IP-optical coordination and automation for 400GE and beyond

Managing coherent routing applications with the Nokia Network Services Platform

Application note

Abstract

The introduction of pluggable DWDM router optics such as 400ZR and 400ZR+ enables to connect routers directly over coherent wavelenghts, but it also creates a set of operational challenges that must be addressed.

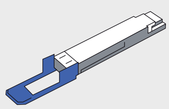
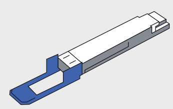
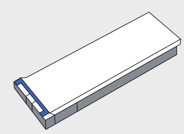
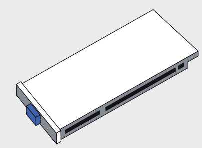
This application note explains how the Nokia Network Services Platform (NSP) brings a holistic approach to IP-optical multilayer operational automation and network optimization of coherent routing applications and use cases. This approach enables network operators to deliver, assure and maintain network infrastructure and services quickly, securely and cost effectively in the 400G era and beyond.

Contents

Drivers and enablers for coherent routing

Relentless demand for more capacity at a lower cost per bit forces network operators to constantly upgrade and optimize their IP-optical network designs. Rapid advances in silicon are fueling a new generation of coherent 400GE router optics that fit the constraints of small pluggable form factors, offering new possibilities to address the ongoing challenges of traffic growth and cost reduction. Pluggable 400GE digital coherent optics (DCOs) allow to connect routers directly over DWDM wavelengths, and can complement conventional DWDM transponders in optical line systems to meet a variety of capacity and reach objectives (Figure 1).

Figure 1. 400ZR and 400ZR+ pluggable coherent 400G router optics

Access and metro DCI	Metro aggregation	Metro and regional core	High-performance long haul
			
400G ZR	400G ZR+	400G Multihaul	400G Any Distance
40 km unamplified 120 km amplified *	Up to ≈750 km (pt-pt) or 6 -8 ROADMs *	Up to ≈750 km (pt-pt) or 6 -8 ROADMs *	Multiple 1000s km Wavelength Switching
400G	100–400G	100–400G	200–600G
16QAM	QPSK/8/16QAM	QPSK/8/16QAM	PCS -shaped QAM
QSFP -DD	QSFP -DD	CFP2	Board-mounted DCO
Ethernet only	Ethernet only	Ethernet & OTN	Ethernet & OTN

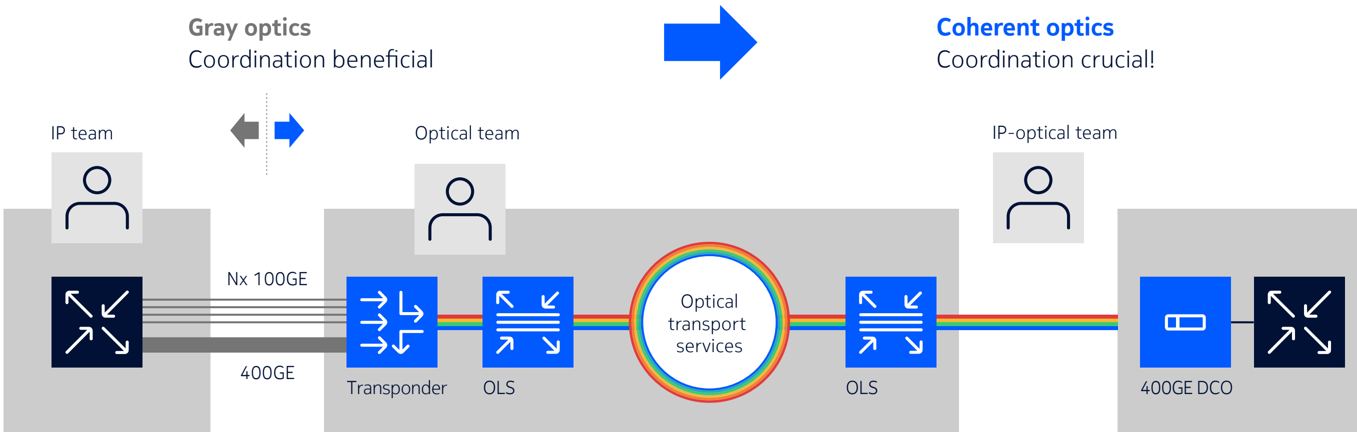
* Reach and ROADM pass-through will vary based on network characteristics

The introduction of pluggable coherent optics such as 400ZR and 400ZR+ into routers enables a smooth network upgrade to 400 Gb/s interface speeds. It also brings new IP-optical network operational challenges that need to be addressed.

As IP routers cross over into the domain of coherent optical transport, they are exposed to new port and link management practices that were traditionally in the jurisdiction of the optical transport network. Operational tasks such as optical channel provisioning, connectivity discovery, maintenance and troubleshooting of optical connectivity must be incorporated into the scope of overall router management. These IP management tasks must also be seamlessly coordinated with the operational management of optical line systems that support coherent DWDM transport between routers with inline amplification, wavelength multiplexing and optical layer protection services.

This shift will accelerate and intensify the need for flexible and powerful tools that can operate efficiently across layers, navigating and coordinating operational activities between the IP and optical worlds. In essence, IP-optical coordination will move from being a very beneficial capability to being a crucial one in automated operational management (Figure 2).

Figure 2. The transition to 400G pluggable coherent optics



The Nokia Network Services Platform (NSP) helps network operators address the multilayer and cross-domain management coordination requirements of converged IP-optical transport through a combination of open, programmable interfaces and intent-based automation applications and use cases.

The NSP unifies service automation, network lifecycle management, network optimization and assurance in a single integrated software platform so that network operators can deliver on-demand network services quickly, securely, cost effectively and at great scale.

The NSP answers the need for more responsive, efficient and reliable IP networks with:

- A complete suite of ready-to-use applications that help network operations teams address all NSP use cases for network management, orchestration and control
- A software-defined networking (SDN) resource controller that lets network engineering teams control the network and optimize traffic in real time
- An open, programmable platform that enables the automation of network operations and eases the integration with orchestrators and operations support systems (OSSs)

This application note describes how the NSP supports converged IP-optical transport services and illustrates the envisioned use cases and applications. Note that this is a subset of the cross-domain, multilayer management capabilities that the NSP supports.[1]

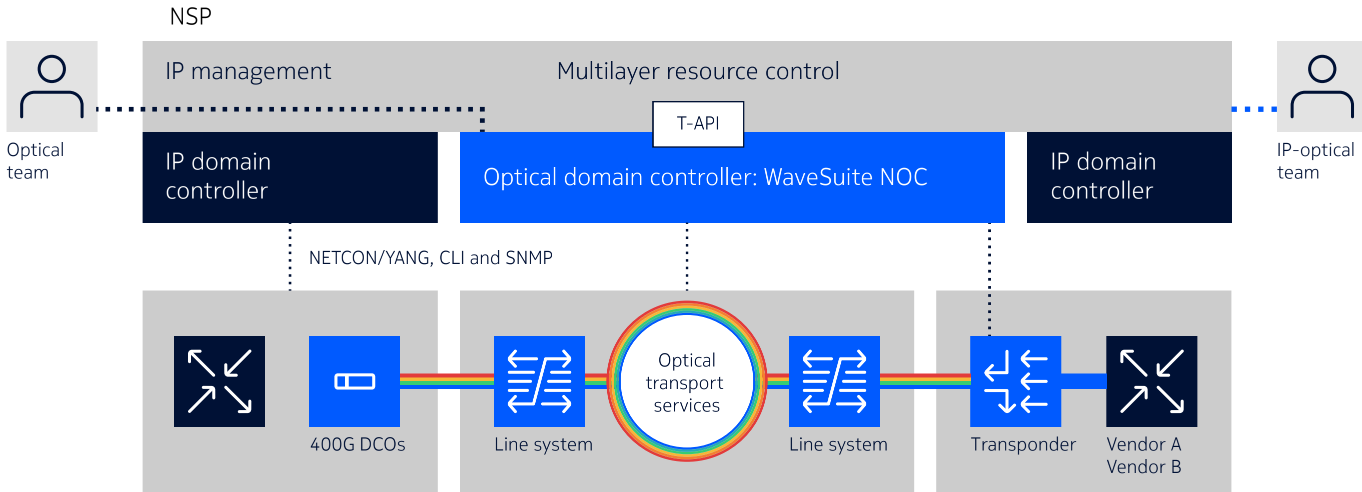
1 For a complete overview of Nokia's extensive support tools in this area, refer to the application note, "Achieving efficient IP-optical network automation: Multilayer coordination with the Nokia NSP."

Managing converged IP-optical transport with the NSP

The NSP delivers IP-optical management of coordinated operations across and between network layers through a set of applications that can be accessed through a "single pane of glass." Regardless of the network architecture and the specific deployment use case, operations can be managed with outcome-focused intents and proven multilayer workflows.

With the NSP, operators can leverage various open and standardized interfaces to integrate IP routing and optical transport domains in multivendor networks (Figure 3).

Figure 3. Nokia NSP cross-domain IP-optical management architecture



The NSP features an extensive set of multilayer resource control and service management applications that interface with underlying infrastructure through model-driven APIs:

- The IP domain controller uses model-driven application programming interfaces (APIs) to manage IP/Ethernet routers from Nokia and third-party vendors. This includes interface ports, equipped gray or coherent router optics, available network resources and services.
- The multilayer resource controller leverages Open Networking Foundation (ONF) Transport API (T-API) extensions to interface with external optical domain controllers from Nokia (i.e., WaveSuite NOC) or third-party vendors to discover, provision and assure optical line systems. This includes dense wavelength-division multiplexing (DWDM) transponders, fixed and reconfigurable optical add-drop multiplexers (FOADMs and ROADMs), and physical layer resources.

Multivendor interoperability between the NSP and third-party domain controllers has been validated through independent tests conducted by the European Advanced Networking Test Center (EANTC). The NSP accommodates different operational arrangements with flexible access rights management for operator roles and responsibilities.

Installation and commissioning of pluggable coherent router optics

The Nokia Service Router Operating System (SR OS) fully integrates Nokia-qualified pluggable DCOs in its standard equipment management practices. This enables consistent management of pluggable coherent and gray router optics with all NSP management tools, including deployment templates, workflows, model-driven mediation (MDM) and streaming telemetry. MDM is used to manage IP routers, including third-party devices, provided that the relevant interface parameters are properly exported and accessible through programmable application interfaces.

When pluggable coherent router optics are equipped in a router, the NSP automatically detects and includes them as part of the router equipment inventory. The NSP identifies the plug type, assigns a port name and allows the user to configure the plug parameters manually or automatically with values retrieved from the optical controller through the T-API interface. These parameters include:

- DCO mode: Optimal settings for the pluggable, such as “Long Haul” or “Metro”
- Optical Center Frequency: 400GE DCOs typically support up to 64 channels in the C-band
- Tx power level: The desired transmit power is configured and a workflow can be deployed to define and execute the power ramp profile

The NSP Intent Manager can simplify the configuration of pluggable optics with deployment templates that specify predefined values for parameters that do not require operator input. When a new pluggable needs to be configured, the operations team can run this intent, which simply requires a few additional input parameters such as channel and site names.

Once pluggable optics are configured and operational, the NSP enables alarm reporting and performance data collection such as BERs.

Management coordination with optical line systems

For simple use cases where two coherent router ports are interconnected over a dark fiber pair, the pluggable coherent optics of the interconnecting routers can be paired to enable consistent, matching optical parameter value settings for the near- and far-end pluggables. Besides this simple point-to-point use case, there are many other use cases that include optical line systems for various functions, including:

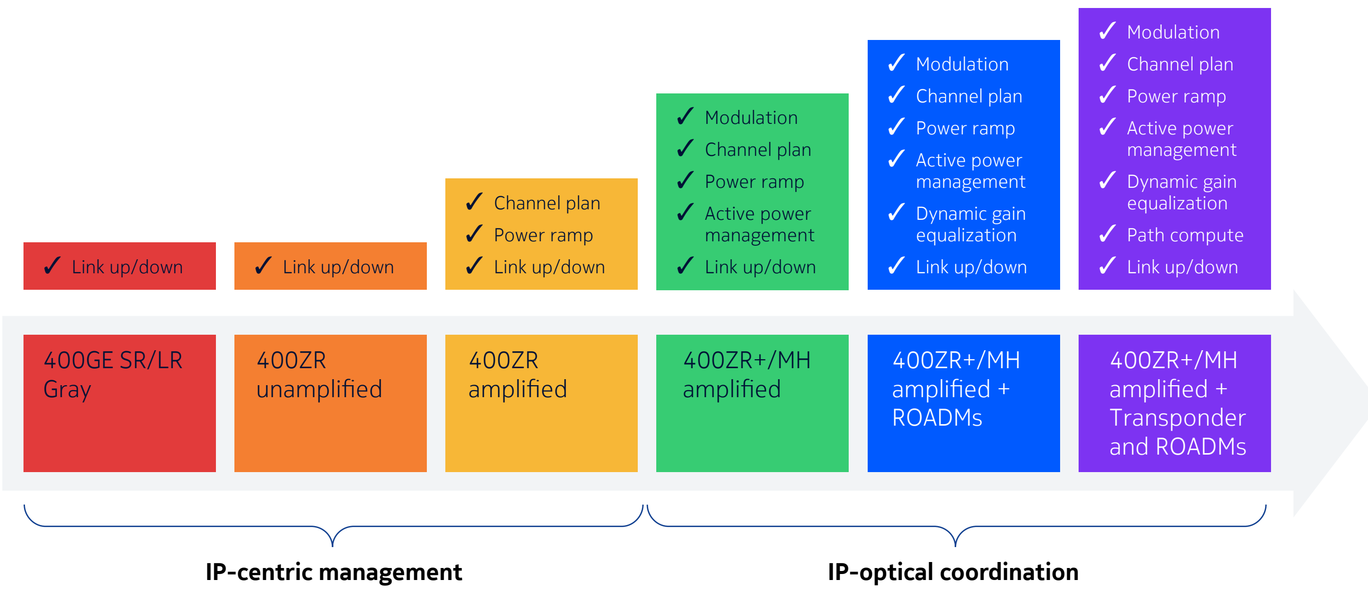
- Fiber multiplexers, to aggregate multiple coherent wavelengths on a single, shared fiber
- Inline amplifiers (ILAs), to extend the reach of coherent wavelengths to multiple fiber spans
- Reconfigurable optical add-drop multiplexors (ROADMs), to interconnect routers with point-to-point wavelengths over a shared fiber topology, and to bypass intermediate routers for transit traffic
- Optical line protection switches, to protect IPoDWDM links against fiber cuts
- Dynamic gain equalizers (DGE), to compensate for differential optical signal propagation losses

The Nokia 1830 modular optical line systems support these functions on the following platforms:

- Nokia 1830 Photonic Service Switch (PSS): Chassis-based line systems with full colorless, directionless, contentionless flexgrid (CDC-F) ROADM capability supporting metro access, regional and long-haul DWDM/OTN applications
- Nokia 1830 Photonic Service Interconnect (PSI-xL): Modular line systems with FOADM and ROADM functionality for data center interconnect and co-location applications
- Nokia 1830 PSI-M: Compact and modular optical transponders and OTN multiplexers optimized for metro, regional and long-haul data center interconnect and backhaul applications

The NSP supports a variety of use cases that include these optical line systems in the data path to coordinate the proper configuration of optical router interface parameters such as modulation, optical channel selection, power balancing, grid space, filter settings, wavelength routes, physical diversity and restoration options (Figure 4).

Figure 4. IP-optical management use case range for 400G pluggable router optics



Simple point-to-point use cases that deploy 400ZR optics over a single fiber spans with ILAs can be managed as an IP-centric management scenario. Examples include 400GE access and data center interconnect. More complex use cases that interconnect 400ZR+ and 400G Multihaul DCOs over multiple amplified fiber spans that optionally include ROADMs require cross-domain and multilayer IP-optical coordination activities that cannot be conducted solely under the jurisdiction of the IP routing operations organization. These cross-domain management tasks can be assigned to an organizational subgroup tasked with multilayer coordination.

The following section discusses the four use cases shown above in Figure 4.

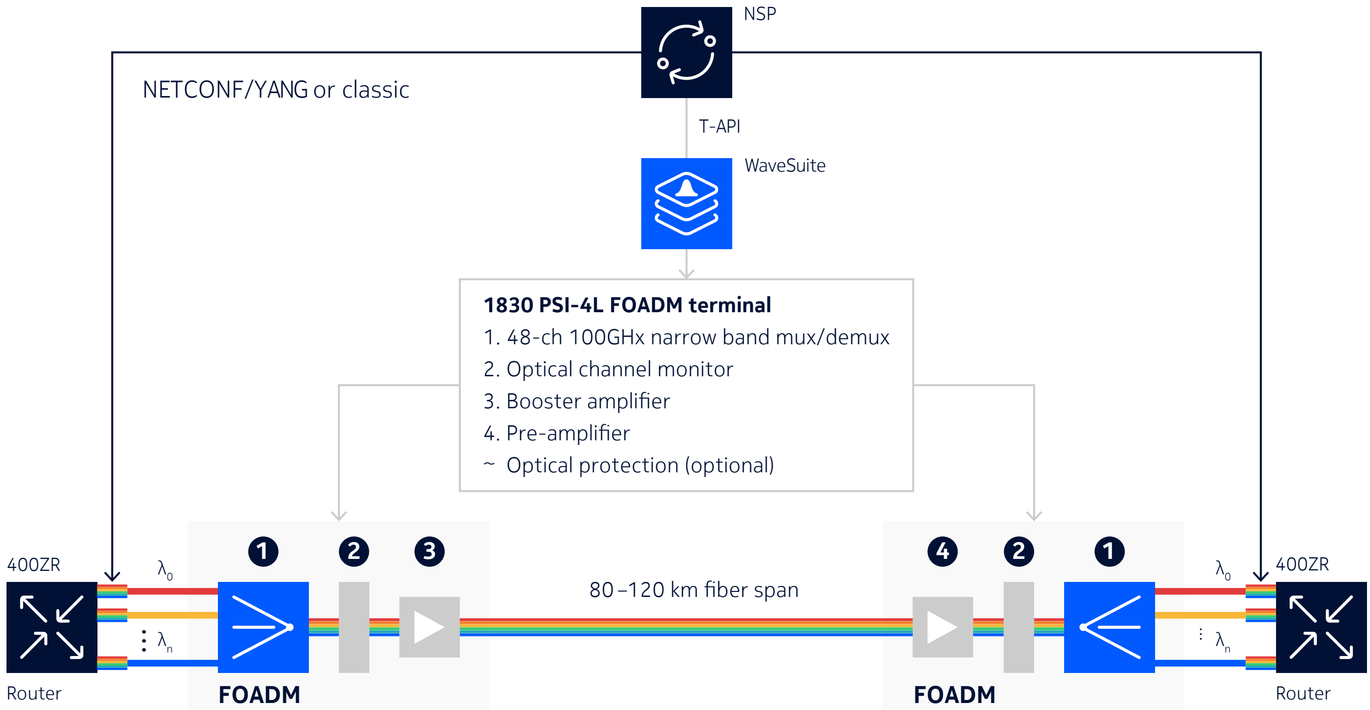
IP-optical coordination use cases

Nokia has teamed up with leading operators to validate the NSP for a representative set of reference use cases that can act as solution blueprints for real-world deployments. This work is reflected in the use case scenarios described in this section and will be included in Nokia's extensive catalog of multilayer network automation use cases as proven management recipes.

400ZR router interconnect with optical amplification and line protection

The use case depicted in Figure 5 shows the interconnection of two routers equipped with 400ZR pluggable optics over a physically diverse fiber pair with optical line systems. In this case, optical line protection is implemented using passive splitters/combiners.

Figure 5. 400ZR point-to-point links with inline amplification and protection



This point-to-point router interconnect use case has several applications:

- Data center interconnect in campus, metro and regional scenarios
- Data center virtualization for synchronization and backup
- Hub-and-spoke metro access networks for backhaul and triple play

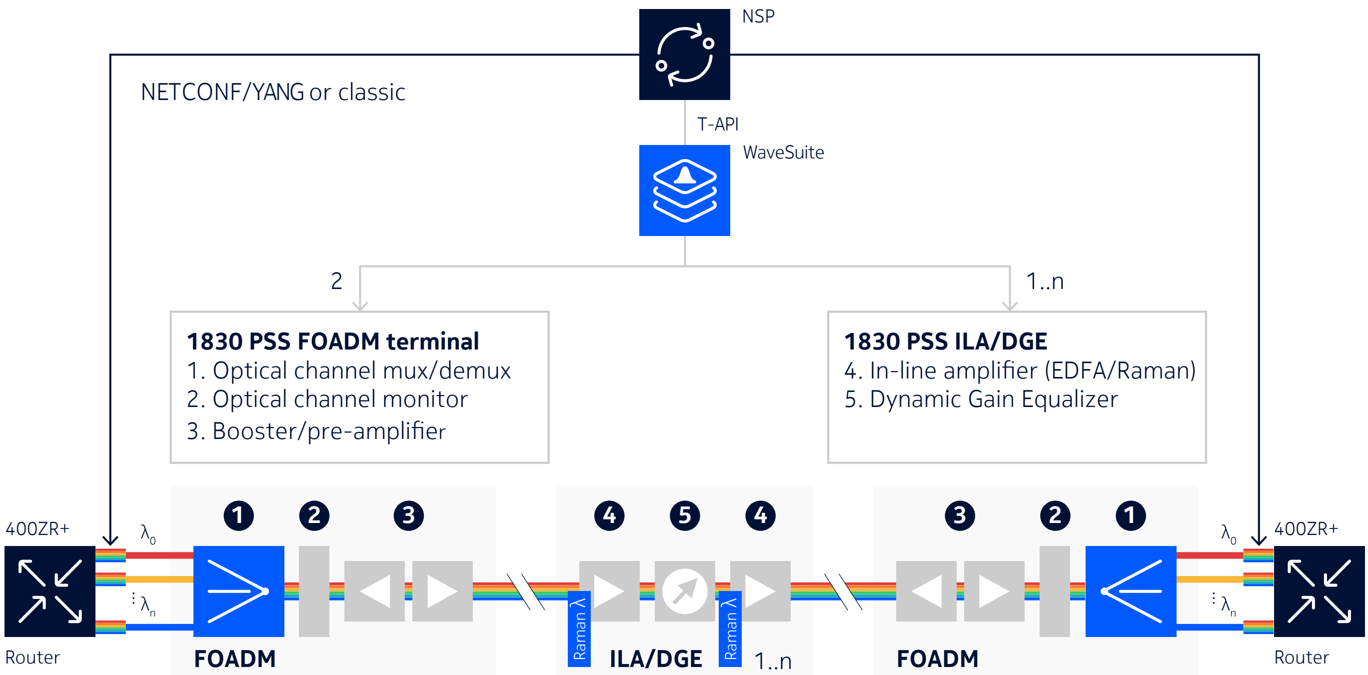
The routers connect with a Nokia 1830 PSI-xL configured as a FOADM terminal to support multiplexing (TX) and demultiplexing (RX) of wavelengths (i.e., optical channel mux), inline amplification and (optional) line protection through an optical protection switch.

A pair of Nokia service routers (SRs) would typically be deployed at the endpoints with element management through classical mode or MDM. The NSP automatically determines the mode to be used when the link is set up.

400ZR+ router interconnect over multi-span fiber links

The capacity–reach performance of 400ZR+ pluggable coherent optics enables 400GE point-to-point transport over multi-span fiber routes, for example, to interconnect metro-regional data centers and peering points. To traverse these longer reaches, multi-span fiber links will require intermediate line systems with inline amplifiers (ILAs) as well as dynamic gain equalizers (DGEs) to compensate for the differential signal propagation losses incurred by wavelengths on the fiber (Figure 6).

Figure 6. 400ZR+ point-to-point links over multi-span fiber



The Nokia 1830 line system can be configured to support the role of FOADM terminals at the router sites as well as the ILA and DGE functions at the intermediate fiber hub locations.

The NSP cross-domain coordinator provisions the 400GE point-to-point transport services and interacts with the optical domain controller to help perform the following functions:

- Physical topology discovery (point-to-point link inventory)
- Configuration of FOADM terminals and ILA/DGE line systems
- Optical channel configuration for 400ZR+ DCOs
- Optical channel power balancing
- Optical equipment alarm collection and propagation to NSP
- Optical channel monitoring and optical time-domain reflectometer (OTDR) measurements where supported

Although 400ZR+ supports additional port and link parameters, the intent-based provisioning and commissioning of 400GE interface ports and optical channels to interconnect source and destination routers is similar to the 400ZR point-to-point interconnect procedure discussed in the previous section. Operators can use the NSP multilayer topology to visualize and verify the relationship between the 400GE IP link topology, the underlying optical channels used and the physical network details.

Once matching point-to-point wavelengths have been configured between the source and destination routers, the NSP can turn up the IP link and commence alarm supervision, performance data collection and service assurance.

400GE aggregation in metro/regional fiber rings

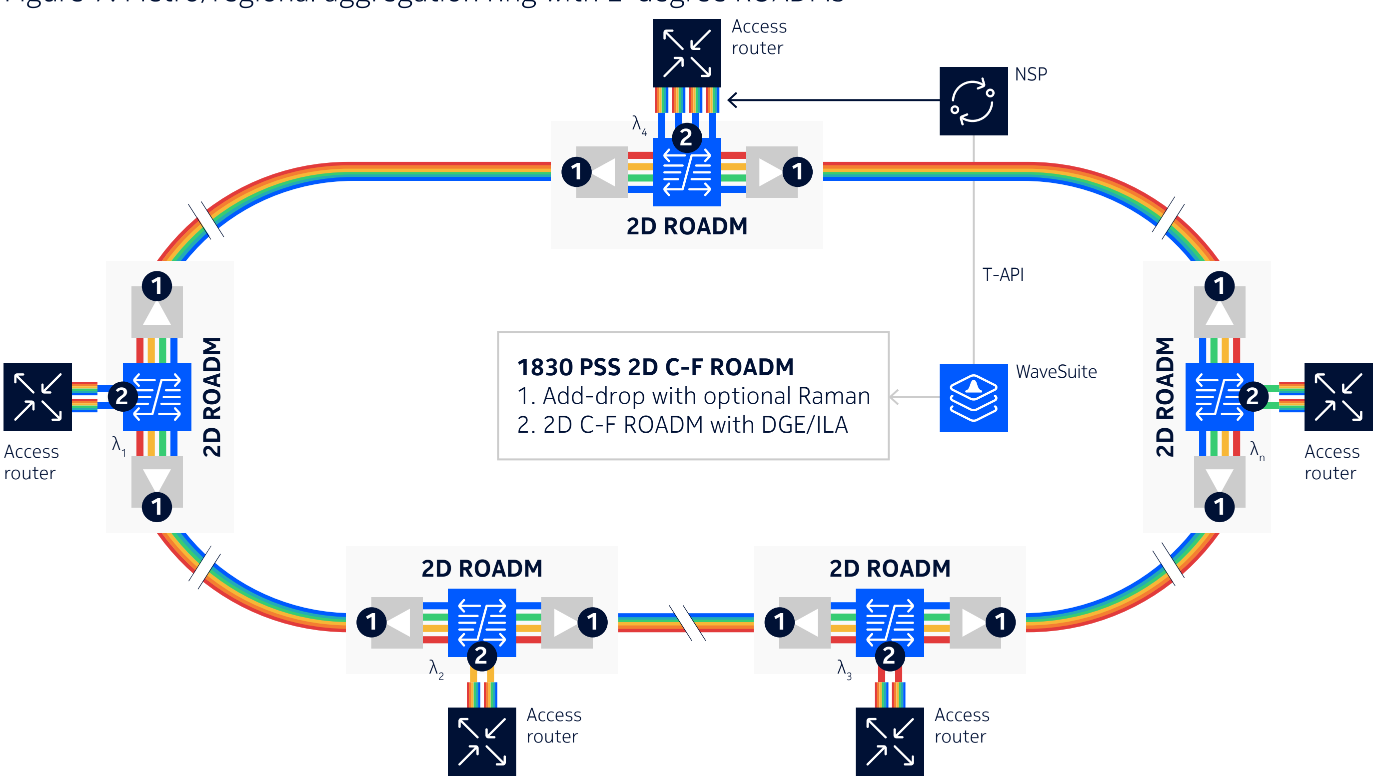
For metro/regional aggregation networks, operators generally deploy interconnected and overlapping fiber rings that aggregate traffic from multiple central offices or edge data center pods. An IP-centric way to look at metro/regional access and aggregation rings is as a distributed leaf-spine fabric with access routers on the ring (the leaves) connecting into a centralized aggregation router at the ring head end (the spine) in a logical hub-and-spoke IP topology. This approach enables efficient, low-latency IP transport because each access router on the ring connects to the centralized hub routers in a single hop.

Present-mode deployments typically leverage an OTN switching layer to interconnect the access routers with the centralized hub routers over protected, point-to-point 100GE circuits. For 400GE-capable routers operators have two options:

1. Use short-reach 400GE gray router optics and performance-optimized DWDM transponders in an optical line system (e.g., Nokia 1830 PSI-M). The high capacity–reach of 400GE optical transponders allows operators to run all point-to-point wavelengths between access routers and hub routers at the full 400 Gb/s line rate, even in large rings with many ROADMs.
2. Equip 400GE router ports with pluggable coherent optics that directly interface with 2-degree colorless-flexgrid (C-F) ROADMs (e.g., Nokia 1830 PSI-xL). 400GE pluggable coherent router optics have a limited capacity-reach, so operators may need to reduce the line rate to increase reach in larger rings with many nodes (if the DCO supports this option), or use optical transponders (i.e., option 1).

Figure 7 shows the application of 400GE pluggable coherent router optics in aggregation rings.

Figure 7. Metro/regional aggregation ring with 2-degree ROADMs



The hub routers connect to access routers on the ring using dedicated single-hop connections over dedicated wavelengths. ROADMs enable reconfigurable add and drop of router connections at both hub and edge nodes, and enable wavelength bypass of end-to-end router connections through intermediate access nodes.

The Nokia ROADMs integrate ILA and DGE functions to compensate for fiber loss across the ring, and enable end-to-end wavelength connections across multiple intermediate nodes and over long spans. They support options for colorless, directionless, contentionless and flexgrid options (C-F, CD-F and CDC-F), and can be implemented in both 1830 PSS and PSI-xL line systems.

The Nokia ROADMs support 2-degree optical add/drop, ideal for access and hub nodes on a ring connected over a single fiber pair. They also support 4 or greater degrees to handle stacked fiber rings with multiple fiber pairs, and for hub nodes that interconnect across multi-ring and mesh topologies.

For this use case, the NSP and the optical domain controller coordinate provisioning of point-to-point wavelengths for the 400GE access uplinks to the hub routers to help support the following operations:

- Optical network topology discovery (ring)
- Configuration of ROADM line systems
- Optical channel configuration and power balancing for 400ZR+ and 400G Multihaul DCOs
- Point-to-point wavelength provisioning (through T-API)
- Optical equipment alarm collection and propagation to NSP
- Optical channel monitoring and OTDR measurements where supported

IP-optical coordination between the NSP and the optical domain controller ensures consistent allocation and assignment of optical channels to matching 400GE interface ports on access and hub routers. Operators can verify the inventory of configured point-to-point wavelengths, associated equipment and interface ports through the NSP cross-domain coordination application.

Once a point-to-point wavelength between 400GE DCOs in the access router and hub router is provisioned across the fiber ring, the NSP can turn up the IP link using the same procedure described for the 400ZR+ and 400G Multihaul point-to-point applications. The NSP can then commence alarm supervision, performance data collection and service assurance.

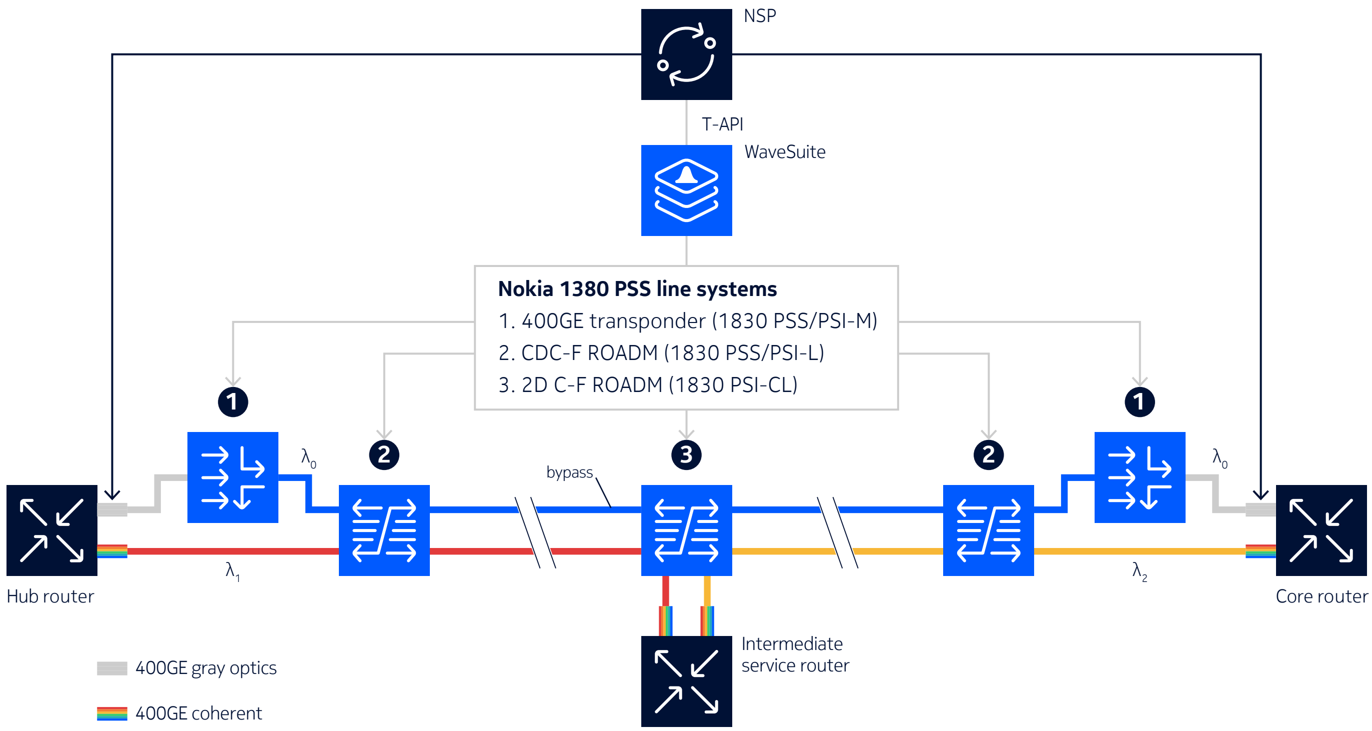
400GE metro/regional core transport with optimized router bypass

Once the hub routers in the metro/regional ring networks have aggregated enough IP traffic to efficiently fill a 400GE port, there are no further packet aggregation gains from subsequent IP aggregation hops. A cost-optimized 400GE IP transport topology can then provide direct, single-hop 400Gb/s IP transit links between source and destination routers that bypass any intermediate router hops. Unnecessary router transits incur an optical–electrical conversion that consumes at least two 400GE ports equipped with DCOs, 400G in IP fabric capacity and at least 100 watts in associated power and cooling.

Most IP traffic in the metro-regional core networks flows to a few large destinations such as edge routers, peering points and data center gateways. This means the optical transport network can be engineered to efficiently support the main IP traffic routes with point-to-point wavelengths over shared or dedicated fiber spans. Source-based routing techniques such as segment routing can then efficiently steer traffic to its destination along the shortest, optimized network itinerary with the smallest number of IP routers (and ROADM hops) required.

Metro/regional core and backbone operators typically deploy N-degree CDC-F ROADMs to enable flexible, efficient and non-blocking wavelength services for IP and OTN transport. However, CDC-F ROADMs incur higher signal propagation losses than the simple 2-degree C-F ROADMs used in metro/regional aggregation rings. Pluggable 400GE DCOs can handle the shorter hops, but 400GE optical transponders will be required to traverse long fiber spans with multiple ROADMs at 400G rates. Figure 8 depicts the mixed use of 400GE gray and coherent router optics for metro/regional IP core transport.

Figure 8. Metro/regional core transport with optimized router bypass



The optical domain controller assists the NSP cross-domain coordinator with the following tasks:

- Optical network inventory and topology discovery
- Configuration of DWDM optical transponders
- Optical channel configuration for 400ZR+ and 400G Multihaul DCOs and DWDM transponders
- Point-to-point wavelength provisioning, including router bypasses (through T-API)
- Optical equipment alarm collection and propagation to NSP
- Optical channel monitoring and OTDR measurements where supported

Nokia network automation use case catalog

The 400GE ecosystem is rapidly evolving, and it goes beyond the scope of this application note to discuss all IP-optical management capabilities and use cases that are supported by the NSP and the Nokia optical management suite. Over time, new 400GE pluggable coherent form factors, configuration options and use cases will expand on the set of applications covered by this edition of the application note.

All supported Nokia NSP use cases are captured in a network automation use case catalog to enable efficient deployments with predictable business outcomes.

Conclusion

The Nokia NSP offers a comprehensive intent-based management application suite that can help network operators coordinate each of the important lifecycle phases of a service instance with that of the network infrastructure on which it is founded.

The introduction of profile-optimized, pluggable coherent router optics for 400GE transport requires new capabilities for orchestrating and automating IP-optical networks. IP-optical management coordination is needed. Nokia has joined forces with a select group of leading network operators to validate the NSP for a set of 400GE IP-optical reference use cases that can act as solution blueprints for real-world deployments.

Visit the NSP web page to learn more about how operators can use the NSP to automate, manage and control IP and optical networks.

Visit the IP-optical coordination web page to discover how Nokia technology helps operators integrate IP routing and optical transport networks into a unified infrastructure.

Abbreviations

API	application programming interface
BER	bit error rate
CDC-F	colorless, directionless, contentionless flexgrid
C-F	colorless-flexgrid
CFP	C form-factor pluggable
DCO	digital coherent optics
DGE	dynamic gain equalizer
DSP	digital signal processor
DWDM	dense wavelength-division multiplexing
EANTC	European Advanced Networking Test Center
FOADM	fixed optical add/drop multiplexer
GE	Gigabit Ethernet
ILA	inline amplifier
IP	Internet Protocol
LLDP	Link Layer Discovery Protocol
MDM	model-driven mediation
MPLS	Multiprotocol Label Switching
NOC	network operations center
NSP	Network Services Platform
ONF	Open Networking Foundation
OSS	operations support system

OTDR	optical time-domain reflectometer
OTN	Optical Transport Network
PSI	Photonic Service Interconnect
PSS	Photonic Service Switch
QAM	quadrature amplitude modulation
QPSK	quadrature phase shift keying
QSFP	Quad Small Form-Factor Pluggable
ROADM	reconfigurable optical add/drop multiplexer
SDN	software-defined networking
SR OS	Service Router Operating System
T-API	Transport API
TLV	type–length–value

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