Coherent routing for 400GE and beyond

Building application-optimized IP-optical networks with digital coherent optics

NOKIA

What is coherent routing?

Coherent routing is breaking down barriers, radically changing economics and redefining the way IP and optical networks are designed, deployed and delivered.

The 400G era promises to unleash a new wave of network innovation. Pluggable coherent transceivers will bring IP and optical together at last, while the latest generation of coherent digital signal processors enables high-performance 400G transmission over any distance.

Nokia is leading the way with an unrivalled portfolio of coherent routing solutions that let you create application-optimized IP-optical transport networks for the 400G era, and beyond. These solutions put our game-changing optical technology in your hands and put your IP and optical networks on the same wavelength.

This ebook offers insights that will enhance your understanding of how advances in pluggable digital coherent optics (DCOs) will support the next generation of IP services at 400 Gigabit Ethernet and beyond. It also explains how you can implement efficient IP-optical solutions for every application that runs on your network – from the metro edge to subsea communications. Read on to find out how you can benefit from coherent routing technology to better meet your evolving network needs.

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IP routing for 400GE and beyond

Is your network ready for the transition to 400 Gigabit Ethernet? A new generation of pluggable coherent optics can help you optimize IP-optical network design.

400GE pluggable coherent optics

Relentless demand for more capacity at a lower cost per bit is forcing network providers to constantly rethink and reoptimize their network designs. Besides delivering more capacity for consumer internet and ultra-high-definition (UHD) video streaming services, they must provide high availability and low latency for the mission-critical and massive machine-type communication services that the cloud and 5G will enable. Rapid advances in silicon are fueling a new generation of compact, pluggable coherent 400G optics that open exciting new avenues for optimizing IP-optical network designs.

Until recently, technology advances in coherent optics have focused on improving transmission performance with increasingly sophisticated DSP algorithms. Enormous progress has been made in this area, with probabilistic constellation shaping (PCS), introduced by Nokia in 2018, taking capacity close to Shannon's limit to enable network operators extract maximum spectral efficiency from their networks. So where to next?

Improving optical transmission performance remains important for long-haul and subsea coherent transport applications, where fiber is expensive and scarce. But a new, complementary innovation focus has emerged, focused on improving the power, space and cost efficiency of coherent optics optimized for access, metro and regional reaches.

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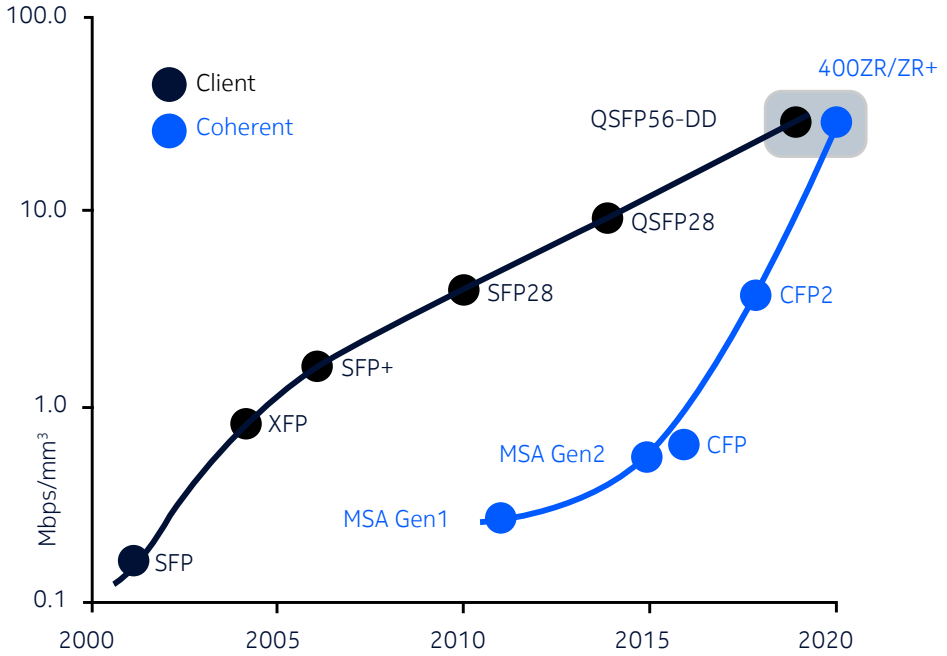
The figure below shows the progress made in developing high-density optics, comparing progress in short-reach client optics for routers with that for pluggable coherent optics. Traditionally, there has been a sizable difference in the port densities of short-reach (gray) router optics and coherent line optics.

Traditionally, there has been a sizable difference in the port densities of short-reach (gray) router optics and coherent line optics. The introduction of 400ZR and 400ZR+ pluggable transceivers closes this gap and removes the I/O density penalty of using coherent optics in the same router ports designed for short-reach client optics.

The compact QSFP56-DD form factor offers tremendous port density but its power dissipation is nominally limited to 14.5 watts. However, coherent WDM transceiver designs are now pushing this up to 20 watts, while the design target for 800GE coherent optics lies in the range of 26-30W per QSFP-DD800 cage. This puts the onus on router engineering practices for efficient airflow and cooling to enable unconstrained use of coherent pluggable optics across a range of features and performance capabilities.

Figure1. Evolution of coherent optics



400GE transceiver options

Network operators need a range of 400G transceiver options to optimally address the different capacity, cost, topology and reach requirements in wide area networks. The table below lists the various options and their key characteristics.

400ZR was one of the first efforts to standardize an interoperable 400G coherent interface specification. Developed by the Optical Internetworking Forum (OIF) and released in March 2020, 400ZR is profile-optimized for high-density point-to-point access and data center interconnect (DCI) applications. It can deliver a single 400 Gb/s channel up to 40 km over a single dark fiber span without external amplification and support up to 64-channel WDM in the C-band over a single span up to 120 km, with external amplification. Although 400ZR can be supported in various pluggable form factors, QSFP-DD is the most prevalent implementation choice.

In contrast, 400ZR+ is a related, non-standardized, extension of 400ZR that targets higher optical performance. It allows for multi-span transport using flexible 100G–400G line rates and longer reaches by leveraging multiple modulation types (16QAM, 8QAM and QPSK) and high-gain forward error correction (open FEC). In 400G mode, 400ZR+ can reach up to 1000 km, and even further using subrates or 0 dBm variants it can traverse multiple fiber spans and reconfigurable add-drop multiplexer (ROADM) nodes.

Technology	400ZR	400ZR+	400G Multihaul	PSE Transponder
Bit rate	400Gb/s only	100 – 400Gb/s	100 – 400Gb/s	100Gb/s – 1.2Tb/s
Reach	40 – 120 km (amp)	400 – 750 km (amp)	500 – 750 km (amp)	>1,000 km (amp)
Modulation	16QAM	QPSK, 8/16QAM	QPSK, 8/16QAM	QPSK, 8 – 64QAM
FEC	CFEC	CFEC+, oFEC	CFEC+, oFEC, NOK FEC	NOK FEC
Tx power	-7 to -10 dBm	-7 to 0 dBm	~0 dBm	>0 dBm
Form factor	QSFP-DD	QSFP-DD	CFP2	pluggable or embedded DCO
Interfaces	100GE, 400GE	100GE, 400GE	100GE/OTU4, 400GE	100GE/OTU4, 400GE, 800GE
ROADM bypass	No	Yes. Multiple (0 dBm)	Yes. Multiple	Yes. Many
Application	Access/Metro DCI	Metro/regional	Metro/regional	Metro/regional Long haul/Subsea

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400G Multihaul DCOs further expand on 400ZR+ capacity-reach performance using the CFP2 pluggable form factor that can be equipped in routers and/or WDM transponder systems. In addition, 400G Multihaul DCOs support 100–400 Gb/s line rates using QPSK, 8QAM and 16QAM modulation. They can also leverage higher launch power of 0 dBm and higher to achieve longer optical reaches up to 750 km and pass multiple ROADM hops.

400G pluggable DCO transceivers are complemented by super-coherent optical transponders, which are performance-optimized to maximize wavelength capacity and reach. These transponders take the form of integrated line cards that reside within WDM optical transport systems. State-of-the-art optical transponders can deliver 400G and 800G services over thousands of kilometers by applying sophisticated DSP techniques and high-gain forward error correction (FEC). Optical transponders are typically deployed in combination with ROADMs for regional and long-haul networks where fiber connectivity is scarce and costly.

Transitioning to 400GE and beyond

Commercially available 400ZR, 400ZR+ and 400G Multihaul products are shipping since mid-2021, and market uptake is facilitated by the large installed base of QSFP-DD and CFP2-capable router ports that can be readily equipped to support 400GE, and by the many potential applications in DCI, metro access and aggregation rings, and metro/regional core networks.

Network operators need flexibility and choice in transceiver types to optimize cost and performance for a given (sub-)network or link because of dependencies relating to fiber availability, quality, reach, link topology and service requirements. IP-optical coordination is critical for seamlessly deploying, operating and assuring these options throughout the network.

Figure 2 depicts the transition to the 400GE era and the IP-optical interworking options that will enable this. The present mode of 100GE operation for most, if not all, operators is depicted on the left. It uses gray client optics in combination with optical transponders. The 100GE era started roughly ten years ago with the transition of IP backbone links to 100GE. It triggered a major upgrade cycle of core routing platforms. Today, 400GE is a ubiquitous interface in most IP backbones, and the transition to 800GE has begun with the first commercial solutions already available from Nokia since 2022.

When IP traffic scales to justify the evolution of router ports to 400GE, plugging a coherent 400G transceiver into a router eliminates the need for an optical muxponder or transponder in the optical transport system. This is the coherent routing scenario that is depicted at the right of Figure 2.

400 Gb/s is ample bandwidth to cost-efficiently fill a single wavelength but in many applications, router connections may need to accommodate prior generations of interface speeds, such as 100GE. Hybrid IP-optical solutions will continue to be used to efficiently meet variable capacity and reach objectives in mixed deployment scenarios that combine 100GE and 400GE interfaces or have link requirements that are beyond the reach of coherent pluggable transceivers.

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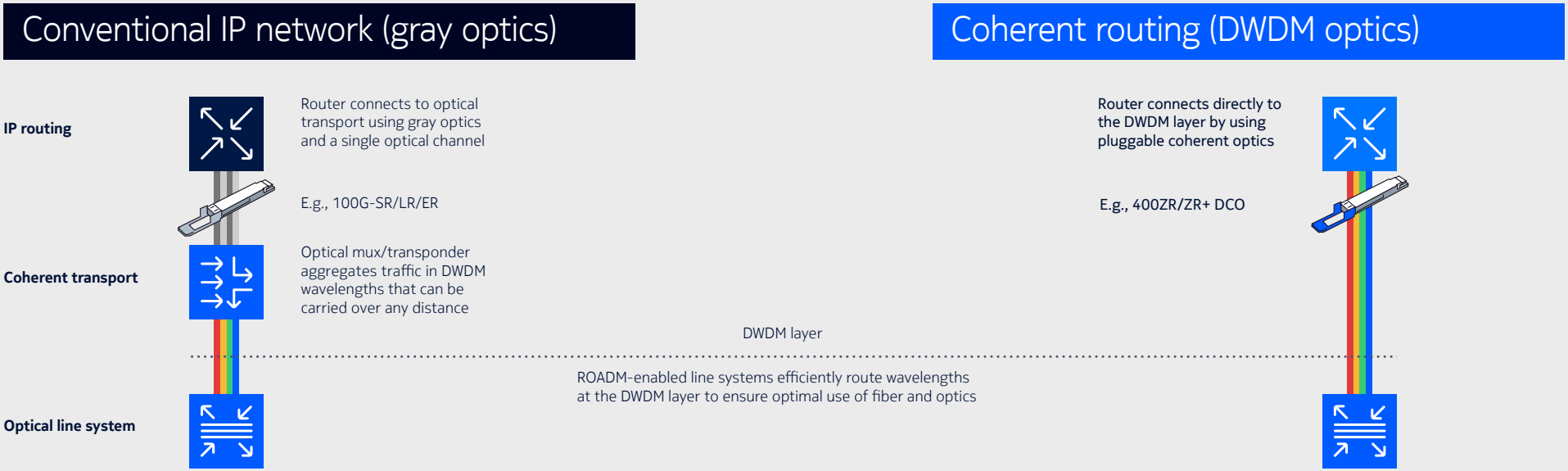
Operators that are evolving their 100GE networks to 400GE are likely to operate in this hybrid mode for an interim period because it leverages their current optical network investments while offering incremental cost savings through the use of pluggable coherent 400GE transceivers. They may also still require present-mode solutions based on transponders on long fiber routes and for traversing larger numbers of ROADM hops in packet aggregation rings.

FIgure2. Coherent routing: IP-optical transport for 400GE and beyond



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Migrating IP-optical networks to 400G and beyond

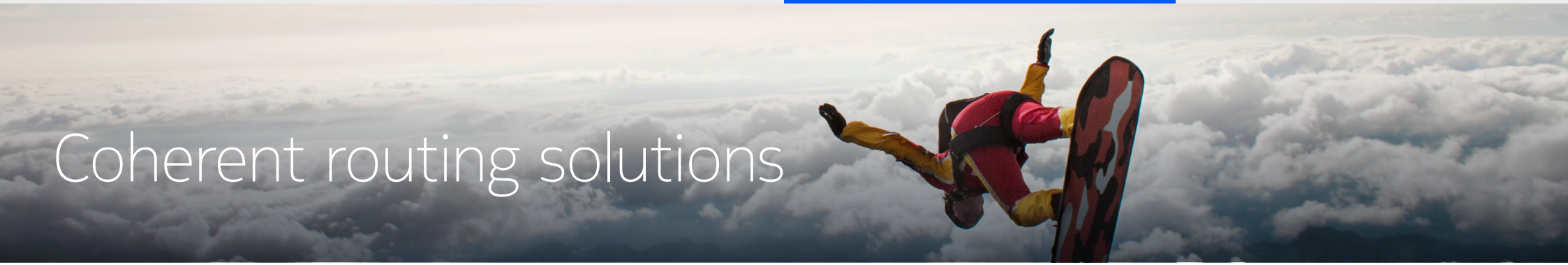
Coherent routing presents an opportunity for network operators to rethink and reoptimize IP-optical networks, and pluggable coherent optical technology will play a key role in many future deployments. The choice of whether to evolve and optimize existing deployments or make a fresh start with next-generation solutions optimized for coherent routing applications will largely depend on the age and longevity of each current network.

The Nokia IP-optical networking portfolio offers the scope, depth and range of 400 and 800GE implementation options that operators need to make these decisions and succeed.

Nokia is a leader in IP routing and optical technology and has achieved several industry firsts, including:

- Launching FP3, the first 400 Gb/s-capable routing silicon, in July 2011
- Demonstrating the first 400 Gb/s IP routing interfaces in February 2015
- Shipping the industry's first commercially available 400GE line cards in July 2018
- Supplying the first commercial deployment of 400GE router interfaces in March 2019
- Shipping the industry's first commercially available 800GE routing platforms in October 2022.

The Nokia optical portfolio support the 400G and 800G ecosystem with new pluggable coherent transceivers and high-performance coherent subsystems designed to meet surging demands from 5G and the cloud. Launched in February 2023, it leverages a new generation of PSE-6 coherent technology and integrated silicon photonics to power and push new benchmarks for transmission performance, cost efficiency and interface density.



Coherent routing solutions

New internetworking standards and pluggable optics technologies are bringing true IP-optical integration within reach. What are the use cases and what ingredients are needed to enable coherent routing at scale for different applications and network topologies?

Use cases and building blocks

New developments in IP and optics are re-igniting discussion about IP-optical integration. Router ports designed to accept 400G pluggable optics can now also be equipped with pluggable WDM coherent transceivers. These transceivers extend high-speed connections to much longer distances across the WAN and allow network operators to forgo the use of transponders implemented in a separate WDM transport system.

All of this leads to two key questions. What are the use cases for coherent IP-optical internetworking? And what IP and optical elements are required to enable a complete solution that is more than the sum of its parts?

There are as many network types as there are network operators, but we can narrow these down to a few typical cases that vary based on the increasing complexity of their service connections and network scope, as shown in the figure below. The first category covers applications that require simple point-to-point connection of multiple 400GE ports between routers. It includes campus networks, high-bandwidth access links and metro DCI, and may extend to longer distances for regional DCI to enable data center virtualization. In such cases, the requirement for an IP-optical solution mainly calls for simple WDM aggregation of multiple 400G interfaces, and optical amplification whenever the link distance exceeds a few tens of kilometers.

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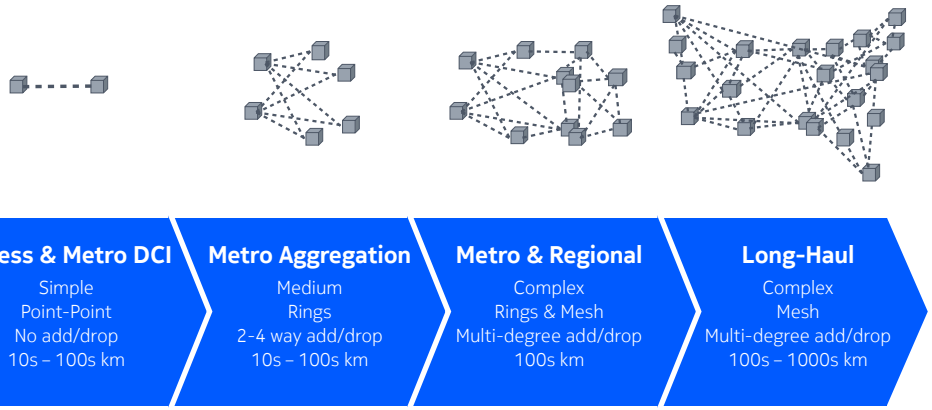
Coherent routing must accommodate a wide range of network types



Besides linear, point-to-point applications, coherent IP-optical solutions must accommodate a wide range of more complex network use cases. These include:

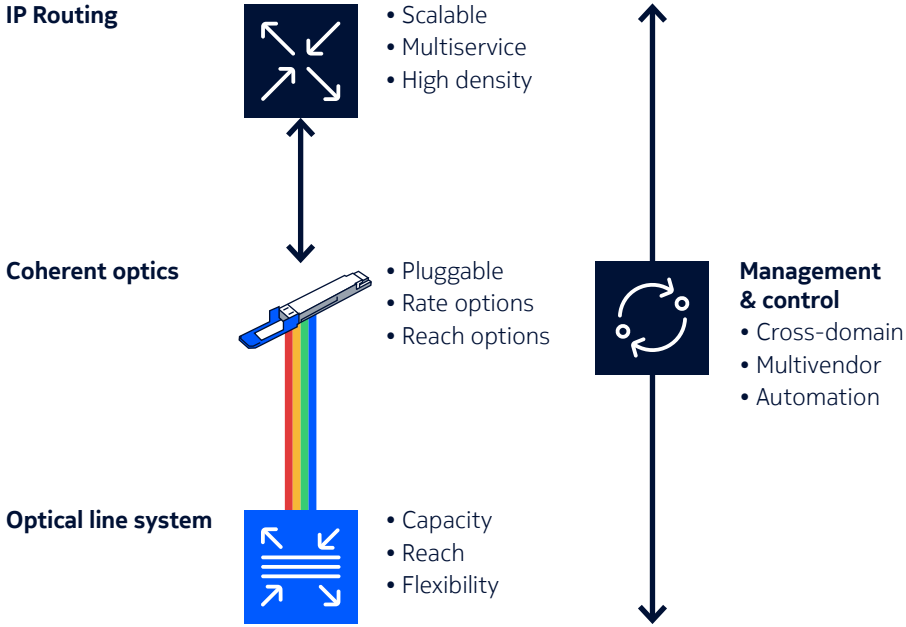
- Metro and regional aggregation rings that collect hub and spoke traffic from access nodes and central offices to one or more service hubs
- Metro core networks with any-to-any traffic connections between central offices (COs), internet exchanges (IXs) and co-location sites
- Regional and long-haul core backbones that interconnect cities and regions, along with widely disparate DCs and internet peering sites

Coherent routing network solutions should offer a range of connectivity and distance options and must cost-effectively transport IP traffic over any fiber topology with minimal optical-electrical-optical (OEO) interface transitions between IP routing and optical transport layers.

To meet these requirements, network operators need to consider four key IP-optical building blocks necessary for providing optimal and versatile solutions across the full range of coherent routing applications:

1. Pluggable coherent WDM optics in different form factors to meet cost and connectivity objectives
2. IP routers designed to support these pluggable coherent optics
3. Optical line systems that efficiently connect routers and multiplex wavelengths on fiber links
4. Cross-domain IP-optical management and control software that supports seamless, end-to-end operation

A complete set of optimized IP-optical solutions



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Router-pluggable coherent optics

Pluggable DCO transceivers can be equipped directly in router ports to provide the scalable WDM capacity required to link high-capacity routers. These transceivers support a range of options:

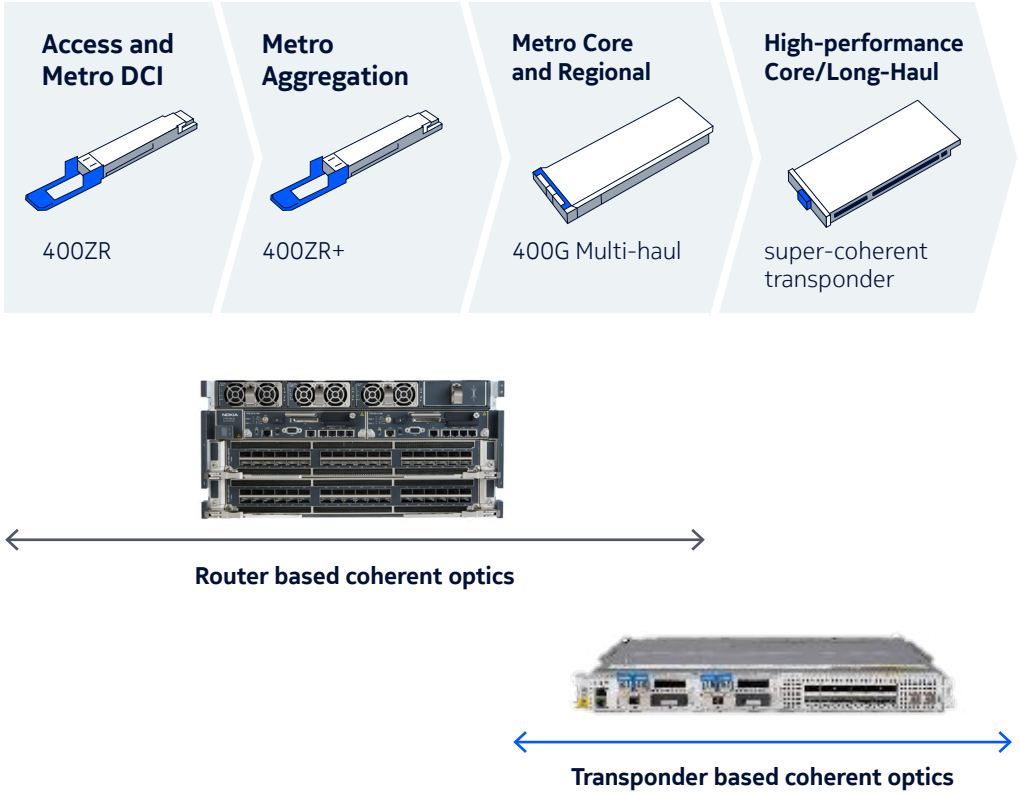
- **400ZR** is designed for short-reach links up to 120 km.
- **400ZR+** adds multi-rate capability and extends reach.
- **400G Multihaul transceivers** further expand capacity–reach capability, add service provider-oriented features and support pass-through traffic for multiple nodes using ROADMs.

The availability of pluggable coherent optics with multiple rate and reach options extends the application space of coherent routing applications into metro and regional networks and across longer distances.

Extended reach options also allow the inclusion of ROADMs for optimized router bypass through point-point wavelengths, allowing end-to-end traffic demands to avoid unnecessary router transits.

By providing the ability to mix and match coherent interface options with different form factors, Nokia coherent routing enables operators to optimally deploy 400GE connectivity across all network applications and topologies.

A complete range of 400G coherent optics in routers and transponders



Optimized routers for coherent interworking

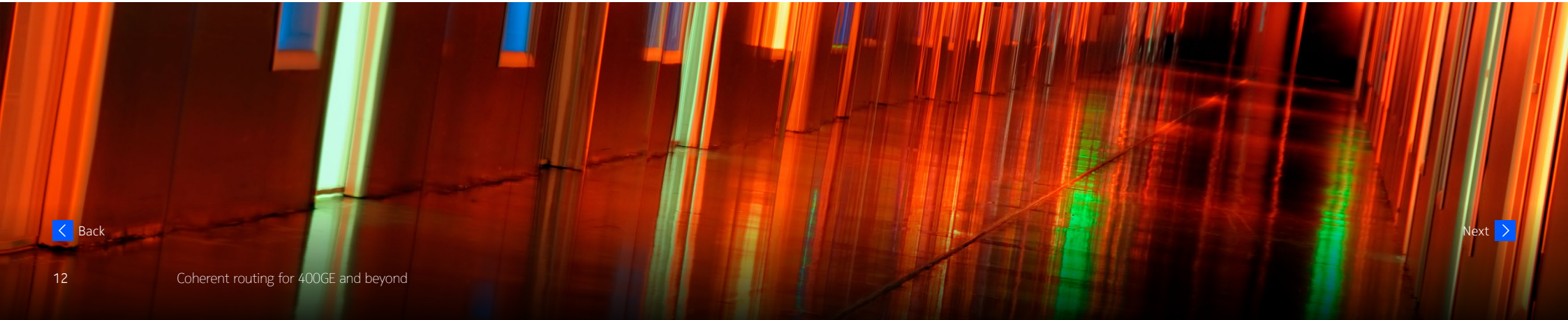
Routing platforms are judged across a wide range of attributes unrelated to optics. However, the ability of routers to successfully integrate pluggable coherent transceivers is a critical part of any successful IP-optical solution. Nokia's market-leading service routers, based on the FP family of scalable, programmable packet processors, are notable for having enabled the first commercial deployment of 400GE interfaces, with QSFP-DD 800GE shipping in 2022. Nokia service routers have been engineered with IP-optical integration in mind. Their design addresses two important requirements for successfully deploying pluggable coherent optics at scale: thermal management and interface diversity.

Power consumption and heat dissipation are higher for pluggable coherent optics than for short-reach client optics. Power and cooling of line card cages can become an issue for routers designed to maximize switching capacity and interface density. The thermal design of IP line cards is thus a critical element for coherent IP-optical integration. It determines a router's ability to efficiently cool all interface ports, including pluggable coherent optics.

Nokia's router design practices prioritize efficient thermal management with features such as dual-sided line card printed circuit boards (PCBs) a large dedicated heatsink for each cage to improve cooling, and air guides to ensure even and unobstructed airflow. This combination of features means that Nokia routers can accept the complete range of pluggable 400G DCO transceivers without limitations such as dedicated slots, equipping rules or leaving some ports empty.

Routers need to support the full range of 400G pluggable form factors to enable IP-optical solutions across all network use cases. While 400ZR and 400ZR+ in QSFP-DD formats can be equipped in the same router ports as short-reach client optics, their capacity–reach performance limits their use to short- or medium-reach point-to-point links for access and metro DCI applications.

Nokia routers also support interface cards with CFP2 ports. This enables operators to use pluggable 400G Multihaul optics to provide superior capacity–reach performance for metro and regional applications, and to transit multi-node links with ROADMs at intermediate sites.



Application-optimized optical line systems

The next consideration is how to best interconnect routers with pluggable coherent optics over a fiber network. Efficiently connecting routers over fiber is the task of the optical line system, which implements a collection of important functions, including:

- Multiplexing/de-multiplexing multiple WDM channels onto a fiber
- Optical amplification at endpoints and intermediate sites to boost optical power levels for greater reach
- ROADMs that can route and switch coherent wavelengths (IPoDWDM links) as needed to optically bypass intermediate router nodes and avoid the unnecessary consumption of router capacity for transit traffic

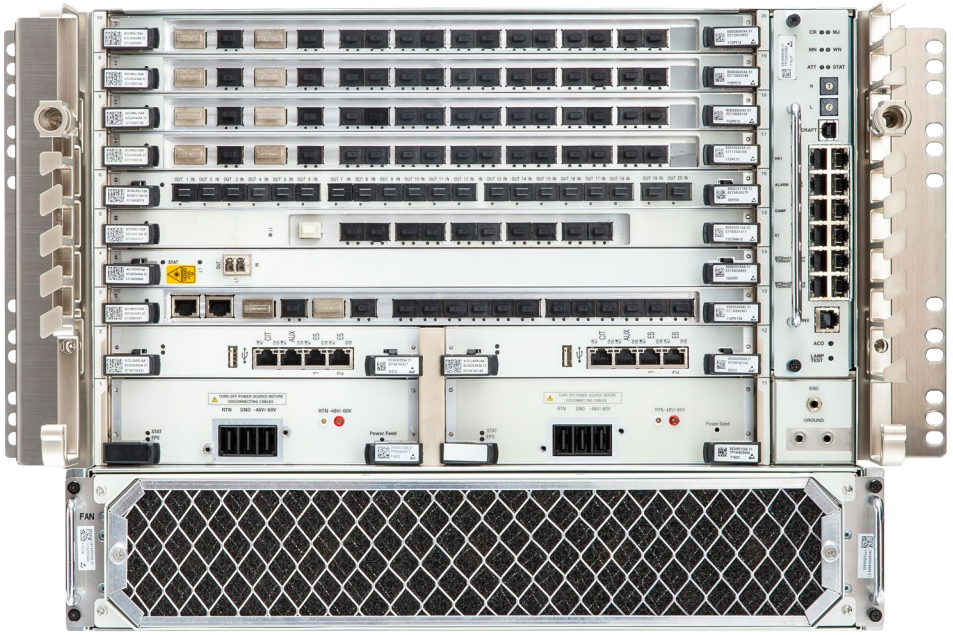
The QSFP-DD-LS pluggable line system is the simplest and most compact solution. It plugs into a 400G QSFP-DD connector and contains an 8-channel optical mux/demux with integrated Tx/Rx line amplifiers. While consuming only 3 Watts, it can interconnect up to eight 400ZR DCOs via a single fiber pair over distances of up to 120 Km.

The Nokia 1830 PSS family provides a full range of line system options to enable optimal configurations for 400ZR+ multi-span, multi-point and mesh applications. For more complex networks, operators can add features such as ROADMs to enable optical bypass in metro aggregation rings, or for multi-degree nodes with a large number of ingress/egress directions. The 1830 PSS also enables operators to optically bypass intermediate router nodes where and when needed.

This makes it easier to engineer and optimize IP-optical links to efficiently accommodate network growth, changing demand patterns, and planned or unplanned network outages.

The key to bringing routers, pluggable coherent optics and line systems together to create a deployable IP-optical solution is to integrate them into a unified end-to-end network management, control and automation platform.

Nokia 1830 Photonic Service Switch (PSS).



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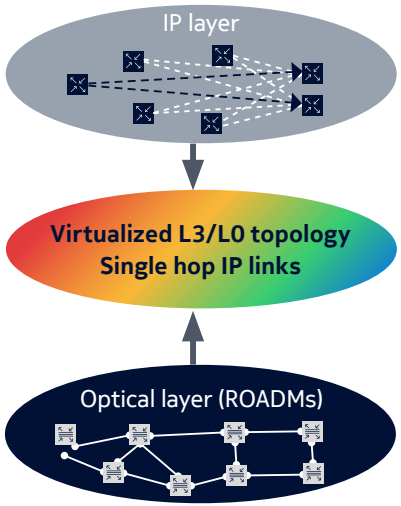
Factoring in fiber topology

In an ideal world,routers with coherent optics would be directly interconnected over dedicated point-to-point fiber links. In real-world networks, however, the shortest path between two points is often neither straight nor short. Fiber in metro-regional access and aggregation networks is typically laid as interconnected and overlapping rings that can span tens to hundreds of kilometers, and interconnect multiple central offices and internet exchange locations. Additional fiber for dedicated router-to-router express paths may also not be available everywhere it is needed. Trenching fiber is costly and time consuming, and may not always provide a direct connection between any two points.

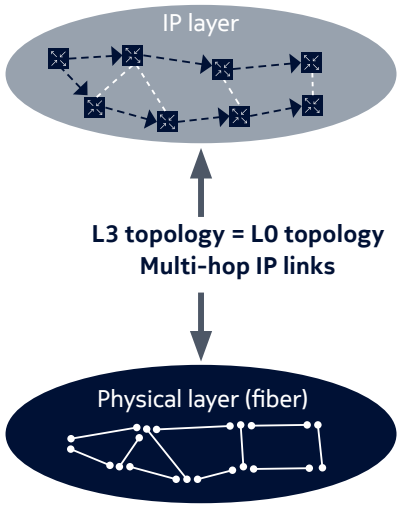
This is where the “optical” in IP-optical integration comes in.Using a combination of wavelength-division multiplexing (WDM) for fiber gain and optical line systems enabled with ROADMs allows network operators to create virtual fiber paths between any two points over complex fiber topologies. These virtual paths allow IP routers to share a common fiber network, such as a ring or interconnected fiber mesh, while simultaneously enabling single-hop leaf-spine IP topologies over dedicated wavelength connections. ROADMs can selectively add or drop wavelengths at any intermediate node, to connect a local router port when needed, or pass them to a remote router through the optical layer. In essence, ROADMs virtualize the physical network by introducing a logical transport underlay of point-to-point single-hop router connections that can then be dynamically provisioned and optimized to match the IP traffic topology.

In contrast, when only connecting routers over point-to-point fiber and line systems as shown at the right, the layer 3 and layer 0 topologies converge and can no longer be optimized independently.

Optimizing IP transport efficiency by leveraging wavelength routing



Coherent routing over ROADMs



Hop-by-hop IP routing

Without ROADMs, IP transit traffic can no longer bypass intermediate routers, so the cost efficiency of this IP transport model depends on the number of router hops that IP traffic must traverse to reach the final destination. This is a non-issue for simple single-hop, point-to-point applications such as data center interconnect. But for network applications such as access and metro aggregation rings and metro-regional core networks, it can result in inefficient and inflexible IP network topologies because IP transit traffic will be forced to traverse any intermediate router hops along the way to its destination.

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Optimizing coherent IP links over ROADMs

One key variable that impacts the cost of ROADM-enabled optimized single-hop IP architectures is the reach of the WDMoptics used to interconnect routers. Router-pluggable 400G DCOs such as 400ZR+ and 400G Multihaul enable cost, power and space savings compared to the use of off-board DWDM transponders. They also eliminate the need for gray router optics to connect with the transponder. However, the capacity–reach and number of ROADM pass-throughs supported by router-pluggable DCOs can be limited. Operators must assess the use case for each type of optic against the distance and topology attributes of the desired end-to-end IP connection.

With respect to capacity–reach performance, 400ZR+ DCO is analogous to a short-haul airplane with the capacity to fly up to 500 km with 400 passengers or longer distances with fewer passengers. 400G Multihaul extends the analogy by providing planes with longer ranges over 400ZR+ and through a greater number of cascaded ROADMs. DWDM transponders are cost-optimized to carry even greater payloads over long-haul fiber spans and through even more ROADMs.

Network links have different rate and reach requirements. To optimize link costs, network operators need a range of optics with capacity–reach specifications suited to different applications and use cases. Each type of coherent optic has its own cap acity–reach sweet spot. Operators should target the use of optics such as 400ZR+, 400G Multihaul and 400G long-reach transponders for the network applications where they can provide the most cost-optimal IP transport solution.

Optimizing capacity, reach and link cost

Application Examples	Trail length	Number ROADMs	400ZR	400ZR+ 0 dBm	400G Multihaul	Transponder
Point-Point Access/DCI	0 - 120 km	0			Lower I/O Density	Lower Density & Higher Cost
Metro Aggregation	0 - 200 km	1 - 3	Limited Reach No ROADMs		Lower I/O Density	Lower Density & Higher Cost
Metro Core	150 - 400 km	2 - 5	Limited Reach No ROADMs			Lower Density
Regional	400-1000 km	5 - 10	Limited Reach No ROADMs			
Long haul	> 1000 km	> 10	Limited Reach No ROADMs	Limited reach operates < 400G	Limited reach operates < 400G	

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IP-optical coordination and automation

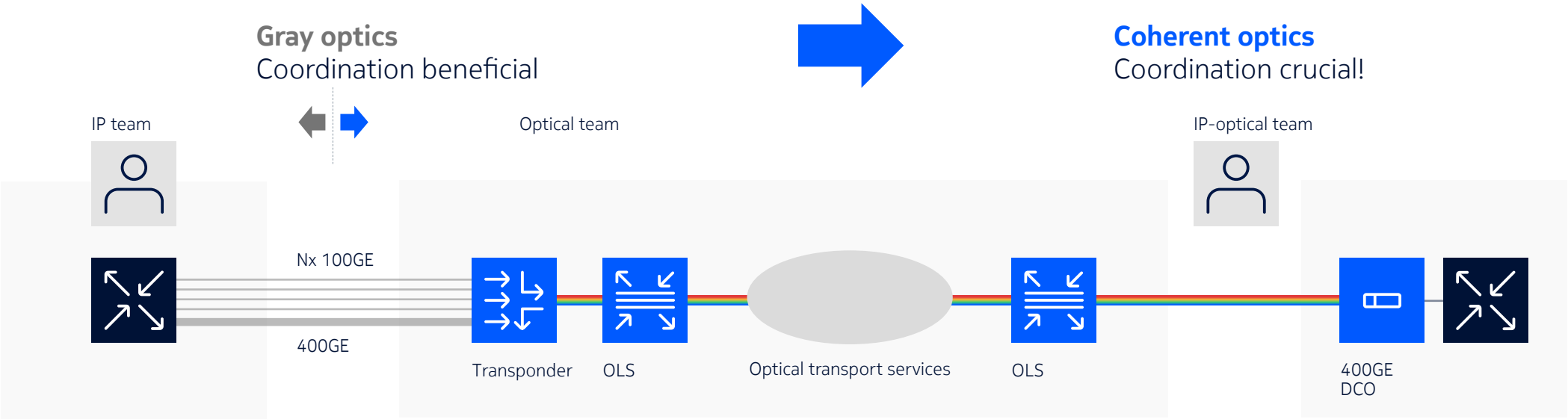
The introduction of small-form-factor coherent optics into the router removes the rigid demarcation between the IP routing and optical transport layers. This makes cross-domain coordination of operations a necessity.

The need for an automated operational approach that transcends and encompasses the IP and photonic layers existed even before the emergence of pluggable coherent optics. Network operators need coordinated operational activities in each of the important lifecycle phases of a service instance and that of the network infrastructure on which it is founded.

One way to dramatically streamline the management of services is to use an intent-based approach that frees the operator from having to micro-manage the network.

Intent-based operations abstract the intricacies of network configurations by giving network operators the ability to express configuration goals and guidelines in simple terms, using a minimal set of high-level parameters. These configuration intents are then automatically applied to the network using appropriate workflows with policy enforcement.

Automating coherent routing applications



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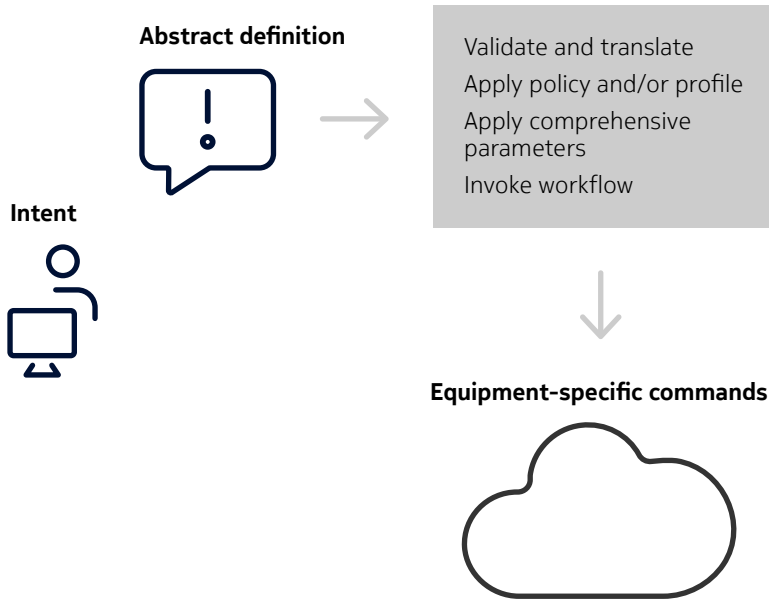


Intent-based automation

An intent-based approach can greatly simplify the commissioning of new 400ZR and ZR+ optics by validating and translating high-level commands and by triggering automated workflows to establish the desired network state.

For example, this approach can be used to:

- Discover and identify the pluggable optics device
- Configure coherent optical interface parameters such as power levels, modulation and wavelength for each type of device
- Monitor key performance indicators such as the pre-forward error correction (FEC) bit error rate (BER)
- Coordinate mutually applicable IP and optical parameters such as channel selection, wavelength routes, physical diversity and restoration options

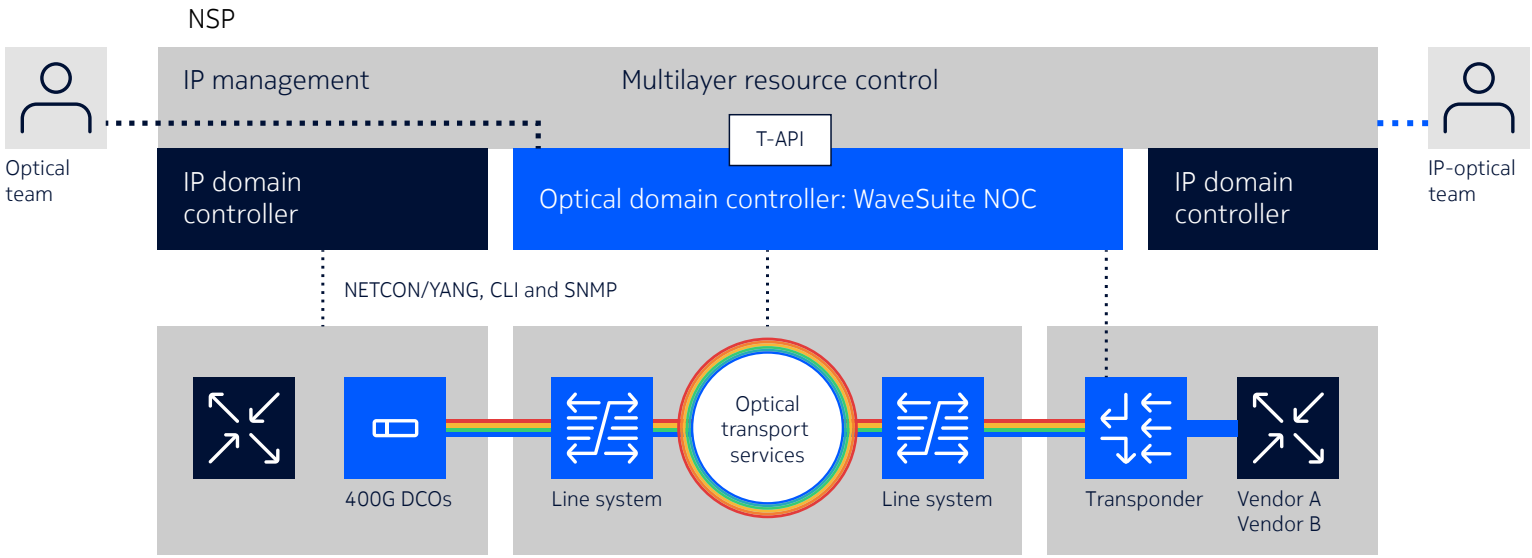
Supporting the operational team effort

The main reason for creating these cross-domain tools and use cases is to help operational teams with different roles and responsibilities work more effectively, gain more flexibility and collaborate more easily.

Teams within the operations group may be horizontally or vertically oriented. For example, some teams and individuals could focus on a specific network domain while others, with the right tools and credentials, may navigate to adjacent domains to coordinate tasks across multiple domains. And one team could oversee the installation and commissioning of IP routers, while another team or individual could supervise configuration of pluggable coherent router optics and coordinate provisioning of the required 400G wavelength within the DWDM transport layer.

A multilayer automation platform greatly improves operational efficiency and flexibility and becomes a valuable asset for sustaining quality as operational dynamics and dependencies evolve. The Nokia NSP meets these automation needs by combining network resource control, service enablement, analytics, assurance and workflow orchestration into a comprehensive tool suite that is built on open, multivendor APIs.

Managing coherent routing applications with the NSP



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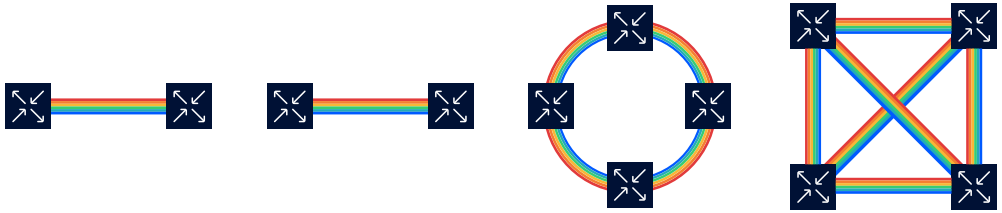
Cross-domain use cases and blueprint solutions

Pluggable coherent router optics are a powerful, new technology that requires new capabilities for orchestrating and automating IP-optical networks. Nokia has joined forces with a select group of leading network operators to validate the NSP for a representative set of IP-optical reference use cases that can act as solution blueprints for real-world deployments. This work will be included in our extensive catalog of cross-domain network automation use cases, and will provide a set of proven technology recipes and roadmaps that lead to targeted business outcomes.



Point-point 400ZR

- Link up/down
- Power ramp
- Channel plan

Point-point 400ZR+

- Link up/down
- Power ramp
- Channel plan
- Modulation
- Active power management

With 2D ROADMs

- Link up/down
- Power ramp
- Channel plan
- Modulation
- Active power management
- Dynamic gain equalization
- Optical add/drop

Mesh ROADMs

- Link up/down
- Power ramp
- Channel plan
- Modulation
- Active power management
- Dynamic gain equalization
- Optical add/drop
- Path compute
- DCOs + TXPs

More to explore

Application note:
400GE IP-optical coordination

Solution page:
Nokia IP-optical coordination

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An IP and optical technology leader

Pluggable coherent technology is a game changer for optimizing IP-optical network designs. These compact and modular coherent transceivers offer a low-cost, high-density alternative to conventional solutions using gray router optics with integrated WDM transponders in optical line systems.

Our IP routing and optical systems portfolio offers the scope, depth, platforms and tools you need to capitalize on pluggable DCOs for a wide range of network topologies and applications. The innovative power and cooling designs of our QSFP56-DD and CFP2 line cards make it easy to equip 400GE coherent pluggable transceivers in existing Nokia routers and line cards.

We also lead the way in coherent optical components and line systems. The combination of our state-of-the-art silicon photonics and sixth-generation PSE-6 digital signal processor will take transmission performance, cost-efficiency and interface density to meet surging demands from 5G and the cloud.

For more on this visit our webpage:
nokia.com/networks/solutions/coherent-routing/

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About Nokia

At Nokia, we create technology that helps the world act together.

As a B2B technology innovation leader, we are pioneering networks that sense, think and act by leveraging our work across mobile, fixed and cloud networks. In addition, we create value with intellectual property and long-term research, led by the award-winning Nokia Bell Labs.

Service providers, enterprises and partners worldwide trust Nokia to deliver secure, reliable and sustainable networks today – and work with us to create the digital services and applications of the future.