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## Revision History

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Version	Date	Comments
1.0	01/10/2022	Initial Routed Optical Networking Publication

## Solution Component Software Versions

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Element	Version
IOS-XR	7.3.2
IOS-XR (NCS 540)	7.4.1
NCS 2000 SVO	12.2
Cisco Optical Network Controller	1.1
Crosswork Network Controller	3.0
Crosswork Hierarchical Controller	5.1
Cisco EPNM	5.1.3

## What is Routed Optical Networking?

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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			
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

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### 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.

### Inefficiencies 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.

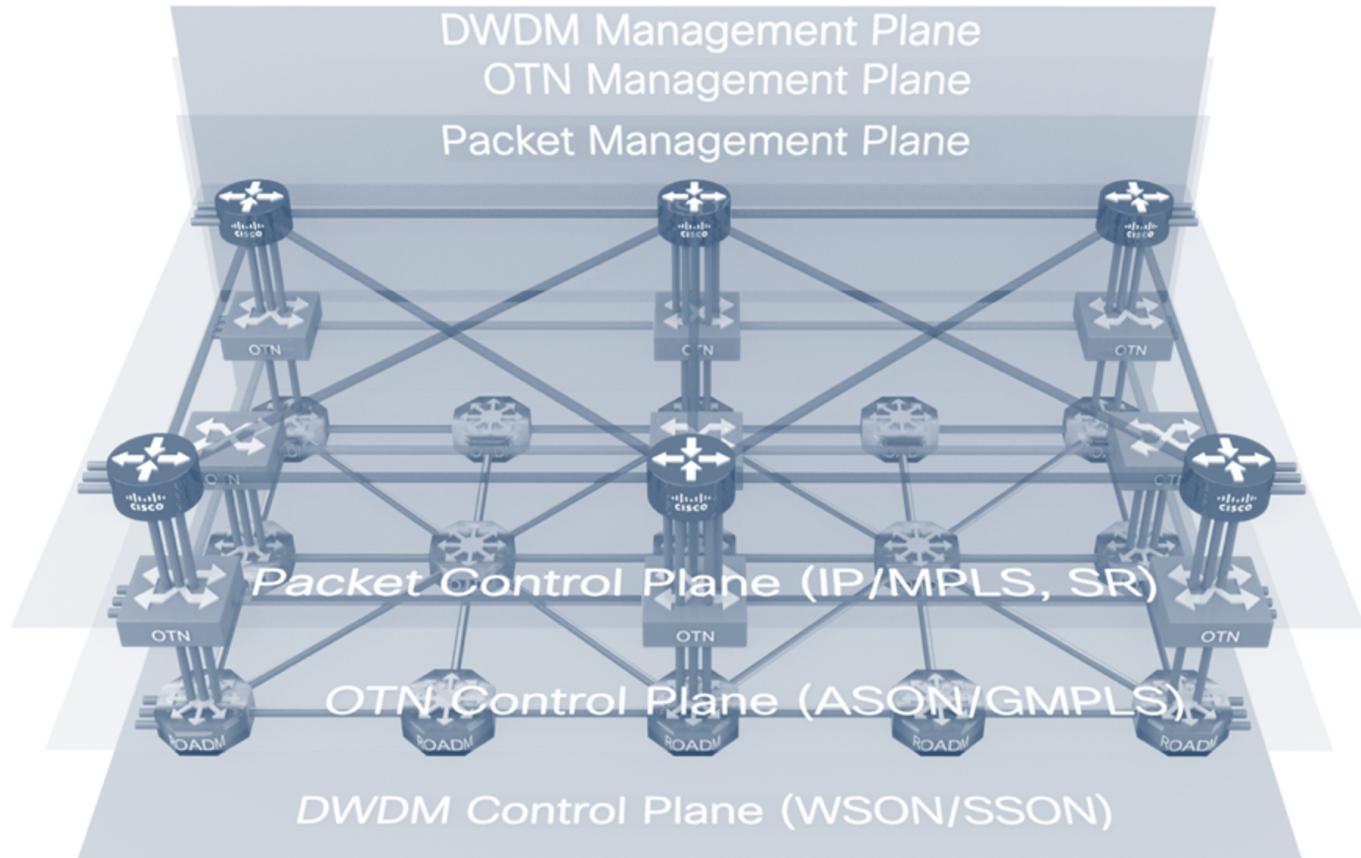
## Network Cost

Simplifying 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

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## 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+ DD optics can be used in the same ports as the highest speed 400G non-DCO transceivers.



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.



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

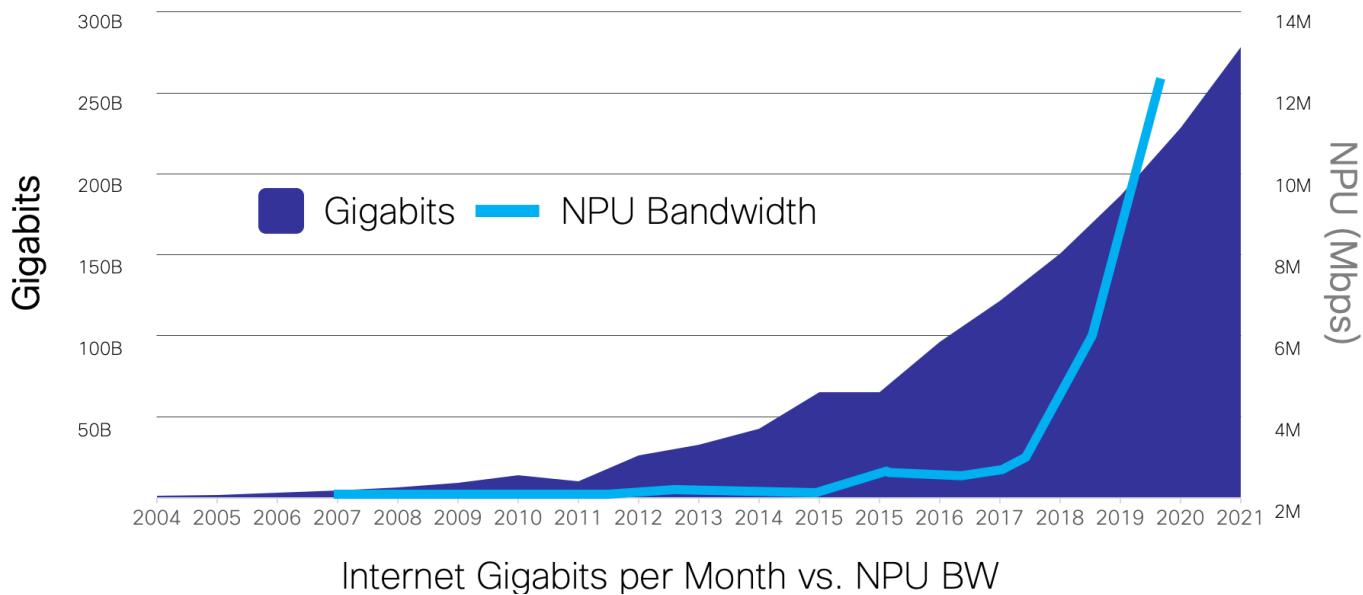
<https://www.cisco.com/c/en/us/products/collateral/interfaces-modules/transceiver-modules/datasheet-c78-744377.html>

## 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



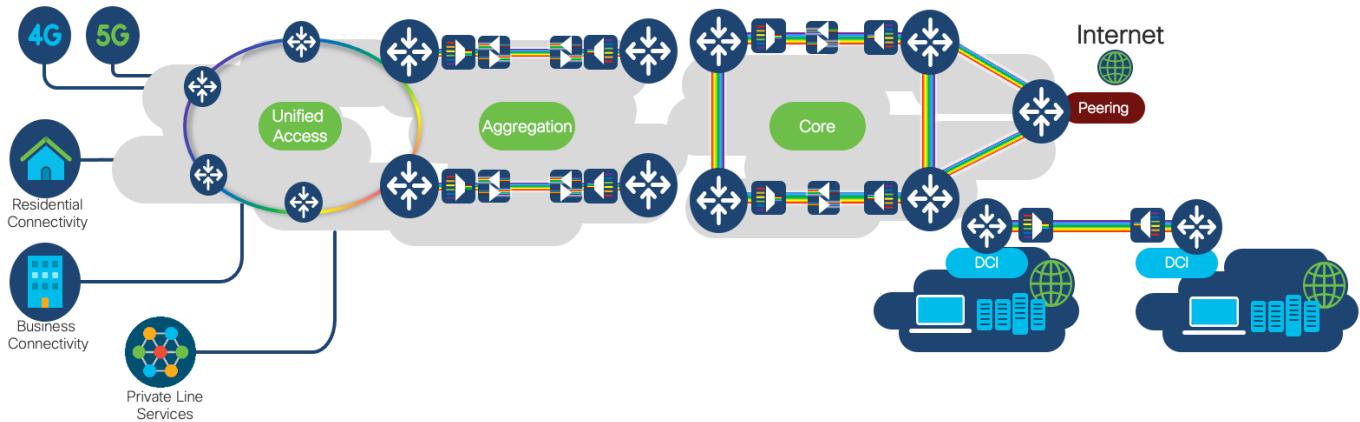
## Cisco DWDM Network Hardware

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. See the validated design hardware section for more information.

## Routed Optical Networking Network Use Cases

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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 networks.

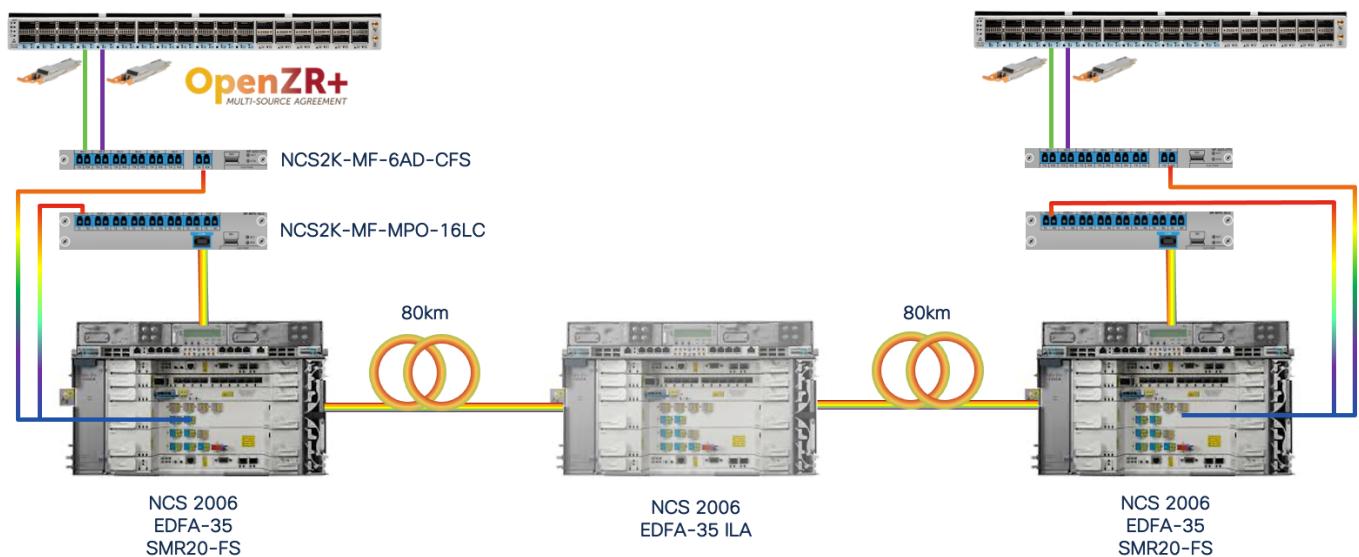
### 64 Channel FOADM P2P Deployment

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.



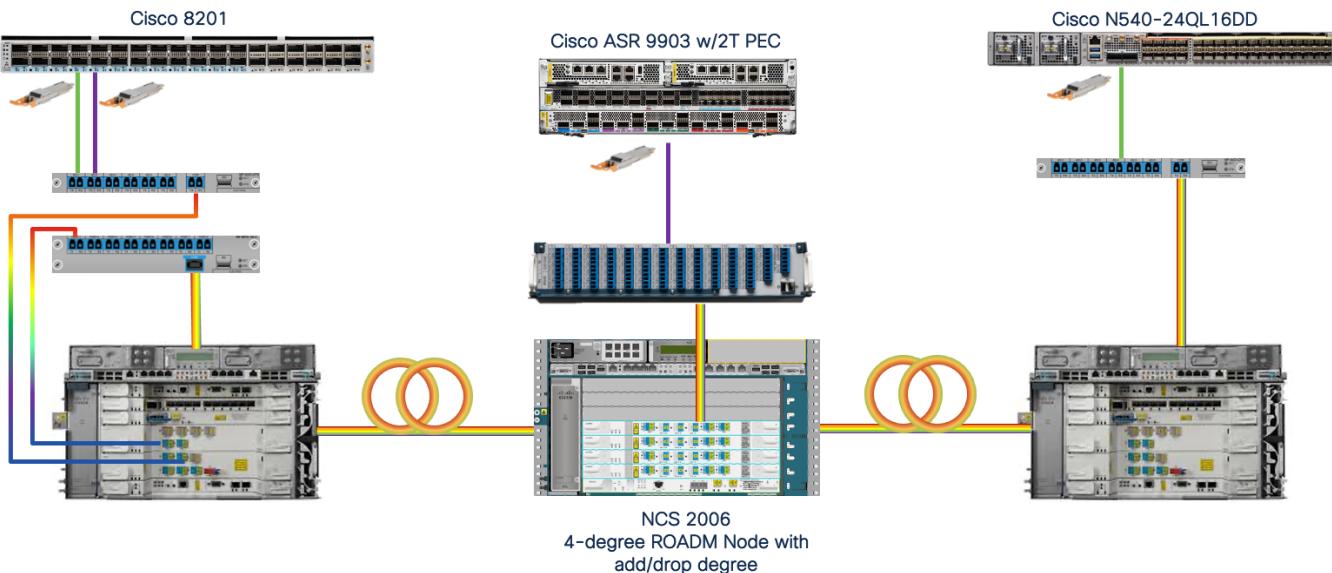
## Colorless Add/Drop Deployment

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+.



## 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.



## Long-Haul Deployment

Cisco has demonstrated in a physical lab 400G OpenZR+ services provisioned across 1200km using NCS 2000 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 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



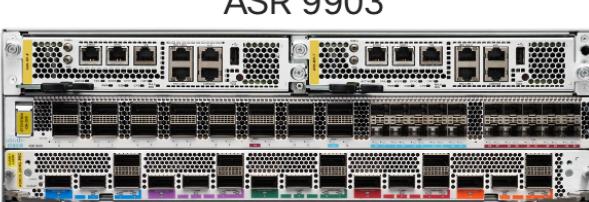
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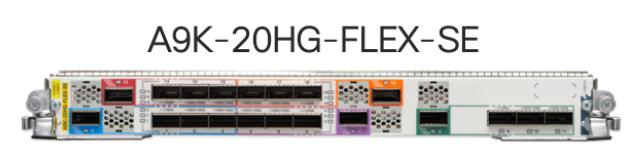
8202



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](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](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

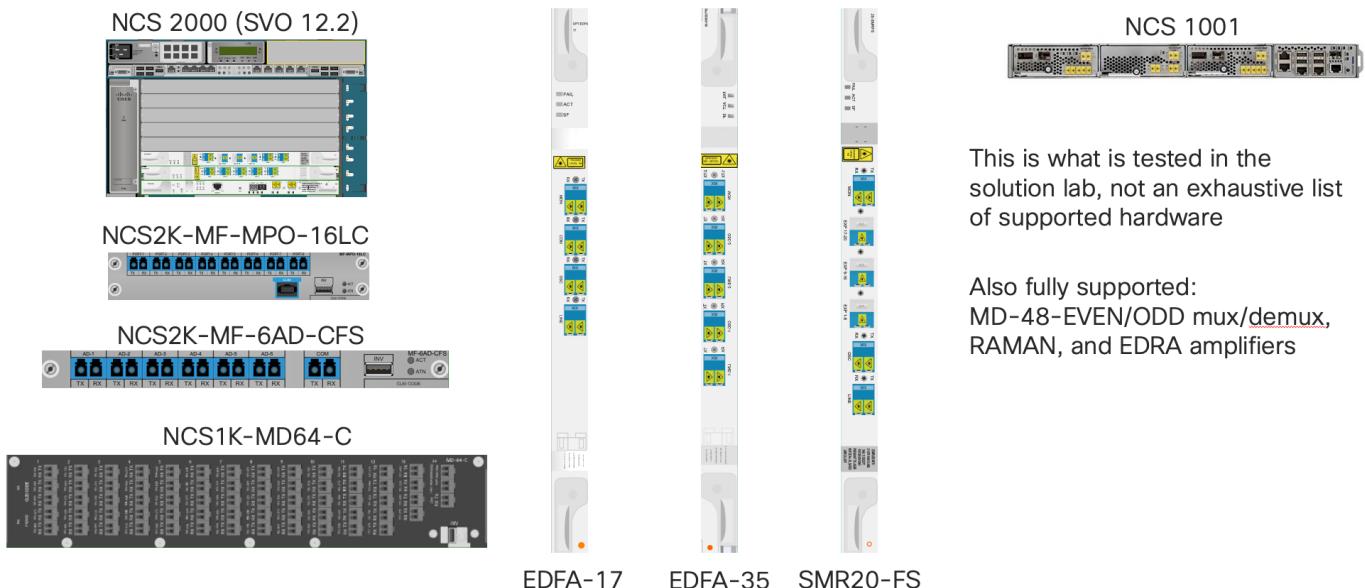
The 1Tbps N540-24QL16DD-SYS high density router brings QSFP-DD and Routed Optical Networking ZR/OpenZR+ optics to a flexible access and aggregation platform. Using OpenZR+ optics it allows a migration path from 100G to 400G access rings or uplinks when used in an aggregation role.

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

Below gives an overview of some of the supported equipment used to build the DWDM layer of the Routed Optical Networking Solution.



This is what is tested in the solution lab, not an exhaustive list of supported hardware

Also fully supported:  
MD-48-EVEN/ODD mux/demux,  
RAMAN, and EDRA amplifiers

## 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 utilized 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>

# Routed Optical Networking Automation

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## 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

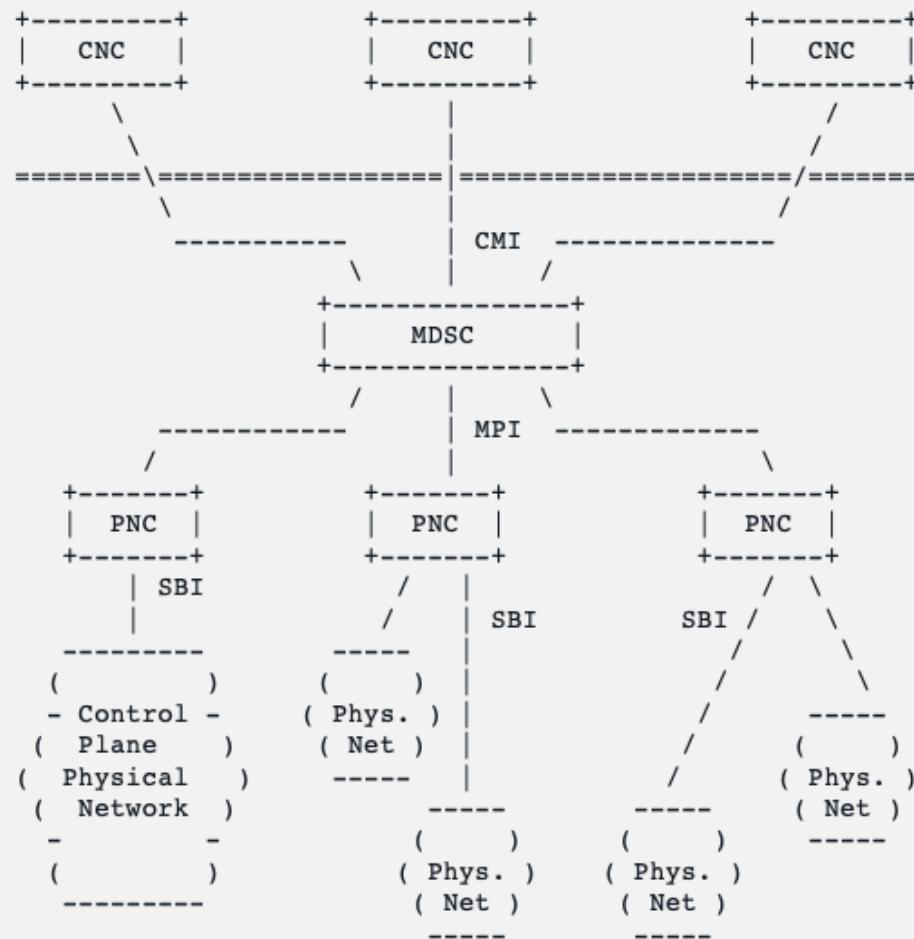
was not originally designed for. Cisco's standards based hierarchical SDN solution allows providers to manage a multi-vendor Routed Optical Networking solution using standard interfaces and YANG models.

## 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 controllers 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)

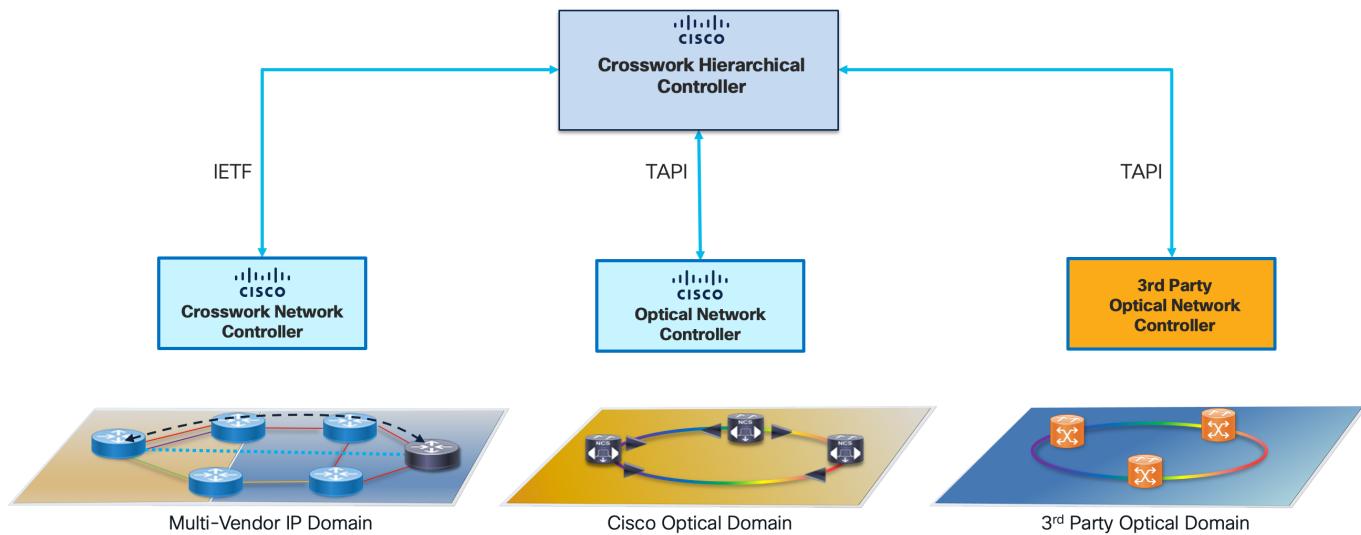
## ACTN SDN Control Framework



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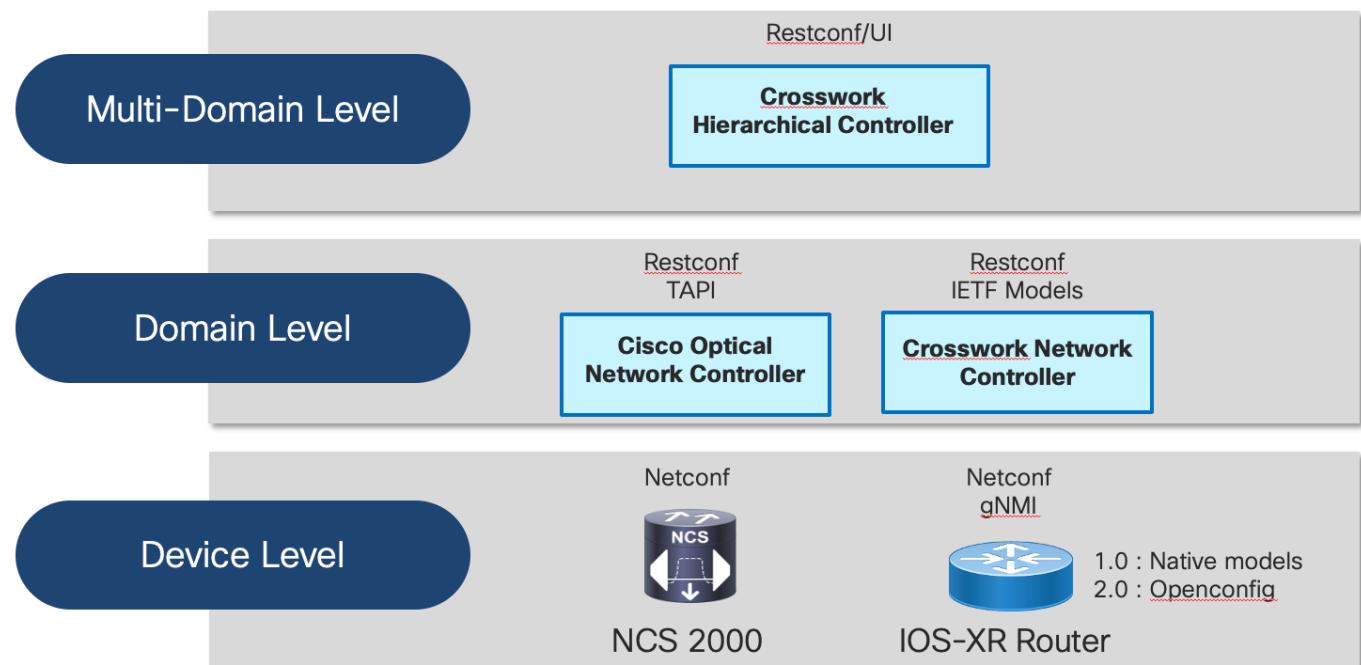
## Cisco's SDN Controller Automation Stack

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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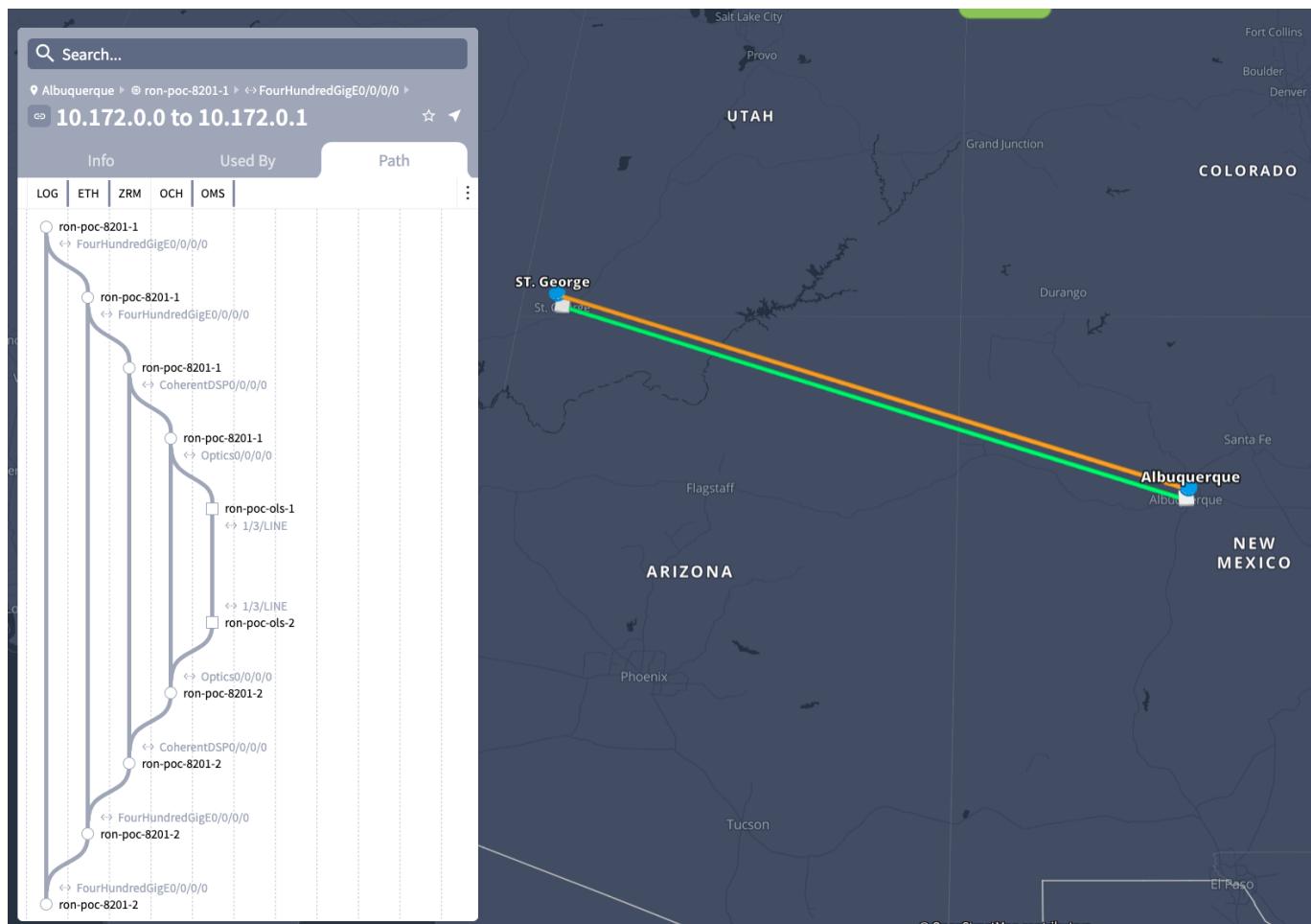
## Crosswork Hierarchical Controller (HCO)

Responsible for Multi-Layer Automation is the Crosswork Hierarchical Controller. CW HCO 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 Root Cause Analysis tool, able to quickly correlate upper layer faults to an underlying cause.

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>



Crosswork Network Controller (CNC) is a multi-vendor IP domain controller. CNC is responsible for the following 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 CW applications to perform telemetry collection/alerting, zero-touch provisioning, and automated and assurance network changes

More information on Crosswork and CNC 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

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## 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
- ZR/ZR+ Optics using IOS-XR Netconf

## 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 HCO UI Provisioning

End-to-End IP+Optical provisioning can be done using HCO GUI IP Link provisioning. Those familiar with traditional GUI EMS/NMS systems for service management will have a very familiar experience. HCO 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 CW HCO. The below screenshot shows defined NMC cross-links.

The screenshot shows the 'NMC Cross Connections' section of the Cisco Crosswork HCO interface. It features two search bars for 'Router OCH port' and 'Optical NMC port', each with a magnifying glass icon. Below the search bars are four filter dropdowns: 'Name', 'Router Port', 'Router Device', 'Optical Port', and 'Optical Device'. A '2 ITEMS MATCHING FILTER' message is displayed above a table. The table has columns for 'Name', 'Router Port', 'Router Device', 'Optical Port', and 'Optical Device'. Two rows of data are listed:

Name	Router Port	Router Device	Optical Port	Optical Device
ron-poc-8201-2/Optics0/0/0 to ron-poc-ols-2/2/PORT-1	Optics0/0/0	ron-poc-8201-2	2/PORT-1	ron-poc-ols-2
ron-poc-8201-1/Optics0/0/0 to ron-poc-ols-1/2/PORT-1	Optics0/0/0	ron-poc-8201-1	2/PORT-1	ron-poc-ols-1

## 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.

Name	P2P Type	Configuration State	Last Operation
ron-8201-4_FourHundred...	IP Link	OK	09-11-
ron-poc-8201-1_FourHund...	IP Link	OK	09-11-
ron-ncs540-2dd-1_FourHu...	IP Link	OK	09-11-
ron-8201-1_FourHundredG...	IP Link	OK	09-11-

Speed [Gbps]	Operation State	Last 24h Operation	Last Operation
400	Up	1	Create IP Link: ✓ Done
400	Up	1	Create IP Link: ✓ Done
400	Up	1	Create IP Link: ✓ Done
400	Up	1	Create IP Link: ✓ Done

## Operational Discovery

The HCO 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 CW 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 [Cisco Routed Optical Networking RON-ML CFP Documentation](#)

## RON 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 relevant 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
```

## IOS-XR NETCONF Configuration

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, modulation, and line side rate (200G) configuration.

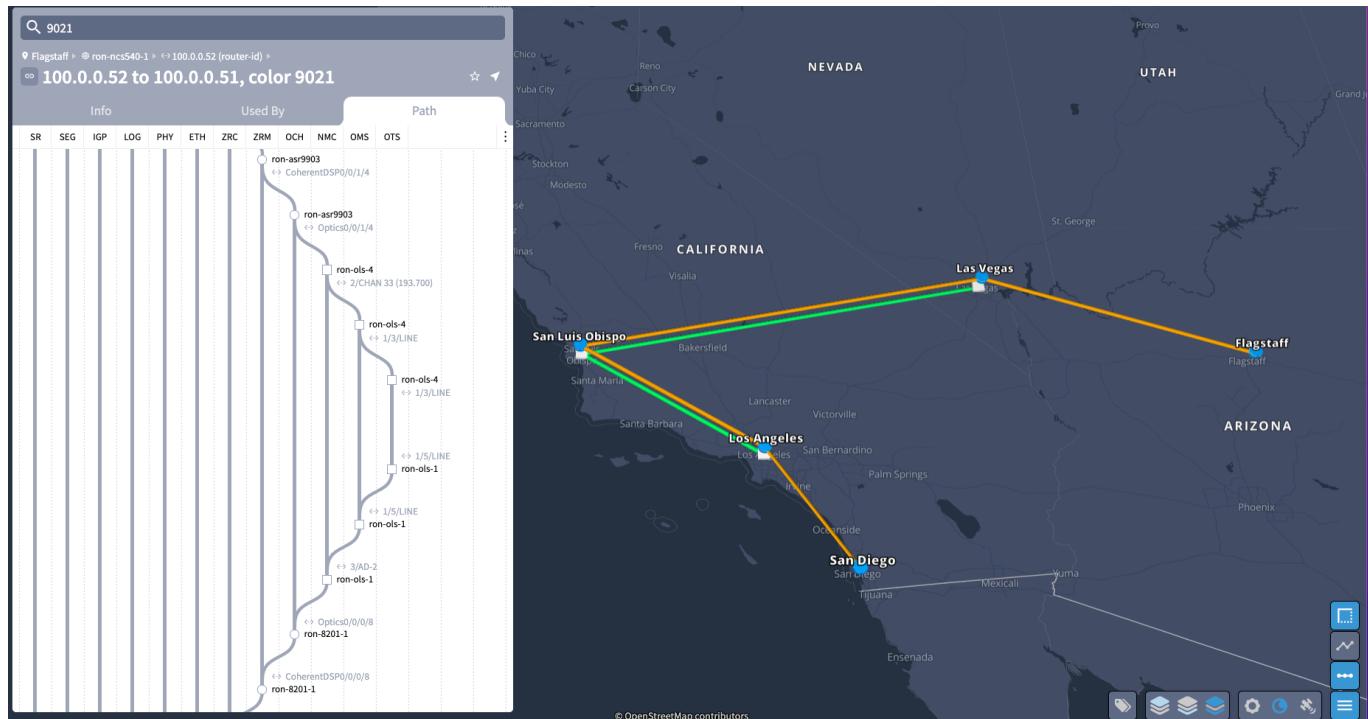
```
<data xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
  <interface-configurations xmlns="http://cisco.com/ns/yang/Cisco-IOS-XR-
  ifmgr-cfg">
    <interface-configuration>
      <active>act</active>
      <interface-name>Optics0/0/0/20</interface-name>
        <description> Managed by NSO .58, do not change manually</description>
        <optics xmlns="http://cisco.com/ns/yang/Cisco-IOS-XR-controller-optics-
        cfg">
          <optics-transmit-power>-100</optics-transmit-power>
          <optics-performance-monitoring>true</optics-performance-monitoring>
            <optics-modulation>16qam</optics-modulation>
          <optics-fec>fec-ofec</optics-fec>
          <optics-dwdm-carrier>
            <grid-type>100Mhz-grid</grid-type>
            <param-type>frequency</param-type>
              <param-value>1956500 </param-value>
            </optics-dwdm-carrier>
          </optics>
          <breakout xmlns="http://cisco.com/ns/yang/Cisco-IOS-XR-optics-driver-
          cfg">2x100</breakout>
        </interface-configuration>
      </interface-configurations>
    </data>
```

# Routed Optical Networking Assurance

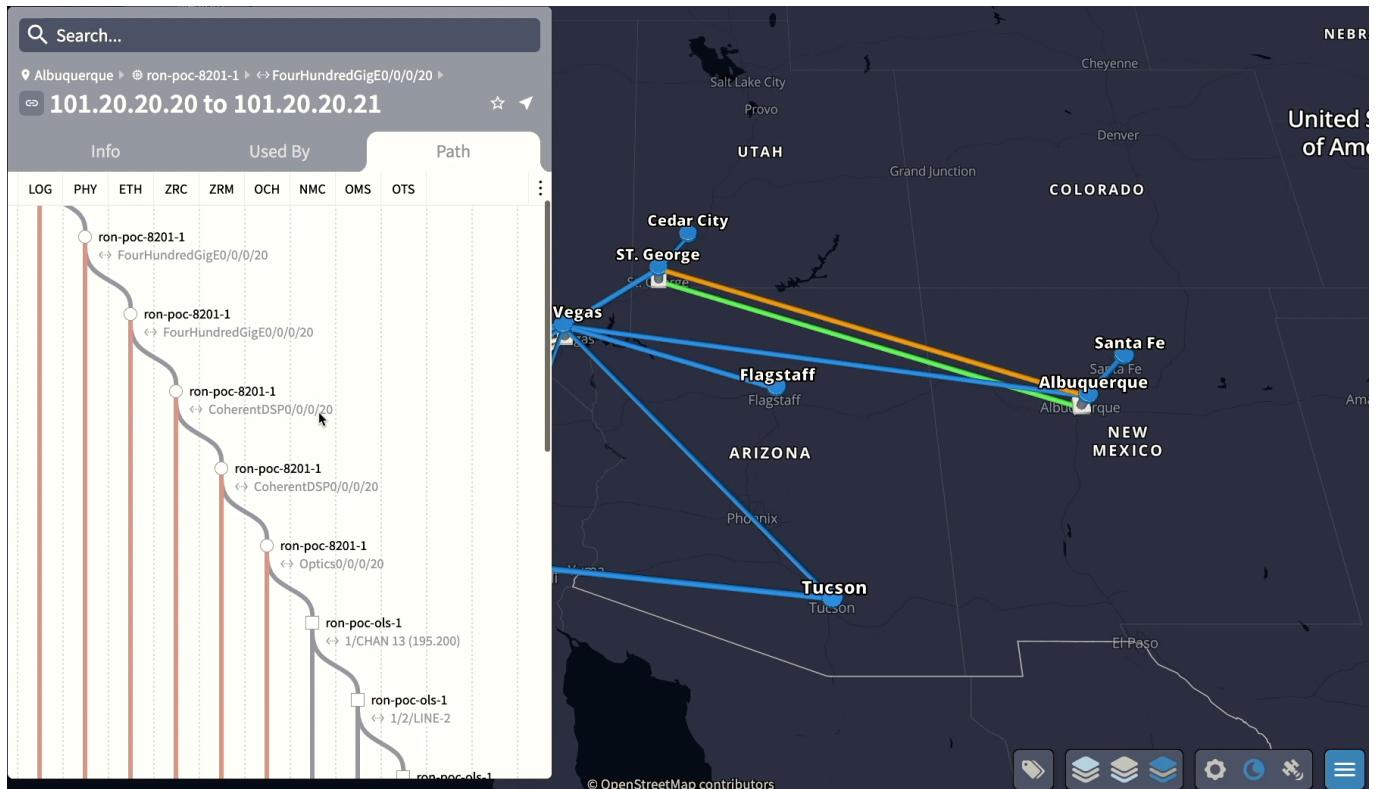
## Crosswork HCO

### 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.



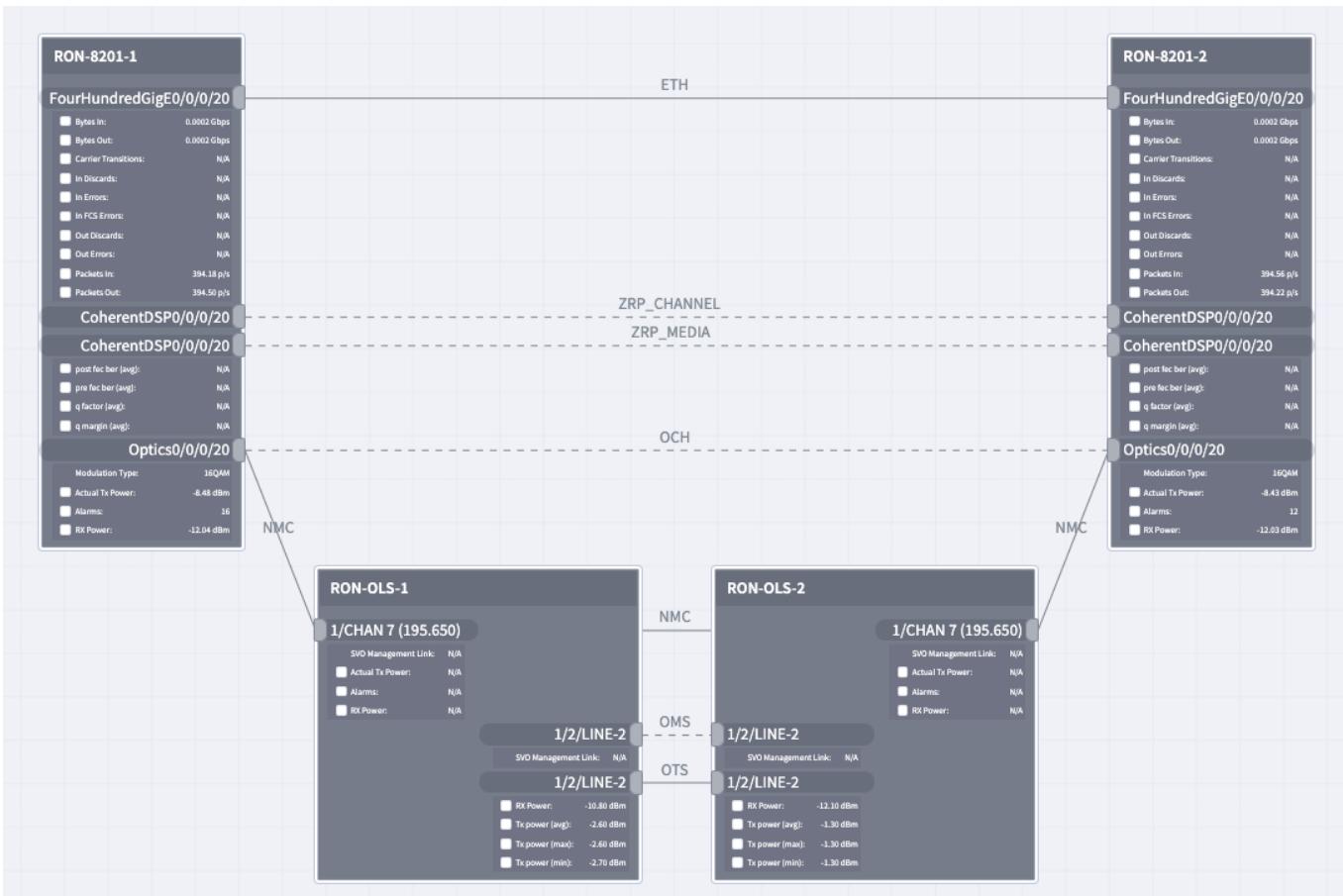
{:height="100%" width="100%"}  
When faults occur at a specific layer, faults will be highlighted in red, quickly identifying the layer a fault has occurred.



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

## Routed Optical Networking Link Assurance

The Link Assurance application isolates the multi-layer path of a single Routed Optical Networking service, showing both the router termination points as well as the optical layer. This information is further enhanced with telemetry data coming from both the ZR/ZR+ optics as well as the optical link system nodes.



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

Optionally the user can see graphs of collected telemetry data to quickly identify trends or changes in specific operational data.



{: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  
00R-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
```

TCA	Operational	MIN	AVG	MAX	Operational	Configured
		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
```

## Cisco IOS-XR Model-Driven Telemetry for ZR/ZR+ Monitoring

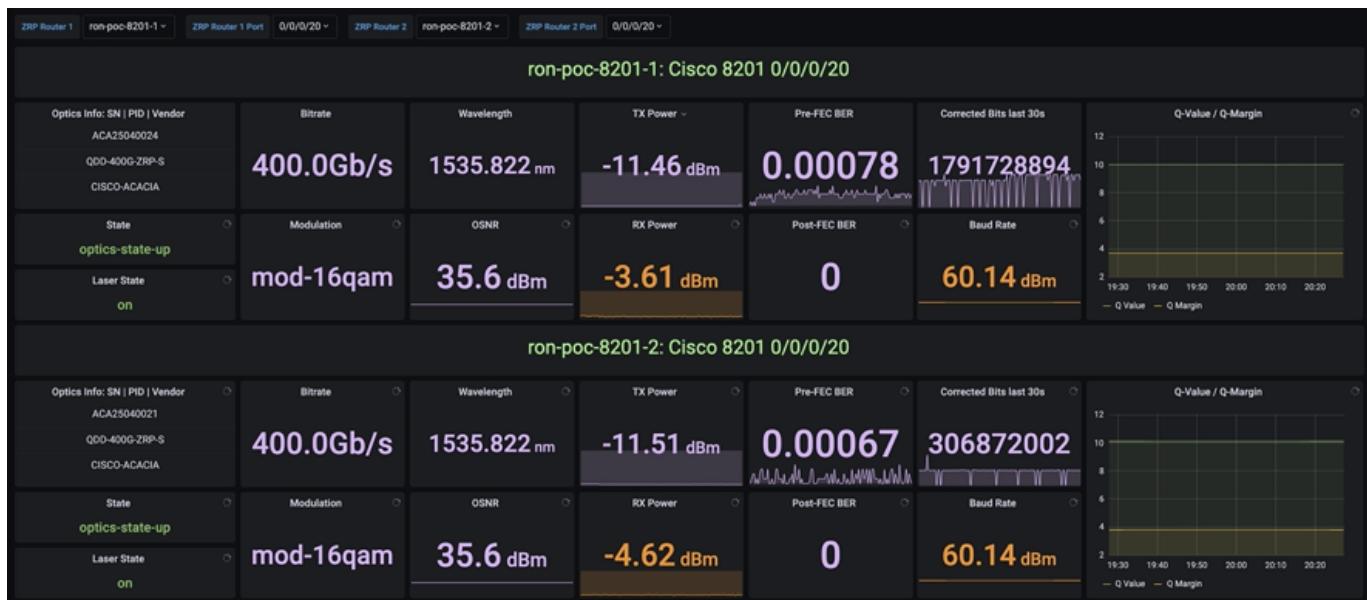
All operational data on IOS-XR routers can be monitored using streaming telemetry based on YANG models. Routed Optical Networking is no different, so a wealth of information can be streamed from the routers in intervals as low as 5s.

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-second30fec/otu-second30fec	ec-bits_data, post-fec-ber_average, pre-fec-ber_average, q_average, qmargin_average, uc-words_data

## Open-source ZR/ZR+ 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+ performance.



## Additional Resources

### 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>>

### Cisco Routed Optical Networking 1.0 Solution Guide

## Appendix A

### Acronyms

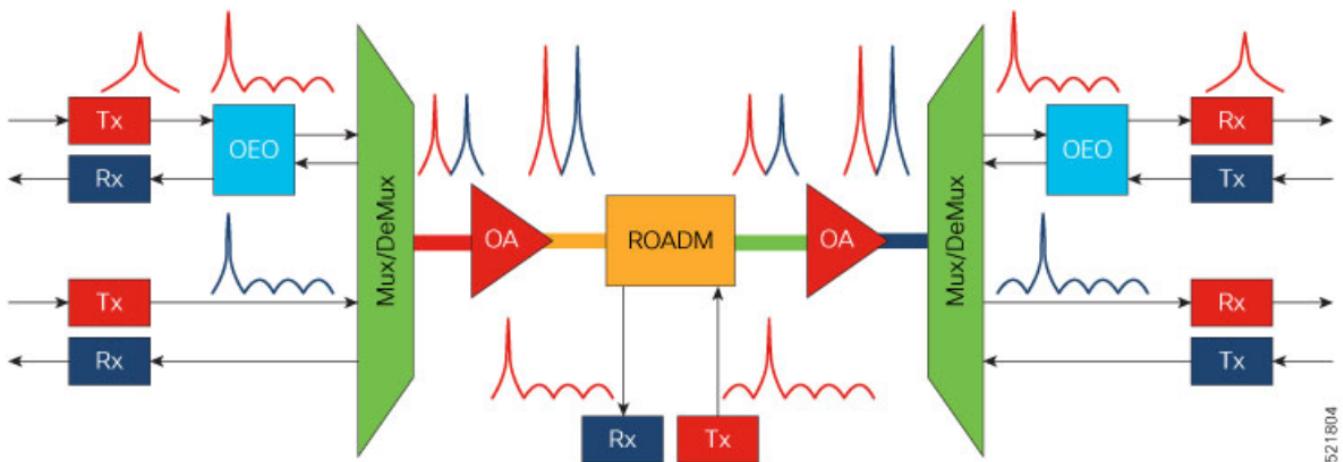
DWDM Dense Waveform Division Multiplexing

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 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 ROADM, you can change the wavelengths that are added or dropped. ROADM make optical networks flexible and easily modifiable.