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Revision History

Version	Date	Comments
1.0	01/10/2022	Initial Routed Optical Networking Publication
2.0	12/01/2022	Private Line Services, NCS 1010, CW HCO updates

Solution Component Software Versions

Element	Version
Router IOS-XR	7.7.1
NCS 2000 SVO	12.3.1
NCS 1010 IOS-XR	7.7.1
Cisco Optical Network Controller	2.0
Crosswork Network Controller	4.1
Crosswork Hierarchical Controller	5.3
Cisco EPNM	6.1.0

What is Routed Optical Networking?

Routed Optical Networking as part of Cisco's Converged SDN Transport architecture brings network simplification to the physical network infrastructure, just as EVPN and Segment Routing simplify the service and traffic engineering network layers. Routed Optical Networking collapses complex technologies and network layers into a single cost efficient and easy to manage network infrastructure. Here we present the Cisco Routed Optical Networking architecture and validated design.

Network Element	Legacy Networks		Converged SDN Transport with Routed Optical Networking
xVPN Services	LDP	BGP	✔ BGP for all L2VPN/L3VPN
IP Network Scaling	BGP-LU		SR Segment Routing
TE, FRR	RSVP-TE		
MPLS Overlay Protocol	RSVP-TE	LDP	
IPv6 Transport Overlay	None		
IP to DWDM Transition	Transponder or Muxponder		✔ DCO transceivers in Cisco routers
Private Line Services	Dedicated OTN	Dedicated Ethernet over DWDM	✔ Circuit-style Segment Routing ✔ Private Line Emulation over Converged SDN Transport

Key Drivers

Changing Networks

Internet traffic has seen a compounded annual growth rate of 30% or higher over the last ten years, as more devices are connected, end user bandwidth speeds increase, and applications continue to move to the cloud. The introduction of 5G in mobile carriers and backhaul providers is also a disruptor, networks must be built to handle the advanced services and traffic increase associated with 5G. Networks must evolve so the infrastructure layer can keep up with the service layer. 400G Ethernet is the next evolution for SP IP network infrastructure, and we must make that as efficient as possible.

Network Complexity

Computer networks at their base are a set of interconnected nodes to deliver data between two endpoints. In the very beginning, these networks were designed using a layered approach to separate functions. The OSI model is an example of how functional separation has led to innovation by allowing different standards bodies to work in parallel at each layer. In some cases even these OSI layers are further split into different layers. While these layers can bring some cost benefit, it also brings added complexity. Each layer has its own management, control plane, planning, and operational model.

Inefficiences Between Network Layers

OTN and IP network traffic must be converted into wavelength signals to traverse the DWDM network. This has traditionally required dedicated external hardware, a transponder. All of these layers bring complexity, and today some of those layers, such as OTN, bring little to the table in terms of efficiency or additional value. OTN switching, like ATM previously, has not been able to keep up with traffic demands due to very complex hardware. Unlike Ethernet/IP, OTN also does not have a widely interoperable control plane, locking providers into a single vendor or solution long-term.

Operational Complexity

Networks involving opaque layers are difficult to plan, build, and operate. IP and optical networks often have duplicate teams covering similar tasks. Network protection and restoration is also often complicated by different schemes running independently across layers. The industry has tried over decades to solve some of these issues with complex control planes such as GMPLS, but we are now at an evolution point where simplifying the physical layers and reducing control plane complexity in the optical layer allows a natural progression to a single control-plane and protection/restoration layer.

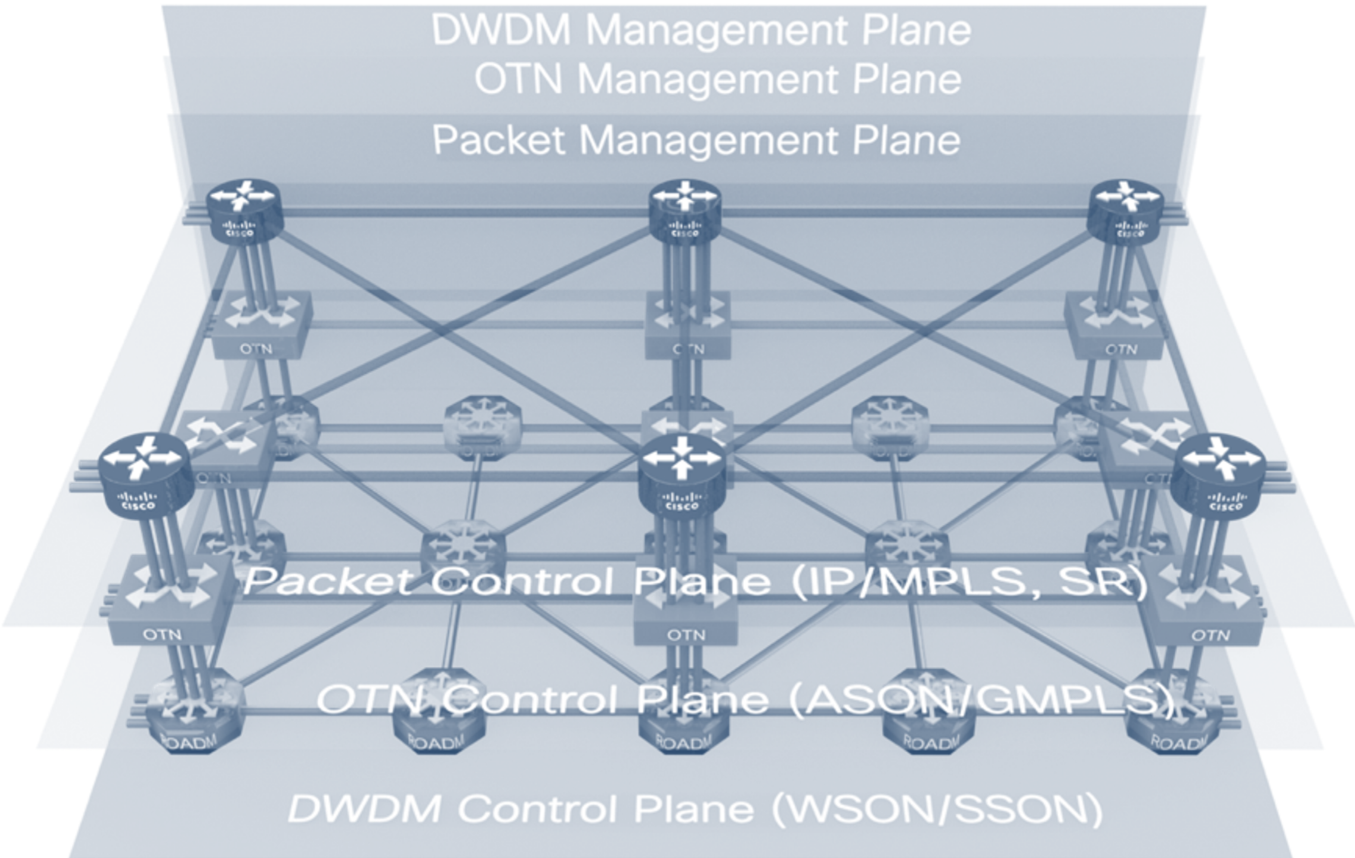
Network Cost

Simplyfing networks reduces both capex and opex. As we move to 400G, the network cost is shifted away from routers and router ports to optics. Any way we can reduce the number of 400G interconnects on the network will greatly reduce cost. Modeling networks with 400ZR and OpenZR+ optics in place of traditional transponders and muxponders shows this in almost any network scenario. It also results in a reduced space and power footprint.

Routed Optical Networking Solution Overview

As part of the Converged SDN Transport architecture, Routed Optical Networking extends the key tenet of network simplification. Routed Optical Networking tackles the challenges of building and managing networks by simplifying both the infrastructure and operations.

Today's Complex Multi-Layer Network Infrastructure



DWDM

Most modern SP networks start at the physical fiber optic layer. Above the physical fiber is technology to allow multiple photonic wavelengths to traverse a single fiber and be switched at junction points, we will call that the DWDM layer.

OTN

In some networks, above this DWDM layer is an OTN layer, OTN being the evolution of traditional SONET/SDH networks. OTN grooms low speed TDM services into higher speed containers, and if OTN switching is involved, allows switching these services at intermediate points in the network. OTN is primarily used in network to carry guaranteed bandwidth services.

Ethernet/IP

In all high bandwidth networks today, there is an Ethernet layer on which IP services traverse, since almost all data traffic today is IP. Ethernet and IP is used due to its ability to support statistical multiplexing, topology flexibility, and widespread interoperability between different vendors based on well-defined standards. In larger networks today carrying Internet traffic, the Ethernet/IP layer does not typically traverse an OTN layer, the OTN layer is primarily used only for business services.

Enabling Technologies

Pluggable Digital Coherent Optics

Simple networks are easier to build and easier to operate. As networks scale to handle traffic growth, the level of network complexity must decline or at least remain flat.

IPoDWDM has attempted to move the transponder function into the router to remove the transponder and add efficiency to networks. In lower bandwidth applications, it has been a very successful approach. CWDM, DWDM SFP/SFP+, and CFP2-DCO pluggable transceivers have been used for many years now to build access, aggregation, and lower speed core networks. The evolution to 400G and advances in technology created an opportunity to unlock this potential in higher speed networks.

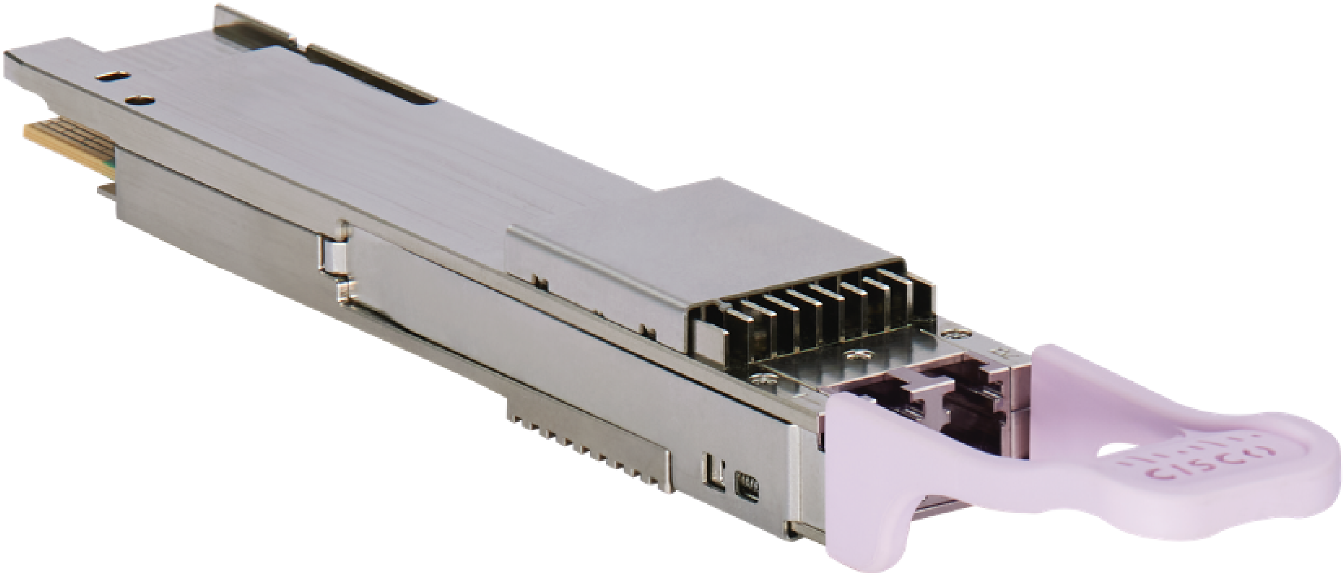
Transponder or muxponders have typically been used to aggregate multiple 10G or 100G signals into a single wavelength. However, with reach limitations, and the fact transponders are still operating at 400G wavelength speeds, the transponder becomes a 1:1 input to output stage in the network, adding no benefit.

The Routed Optical Networking architecture unlocks this efficiency for networks of all sizes, due to advancements in coherent plugable technology.

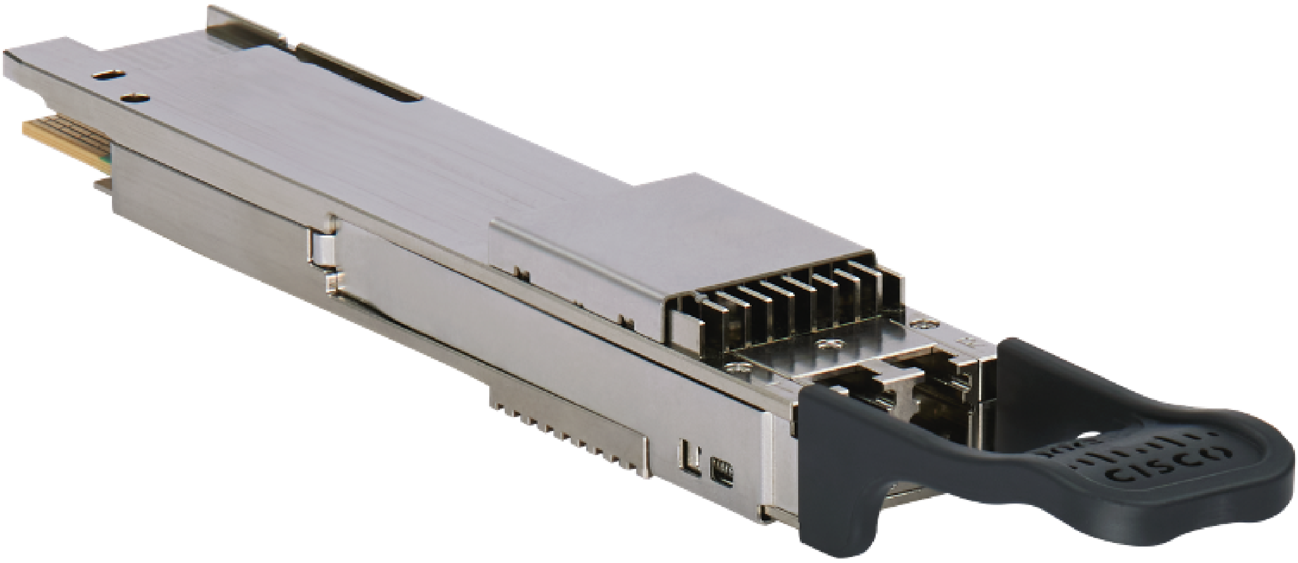
QSFP-DD and 400ZR and OpenZR+ Standards

As mentioned, the industry saw a point to improve network efficiency by shifting coherent DWDM functions to router pluggables. Technology advancements have shrunk the DCO components into the standard QSFP-DD form factor, meaning no specialized hardware and the ability to use the highest capacity routers available today. ZR/OpenZR+ QSFP-DD optics can be used in the same ports as the highest speed 400G non-DCO transceivers.

Cisco OpenZR+ Transceiver (QDD-400G-ZRP-S)



Cisco OIF 400ZR Transceiver (QDD-400G-ZR-S)



Two industry optical standards have emerged to cover a variety of use cases. The OIF created the 400ZR specification, https://www.oiforum.com/technical-work/hot-topics/400zr-2 as a 400G interopable standard for metro reach coherent optics. The industry saw the benefit of the approach, but wanted to cover longer distances and have flexibility in wavelength rates, so the OpenZR+ MSA was created, https://www.openzrplus.org. The following table outlines the specs of each standard. ZR400 and OpenZR+ transceivers are tunable across the ITU C-Band, 196.1 To 191.3 THz.

	OIF 400ZR	OpenZR+ MULTI-SOURCE AGREEMENT
Reach	< 120km	> 120km
Client	400GbE Only	100-400GbE
Application	Campus, Metro, Edge DCI	DCI, Metro, Regional, Long Haul
FEC	C-FEC	oFEC
Max. Power Consumption	15W	~20W
Multi-vendor Interop	Yes	Yes
Standards	OIF	OpenZR+ MSA

The following part numbers are used for Cisco's ZR400 and OpenZR+ MSA transceivers

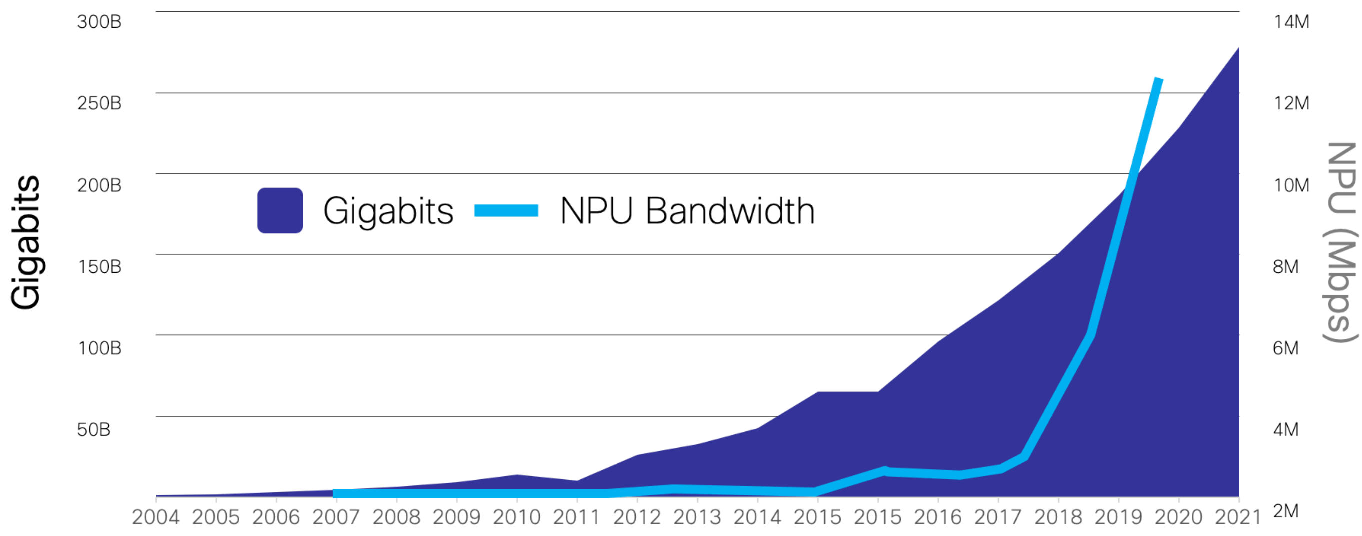
Standard	Part
400ZR	QDD-400G-ZR-S
OpenZR+	QDD-400G-ZRP-S

Cisco datasheet for these transceivers can be found at https://www.cisco.com/c/en/us/products/collateral/interfaces-modules/transceiver-modules/datasheet-c78-744377.html

Cisco Routers

We are at a point in NPU development where the pace of NPU bandwidth growth has outpaced network traffic growth. Single NPUs such as Cisco's Silicon One have a capacity exceeding 12.8Tbps in a single NPU package without sacrificing flexibility and rich feature support. This growth of NPU capacity also brings reduction in cost, meaning forwarding traffic at the IP layer is more advantageous vs. a network where layer transitions happen often.

Cisco supports 400ZR and OpenZR+ optics across the NCS 540, NCS 5500, NCS 5700, ASR 9000, and Cisco 8000 series routers. This enabled providers to utilize the architecture across their end to end infrastructure in a variety of router roles. See



Internet Gigabits per Month vs. NPU BW

Cisco Private Line Emulation

Starting in Routed Optical Networking 2.0, Cisco now supports Private Line Emulation (PLE) hardware and IOS-XR support to provide bit-transparent private line services over the converged packet network. Private Line Emulation supports the transport of Ethernet, SONET/SDH, OTN, and Fiber Channel services. See the PLE section of the document for in-depth information on PLE.

Circuit Style Segment Routing

Circuit Style Segment Routing (CS-SR) is another Cisco advancement bringing TDM circuit like behavior to SR-TE Policies. These policies use deterministic hop by hop routing, co-routed bi-directional paths, hot standby protect paths, and end to end liveness detection. Standard Ethernet services not requiring bit transparency can be transported over a Segment Routing network similar to OTN networks without the additional cost, complexity, and inefficiency of an OTN network layer.

Cisco DWDM Network Hardware

Routed Optical Networking shifts an expensive and now often redundant transponder function into a pluggable transceiver. However, to make the most efficient use of a valuable resource, the underlying fiber optic network, we still need a DWDM layer. Routed Optical Networking is flexible enough to work across point to point, ROADM based optical networks, or a mix of both. Cisco multiplexers, amplifiers, and ROADMs can satisfy any network need.

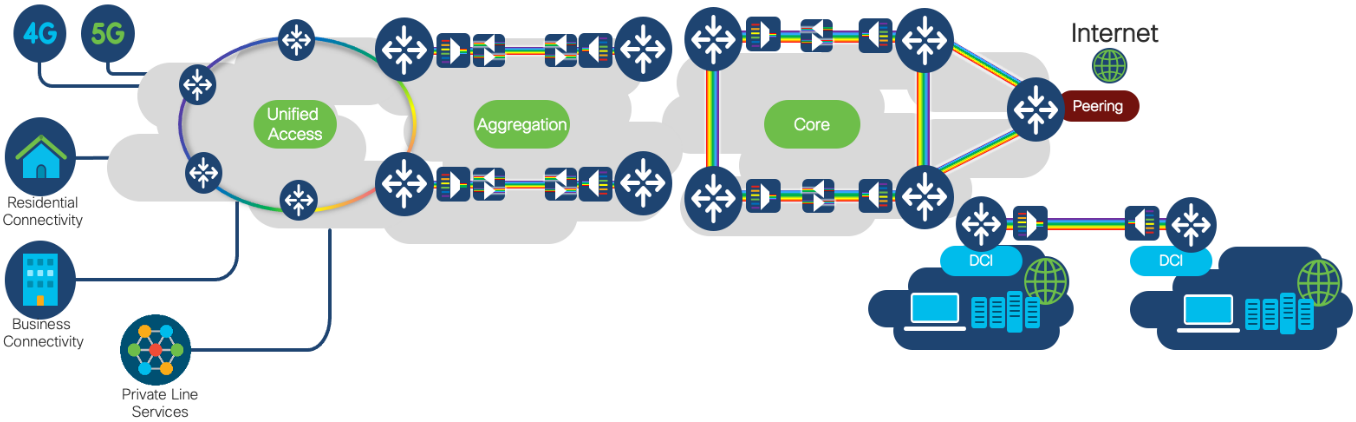
Cisco NCS 1010

Routed Optical Networking 2.0 introduces the new Cisco NCS 1010 open optical line system. The NCS 1010 represents an evolution in open optical line systems, utilizing the same IOS-XR software as Cisco routers and NCS 1004 series transponders. This enables the rich XR automation and telemetry support to extend to the DWDM photonic line system. The NCS 1010 also simplifies how operators build DWDM networks with advanced integrated functions and a flexible twin 1x33 WSS.

See the validated design hardware section for more information.

Routed Optical Networking Network Use Cases

Cisco is embracing Routed Optical Networking in every SP router role. Access, aggregation, core, peering, DCI, and even PE routers can be enabled with high speed DCO optics. Routed Optical Networking is also not limited to SP networks, there are applications across enterprise, government, and education networks.



Where to use 400ZR and where to use OpenZR+

The OIF 400ZR and OpenZR+ MSA standards have important differences.

400ZR supports 400G rates only, and targets metro distance point to point connections up to 120km. 400ZR mandates a strict power consumption of 15W as well. Networks requiring only 400G over distances less than 120km may benefit from using 400ZR optics. DCI and 3rd party peering interconnection are good use cases for 400ZR.

If a provider needs flexibility in rates and distances and wants to standardize on a single optics type, OpenZR+ can fulfill the need. In areas of the network where 400G may not be needed, OpenZR+ optics can be run at 100G or 200G. Additionally, hardware with QSFP-DD 100G ports can utilize OpenZR+ optics in 100G mode. This can be ideal for high density access and aggregation networks.

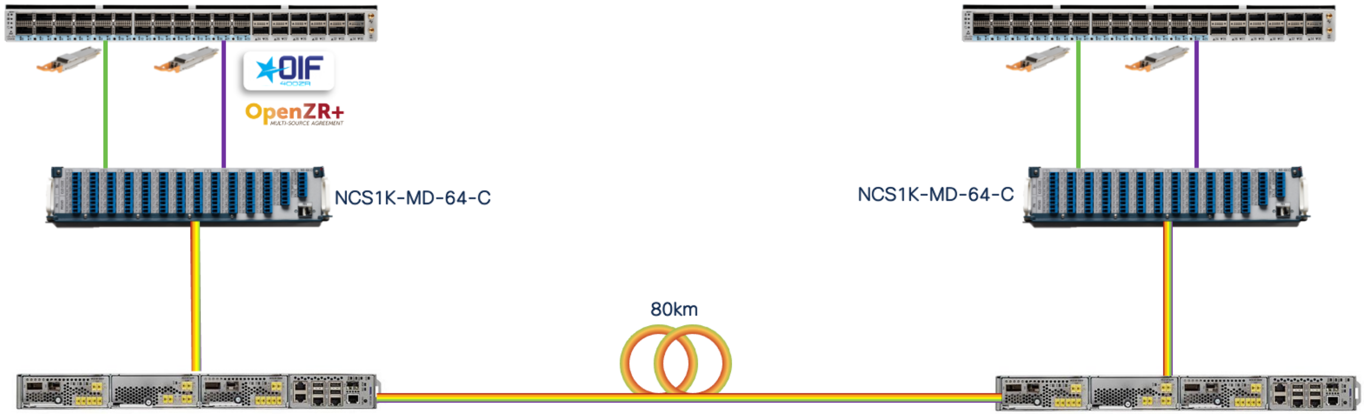
Supported DWDM Optical Topologies

For those unfamiliar with DWDM hardware, please see the overview of DWDM network hardware in Appendix A {: .notice--warning}

The future of networks may be a flat L3 network with simple point to point interconnection, but it will take time to migrate to this type of architecture. Routed Optical Network supports an evolution to the architecture by working over most modern photonic DWDM networks. Below gives just a few of the supported optical topologies including both point to point and ROADM based DWDM networks.

NCS 2000 64 Channel FOADM P2P Deployment

This example provides up to 25.6Tb on a single network span, and highlights the simplicity of the Routed Optical Networking solution. The "optical" portion of the network including the ZR/ZR+ configuration can be completed in a matter of minutes from start to finish.

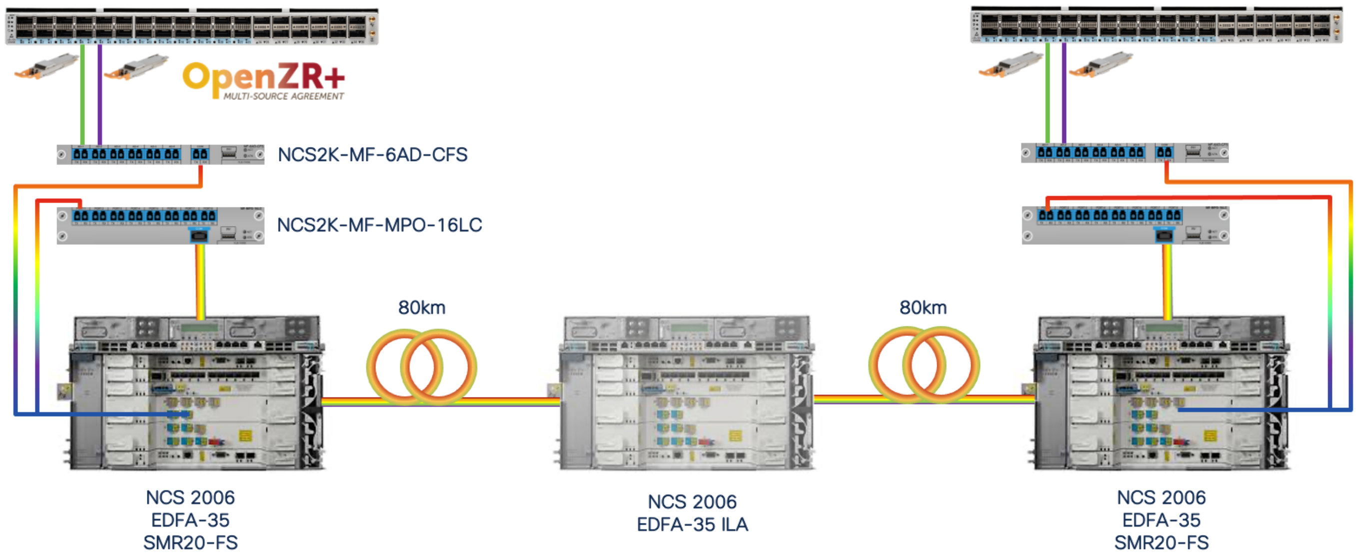


NCS 1010 64 Channel FOADM P2P Deployment

The NCS 1010 includes two add/drop ports with embedded bi-directional EDFA amplifiers, ideal for connecting the new MD-32-E/O 32 channel, 150Ghz spaced passive multiplexer. Connecting both even and odd multiplexers allows the use of 64 total channels.

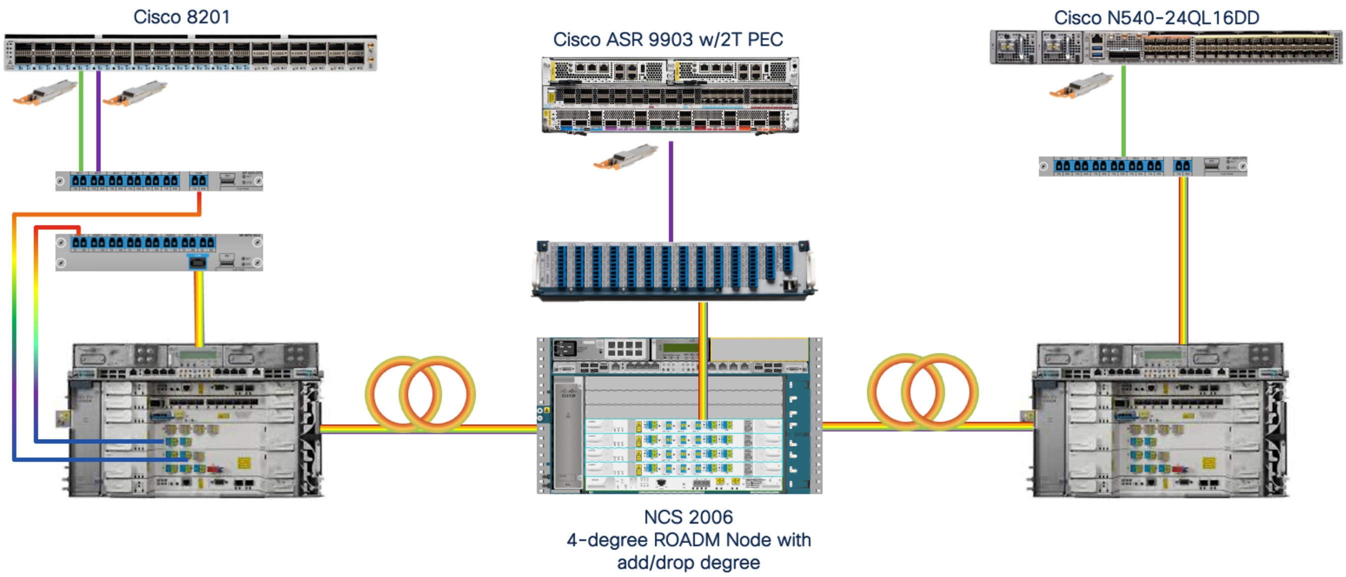
NCS 2000 Colorless Add/Drop Deployment

Using the NCS2K-MF-6AD-CFS colorless NCS2K-MF-LC module along with the LC16 LC aggregation module, and SMR20-FS ROADM module, a scalable colorless add/drop complex can be deployed to support 400ZR and OpenZR+.



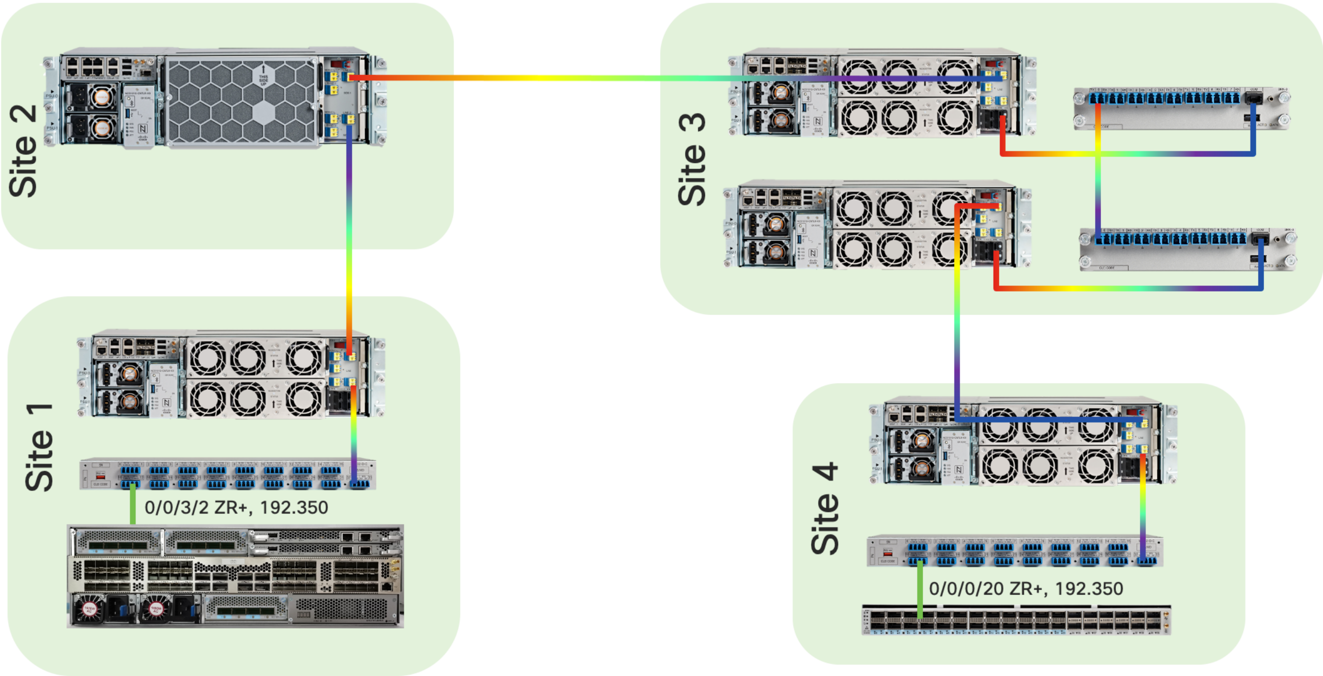
NCS 2000 Multi-Degree ROADM Deployment

In this example a 3 degree ROADM node is shown with a local add/drop degree. The Routed Optical Networking solution fully supports ROADM based networks with optical bypass. The traffic demands of the network will dictate the most efficient network build. In cases where an existing or new build requires DWDM switching capability, ZR and ZR+ wavelengths are easily provisioned over the infrastructure.



NCS 1010 Multi-Degree Deployment

A multi-degree NCS 1010 site utilizes a separate NCS 1010 OLT device for each degree. The degree may be an add/drop or bypass degree. In our example Site 3 can support the add/drop of wavelengths via its A/D ports on the upper node, or express those wavelengths through the interconnect to site 4 via the additional 1010 OLT unit connected to site 4. In our example the wavelength originating at sites 1 and 4 using ZR+ optics is expressed through site 3.



Long-Haul Deployment

Cisco has demonstrated in a physical lab 400G OpenZR+ services provisioned across 1200km using NCS 2000 and NCS 1010 optical line systems. 300G, 200G, and 100G signals can achieve even greater distances. OpenZR+ is not just for shorter reach applications, it fulfills an ideal sweet spot in most provider networks in terms of bandwidth and reach.

Core Networks

Long-haul core networks also benefit from the CapEx and OpEx savings of moving to Routed Optical Networking. Moving to a simpler IP enabled converged infrastructure makes networks easier to manage and operate vs. networks with complex underlying optical infrastructure. The easiest place to start in the journey is replacing external transponders with OpenZR+ QSFP-DD transceivers. At 400G connecting a 400G gray Ethernet port to a transponder with a 400G or 600G line side is not cost or environmentally efficient. Cisco can assist in modeling your core network to determine the TCO of Routed Optical Networking compared to traditional approaches.

Metro Aggregation

Tiered regional or metro networks connecting hub locations to larger aggregation site or datacenters can also benefit from Routed Optical Networking. Whether deployed in a hub and spoke topology or hop by hop IP ring, Routed Optical Networking satisfied provider's growth demands at a lower cost than traditional approaches.

Access

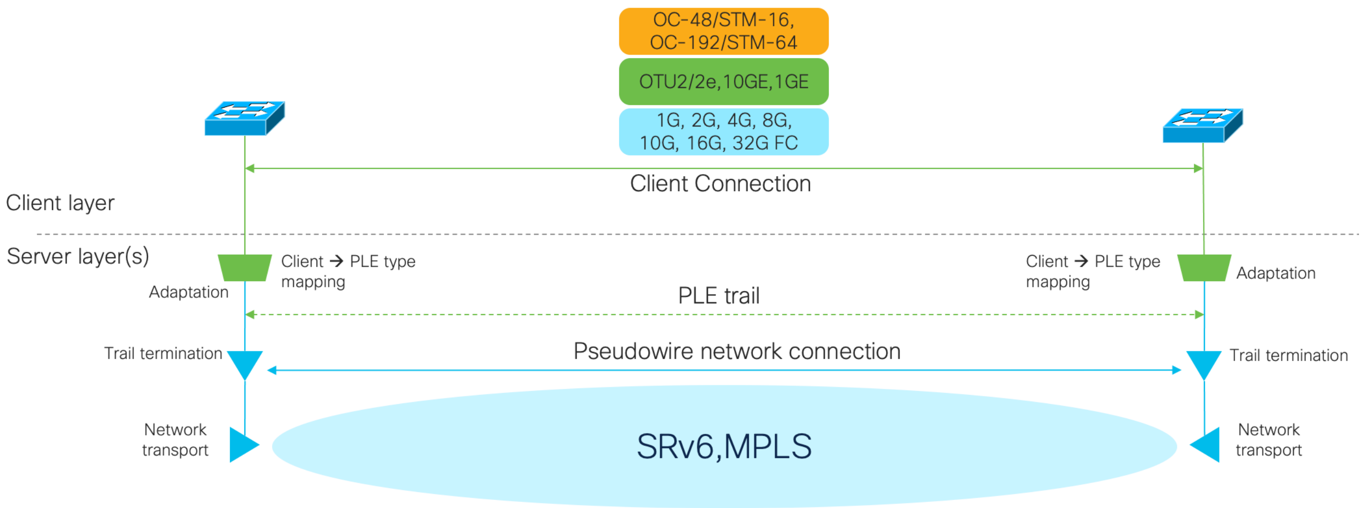
Access deployments in a ring or point-to-point topology are ideal for Routed Optical Networking. Shorter distances over dark fiber may not require active optical equipment, and with up to 400G per span may provide the bandwidth necessary for growth over a number of years without the use of additional multiplexers.

DCI and 3rd Party Location Interconnect

In this use case, Routed Optical Networking simplifies deployments by eliminating active transponders, reducing power, space, and cabling requirements between end locations. 25.6Tbps of bandwidth is available over a single fiber using 64 400G wavelengths and simple optical amplifiers and multiplexers requiring no additional configuration after initial turn-up.

Routed Optical Networking Private Line Services

Release 2.0 introduces Circuit Style Segment Routing TE Policies and Private Line Emulation hardware to enable traditional TDM-like private line services over the converged Segment Routing packet network. The following provides an overview of the hardware and software involved in supporting PL services. The figure below gives an overview of PLE service signaling and transport.



Circuit Style Segment Routing

CS-SR provides the underlying TDM-like transport to support traditional private line Ethernet services without additional hardware and emulated bit-transparent services using Private Line Emulation hardware.

CS SR-TE paths characteristics

- Co-routed Bidirectional - Meaning the paths between two client ports are symmetric
- Deterministic without ECMP - Meaning the path does not vary based on any load balancing criteria
- Persistent - Paths are routed on a hop by hop basis, so they are not subject to path changes induced by network changes
- End-to-end path protection - Entire paths are switched from working to protect with the protect path in a hot standby state for fast transition

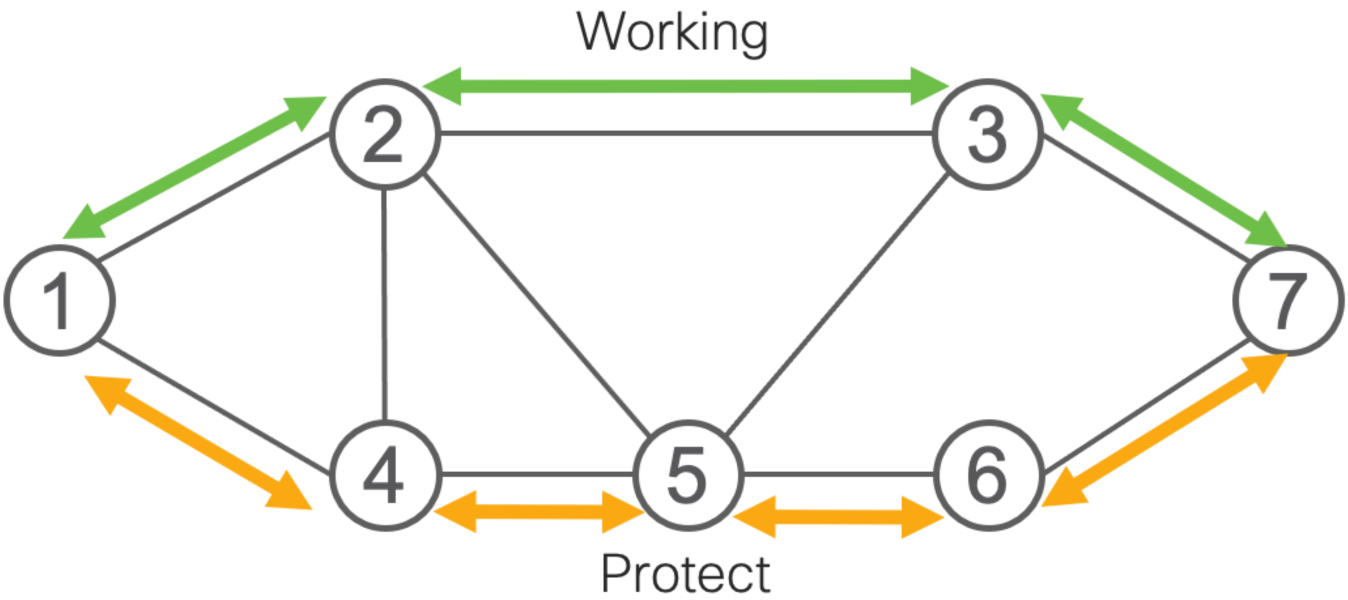
SR CS-TE policies are built using link adjacency SIDs without protection to ensure the paths do not take a TI-LFA path during path failover and instead fail over to the pre-determined protect path.

CS SR-TE path liveness detection

Paths can be configured with end to end liveness detection. Liveness detection uses TWAMP-lite probes which are looped at the far end to determine if the end to end path is up bi-directionally. If more than the set number of probes is missed (set by the multiplier) the path will be considered down. Once liveness detection is enabled probes will be sent on all candidate paths. Either the default liveness probe profile can be used or if you want to modify the default parameters a customized one can be created.

CS SR-TE path failover behavior

CS SR-TE policies contain multiple candidate paths. The highest preference candidate path is considered the working path, the second highest preference path is the protect path, and if a third lower preference path is configured would be a dynamic restoration path. This provides 1:1+R protection for CS SR-TE policies. The following below shows the configuration of a CS SR-TE Policy with a working, protect, and restoration path. T




```
segment-routing
 traffic-eng
  policy to-55a2-1
   color 1001 end-point ipv4 100.0.0.44
   path-protection
   !
   candidate-paths
    preference 25
     dynamic
       metric-type igp
     !
    !
    preference 50
     explicit segment-list protect-forward-path
      reverse-path segment-list protect-reverse-path
     !
    !
    preference 100
     explicit segment-list working-forward-path
```

```
        reverse-path segment-list working-reverse-path
       !
      !
     !
    performance-measurement
     liveness-detection
      liveness-profile name liveness-check
```

CS SR-TE Policy operational details

```
RP/0/RP0/CPU0:ron-ncs55a2-1#show segment-routing traffic-eng policy color
1001
Sat Dec  3 13:32:38.356 PST
```

SR-TE policy database

Color: 1001, End-point: 100.0.0.42 Name: srte_c_1001_ep_100.0.0.42 Status: adjmin: up Operational: up for 2d09h (since Dec 1 04:08:12.648) Candidate-paths: Preference: 100 (configuration) (active) Name: to-100.0.0.42 Requested BSID: dynamic PCC info: Symbolic name: cfg_to-100.0.0.42_discr_100 PLSP-ID: 1 Constraints: Protection Type: protected-preferred Maximum SID Depth: 12 Explicit: segment-list forward-adj-path-working (valid) Reverse: segment-list reverse-adj-path-working Weight: 1, Metric Type: TE SID[0]: 15101 [adjacency-SID, 100.1.1.21 - 100.1.1.20] SID[1]: 15102 SID[2]: 15103 SID[3]: 15104 Reverse path: SID[0]: 15001 SID[1]: 15002 SID[2]: 15003 SID[3]: 15004 Protection Information: Role: WORKING Path Lock: Timed Lock Duration: 300(s) State: ACTIVE Preference: 50 (configuration) (protect) Name: to-100.0.0.42 Requested BSID: dynamic PCC info: Symbolic name: cfg_to-100.0.0.42_discr_50 PLSP-ID: 2 Constraints: Protection Type: protected-preferred Maximum SID Depth: 12 Explicit: segment-list forward-adj-path-protect(valid) Reverse: segment-list reverse-adj-path-protect Weight: 1, Metric Type: TE SID[0]: 15119 [adjacency-SID, 100.1.42.1 - 100.1.42.0] Reverse path: SID[0]: 15191 Protection Information: Role: PROTECT Path Lock: Timed Lock Duration: 300(s) State: STANDBY Attributes: Binding SID: 24017 Forward Class: Not Configured Steering labeled-services disabled: no Steering BGP disabled: no IPv6 caps enable: yes Invalidation drop enabled: no Max Install Standby Candidate Paths: 0

Private Line Emulation Hardware

Starting in IOS-XR 7.7.1 the NC55-OIP-02 Modular Port Adapter (MPA) is supported on the NCS-55A2-MOD and NCS-57C3-MOD platforms. The NC55-OIP-02 has 8 SFP+ ports

NCS-57C3-MOD

NCS-55A2-MOD

8x PLE MPA - NC55-OIP-02

{:height="100%" width="100%"}

Each port on the PLE MPA can be configured independently. The PLE MPA is responsible for receiving data frames from the native PLE client and packaging those into fixed frames for transport over the packet network.

More information on the NC55-OIP-02 can be found in its datasheet located at https://www.cisco.com/c/en/us/products/collateral/routers/network-convergence-system-5500-series/network-con-5500-series-ds.pdf. A full detailed to end to end configuration for PLE can be found in the Routed Optical Networking 2.0 Solution Guide found at https://www.cisco.com/c/en/us/td/docs/optical/ron/2-0/solution/guide/b-ron-solution-20/m-ron.pdf

Supported Client Transceivers

Transport Type	Supported Transceivers
Ethernet	SFP-10G-SR/LR/ER, GLC-LH/EX/ZX-SMD, 1G/10G CWDM
OTN (OTU2e)	SFP-10G-LR-X, SFP-10G-ER-I, SFP-10G-Z
SONET/SDH	ONS-SC+-10G-LR/ER/SR (OC-192/STM-64), ONS-SI-2G-L1/L2/S1 (OC-48/STM-16)
Fiber Channel	DS-SFP-FCGE, DS-SFP-FC8G, DS-SFP-FC16G, DS-SFP-FC32G, 1/2/4/8G FC CWDM

Note FC32G transceivers are supported in the even ports only and will disable the adjacent odd SFP+ port. {: .notice--warning}

Private Line Emulation Pseudowire Signaling

PLE utilizes IETF SAToP pseudowire encoding carried over dynamically signalled EVPN-VPWS circuits. Enhancements to the EVPN VPWS service type have been introduced to the IETF via https://datatracker.ietf.org/doc/draft-schmutzer-bess-ple.

PLE services use Differential Clock Recovery (DCR) to ensure proper frame timing between the two PLE clients. In order to mmaintain accuracy of the clock each PLE endpoint router must have its frequency source traceable to a common primary reference clock (PRC).

Private Line Emulation EVPN-VPWS Configuration

PLE services can be configured to utilize a CS SR-TE Policy or use dynamic MPLS protocols. The example belows shows the use of CS SR-TE Policy as transport for the PLE EVPN-VPWS service. Note the name of the sr-te policy in the preferred path command is the persistent generated name and not the name used in the CLI configuration. This can be determined using the "show segment-routing traffic-engineering policies" command.

```
l2vpn
 pw-class circuit-style-srte
  encapsulation mpls
   preferred-path sr-te policy srte_c_1001_ep_100.0.0.42
  !
 !
 xconnect group ple
  p2p ple-cs-1
   interface CEM0/0/2/1
   neighbor evpn evi 100 target 4201 source 4401
    pw-class circuit-style-srte
   !
  !
```

PLE Monitoring and Telemetry

The following "show" command can be used to monitor the state of PLE ports and services.

Client Optics Port State

```
RP/0/RP0/CPU0:ron-ncs55a2-1#show controllers optics 0/0/2/1
Sat Dec  3 14:00:10.873 PST
```

Controller State: Up

Transport Admin State: In Service

Laser State: On

LED State: Not Applicable

Optics Status

```
     Optics Type:  SFP+ 10G SR
     Wavelength = 850.00 nm

     Alarm Status:
     -------------
     Detected Alarms: None
```

```
    LOS/LOL/Fault Status:

    Laser Bias Current = 8.8 mA
    Actual TX Power = -2.60 dBm
    RX Power = -2.33 dBm

    Performance Monitoring: Disable

    THRESHOLD VALUES
    ----------------

    Parameter                 High Alarm  Low Alarm  High Warning  Low
Warning
    ------------------------  ----------  ---------  ------------  ------
-----
    Rx Power Threshold(dBm)          2.0      -13.9          -1.0
-9.9
    Tx Power Threshold(dBm)          1.6      -11.3          -1.3
-7.3
    LBC Threshold(mA)              13.00       4.00         12.50
5.00
    Temp. Threshold(celsius)       75.00      -5.00         70.00
0.00
    Voltage Threshold(volt)         3.63       2.97          3.46
3.13

    Polarization parameters not supported by optics

    Temperature = 33.00 Celsius
    Voltage = 3.30 V
```

Transceiver Vendor Details

```
    Form Factor              : SFP+
    Optics type              : SFP+ 10G SR
    Name                     : CISCO-FINISAR
    OUI Number               : 00.90.65
    Part Number              : FTLX8574D3BCL-CS
    Rev Number               : A
    Serial Number            : FNS23300J42
    PID                      : SFP-10G-SR
    VID                      : V03
    Date Code(yy/mm/dd)      : 19/07/25
```

PLE CEM Controller Stats

```
RP/0/RP0/CPU0:ron-ncs57c3-1#show controllers CEM 0/0/3/1
Sat Sep 24 11:34:22.533 PDT
Interface                           : CEM0/0/3/1
Admin state                         : Up
Oper  state                         : Up
Port bandwidth                      : 10312500 kbps
Dejitter buffer (cfg/oper/in-use)   : 0/813/3432 usec
Payload size (cfg/oper)             : 1280/1024 bytes
PDV (min/max/avg)                   : 980/2710/1845 usec
Dummy mode                          : last-frame
Dummy pattern                       : 0xaa
Idle pattern                        : 0xff
Signalling                          : No CAS
RTP                                 : Enabled
Clock type                          : Differential
Detected Alarms                     : None
```

Statistics Info

Ingress packets : 517617426962, Ingress packets drop : 0 Egress packets : 517277124278, Egress packets drop : 0 Total error : 0 Missing packets : 0, Malformed packets : 0 Jitter buffer underrun : 0, Jitter buffer overrun : 0 Misorder drops : 0 Reordered packets : 0, Frames fragmented : 0 Error seconds : 0, Severely error seconds : 0 Unavailable seconds : 0, Failure counts : 0

Generated L bits : 0, Received L bits : 0 Generated R bits : 339885178, Received R bits : 17

Endpoint Info

Passthrough : No

PLE CEM PM Statistics

```
RP/0/RP0/CPU0:ron-ncs57c3-1#show controllers CEM 0/0/3/1 pm current 30-sec
cem
Sat Sep 24 11:37:02.374 PDT
```

CEM in the current interval [11:37:00 - 11:37:02 Sat Sep 24 2022]

CEM current bucket type : Valid INGRESS-PKTS : 2521591 Threshold : 0 TCA(enable) : NO EGRESS-PKTS : 2521595 Threshold : 0 TCA(enable) : NO INGRESS-PKTS-DROPPED : 0 Threshold : 0 TCA(enable) : NO EGRESS-PKTS-DROPPED : 0 Threshold : 0 TCA(enable) : NO INPUT-ERRORS : 0 Threshold : 0 TCA(enable) : NO OUTPUT-ERRORS : 0 Threshold : 0 TCA(enable) : NO MISSING-PKTS : 0 Threshold : 0 TCA(enable) : NO PKTS-REORDER : 0 Threshold : 0 TCA(enable) : NO JTR-BFR-UNDERRUNS : 0 Threshold : 0 TCA(enable) : NO JTR-BFR-OVERRUNS : 0 Threshold : 0 TCA(enable) : NO MIS-ORDER-DROPPED : 0 Threshold : 0 TCA(enable) : NO MALFORMED-PKT : 0 Threshold : 0 TCA(enable) : NO ES : 0 Threshold : 0 TCA(enable) : NO SES : 0 Threshold : 0 TCA(enable) : NO UAS : 0 Threshold : 0 TCA(enable) : NO FC : 0

Threshold : 0 TCA(enable) : NO TX-LBITS : 0 Threshold : 0 TCA(enable) : NO TX-RBITS : 0 Threshold : 0 TCA(enable) : NO RX-LBITS : 0 Threshold : 0 TCA(enable) : NO RX-RBITS : 0 Threshold : 0 TCA(enable) : NO

PLE Client PM Statistics

```
RP/0/RP0/CPU0:ron-ncs57c3-1#show controllers EightGigFibreChanCtrlr0/0/3/4
pm current 30-sec fc
Sat Sep 24 11:51:55.168 PDT
```

FC in the current interval [11:51:30 - 11:51:55 Sat Sep 24 2022]

FC current bucket type : Valid IFIN-OCTETS : 16527749196 Threshold : 0 TCA(enable) : NO RX-PKT : 196758919 Threshold : 0 TCA(enable) : NO IFIN-ERRORS : 0 Threshold : 0 TCA(enable) : NO RX-BAD-FCS : 0 Threshold : 0 TCA(enable) : NO IFOUT-OCTETS : 0 Threshold : 0 TCA(enable) : NO TX-PKT : 0 Threshold : 0 TCA(enable) : NO TX-BAD-FCS : 0 Threshold : 0 TCA(enable) : NO RX-FRAMES-TOO-LONG : 0 Threshold : 0 TCA(enable) : NO RX-FRAMES-TRUNC : 0 Threshold : 0 TCA(enable) : NO TX-FRAMES-TOO-LONG : 0 Threshold : 0 TCA(enable) : NO TX-FRAMES-TRUNC : 0 Threshold : 0 TCA(enable) : NO

Routed Optical Networking Architecture Hardware

All Routed Optical Networking solution routers are powered by Cisco IOS-XR.

Routed Optical Networking Validated Routers

Below is a non-exhaustive snapshot of platforms validated for use with ZR and OpenZR+ transceivers. Cisco supports Routed Optical Networking in the NCS 540, NCS 5500/5700, ASR 9000, and Cisco 8000 router families. The breadth of coverage enabled the solution across all areas of the network.

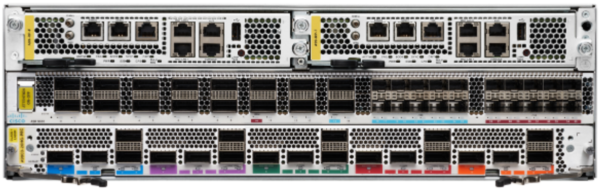
8201

8201-32FH

8202

NC57-18DD-SE

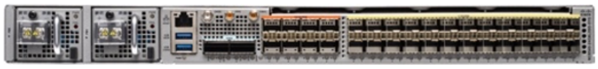
ASR 9903



A9K-20HG-FLEX-SE

NCS57B1-6D24H

N540-24Q8L2DD-SYS



NCS-57C3-MOD *(R2.0)*

Cisco 8000 Series

The Cisco 8000 and its Silicone One NPU represents the next generation in routers, unprecedented capacity at the lowest power consumption while supporting a rich feature set applicable for a number of network roles.

See more information on Cisco 8000 at https://www.cisco.com/c/en/us/products/collateral/routers/8000-series-routers/datasheet-c78-742571.html

Specific information on ZR/ZR+ support can be found at https://www.cisco.com/c/en/us/td/docs/iosxr/cisco8000/Interfaces/73x/configuration/guide/b-interfaces-config-guide-cisco8k-r73x/m-zr-zrp-cisco-8000.html

Cisco 5700 Systems and NCS 5500 Line Cards

The Cisco 5700 family of fixed and modular systems and line cards are flexible enough to use at any location in the networks. The platform has seen widespread use in peering, core, and aggregation networks.

See more information on Cisco NCS 5500 and 5700 at https://www.cisco.com/c/en/us/products/collateral/routers/network-convergence-system-5500-series/datasheet-c78-736270.html and https://www.cisco.com/c/en/us/products/collateral/routers/network-convergence-system-5500-series/datasheet-c78-744698.html

Specific information on ZR/ZR+ support can be found at https://www.cisco.com/c/en/us/td/docs/iosxr/ncs5500/interfaces/73x/configuration/guide/b-interfaces-hardware-component-cg-ncs5500-73x/m-zr-zrp.html

ASR 9000 Series

The ASR 9000 is the most widely deployed SP router in the industry. It has a rich heritage dating back almost 20 years, but Cisco continues to innovate on the ASR 9000 platform. The ASR 9000 series now supports 400G QSFP-DD on a variety of line cards and the ASR 9903 2.4Tbps 3RU platform.

See more information on Cisco ASR 9000 at https://www.cisco.com/c/en/us/products/collateral/routers/asr-9000-series-aggregation-services-routers/data_sheet_c78-501767.html

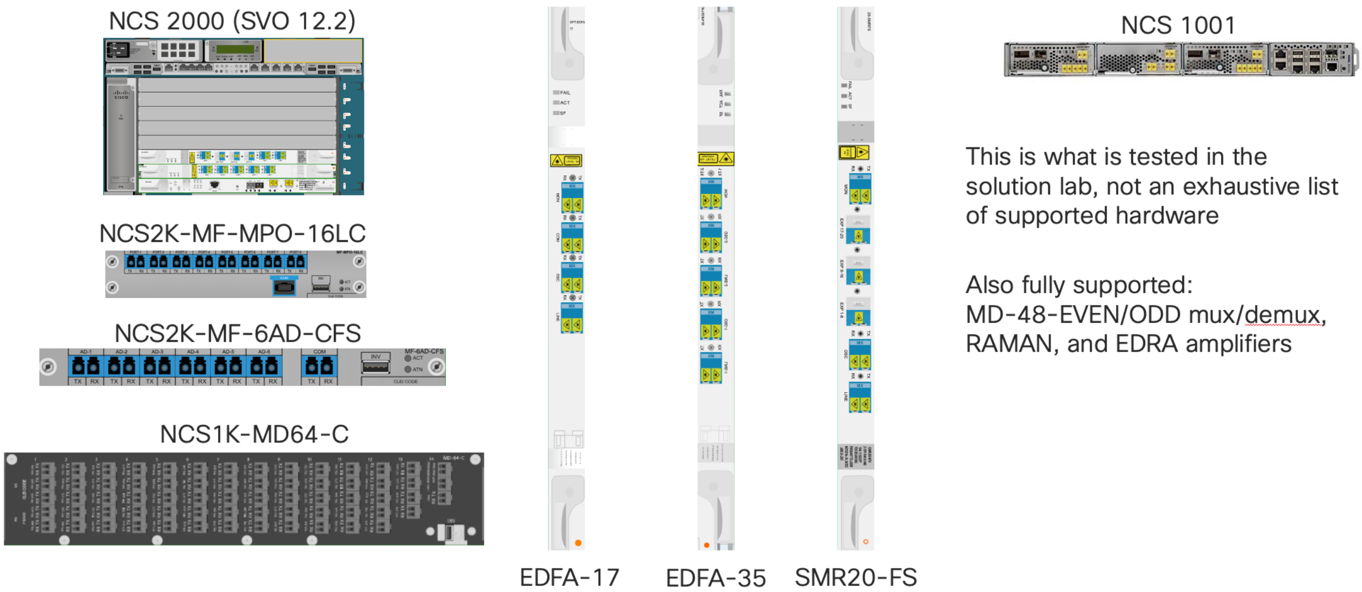
Specific information on ZR/ZR+ support can be found at https://www.cisco.com/c/en/us/td/docs/routers/asr9000/software/asr9k-r7-3/interfaces/configuration/guide/b-interfaces-hardware-component-cg-asr9000-73x/m-zr-zrp.html#Cisco_Concept.dita_59215d6f-1614-4633-a137-161ebe794673

NCS 500 Series

The 1Tbps N540-24QL16DD-SYS high density router brings QSFP-DD and Routed Optical Networking ZR/OpenZR+ optics to a flexible access and aggregation platform. Using OpenZR+ optics it allows a migration path from 100G to 400G access rings or uplinks when used in an aggregation role.

See more information on Cisco NCS 540 at https://www.cisco.com/c/en/us/products/collateral/routers/network-convergence-system-500-series-routers/ncs-540-large-density-router-ds.html

Routed Optical Networking Optical Hardware



Network Convergence System 1010

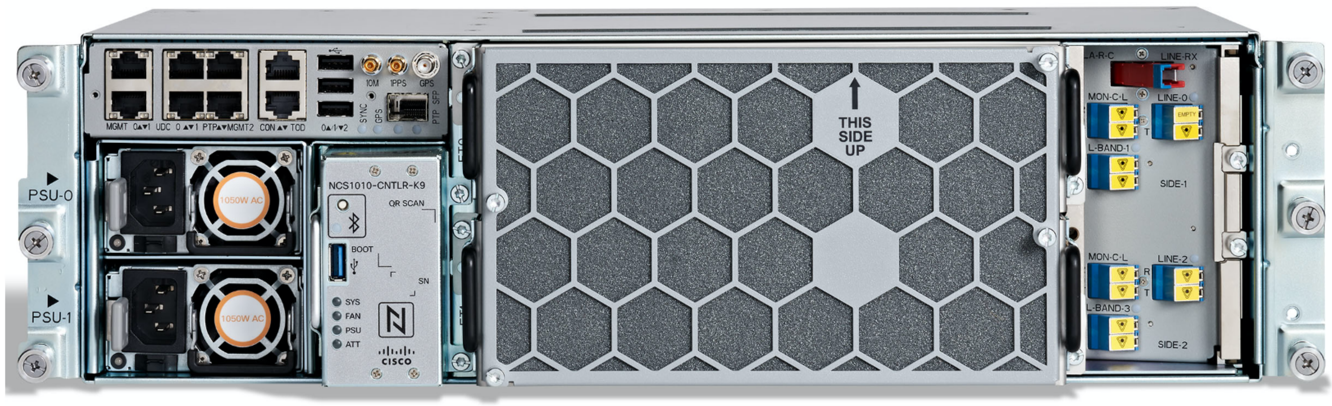
The NCS 1010 Open Optical Line System (O-OLS) is a next-generation DWDM platform available in fixed variants to satisfy building a modern flexible DWDM photonic network.

The NCS 1010 Optical Line Terminal (OLT) uses a twin 33-port WSS architecture allowing higher scale for either add/drop or express wavelengths. The OLT also has two LC add/drop ports with integrated fixed gain EDFA to support the add/drop of lower power optical signals. OLTs are available in models with or without RAMAN amplification. NCS 1010 Inline Amplifier nodes are available as bi-directional EDFA, EDFA with RAMAN in one direction, or bi-directional RAMAN. Each model of NCS 1010 is also available to support both C and L bands. In Routed Optical Networking 2.0 ZR and ZR+ optics utilize the C band, but may be used on the same fiber with L band signals using the NCS 1010 C+L combiner.

The NCS 1010 utilizes IOS-XR, inheriting the advanced automation and telemetry features similar to IOS-XR routers.

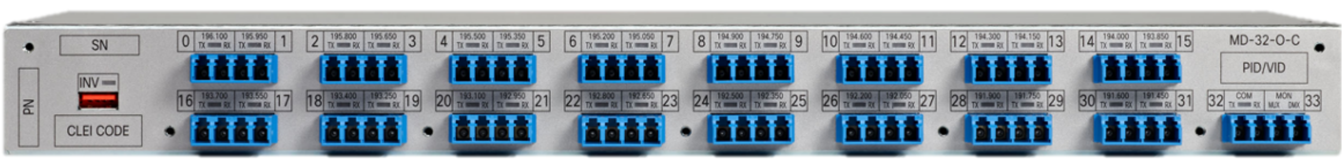
NCS 1010 OLT with RAMAN

NCS 1010 ILA with RAMAN



The NCS1K-MD32-E/O-C 32-port 150Ghz spaced passive multiplexer is used with the NCS 1010, supporting the 75Ghz ZR/ZR+ signals and future higher baud rate signals. The MD-32 contains photodiodes to monitor RX power levels on each add/drop port.

NCS 1010 MD-32 Passive Filter



The NCS 1010 supports point to point and express DWDM optical topologies in Routed Optical Networking 2.0. All NCS 1010 services in Routed Optical Networking are managed using Cisco Optical Network Controller.

See more information on the NCS 1010 series at https://www.cisco.com/c/en/us/products/collateral/optical-networking/network-convergence-system-1000-series/network-conver-system-1010-ds.html

Network Convergence System 2000

The NCS 2000 Optical Line System is a flexible platform supporting all modern optical topologies and deployment use cases. Simple point to point to multi-degree CDC deployments are all supported as part of Routed Optical Networking.

See more information on the NCS 2000 series at https://www.cisco.com/c/en/us/products/optical-networking/network-convergence-system-2000-series/index.html

Network Convergence System 1000 Multiplexer

The NCS1K-MD-64-C is a new fixed multiplexer designed specifically for the 400G 75Ghz 400ZR and OpenZR+ wavelengths, allowing up to 25.6Tbps on a single fiber.

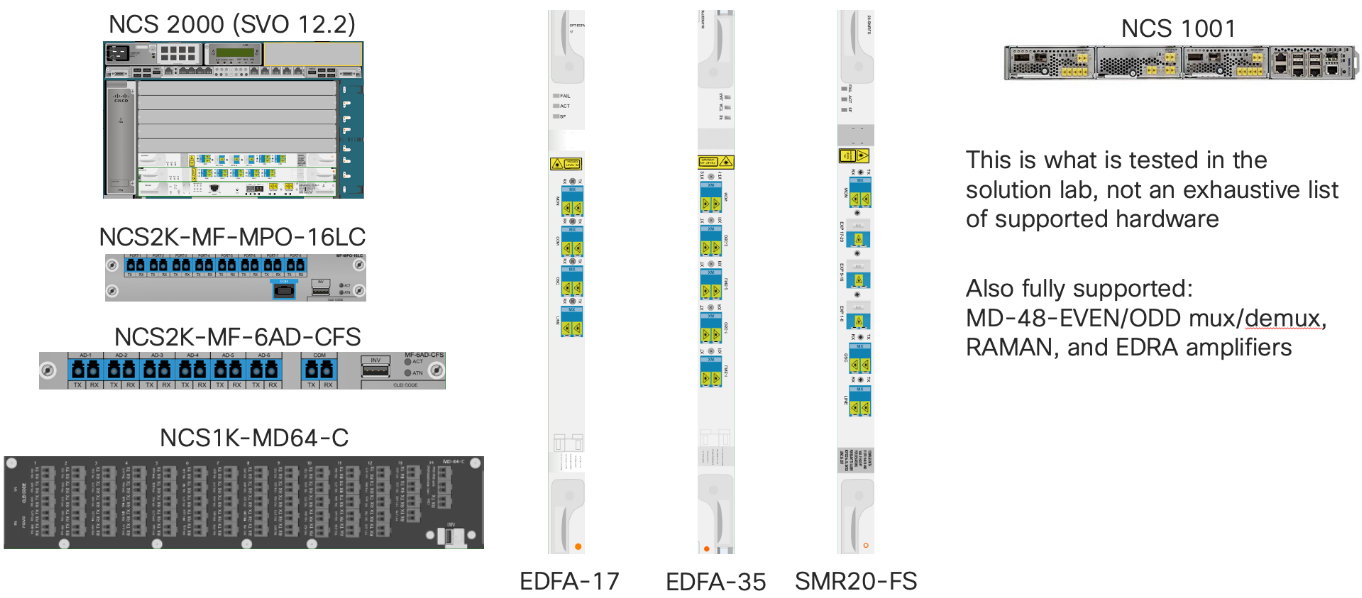
Network Convergence System 1001

The NCS 1001 is utiized in point to point network spans as an amplifier and optionally protection switch. The NCS 1001 now has specific support for 75Ghz spaced 400ZR and OpenZR+ wavelengths, with the ability to monitor incoming wavelengths for power. The 1001 features the ability to determine the proper amplifier gain setpoints based on the desired user power levels.

See more information on the NCS 1001 at https://www.cisco.com/c/en/us/products/collateral/optical-networking/network-convergence-system-1000-series/datasheet-c78-738782.html

NCS 2000 and NCS 1001 Hardware

The picture below does not represent all available hardware on the NCS 2000, however does capture the modules typically used in Routed Optical Networking deployments.



Routed Optical Networking Automation

Overview

Routed Optical Networking by definition is a disaggregated optical solution, creating efficiency by moving coherent endpoints in the router. The solution requires a new way of managing the network, one which unifies the IP and Optical layers, replacing the traditional siloed tools used in the past. Real transformation in operations comes from unifying teams and workflows, rather than trying to make an existing tool fit a role it was not originally designed for. Cisco's standards based hierarchical SDN solution allows providers to manage a multi-vendor Routed Optical Networking solution using standard interfaces and YANG models.

IETF ACTN SDN Framework

The IETF Action and Control of Traffic Engineered Networks group (ACTN) has defined a hierarchical controller framework to allow vendors to plug components into the framework as needed. The lowest level controller, the Provisioning Network Controller (PNC), is responsible for managing physical devices. These controller expose their resources through standard models and interface to a Hierarchical Controller (HCO), called a Multi-Domain Service Controller (MDSC) in the ACTN framework.

Note that while Cisco is adhering to the IETF framework proposed in RFC8453 , Cisco is supporting the most widely supported industry standards for controller to controller communication and service definition. In optical the de facto standard is Transport API from the ONF for the management of optical line system networks and optical services. In packet we are leveraging Openconfig device models where possible and IETF models for packet topology (RFC8345) and xVPN services (L2NM and L3NM)

ACTN SDN Control Framework

```
+---------+         +---------+              +---------+
|   CNC   |         |   CNC   |              |   CNC   |
+---------+         +---------+              +---------+
      \                  |                        /
       \                 |                       /
========\==================|=====================/=======
         \                 |                   /
          -----------      | CMI  --------------
                     \     |     /
                   +---------------+
                   |     MDSC      |
                   +---------------+
                     /     |     \
         ------------      | MPI  -------------
        /                  |                   \
   +-------+          +-------+             +-------+
   |  PNC  |          |  PNC  |             |  PNC  |
   +-------+          +-------+             +-------+
       | SBI           /    |                  /   \
       |              /     | SBI        SBI /     \
   ---------      -----     |               /       \
  (         )    (     )    |              /         \
  - Control -   ( Phys. )   |             /         -----
 (  Plane    )  ( Net )     |            /         (     )
(  Physical   )  -----      |           /         ( Phys. )
 (  Network  )            -----       -----       ( Net )
  -         -            (     )     (     )       -----
  (         )           ( Phys. )   ( Phys. )
   ---------             ( Net )     ( Net )
                          -----       -----
```

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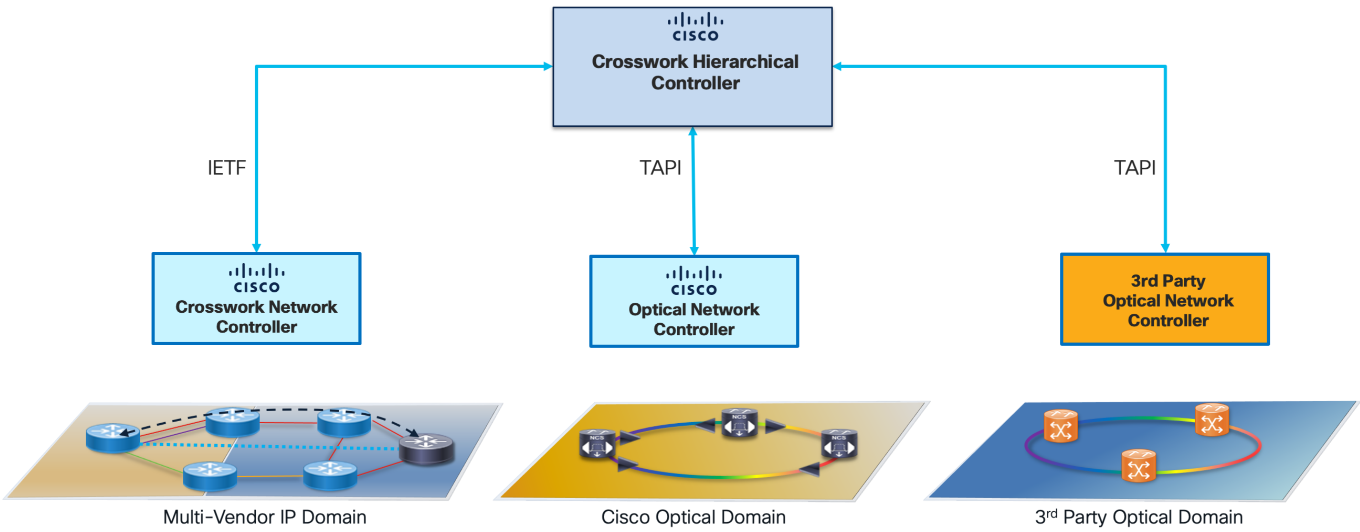
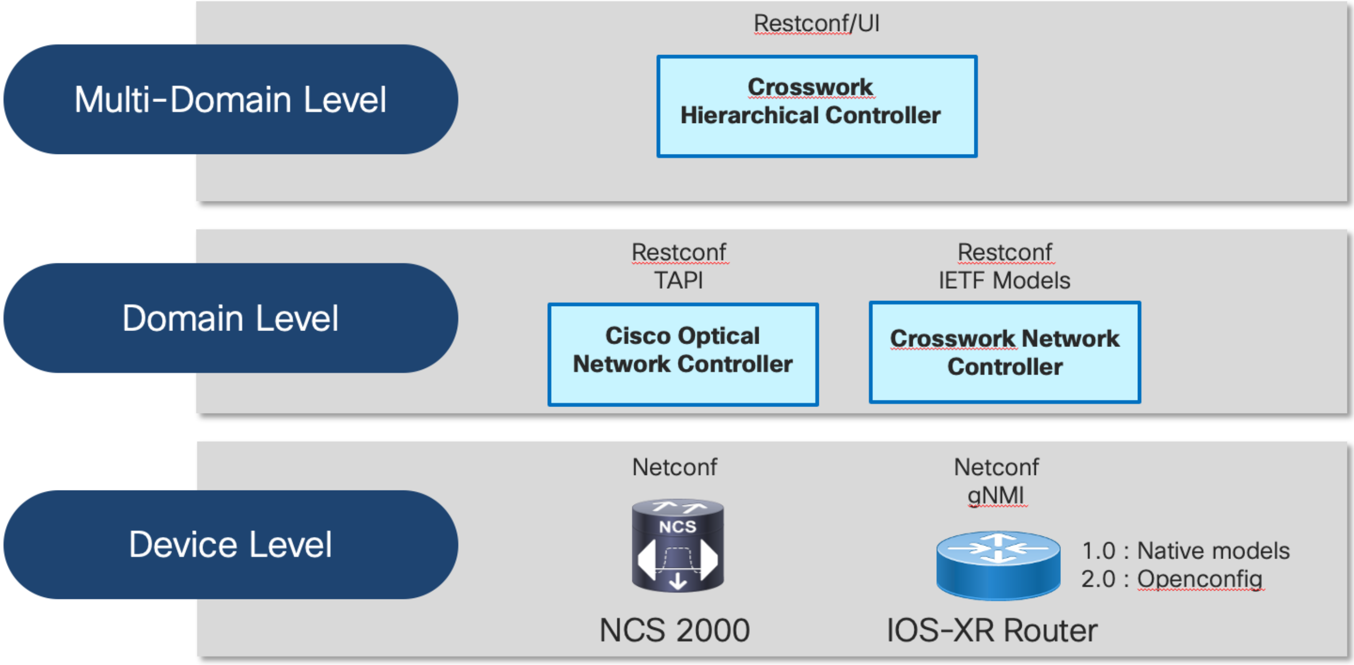
Cisco's SDN Controller Automation Stack

Aligning to the ACTN framework, Cisco's automation stack includes a multi-vendor IP domain controller (PNC), optical domain controller (PNC), and multi-vendor hierarchical controller (HCO/MDSC).



Cisco Open Automation

Cisco believes not all providers consume automation in the same way, so we are dedicated to make sure we have open interfaces at each layer of the network stack. At the device level, we utilize standard NETCONF, gRPC, and gNMI interfaces along with native, standard, and public consortium YANG models. There is no aspect of a Cisco IOS-XR router today not covered by YANG models. At the domain level we have Cisco's network controllers, which use the same standard interfaces to communicate with devices and expose standards based NBIs. Our multi-layer/multi-domain controller likewise uses the same standard interfaces.



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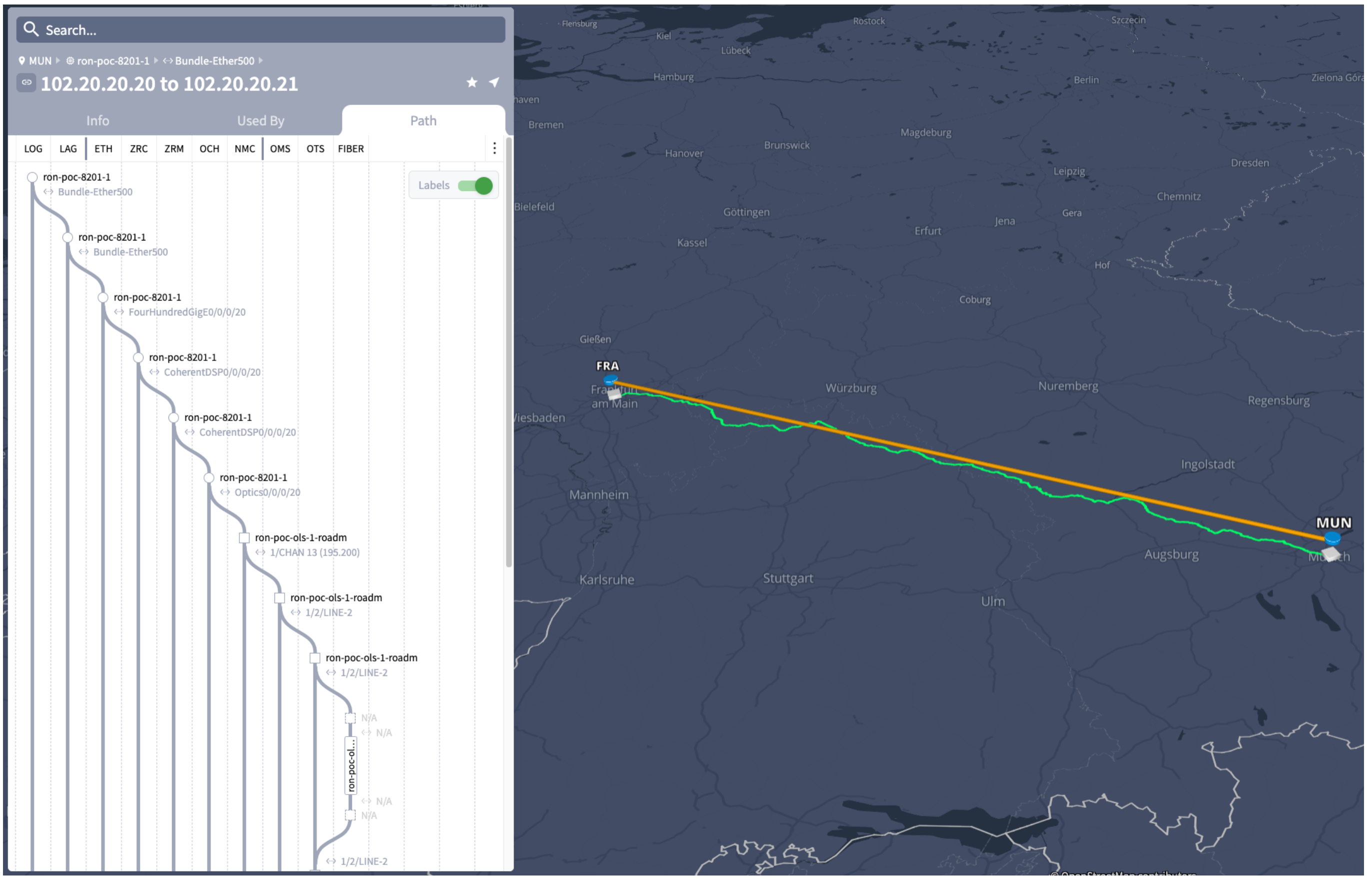
Crosswork Hierarchical Controller

Responsible for Multi-Layer Automation is the Crosswork Hierarchical Controller. Crosswork Hierarchical Controller is responsible for the following network functions:

- CW HCO unifies data from the IP and optical networks into a single network model. HCO utilizes industry standard IETF topology models for IP and TAPI for optical topology and service information. HCO can also leverage legacy EMS/NMS systems or device interrogation.
- Responsible for managing multi-layer Routed Optical Networking links using a single UI.
- Providing assurance at the IP and optical layers in a single tool. The network model allows users to quickly correlate faults and identify at which layer faults have occurred.
- Additional HCO applications include the following
  - Root Cause Analysis: Quickly correlate upper layer faults to an underlying cause.
  - Layer Relations: Quickly identify the lower layer resources supporting higher layer network resource or all network resources reliant on a selected lower layer network resource.
  - Network Inventory: View IP and optical node hardware inventory along with with network resources such as logical links, optical services, and traffic engineering tunnels
  - Network History: View state changes across all network resources at any point in time
  - Performance: View historical link utilization

Please see the following resources for more information on Crosswork HCO.
https://www.cisco.com/c/en/us/products/collateral/cloud-systems-management/crosswork-network-

automation/solution-overview-c22-744695.html



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Crosswork Network Controller

Crosswork Network Controller is a multi-vendor IP domain controller. Crosswork Network Controller is responsible for the following IP network functions.

- Collecting Ethernet, IP, RSVP-TE, and SR network information for internal applications and exposing northbound via IETF RFC 8345 topology models
- Collecting traffic information from the network for use with CNC's traffic optimization application, Crosswork Optimization Engine
- Perform provisioning of SR-TE, RSVP-TE, L2VPN, and L3VPN using standard industry models (IETF TEAS-TE, L2NM, L3NM) via UI or northbound API
- Visualization and assurance of SR-TE, RSVP-TE, and xVPN services
- Use additional Crosswork applications to perform telemetry collection/alerting, zero-touch provisioning, and automated and assurance network changes

More information on Crosswork and Crosswork Network Controller can be found at https://www.cisco.com/c/en/us/products/collateral/cloud-systems-management/crosswork-network-automation/datasheet-c78-743456.html

Cisco Optical Network Controller

Cisco Optical Network Controller (Cisco ONC) is responsible for managing Cisco optical line systems and circuit services. Cisco ONC exposes a ONF TAPI northbound interface, the de facto industry standard for optical network management. Cisco ONC runs as an application on the same Crosswork Infrastructure as CNC.

More information on Cisco ONC can be found at https://www.cisco.com/c/en/us/support/optical-networking/optical-network-controller/series.html

Cisco Network Services Orchestrator and Routed Optical Networking ML Core Function Pack

Cisco NSO is the industry standard for service orchestration and device configuration management. The RON-ML CFP can be used to fully configure an IP link between routers utilizing 400ZR/OpenZR+ optics over a Cisco optical line system using Cisco ONC. This includes IP addressing and adding links to an existing Ethernet LAG. The CFP can also support optical-only provisioning on the router to fit into existing optical provisioning workflows.

Routed Optical Networking Service Management

Supported Provisioning Methods

We support multiple ways to provision Routed Optical Networking services based on existing provider workflows.

- Unified IP and Optical using Crosswork Hierarchical Controller
- Unified IP and Optical using Cisco NSO Routed Optical Networking Multi-Layer Function Pack
- ZR/ZR+ Optics using IOS-XR CLI
- Model-driven ZR/ZR+ Optics configuration using Netconf or gNMI
- OpenConig ZR/ZR+ Optics configuration using Netconf or gNMI

OpenZR+ and 400ZR Properties

ZR/ZR+ Supported Frequencies

The frequency on Cisco ZR/ZR+ transceivers may be set between 191.275Thz and 196.125Thz in increments of 6.25Ghz, supporting flex spectrum applications. To maximize the available C-Band spectrum, these are the recommended 64 75Ghz-spaced channels, also aligning to the NCS1K-MD-64-C fixed channel add/drop multiplexer.

196.100	196.025	195.950	195.875	195.800	195.725	195.650	195.575
195.500	195.425	195.350	195.275	195.200	195.125	195.050	194.975
194.900	194.825	194.75	194.675	194.600	194.525	194.450	194.375
194.300	194.225	194.150	194.075	194.000	193.925	193.850	193.775
193.700	193.625	193.550	193.475	193.400	193.325	193.250	193.175
193.100	193.025	192.950	192.875	192.800	192.725	192.650	192.575

192.500	192.425	192.350	192.275	192.200	192.125	192.050	191.975
191.900	191.825	191.750	191.675	191.600	191.525	191.450	191.375

Supported Line Side Rate and Modulation

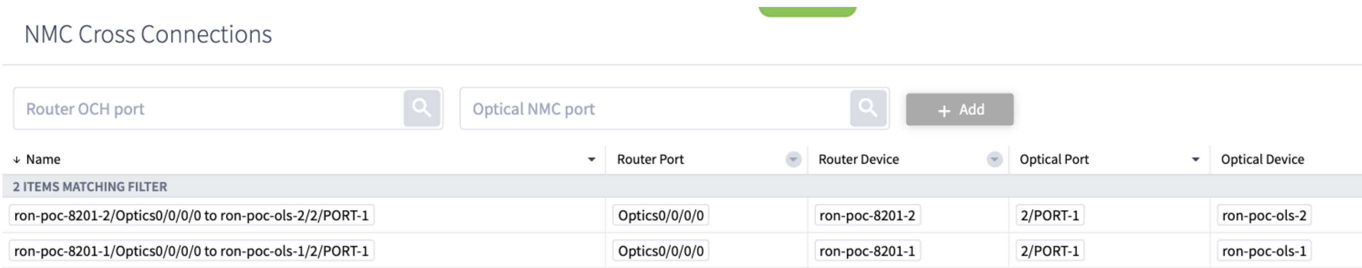
OIF 400ZR transceivers support 400G only per the OIF specification. OpenZR+ transceivers can support 100G, 200G, 300G, or 400G line side rate. See router platform documentation for supported rates. The modulation is determined by the line side rate. 400G will utilize 16QAM, 300G 8QAM, and 200G/100G rates will utilize QPSK.

Crosswork Hierarchical Controller UI Provisioning

End-to-End IP+Optical provisioning can be done using Crosswork Hierarchical Controller's GUI IP Link provisioning. Those familiar with traditional GUI EMS/NMS systems for service management will have a very familiar experience. Crosswork Hierarchical Controller provisioning will provision both the router optics as well as the underlying optical network to support the ZR/ZR+ wavelength.

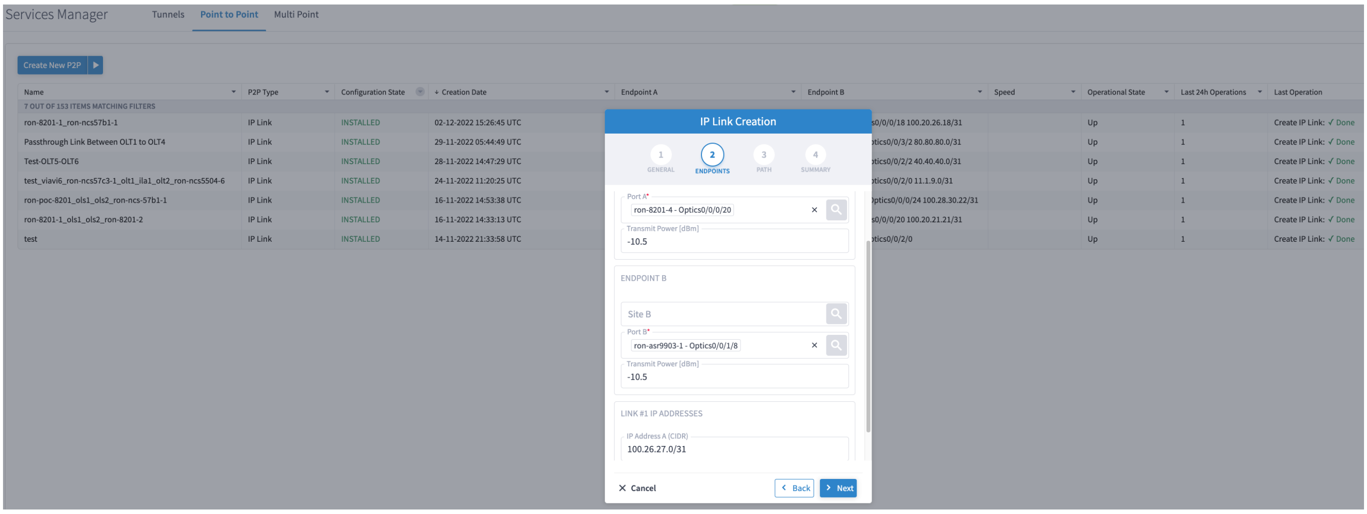
Inter-Layer Link Definition

End to end provisioning requires first defining the Inter-Layer link between the router ZR/ZR+ optics and the optical line system add/drop ports. This is done using a GUI based NMC (Network Media Channel) Cross-Link application in Crosswork HCO. The below screenshot shows defined NMC cross-links.



IP Link Provisioning

Once the inter-layer links are created, the user can then proceed in provisioning an end to end circuit. The provisioning UI takes as input the two router endpoints, the associated ZR/ZR+ ports, and the IP addressing or bundle membership of the link. The optical line system provisioning is abstracted from the user, simplifying the end to end workflow. The frequency and power is automatically derived by Cisco Optical Network Controller based on the add/drop port and returned as a parameter to be used in router optics provisioning.



Operational Discovery

The Crosswork Hierarchical Controller provisioning process also performs a discovery phase to ensure the service is operational before considering the provisioning complete. If operational discovery fails, the end to end service will be rolled back.

NSO RON-ML CFP Provisioning

Providers familiar with using Cisco Network Service Orchestrator have an option to utilize NSO to perform IP+Optical provisioning of Routed Optical Networking services. Cisco has created the Routed Optical Network Multi-Layer Core Function Pack, RON-ML CFP to perform end to end provisioning of services. The aforementioned Crosswork HCO provisioning utilizes the RON-ML CFP to perform end device provisioning.

Please see the Cisco Routed Optical Networking RON-ML CFP documentation located at

Routed Optical Networking Inter-Layer Links

Similar to the use case with CW HCO provisioning, before end to end provisioning can be performed, inter-layer links must be provisioned between the optical ZR/ZR+ port and the optical line system add/drop port. This is done using the "inter-layer-link" NSO service. The optical end point can be defined as either a TAPI SIP or by the TAPI equipment inventory identifier. Inter-layer links are not required for router-only provisioning.

RON-ML End to End Service

The RON-ML service is responsible for end to end IP+optical provisioning. RON-ML supports full end to end provisioning, router-only provisioning, or optical-only provisioning where only the router ZR/ZR+ configuration is performed. The frequency and transmit power can be manually defined or optionally provided by Cisco ONC when end to end provisioning is performed.

RON-ML API Provisioning

Use the following URL for NSO provisioning: `http://<nso host>/restconf/data`

Inter-Layer Link Service

```
{
  "data": {
    "cisco-ron-cfp:ron": {
      "inter-layer-link": [
        {
          "end-point-device": "ron-8201-1",
          "line-port": "0/0/0/20",
          "ols-domain": {
            "network-element": "ron-ols-1",
            "optical-add-drop": "1/2008/1/13,14",
            "optical-controller": "onc-real-new"
          }
        }
      ]
    }
  }
}
```

Provisioning ZR+ optics and adding interface to Bundle-Ether 100 interface

```
{
    "cisco-ron-cfp:ron": {
      "ron-ml": [
        {
          "name": "E2E_Bundle_ZRP_ONC57_2",
          "mode": "transponder",
          "bandwidth": "400",
          "circuit-id": "E2E Bundle ONC-57 S9|chan11 - S10|chan11",
          "grid-type": "100mhz-grid",
          "ols-domain": {
            "service-state": "UNLOCKED"
          },
          "end-point": [
            {
              "end-point-device": "ron-8201-1",
              "terminal-device-optical": {
                "line-port": "0/0/0/11",
                "transmit-power": -100
              },
              "ols-domain": {
                "end-point-state": "UNLOCKED"
              },
              "terminal-device-packet": {
                "bundle": [
                  {
                    "id": 100
                  }
                ],
                "interface": [
                  {
```

```
                    "index": 0,
                    "membership": {
                      "bundle-id": 100,
                      "mode": "active"
                    }
                  }
                ]
              }
            },
            {
              "end-point-device": "ron-8201-2",
              "terminal-device-optical": {
                "line-port": "0/0/0/11",
                "transmit-power": -100
              },
              "ols-domain": {
                "end-point-state": "UNLOCKED"
              },
              "terminal-device-packet": {
                "bundle": [
                  {
                    "id": 100
                  }
                ],
                "interface": [
                  {
                    "index": 0,
                    "membership": {
                      "bundle-id": 100,
                      "mode": "active"
                    }
                  }
                ]
              }
            }
          ]
        }
      ]
    }
  }
```


IOS-XR CLI Configuration

Configuring the router portion of the Routed Optical Networking link is very simple. All optical configuration related to the ZR/ZR+ optics configuration is located under the optics controller relevent to the faceplate port. Default configuration the optics will be in an up/up state using a frequency of 193.10Thz.

The basic configuration with a specific frequency of 195.65 Thz is located below,
the only required component is the bolded channel frequency setting.

ZR/ZR+ Optics Configuration

```
controller Optics0/0/0/20
 transmit-power -100
 dwdm-carrier 100MHz-grid frequency 1956500
 logging events link-status
```

Model-Driven Configuration using IOS-XR Native Models using NETCONF or gNMI

All configuration performed in IOS-XR today can also be done using NETCONF/YANG. The following payload exhibits the models and configuration used to perform router optics provisioning. This is a more complete example showing the FEC, power, and frequency configuration. .

Note in Release 2.0 using IOS-XR 7.7.1 the newer IOS-XR Unified Models are utilized for provisioning


```
<data xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
<controllers xmlns="http://cisco.com/ns/yang/Cisco-IOS-XR-um-interface-cfg">
    <controller>
        <controller-name>Optics0/0/0/0</controller-name>
        <transmit-power xmlns="http://cisco.com/ns/yang/Cisco-IOS-XR-um-cont-optics-cfg">-115</transmit-power>
        <fec xmlns="http://cisco.com/ns/yang/Cisco-IOS-XR-um-cont-optics-cfg">OFEC</fec>
        <dwdm-carrier xmlns="http://cisco.com/ns/yang/Cisco-IOS-XR-um-cont-optics-cfg">
          <grid-100mhz>
            <frequency>1913625</frequency>
          </grid-100mhz>
        </dwdm-carrier>
        <dac-rate xmlns="http://cisco.com/ns/yang/Cisco-IOS-XR-um-dac-rate-cfg">1x1.25</dac-rate>
      </controller>
</controllers>

</data>
```


Model-Driven Configuration using OpenConfig Models

Starting on Release 2.0 all IOS-XR 7.7.1+ routers supporting ZR/ZR+ optics can be configured using OpenConfig models. Provisioning utilizes the openconfig-terminal-device model and its extensions to the openconfig-platform model to support DWDM configuration parameters.

Below is an example of an OpenConfig payload to configure ZR/ZR+ optics port 0/0/0/20 with a 300G trunk rate with frequency 195.20 THz.

Please visit the blog at https://xrdocs.io/design/blogs/zr-openconfig-mgmt for in depth information about configuring and monitoring ZR/ZR+ optics using OpenConfig models.

```
<config>
        <terminal-device xmlns="http://openconfig.net/yang/terminal-
device">
            <logical-channels>
                <channel>
                    <index>100</index>
                    <config>
                        <index>200</index>
                        <rate-class
xmlns:idx="http://openconfig.net/yang/transport-
types">idx:TRIB_RATE_100G</rate-class>
                        <admin-state>ENABLED</admin-state>
                        <description>ETH Logical Channel</description>
                        <trib-protocol
xmlns:idx="http://openconfig.net/yang/transport-
types">idx:PROT_100G_MLG</trib-protocol>
                        <logical-channel-type
xmlns:idx="http://openconfig.net/yang/transport-
types">idx:PROT_ETHERNET</logical-channel-type>
                    </config>
                    <logical-channel-assignments>
                        <assignment>
                            <index>1</index>
                            <config>
                                <index>1</index>
                                <allocation>100</allocation>
                                <assignment-
type>LOGICAL_CHANNEL</assignment-type>
                                <description>ETH to Coherent
assignment</description>
                                <logical-channel>200</logical-channel>
                            </config>
                        </assignment>
                    </logical-channel-assignments>
                </channel>
                <channel>
                    <index>101</index>
                    <config>
                        <index>101</index>
                        <rate-class
xmlns:idx="http://openconfig.net/yang/transport-
types">idx:TRIB_RATE_100G</rate-class>
                        <admin-state>ENABLED</admin-state>
                        <description>ETH Logical Channel</description>
                        <trib-protocol
xmlns:idx="http://openconfig.net/yang/transport-
types">idx:PROT_100G_MLG</trib-protocol>
                        <logical-channel-type
xmlns:idx="http://openconfig.net/yang/transport-
types">idx:PROT_ETHERNET</logical-channel-type>
                    </config>
```

```
                    <logical-channel-assignments>
                        <assignment>
                            <index>1</index>
                            <config>
                                <index>1</index>
                                <allocation>100</allocation>
                                <assignment-
type>LOGICAL_CHANNEL</assignment-type>
                                <description>ETH to Coherent
assignment</description>
                                <logical-channel>200</logical-channel>
                            </config>
                        </assignment>
                    </logical-channel-assignments>
                </channel>
                <channel>
                    <index>102</index>
                    <config>
                        <index>102</index>
                        <rate-class
xmlns:idx="http://openconfig.net/yang/transport-
types">idx:TRIB_RATE_100G</rate-class>
                        <admin-state>ENABLED</admin-state>
                        <description>ETH Logical Channel</description>
                        <trib-protocol
xmlns:idx="http://openconfig.net/yang/transport-
types">idx:PROT_100G_MLG</trib-protocol>
                        <logical-channel-type
xmlns:idx="http://openconfig.net/yang/transport-
types">idx:PROT_ETHERNET</logical-channel-type>
                    </config>
                    <logical-channel-assignments>
                        <assignment>
                            <index>1</index>
                            <config>
                                <index>1</index>
                                <allocation>100</allocation>
                                <assignment-
type>LOGICAL_CHANNEL</assignment-type>
                                <description>ETH to Coherent
assignment</description>
                                <logical-channel>200</logical-channel>
                            </config>
                        </assignment>
                    </logical-channel-assignments>
                </channel>
                <channel>
                    <index>200</index>
                    <config>
                        <index>200</index>
                        <admin-state>ENABLED</admin-state>
                        <description>Coherent Logical
Channel</description>
```

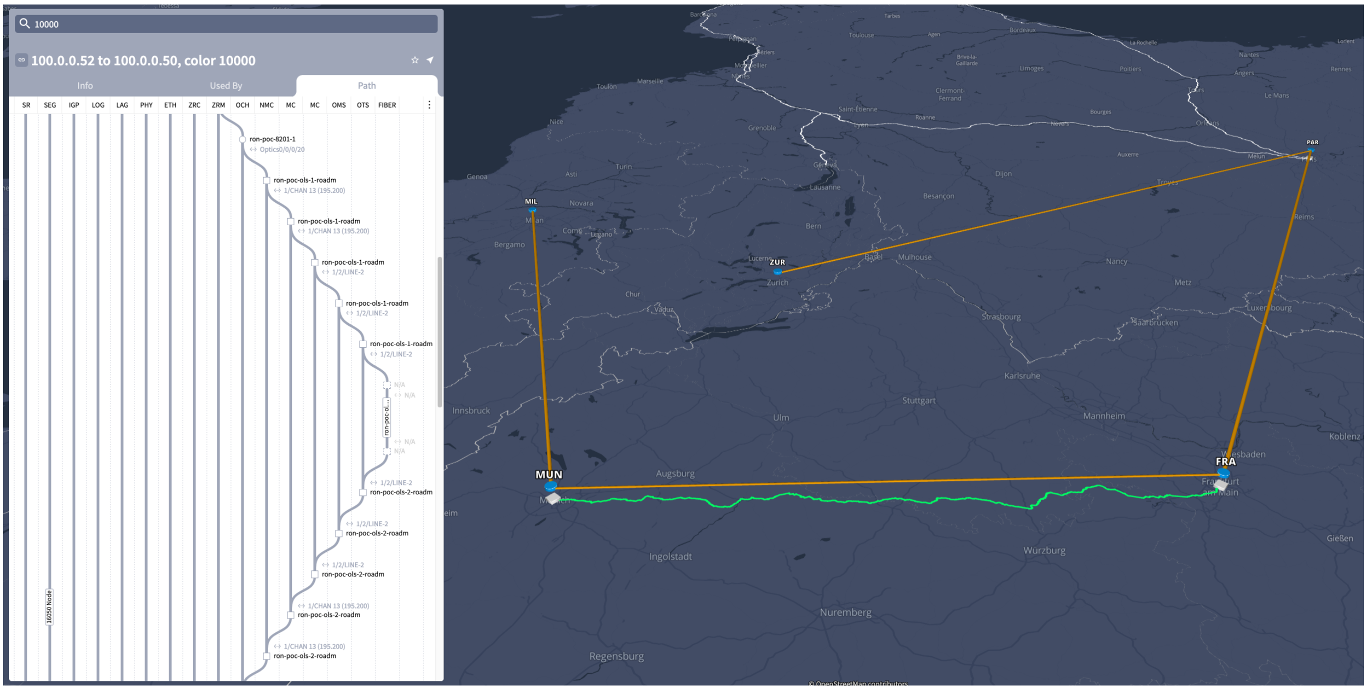
```
                        <logical-channel-type
xmlns:idx="http://openconfig.net/yang/transport-
types">idx:PROT_OTN</logical-channel-type>
                    </config>
                    <logical-channel-assignments>
                        <assignment>
                            <index>1</index>
                            <config>
                                <index>1</index>
                                <allocation>300</allocation>
                                <assignment-
type>OPTICAL_CHANNEL</assignment-type>
                                <description>Coherent to optical
assignment</description>
                                <optical-channel>0/0-
OpticalChannel0/0/0/20</optical-channel>
                            </config>
                        </assignment>
                    </logical-channel-assignments>
                </channel>
            </logical-channels>
        </terminal-device>
        <components xmlns="http://openconfig.net/yang/platform">
            <component>
                <name>0/0-OpticalChannel0/0/0/20</name>
                <optical-channel
xmlns="http://openconfig.net/yang/terminal-device">
                    <config>
                        <operational-mode>5007</operational-mode>
                        <frequency>195200000</frequency>
                    </config>
                </optical-channel>
            </component>
        </components>
    </config>
```

Routed Optical Networking Assurance

Crosswork Hierarchical Controller

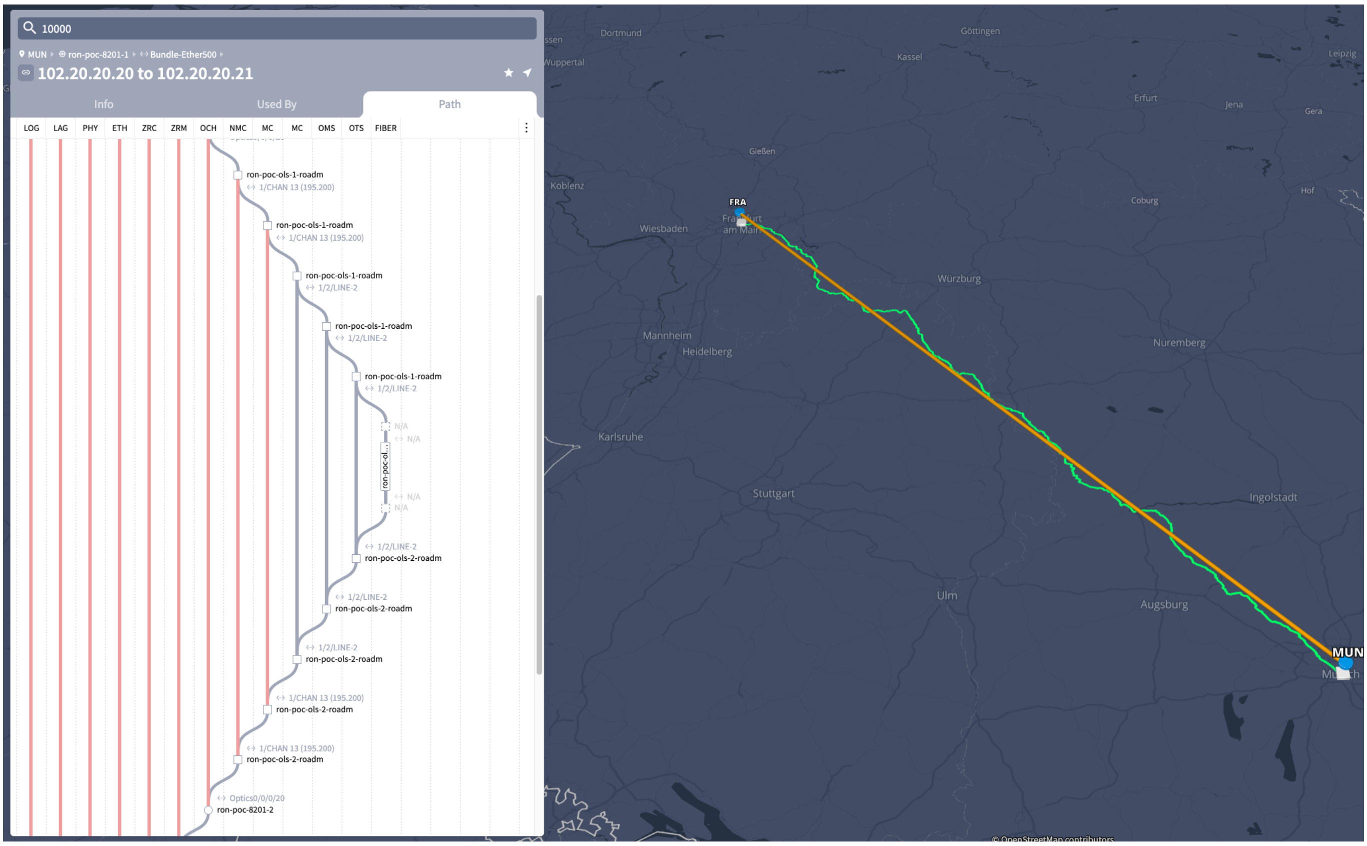
Multi-Layer Path Trace

Using topology and service data from both the IP and Optical network CW HCO can display the full service from IP services layer to the physical fiber. Below is an example of the "waterfall" trace view from the OTS (Fiber) layer to the Segment Routing TE layer across all layers. CW HCO identifies specific Routed Optical Networking links using ZR/ZR+ optics as seen by the ZRC (ZR Channel) and ZRM (ZR Media) layers from the 400ZR specification.



{:height="100%" width="100%"}

When faults occur at a specific layer, faults will be highlighted in red, quickly identifying the layer a fault has occurred. In this case we can see the fault has occurred at an optical layer, but is not a fiber fault. Having the ability to pinpoint the fault layer even within a specific domain is a powerful way to quickly determine the root cause of the fault.

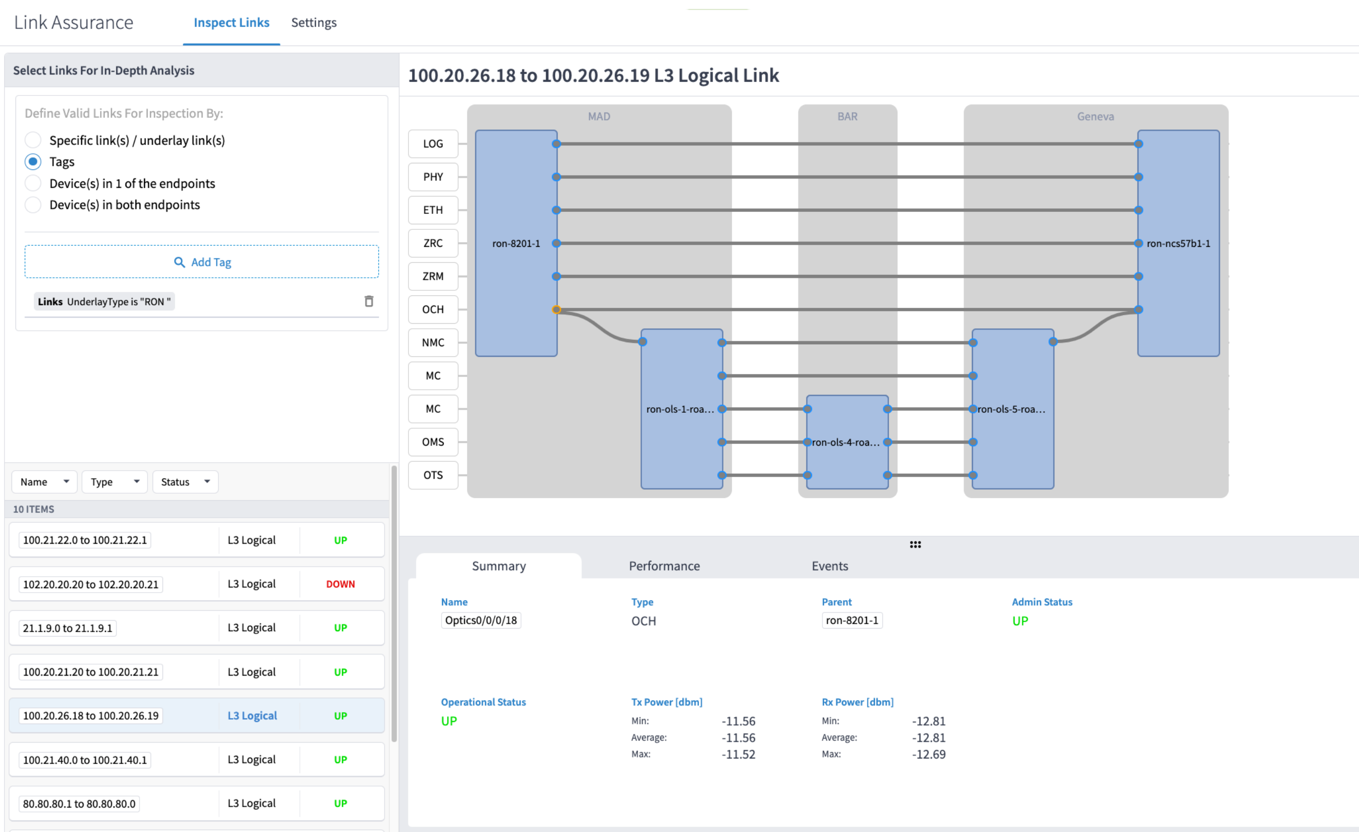


{:height="100%" width="100%"}

Routed Optical Networking Link Assurance

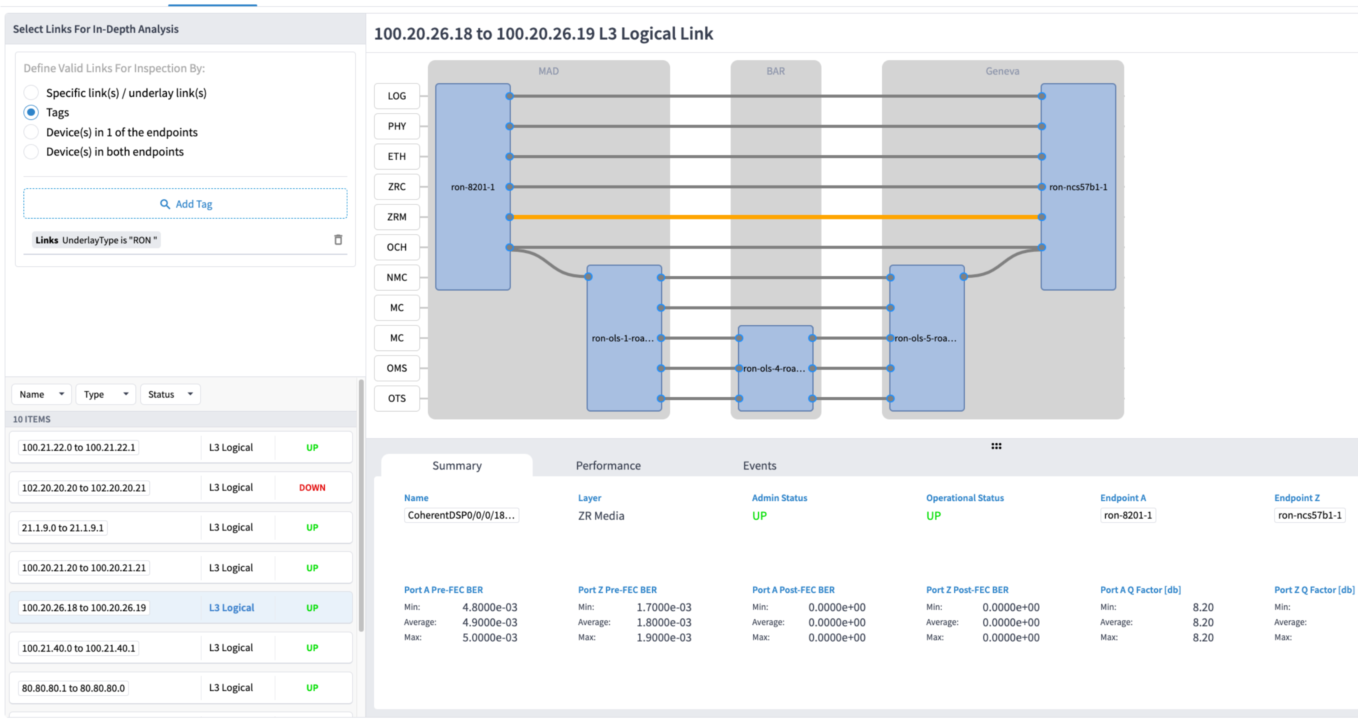
The Link Assurance application allows users to view a network link and all of its dependent layers. This includes Routed Optical Networking multi-layer services. In addition to viewing layer information, fault and telemetry information is also available by simply selecting a link or port.

ZRM Layer TX/RX Power



{:height="100%" width="100%"}

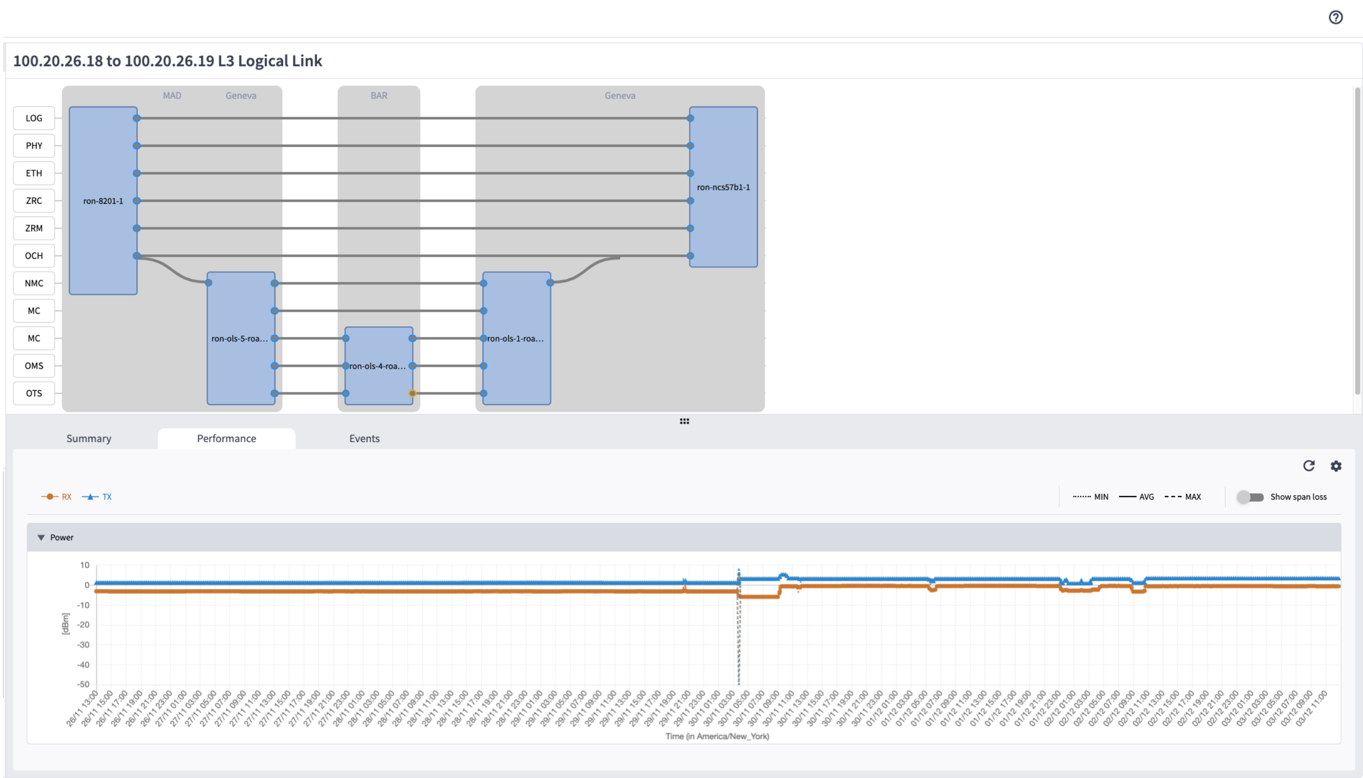
ZRC Layer BER and Q-Factor / Q-Margin



{:height="100%" width="100%"}

Optionally the user can see graphs of collected telemetry data to quickly identify trends or changes in specific operational data. Graphs of collected performance data is accessed using the "Performance" tab when a link or port is selected.

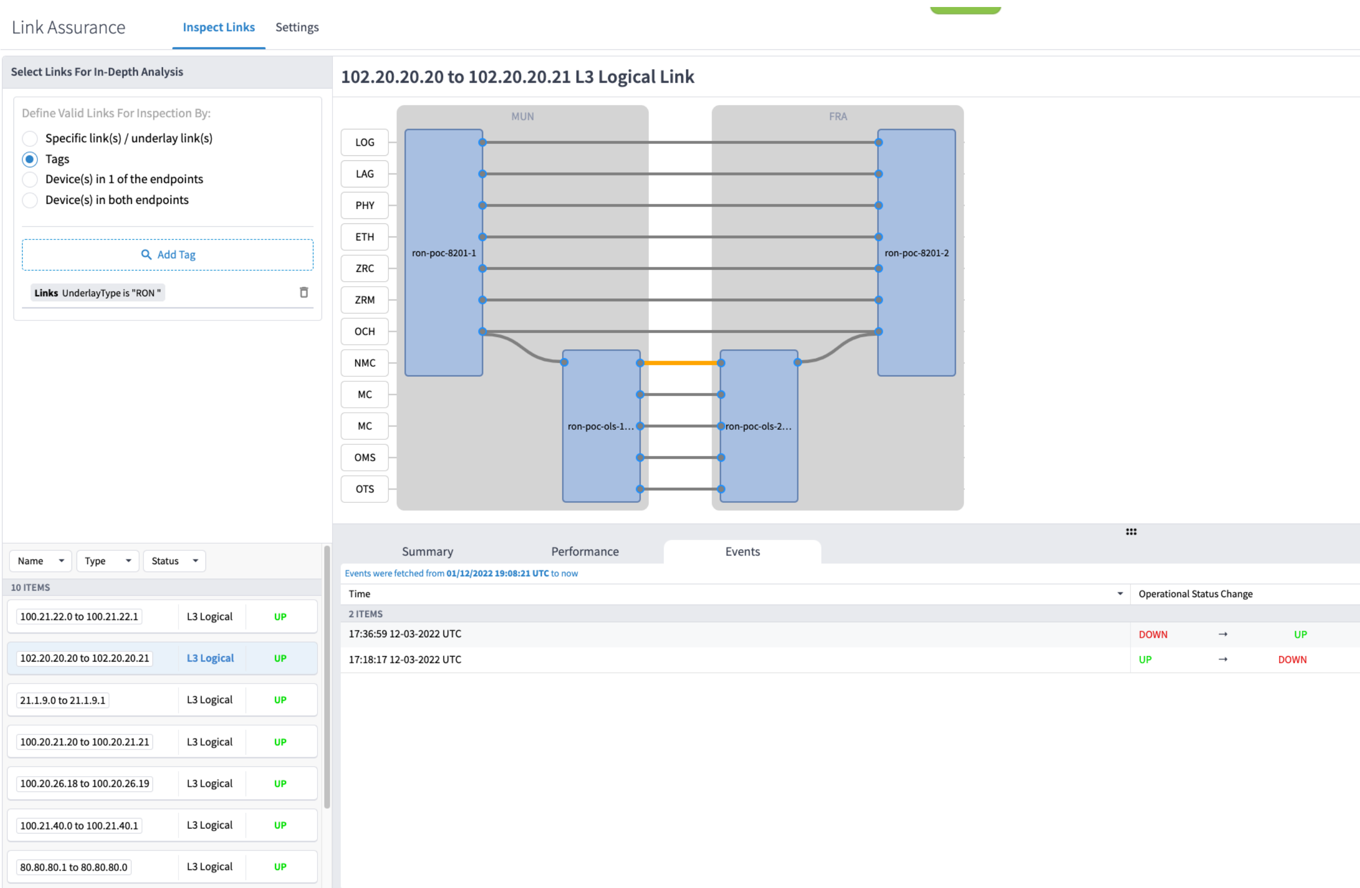
OTS Layer RX/TX Power Graph



{:height="100%" width="100%"}

Event Monitoring

Crosswork HCO records any transition of a network resource between up/down operational states. This is reflected in the Link Assurance tool under the "Events" tab.



{:height="100%" width="100%"}

IOS-XR CLI Monitoring of ZR400/OpenZR+ Optics

Optics Controller

The optics controller represents the physical layer of the optics. In the case of ZR/ZR+ optics this includes the frequency information, RX/TX power, OSNR, and other associated physical layer information.

```
RP/0/RP0/CPU0:ron-8201-1#show controllers optics 0/0/0/20
Thu Jun  3 15:34:44.098 PDT

 Controller State: Up
 Transport Admin State: In Service
 Laser State: On
 LED State: Green
 FEC State: FEC ENABLED

 Optics Status

         Optics Type:  QSFPDD 400G ZR
         DWDM carrier Info: C BAND, MSA ITU Channel=10,
Frequency=195.65THz,
         Wavelength=1532.290nm
```

```
        Alarm Status:
        -------------
        Detected Alarms: None

        LOS/LOL/Fault Status:

        Alarm Statistics:

        -------------
        HIGH-RX-PWR = 0             LOW-RX-PWR = 0
        HIGH-TX-PWR = 0             LOW-TX-PWR = 4
        HIGH-LBC = 0                HIGH-DGD = 1
        OOR-CD = 0                  OSNR = 10
        WVL-OOL = 0                 MEA  = 0
        IMPROPER-REM = 0
        TX-POWER-PROV-MISMATCH = 0
        Actual TX Power = -7.17 dBm
        RX Power = -9.83 dBm
        RX Signal Power = -9.18 dBm
        Frequency Offset = 9 MHz
        Baud Rate =  59.8437500000 GBd
        Modulation Type: 16QAM
        Chromatic Dispersion 6 ps/nm
        Configured CD-MIN -2400 ps/nm  CD-MAX 2400 ps/nm
        Second Order Polarization Mode Dispersion = 34.00 ps^2
        Optical Signal to Noise Ratio = 35.50 dB
        Polarization Dependent Loss = 1.20 dB
        Polarization Change Rate = 0.00 rad/s
        Differential Group Delay = 2.00 ps
```

Performance Measurement Data

```
RP/0/RP0/CPU0:ron-8201-1#show controllers optics 0/0/0/20 pm current 30-
sec optics 1
Thu Jun  3 15:39:40.428 PDT

Optics in the current interval [15:39:30 - 15:39:40 Thu Jun 3 2021]

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[% ]      : 0.0       0.0       0.0      0.0               NA
NO   100.0             NA              NO
OPT[dBm]     : -7.17     -7.17     -7.17    -15.09            NA
NO   0.00              NA              NO
OPR[dBm]     : -9.86     -9.86     -9.85    -30.00            NA
NO   8.00              NA              NO
CD[ps/nm]    : -489      -488      -488     -80000            NA
```

```
NO   80000              NA              NO
DGD[ps ]      : 1.00      1.50      2.00     0.00              NA
NO   80.00              NA              NO
SOPMD[ps^2]   : 28.00     38.80     49.00    0.00              NA
NO   2000.00            NA              NO
OSNR[dB]      : 34.90     35.12     35.40    0.00              NA
NO   40.00              NA              NO
PDL[dB]       : 0.70      0.71      0.80     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]   : -9.23     -9.22     -9.21    -30.00            NA
NO   1.00               NA              NO
FREQ_OFF[Mhz]: -2         -1        4        -3600             NA
NO   3600               NA              NO
SNR[dB]       : 16.80     16.99     17.20    7.00              NA
NO   100.00             NA              NO
```

Coherent DSP Controller

The coherent DSP controller represents the framing layer of the optics. It includes Bit Error Rate, Q-Factor, and Q-Margin information.

```
RP/0/RP0/CPU0:ron-8201-1#show controllers coherentDSP 0/0/0/20
Sat Dec  4 17:24:38.245 PST

Port                                            : CoherentDSP 0/0/0/20
Controller State                                : Up
Inherited Secondary State                       : Normal
Configured Secondary State                      : Normal
Derived State                                   : In Service
Loopback mode                                   : None
BER Thresholds                                  : SF = 1.0E-5  SD = 1.0E-7
Performance Monitoring                          : Enable
Bandwidth                                       : 400.0Gb/s

Alarm Information:
LOS = 10        LOF = 0 LOM = 0
OOF = 0 OOM = 0 AIS = 0
IAE = 0 BIAE = 0        SF_BER = 0
SD_BER = 0      BDI = 0 TIM = 0
FECMISMATCH = 0 FEC-UNC = 0     FLEXO_GIDM = 0
FLEXO-MM = 0    FLEXO-LOM = 3   FLEXO-RDI = 0
FLEXO-LOF = 5
Detected Alarms                                 : None

Bit Error Rate Information
PREFEC  BER                                     : 1.7E-03
POSTFEC BER                                     : 0.0E+00
Q-Factor                                        : 9.30 dB
```

```
Q-Margin                                        : 2.10dB


FEC mode                                        : C_FEC
```

Performance Measurement Data

```
RP/0/RP0/CPU0:ron-8201-1#show controllers coherentDSP 0/0/0/20 pm current
30-sec fec
Thu Jun  3 15:42:28.510 PDT

g709 FEC in the current interval [15:42:00 - 15:42:28 Thu Jun 3 2021]

FEC current bucket type : Valid
    EC-BITS    : 20221314973             Threshold : 83203400000
TCA(enable)  : YES
    UC-WORDS  : 0                        Threshold : 5
TCA(enable)  : YES

                                      MIN       AVG        MAX
Threshold      TCA     Threshold     TCA

(min)     (enable)    (max)     (enable)
PreFEC BER                  :   1.5E-03   1.5E-03   1.6E-03          0E-
15         NO       0E-15        NO
PostFEC BER                 :     0E-15     0E-15     0E-15          0E-
15         NO       0E-15        NO
Q[dB]                       :      9.40      9.40      9.40
0.00        NO        0.00        NO
Q_Margin[dB]                :      2.20      2.20      2.20
0.00        NO        0.00        NO
```

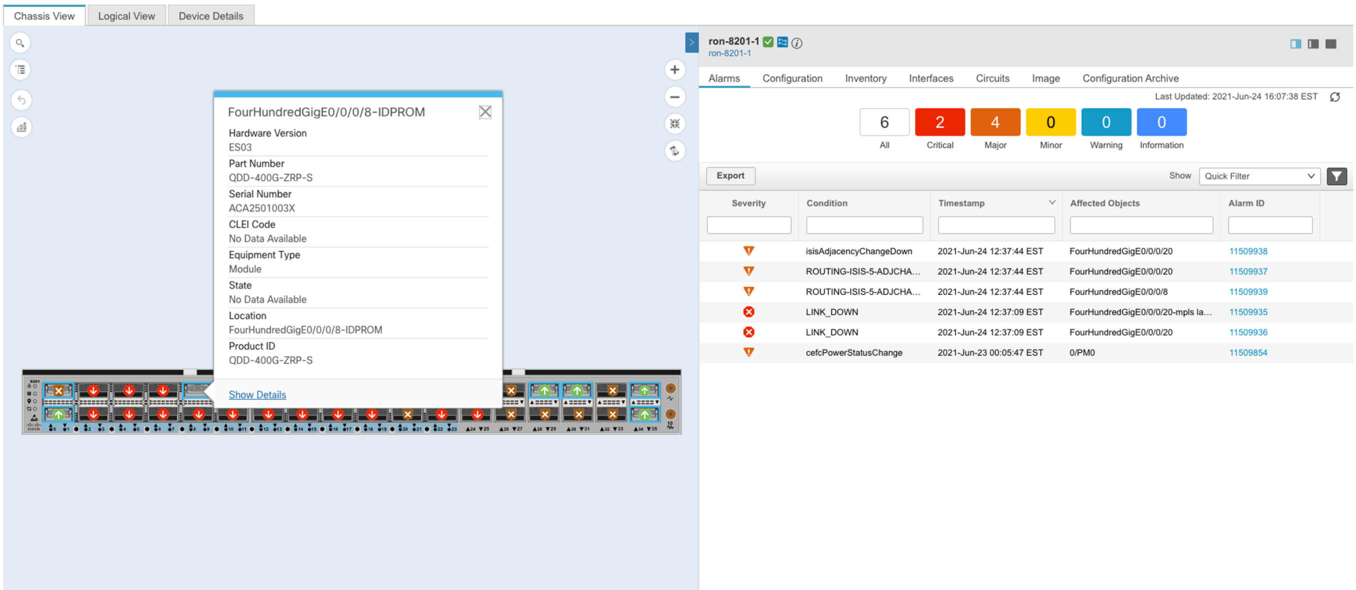
EPNM Monitoring of Routed Optical Networking

Evolved Programmable Network Manager, or EPNM, can also be used to monitor router ZR/ZR+ performance measurement data and display device level alarms when faults occur. EPNM stores PM and alarm data for historical analysis.

EPNM Chassis View of DCO Transceivers

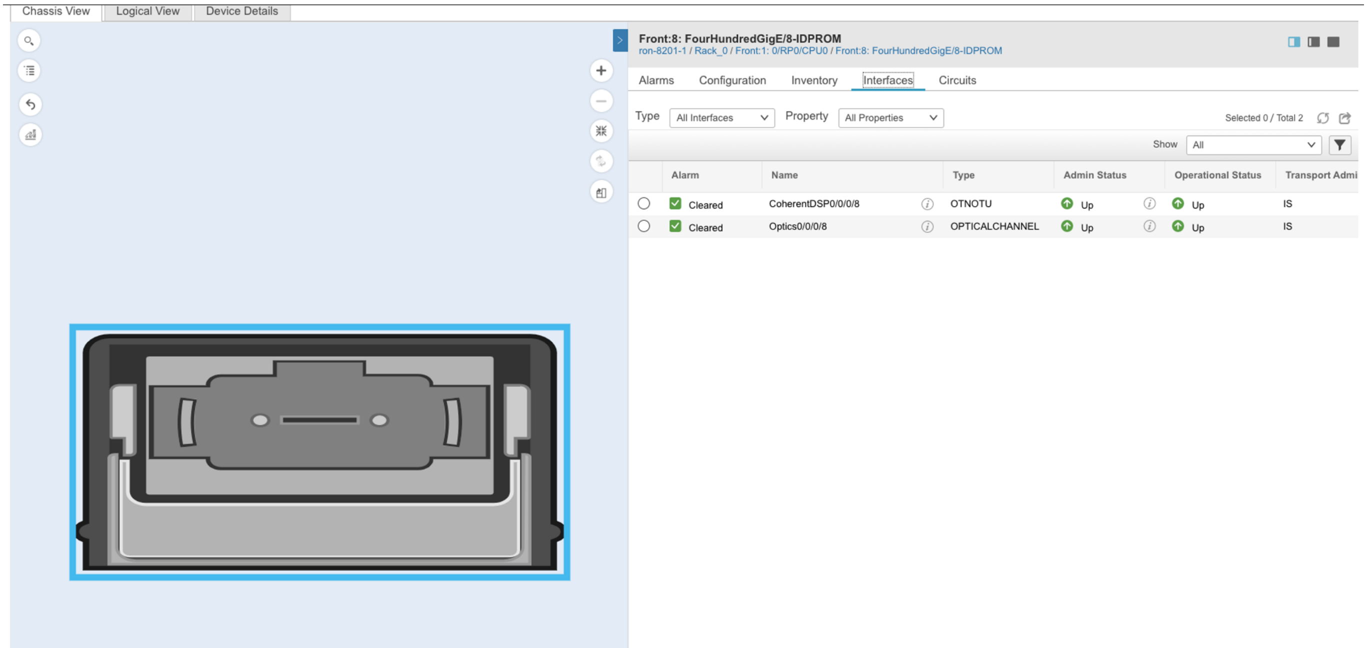
The following shows a chassis view of a Cisco 8201 router. The default view is to show all active alarms on the device and its components. Clicking on a specific component will give information on the component and narrow the scope of alarms and data.

Chassis View



{:height="100%" width="100%"}

Interface/Port View



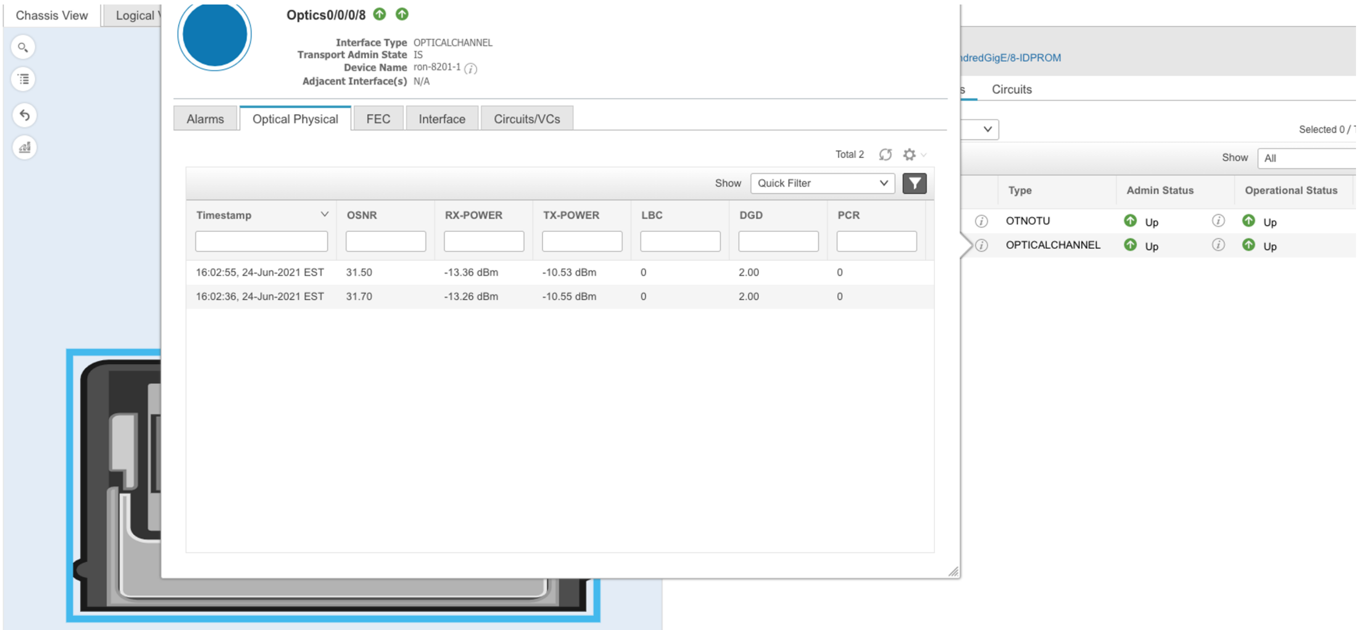
{:height="100%" width="100%"}

EPNM DCO Performance Measurement

EPNM continuously monitors and stores PM data for DCO optics for important KPIs such as TX/RX power, BER, and Q values. The screenshots below highlight monitoring. While EPNM stores historical data, clicking on a speciic KPI will enable realtime monitoring by polling for data every 20 seconds.

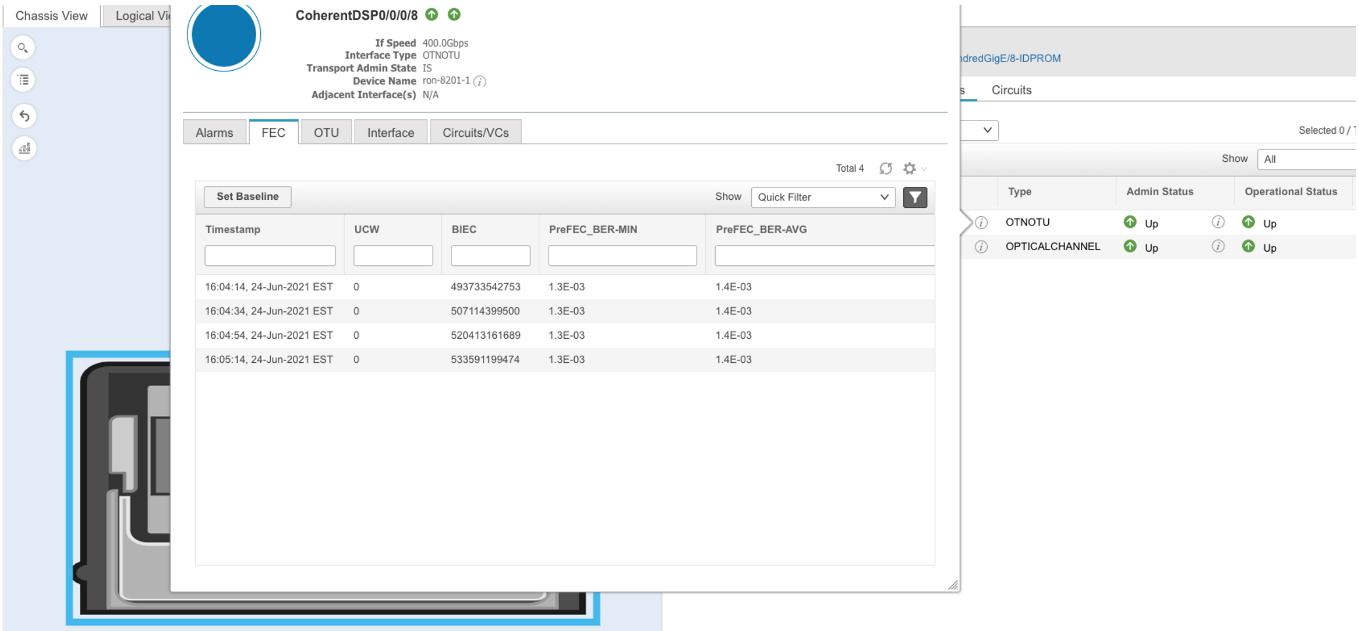
DCO Physical Layer PM KPIs

The following shows common physical layer KPIs such as OSNR and RX/TX power. This is exposed by monitoring the Optics layer of the interface.
DCO.



{:height="100%" width="100%"}

The following shows common framing layer KPIs such as number of corrected words per interval and (BIEC) Bit Error Rate. This is exposed by monitoring the CoherentDSP layer of the interface.



{:height="100%" width="100%"}

Cisco IOS-XR Model-Driven Telemetry for Routed Optical Networking Monitoring

All operational data on IOS-XR routers and optical line systems can be monitored using streaming telemetry based on YANG models. Routed Optical Networking is no different, so a wealth of information can be streamed from the routers in intervals as low as 5s.

ZR/ZR+ DCO Telemetry

The following represents a list of validated sensor paths useful for monitoring the DCO optics in IOS-XR and the data fields available within these sensor paths. Note PM fields also support 15m and 24h paths in addition to the 30s paths shown in the table below.

Sensor Path	Fields
Cisco-IOS-XR-controller-optics-oper:optics-oper/optics-ports/optics-port/optics-info	alarm-detected, baud-rate, dwdm-carrier-frequency, controller-state, laser-state, optical-signal-to-noise-ratio, temperature, voltage
Cisco-IOS-XR-controller-optics-oper:optics-oper/optics-ports/optics-port/optics-lanes/optics-lane	receive-power, receive-signal-power, transmit-power
Cisco-IOS-XR-controller-otu-oper:otu/controllers/controller/info	bandwidth, ec-value, post-fec-ber, pre-fec-ber, qfactor, qmargin, uc
Cisco-IOS-XR-pmengine-oper:performance-management/optics/optics-ports/optics-port/optics-current/optics-second30/optics-second30-optics/optics-second30-optic	dd__average, dgd__average, opr__average, opt__average, osnr__average, pcr__average, pmd__average, rx-sig-pow__average, snr__average, sopmd__average
Cisco-IOS-XR-pmengine-oper:performance-management/otu/otu-ports/otu-port/otu-current/otu-second30/otu-second30fecs/otu-second30fec	ec-bits__data, post-fec-ber__average, pre-fec-ber__average, q__average, qmargin__average, uc-words__data

NCS 1010 Optical Line System Monitoring

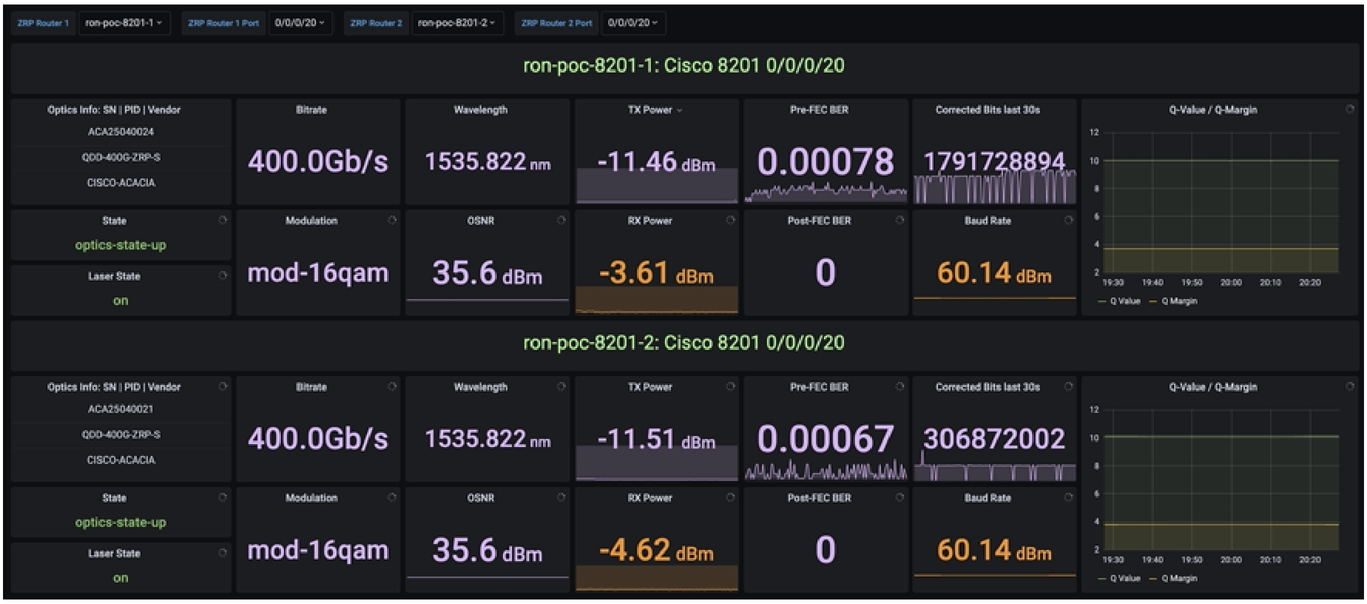
The following represents a list of validated sensor paths useful for monitoring the different optical resources on the NCS 1010 OLS. The OTS controller represents the lowest layer port interconnecting optical elements. The NCS 1010 supports per-channel monitoring, exposed as the OTS-OCH

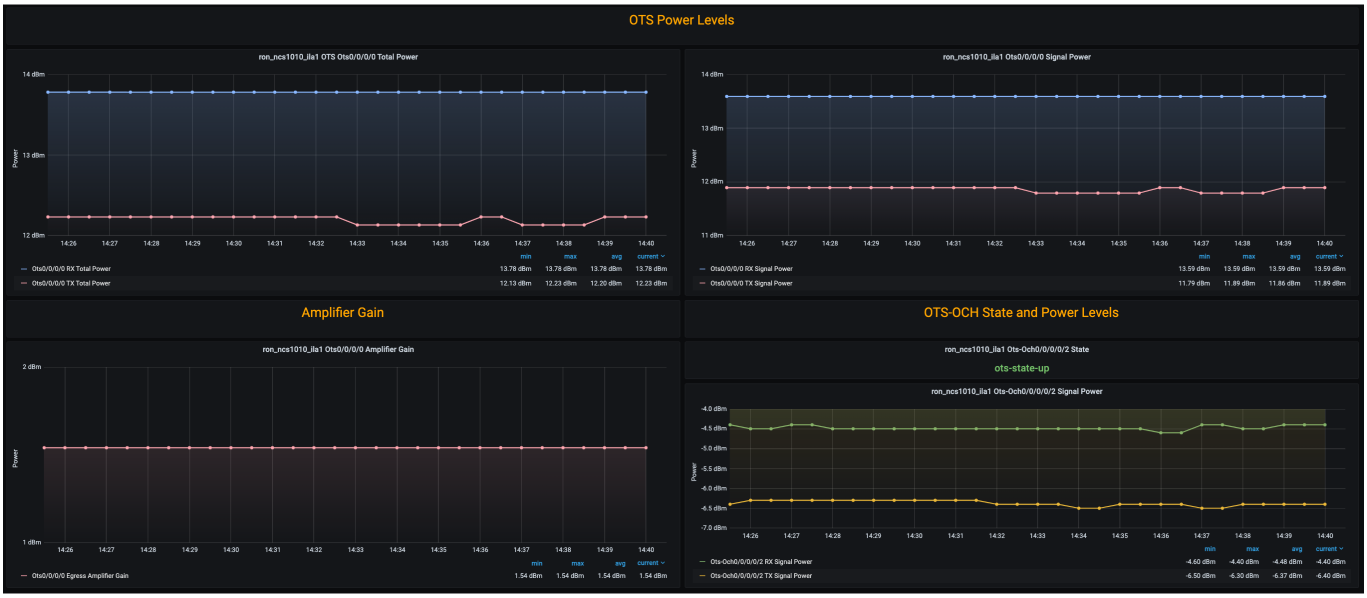
Sensor Path	Fields
Cisco-IOS-XR-controller-ots-oper:ots-oper/ots-ports/ots-port/ots-info	total-tx-power, total-rx-power, transmit-signal-power, receive-signal-power, agress-ampi-gain, ingress-ampli-gain, controller-state
Cisco-IOS-XR-controller-ots-och-oper:ots-och-oper/ots-och-ports/ots-och-port/ots-och-info	total-tx-power, total-rx-power, transport-admin-state, line-channel, add-drop-channel
Cisco-IOS-XR-controller-oms-oper	rx-power, tx-power, controller-state, led-state
Cisco-IOS-XR-controller-och-oper:och-oper/och-ports/och-port/och-info	channel-frequency, channel-wavelength, controller-state, rx-power, tx-power, channel-width, led-state
Cisco-IOS-XR-pmengine-oper:performance-management/optics/optics-ports	opr, opt, opr-s, opt-s

Sensor Path	Fields
Cisco-IOS-XR-olc-oper:olc/span-loss-ctrlr-tables/span-loss-ctrlr-table	neighbor-rid, rx-span-loss, tx-span-loss, name

Open-source Monitoring

Cisco model-driven telemetry along with the open source collector Telegraf and the open source dashboard software Grafana can be used to quickly build powerful dashboards to monitor ZR/ZR+ and NCS 1010 OLS performance.





Additional Resources

Cisco Routed Optical Networking 2.0 Solution Guide

https://www.cisco.com/content/en/us/td/docs/optical/ron/2-0/solution/guide/b-ron-solution-20.html

Cisco Routed Optical Networking Home

- https://www.cisco.com/c/en/us/solutions/service-provider/routed-optical-networking.html

Cisco Routed Optical Networking Tech Field Day

- Solution Overview: https://techfieldday.com/video/build-your-network-with-cisco-routed-optical-networking-solution/
- Automation Demo: https://techfieldday.com/video/cisco-routed-optical-networking-solution-demo/

Cisco Champion Podcasts

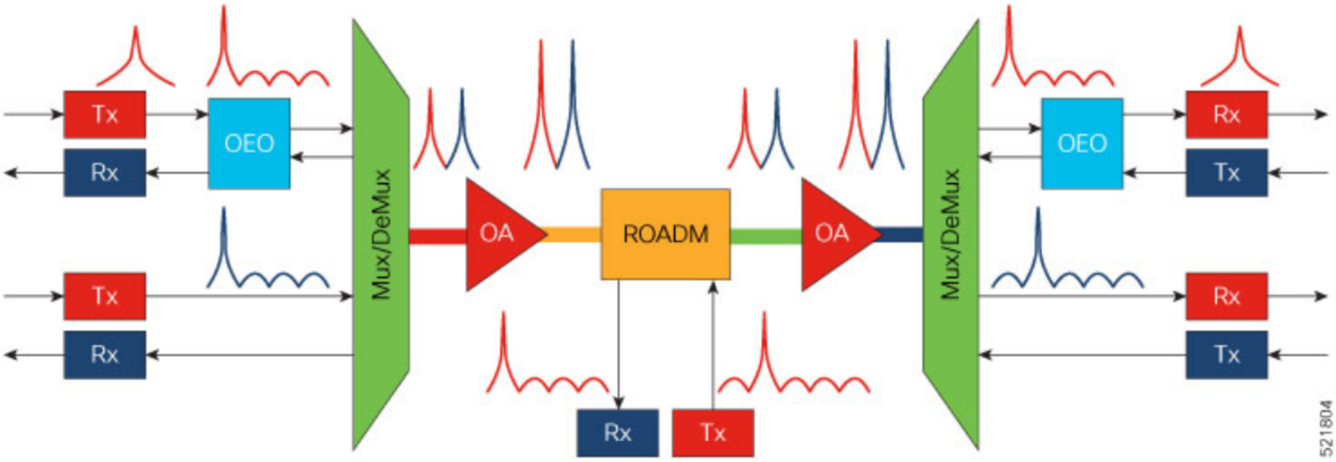
- Cisco Routed Optical Networking Solution for the Next Decade https://smarturl.it/CCRS8E24
- Simplify Network Operations with Crosswork Hierarchical Controller: <https://smarturl.it/CCRS8E48 >

Appendix A

Acronyms

DWDM	Dense Waveform Division Multiplexing
OADM	Optical Add Drop Multiplexer
FOADM	Fixed Optical Add Drop Multiplexer
ROADM	Reconfigurable Optical Add Drop Multiplexer
DCO	Digital Coherent Optics
FEC	Forward Error Correction
OSNR	Optical Signal to Noise Ratio
BER	Bit Error Rate

DWDM Network Hardware Overview



Optical Transmitters and Receivers

Optical transmitters provide the source signals carried across the DWDM network. They convert digital electrical signals into a photonic light stream on a specific wavelength. Optical receivers detect pulses of light and and convert signals back to electrical signals. In Routed Optical Networking, digital coherent QSFP-DD OpenZR+ and 400ZR transceivers in routers are used as optical transmitters and receivers.

Multiplexers/Demultiplexers

Multiplexers take multiple wavelengths on separate fibers and combine them into a single fiber. The output of a multiplexer is a composite signal. Demultiplexers take composite signals that compatible multiplexers generate and separate the individual wavelengths into individual fibers.

Optical Amplifiers

Optical amplifiers amplify an optical signal. Optical amplifiers increase the total power of the optical signal to enable the signal transmission across longer distances. Without amplifiers, the signal attenuation over longer distances makes it impossible to coherently receive signals. We use different types of optical amplifiers in optical networks. For example: preamplifiers, booster amplifiers, inline amplifiers, and optical line amplifiers.

Optical add/drop multiplexers (OADMs)

OADMs are devices capable of adding one or more DWDM channels into or dropping them from a fiber carrying multiple channels.

Reconfigurable optical add/drop multiplexers (ROADMs)

ROADMs are programmable versions of OADMs. With ROADMs, you can change the wavelengths that are added or dropped. ROADMs make optical networks flexible and easily modifiable.