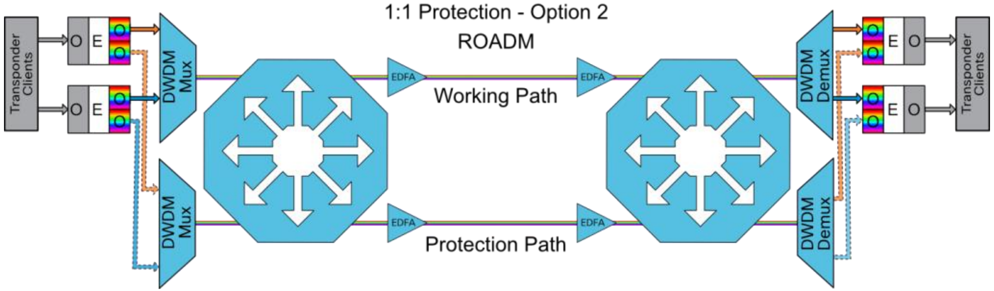


Routing layer considerations:

- Routers/switches never "bridge" the traffic to working and protection paths. Only exception could be with APS protection which is not used for Ethernet.

1:1 Protection options – Transponder example





Notes:

- 1:1 sometimes is referred to as “bi-directional” protection as it requires network signalling to propagate failure and switch at both source and sink.

1:1 Protection for DCO

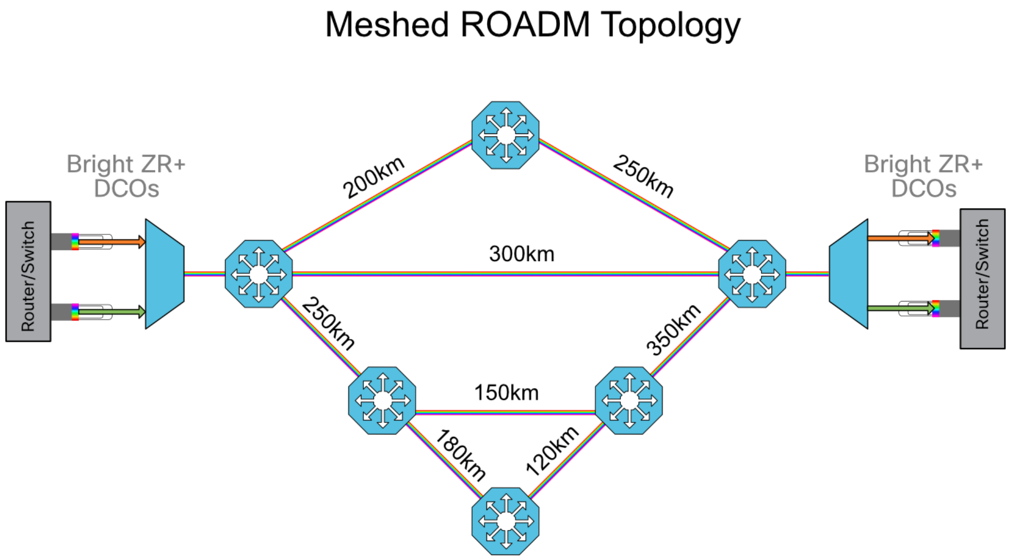
- If we focus on the network behaviour instead of the implemenation, then:
  - TI-LFA and CS-SR can ben seen as modern, packet based implementations of 1:1 “like” protection, considering:
    - Traffic is transferred to back-up path only when a failure is detected
    - Switch to back-up LSP happens at source and sink
  - TI-LFA exceptions:
    - No requirement for manual, explicit paths (including co-routing of up/down paths)
    - Control plane is dynamic (versus static), with post-convergence topology updates

Optical Restoration for Routed Optical Networking

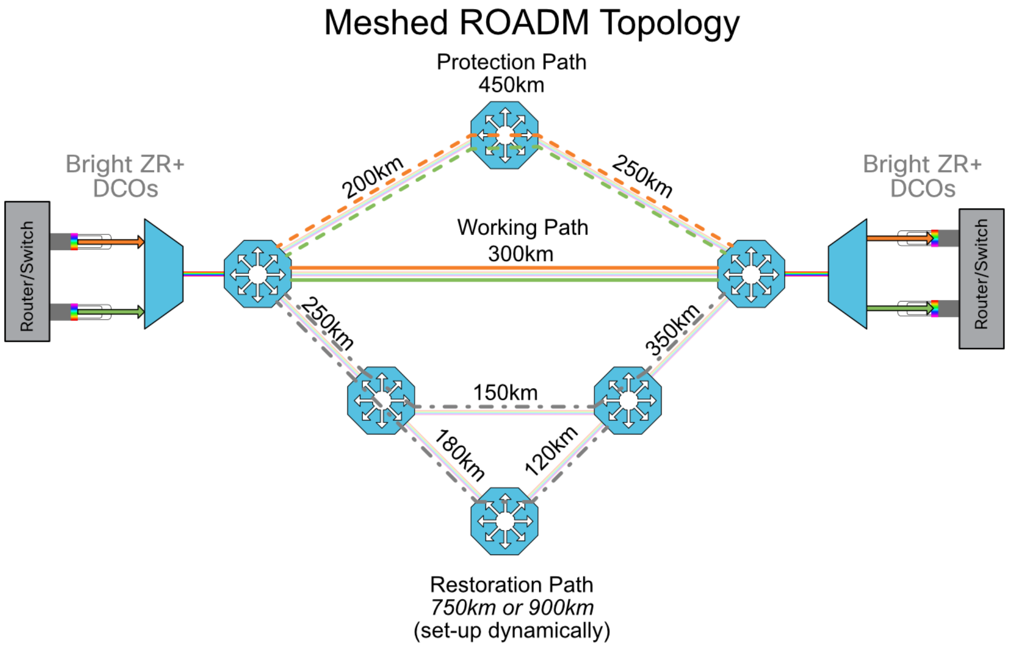
- Can you use Optical Restoration?
- Answer: Yes, keeping in mind the caveats discussed earlier (BW vs Reach vs Spectrum).

Let's walk through an example to understand the challenge.

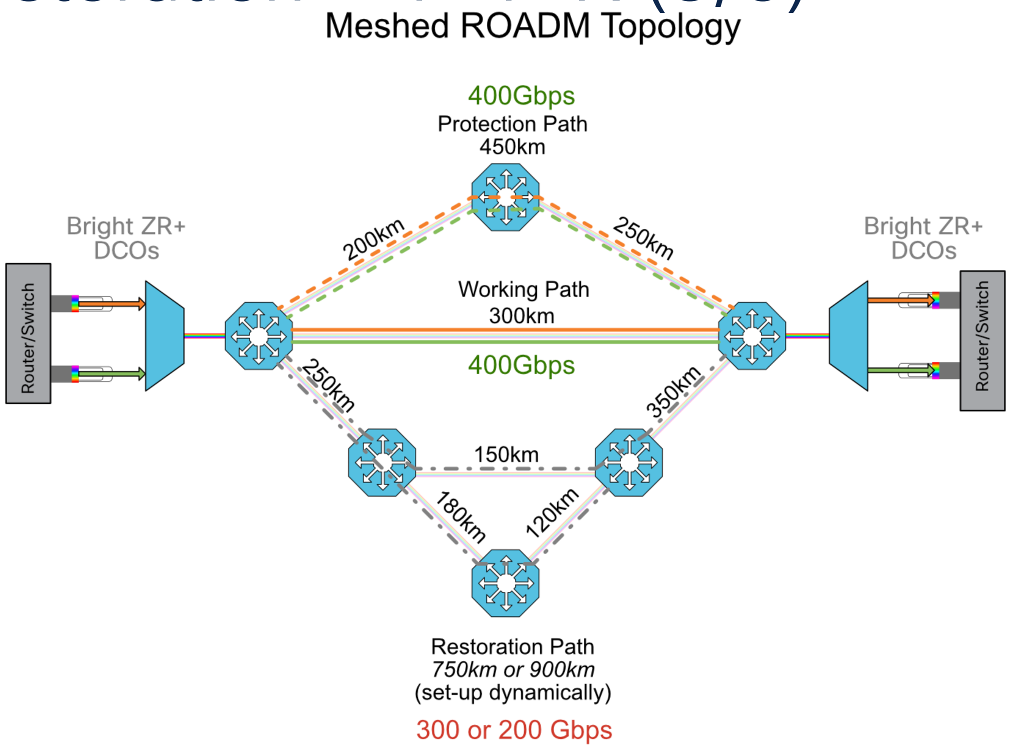
Optical Restoration – 1+1+R (1/5)



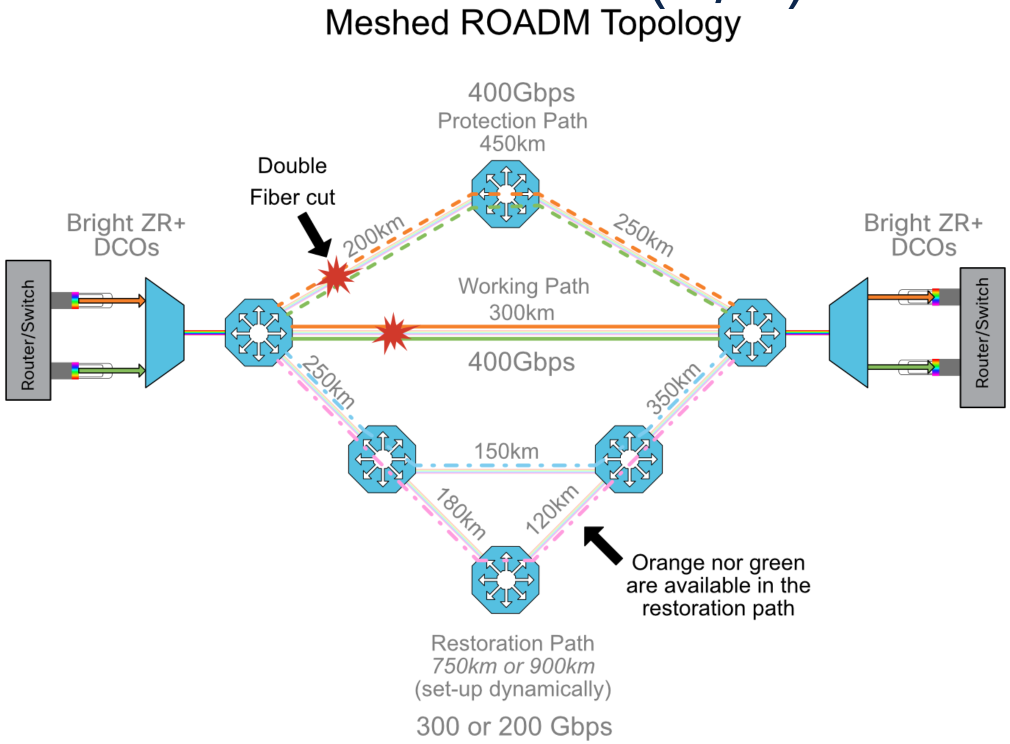
Optical Restoration – 1+1+R (2/5)



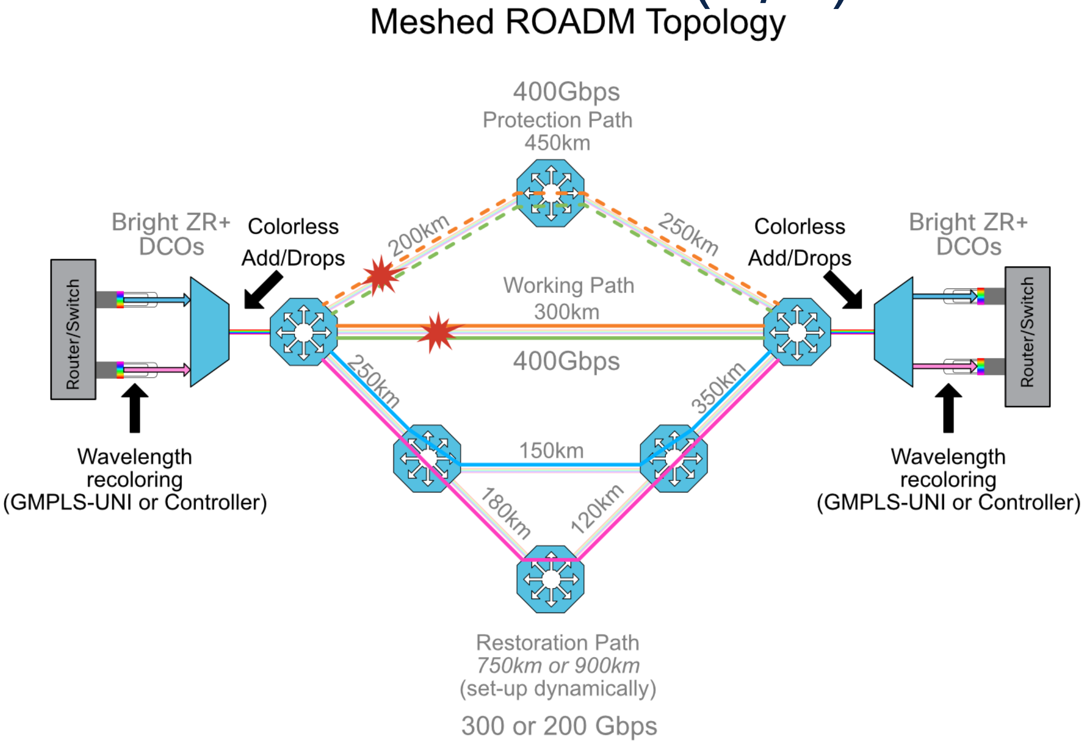
Optical Restoration – 1+1+R (3/5)



Optical Restoration – 1+1+R (4/5)

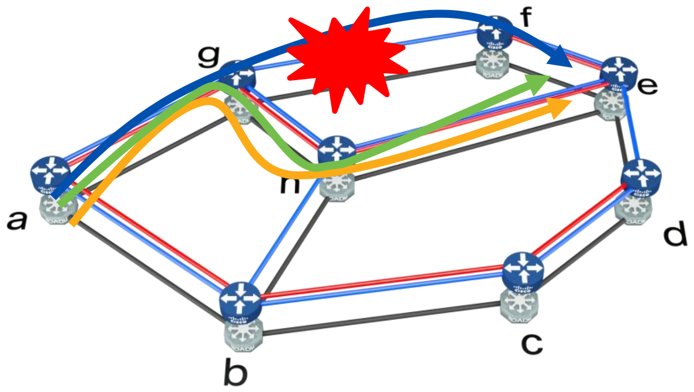


Optical Restoration – 1+1+R (5/5)



Protection & Restoration at the IP/MPLS layer

Internet, MPLS and Ethernet using SR with TI-LFA example:



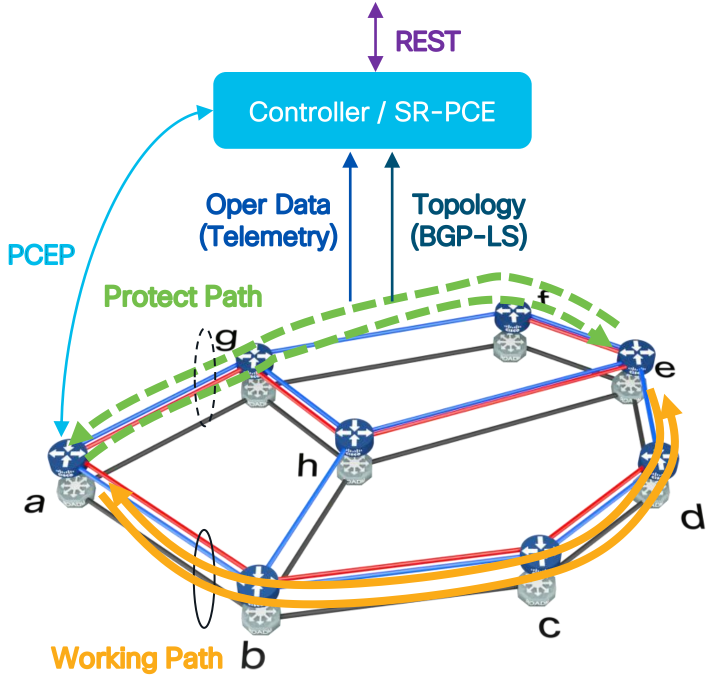
Path before failure

TI-LFA backup path (SID list at G is <H, E>)

Post-convergence path

- <50 ms restoration for link, node and SRLG failures using TI-LFA FRR
- Simple to operate and understand; Automatically computed by the SR-enabled IGP
- No stateful core tunnels required
- 100% topology coverage
- Optimum: backup path follows the post-convergence path
- Can co-exist with other protection schemes (e.g., PLE circuit-style)

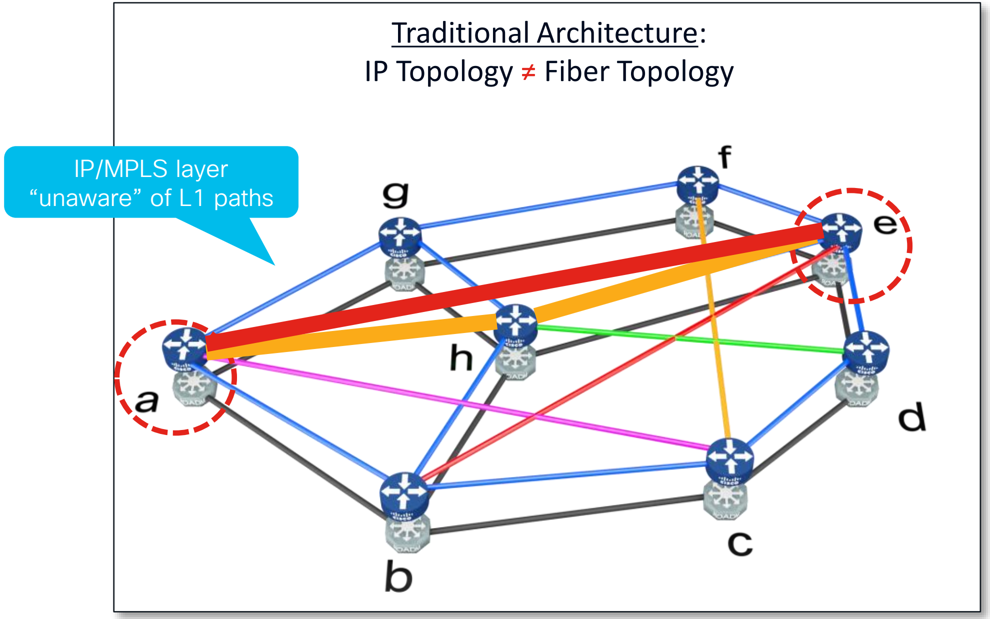
Circuit-Style Segment Routing (CS-SR)



* Assumes all link IGP metrics equal

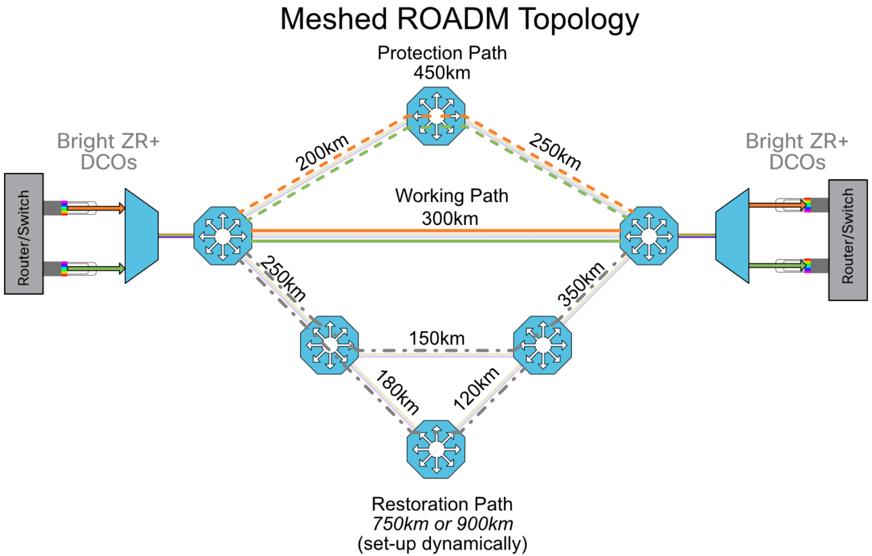
- To deliver transport-like services, the IP network must support new capabilities:
  - ✓ Co-routed bi-directional path
  - ✓ Control plane independent persistence
  - ✓ Path integrity monitoring with end-to-end path protection switching
  - ✓ Non-ECMP path with guaranteed latency
  - ✓ Guaranteed bandwidth
  - ✓ Controller/SR-PCE network abstraction layer

Shared Risk Link Groups (SRLG)



- With a traditional architecture, IP layer has no Optical topology awareness
  - IP layer MUST rely on L1 wavelength planning to avoid active & backup paths using SRLG
  - Increases risk of SRLG events. Active & backup in the example above may go through *A-G*

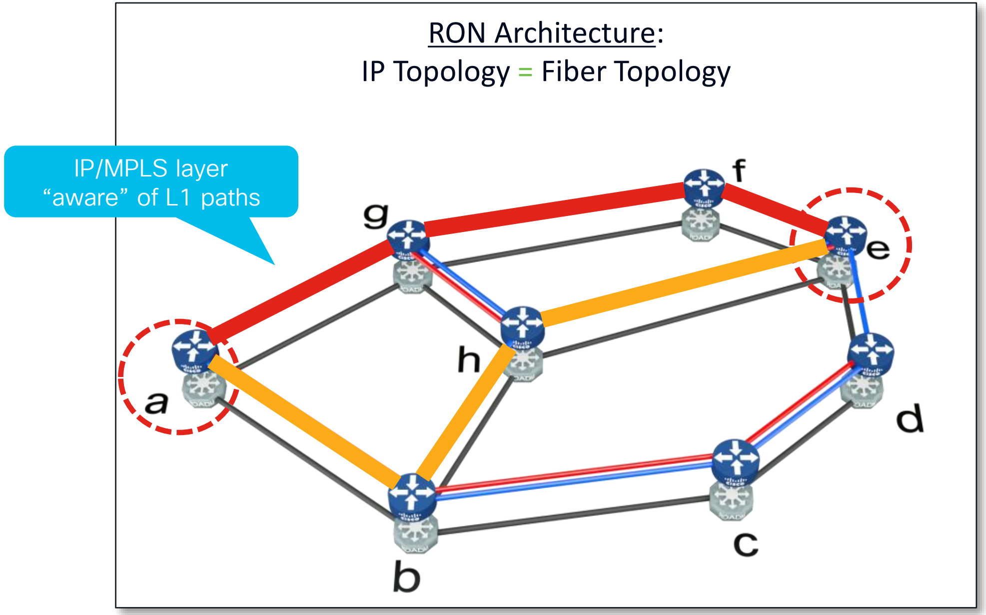
Breaking SRLGs example



Notes:

- In the above example, Orange and Green links are supposed to protect each-other and optical RWA (routing and wavelength assignment) didn't have that information. SRLG is broken.
- Even if they take different paths (top and middle), after the first fiber break, both will share the same path.

Shared Risk Link Groups (SRLG)



- With RON, IP and Optical topologies are congruent
  - IP layer able to guarantee disjoint active & backup paths – reduces risk of SRLG events
  - Includes failure and/or maintenance events that affect active & backup paths simultaneously

Management considerations

Management of DCO transceivers in routers

- DCO is like a traditional transponder:
  - Same configuration knobs with fewer options
  - Same performance data information for optical interface and DSP
- Difference is now the coherent interface is in the IP router
  - Configuration modes allow for easier operations
  - Logical separation of functional blocks
  - Different optical channel speeds, different logical links

How to manage DCO transceivers without CLI?

- More data to manage - configuration and operational
- Transport operations is done traditionally using visual tools
- End goal is automation, i.e., must be friendly for machine-to-machine communication
- Operators are embracing open/standard management frameworks

Open management and automation initiatives

OPENCONFIG

Over 30 companies
Webscales and CSPs

- Common data models *(covers DCO pluggables)*
- gRPC management protocol
- Subscription based streaming telemetry
- Vendor neutral testing and compliance

IETF

- YANG language, NETCONF and RESTCONF protocols
- Consensus based data models, hackatons, catalog
- Abstraction and Control of Traffic Engineered Networks framework (ACTN – see next slides)

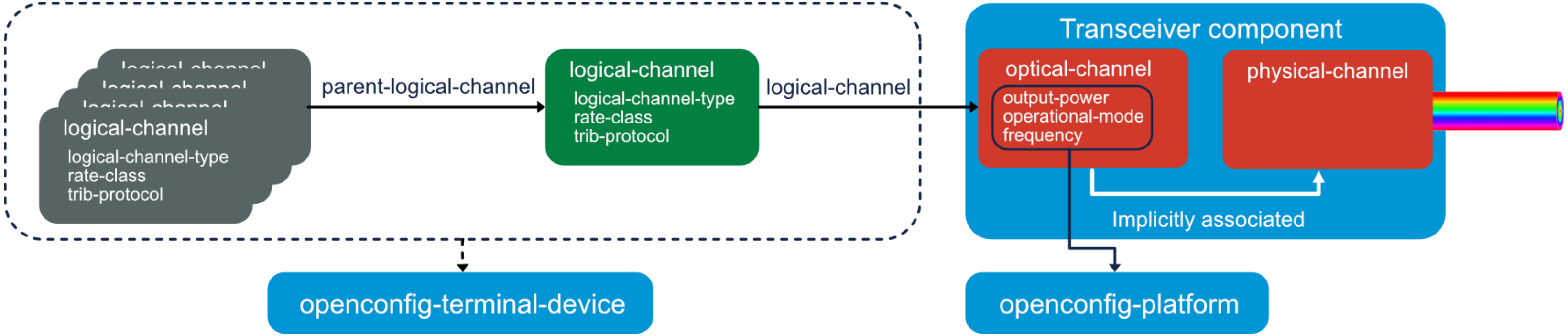
Open ROADM

- YANG models for disaggregated DWDM systems *(covers DCO pluggables)*, RPCs and device templates
- Controller based archtiecture (see next slides)

TELECOM INFRA PROJECT

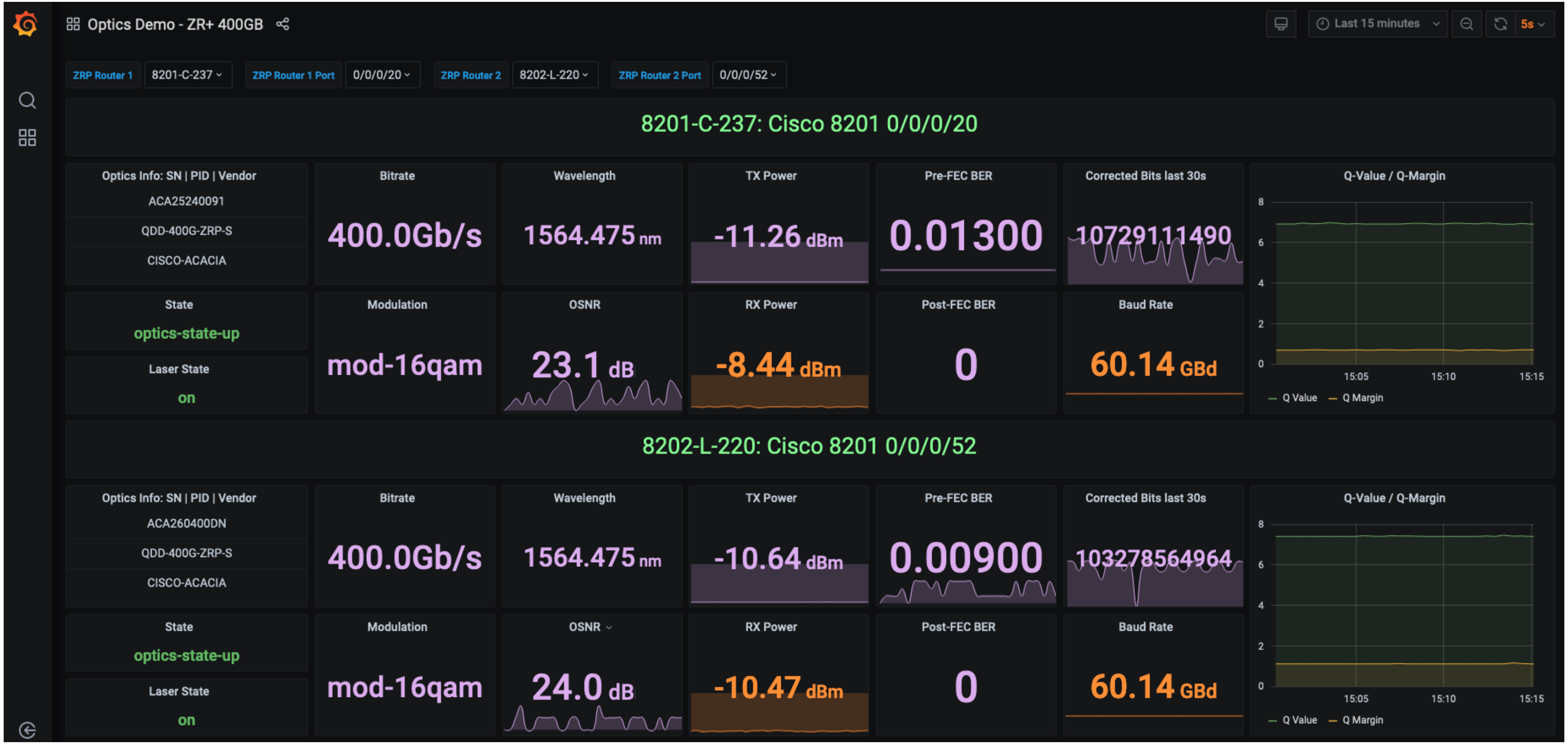
- MANTRA subgroup
- Aims to build an end-to-end reference network architecture based on Open Optical Networks (OON)
- Enabling “new generation” IPoDWDM with DCO

OpenConfig DCO model logical view



Full DCO programmability example using NETCONF: https://xrdocs.io/design/blogs//zr-openconfig-mgmt

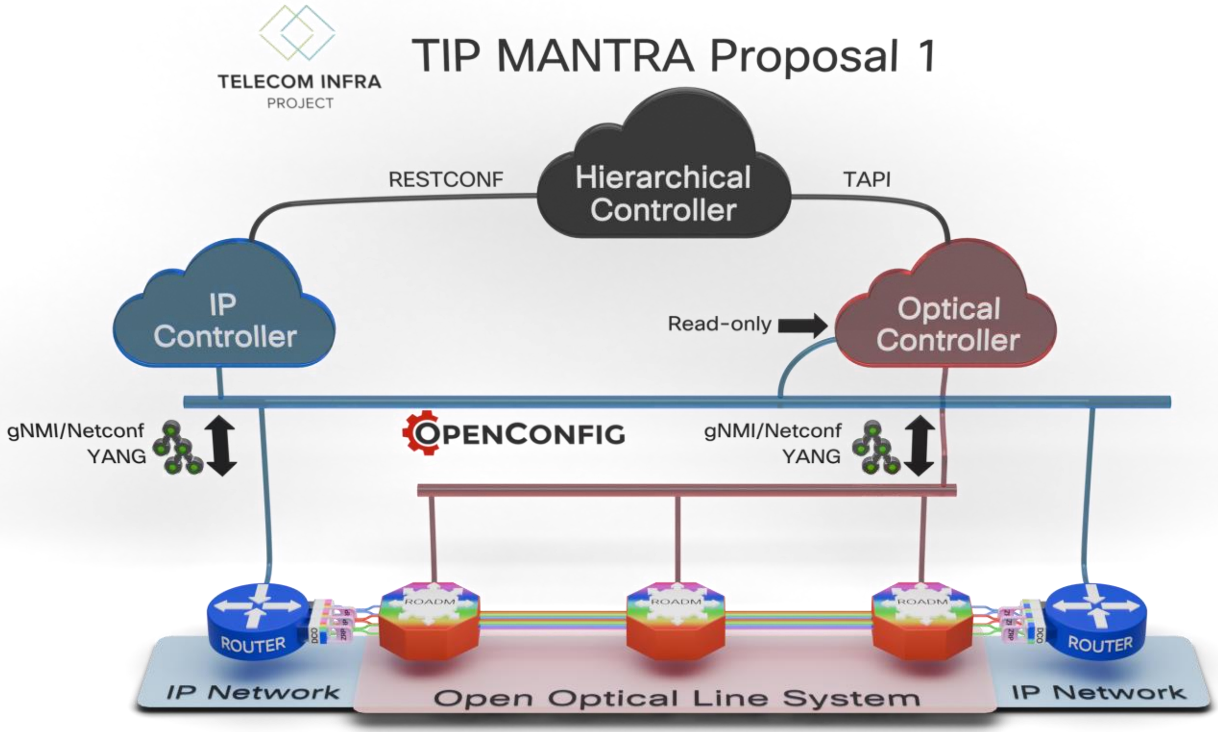
DCO monitoring using Grafana and MDT



Additional management considerations

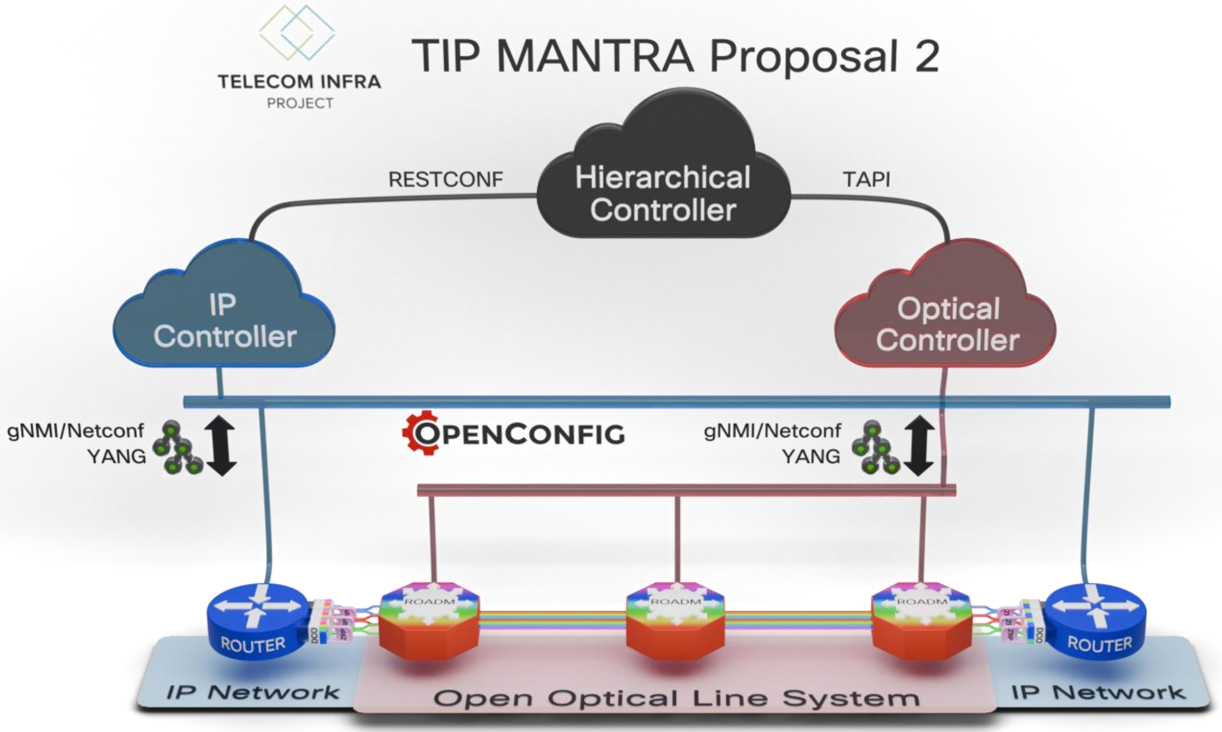
- Logical split of DCO allows different groups to configure and manage them individually:
  - Ex: Transport > Coherent DSP and Optics
    IP > Logical interfaces (Ethernet)
- Same applies to connecting components to different tools
  - Exporting data from different nodes in the data model to different subscribers
- This is not a solution for the past closed/proprietary systems, but for the present and the future based on open systems

Management Models and Controller Architectures



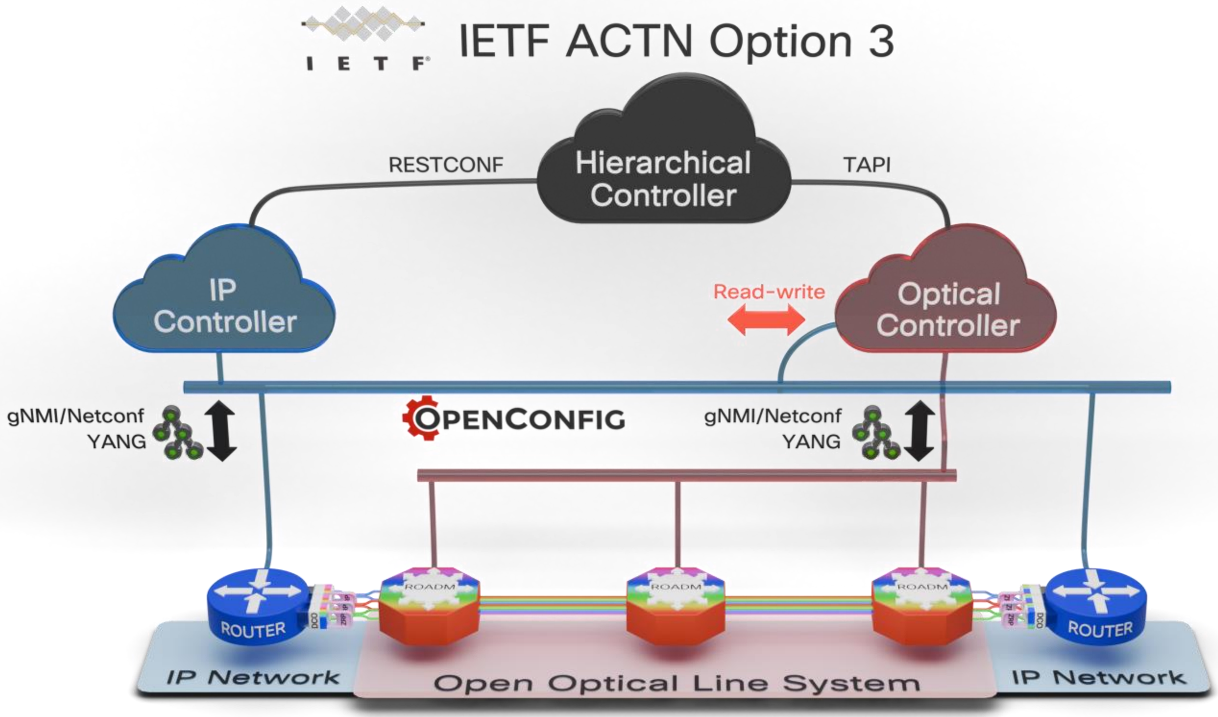
Reference: draft-poidt-ccamp-actn-poi-pluggable - Option 1: Dual SBI management of packet devices

Management Models and Controller Architectures



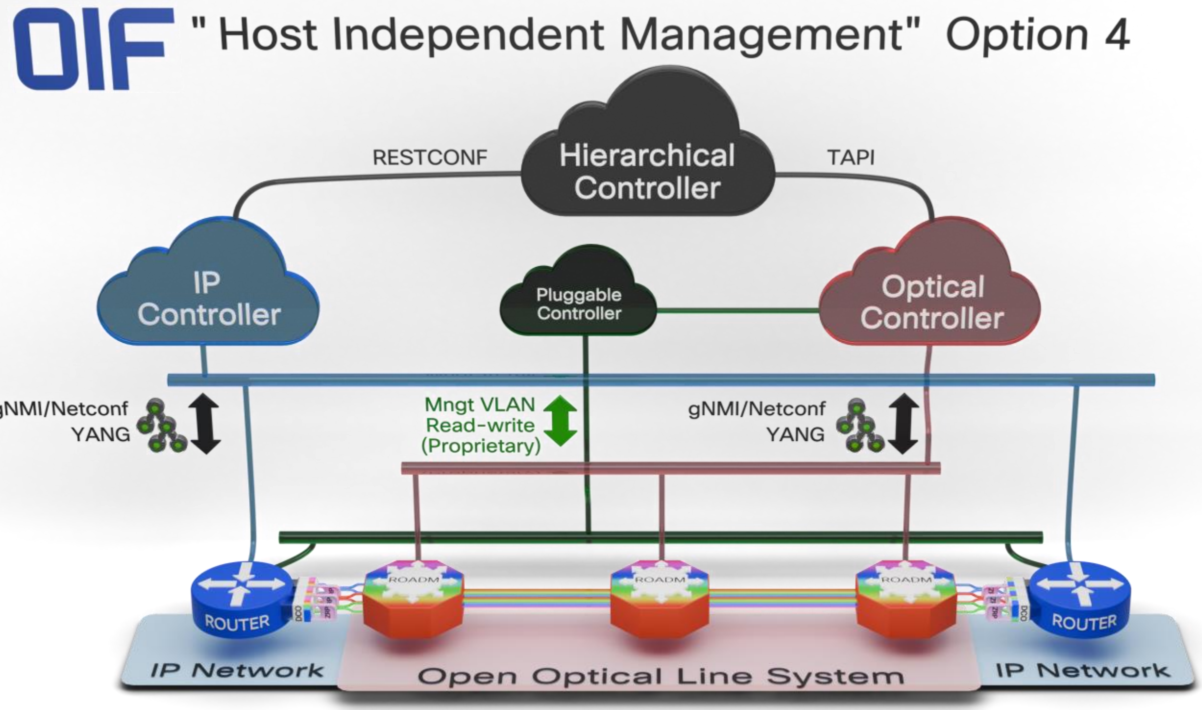
Reference: draft-poidt-ccamp-actn-poi-pluggable – Option 2: Single SBI management of packet devices

Management Models and Controller Architectures



Reference: draft-davis-ccamp-photonic-plug-control-arch - Option 3: Read/Write Optical controller access with dual SBI management on packet devices

Management Models and Controller Architectures

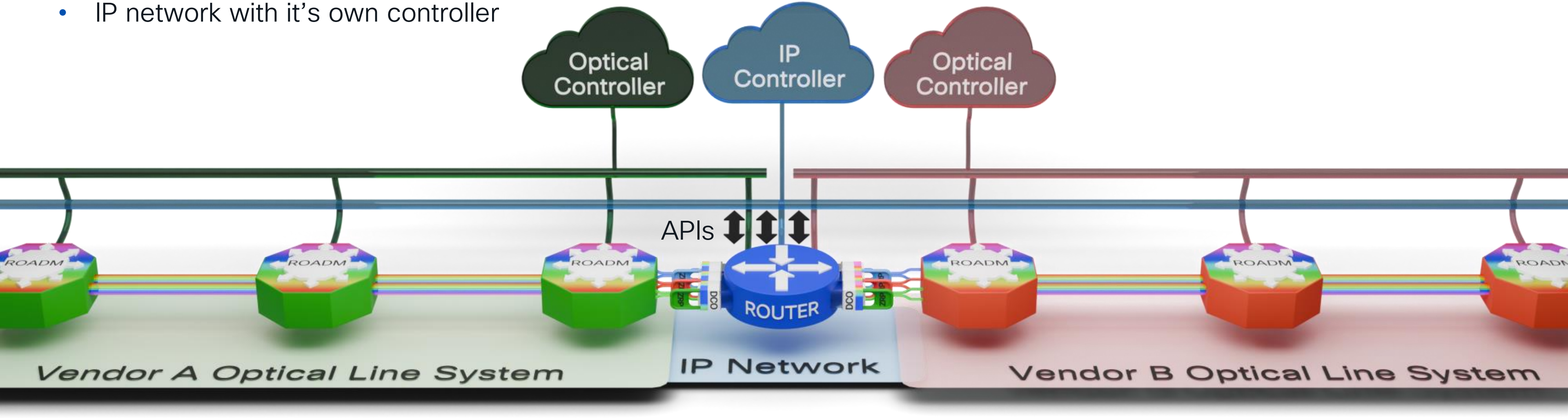


Reference: OIF White Paper (*Draft*) White Paper: Management of Smart Optical Modules

Why the hierarchical approach is better

Network scenario:

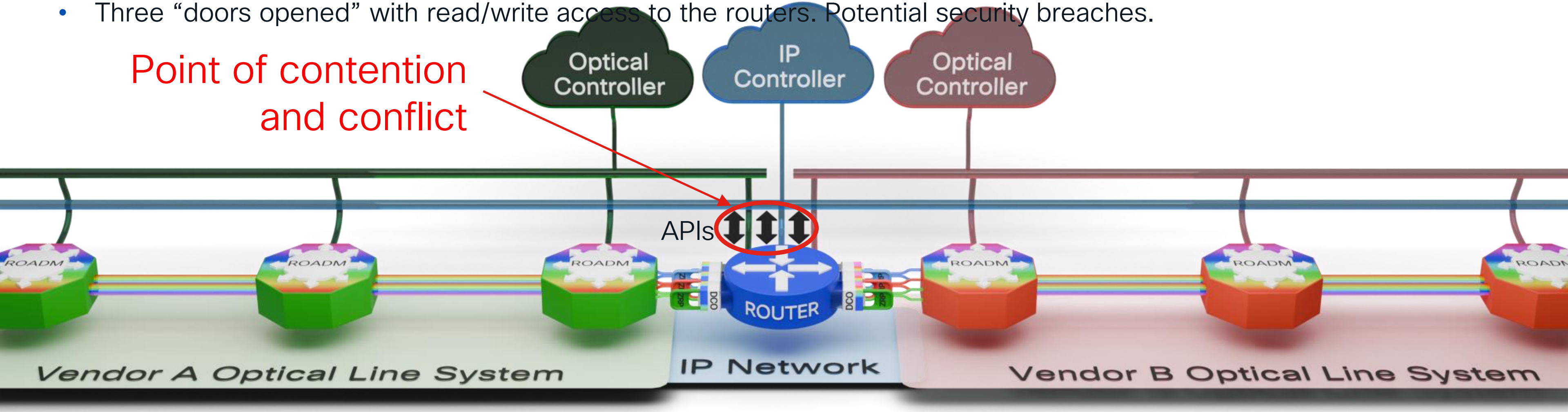
- Dual vendor optical network (very common)
- Each optical vendor controller wants to control the pluggables going through it's network talking director to router
- IP network with it's own controller



Why the hierarchical approach is better

Challenges:

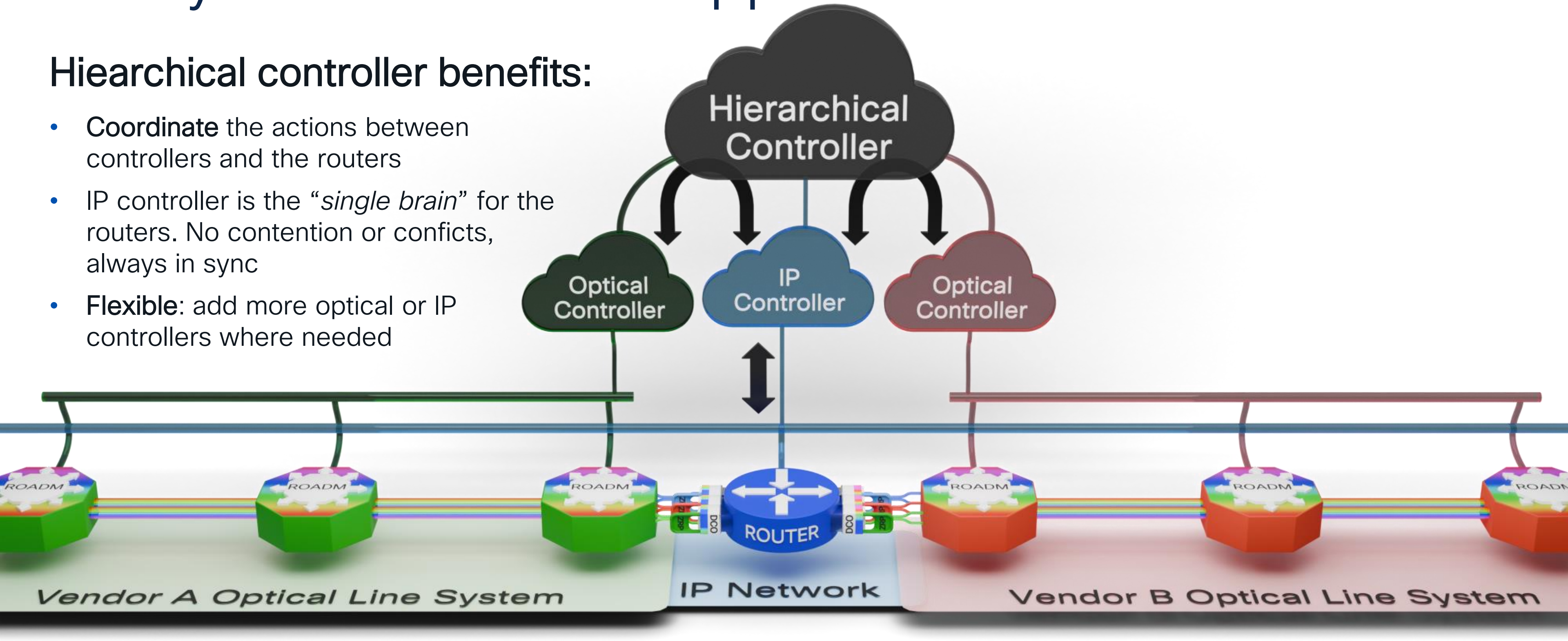
- Who controls what? How will the router know who to prioritize?
- Three controllers to listen to, report to, potentially wanting to change the same device. How to keep in sync?
- Three "doors opened" with read/write access to the routers. Potential security breaches.



Why the hierarchical approach is better

Hiearchical controller benefits:

- **Coordinate** the actions between controllers and the routers
- IP controller is the "*single brain*" for the routers. No contention or conficts, always in sync
- **Flexible**: add more optical or IP controllers where needed

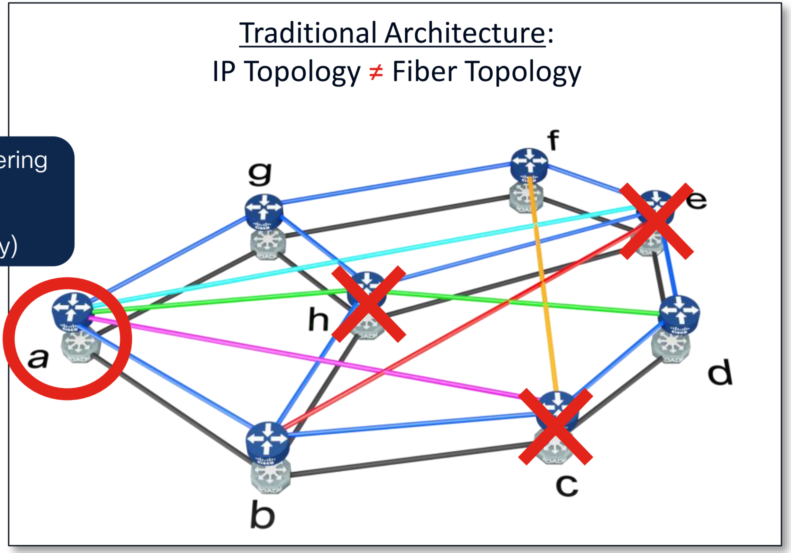


Summary: Comparison between the options

Options 1, 3 & 4 – optical controller talks to routers for QDD module info & config	Option 2: Only IP controller talks to routers. IP+OPT come together at HCO
The optical team manages connections via optical controller(s)	The optical team manages connections via HCO (unified for all vendors)
Simpler if you are only planning to automate the optical layer (and have 1 vendor)	Requires more controllers (HCO, IP controller) – if you're only planning to automate the optical layer
Breaks the standards (IETF, TIP)	Compliant with the standards
Requires mixing IP and optical DCNs – security concern	DCNs stay separate as today
Creates contention on router config or blocks router automation from accessing DCO data	Single owner of router config – no contention & no limitation for router automation
Blocks IP+OPT automation	Enables IP+OPT automation

Final considerations

Traffic Forwarding for Apps, Content & Peering

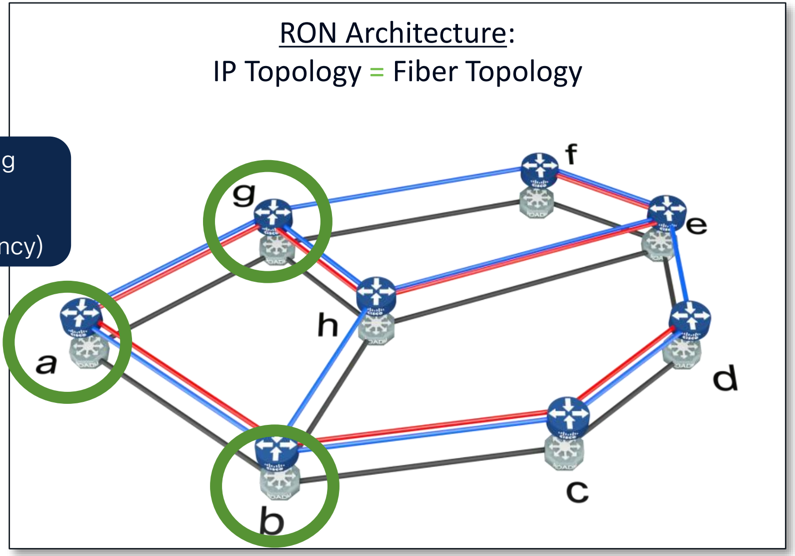


Sites C, E and H are DCs / Internet Peering Interconnects with FALSE proximity to Site A (1 IP hop but higher distance/latency)

- In general, the speed of light (i.e., fiber distance) determines network latency
- Traditional architecture lacks IP awareness of the optical topology which may result in sub-optimal traffic forwarding (e.g., DC/Internet peer selection) and higher latency

Traffic Forwarding for Apps, Content & Peering

Sites B and G are DCs / Internet Peering Interconnects with TRUE proximity to Site A (1 IP hop with shorter distance/lower latency)



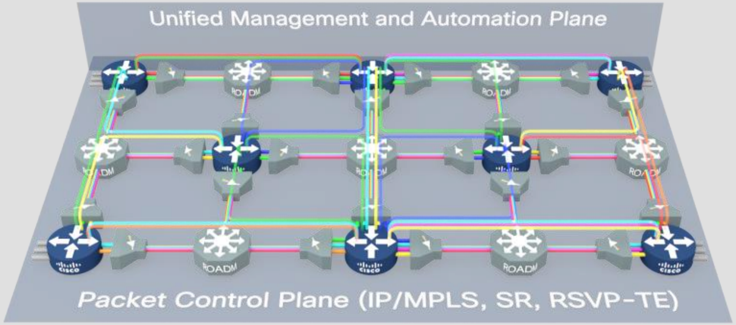
- RON architecture enables optimal forwarding and DC/Internet peer selection given IP awareness of the optical topology
  - Improves application performance, lowers latency and reduces backhaul bandwidth
  - Enables optimal placement of applications, content and Internet peering
  - SR-TE also enables SLA policies that can be tailored for service/application needs

Summary

Key Takeaways

- Routed Optical Networking architecture can considerably improve the economics and efficiency of networking through:
  - Simplified network architecture
  - Use of DCO pluggable optics on routers
  - IP/MPLS awareness of the optical network and its performance
  - Higher utilization of network assets
  - Full services convergence
  - Improved failure protection & restoration and reduced risk of SRLG events
  - Optimal traffic forwarding for applications and content

RON Architecture
Single Switching Layer (IP)
Service Convergence



Summary

Designing Routed Optical Networks IP/MPLS Routing Layer Considerations

- Routed Optical Networking is made possible by recent innovations and open standards in both the IP/MPLS and Optical layers
- The solution works on a classical IP/MPLS infrastructure; however, it delivers the best results on a programmable SR network which enables mass simplification, scale and service convergence
- Private Line and Wavelength service requirements are well addressed by PLE
- Operators can start today by leveraging 400G DCO transceivers in IP routers and preparing for an evolution to an IP-centric traffic switching architecture

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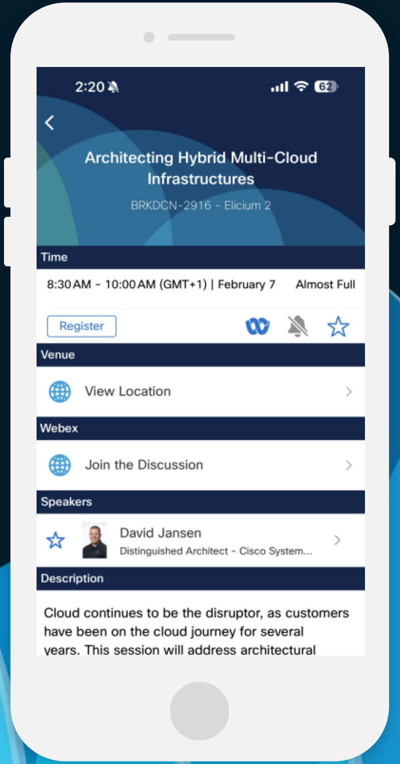
Webex spaces will be moderated by the speaker until February 28, 2025.



Thank you

GO **BEYOND**

Resources & References

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