IP/optical interworking for 5G

Building an SDN programmable network fabric for the digital era of 5G and the cloud

White paper

The digital era of 5G and the cloud triggers a new cycle of network investments and presents key opportunity for operators to reflect and reassess the present network and determine what improvements or changes are needed for the future.

The evolution and interworking of IP routing and optical transport is a critical success factor for many operators because it greatly determines the quality, reliability and cost-efficiency of their network and the services it delivers.

This white paper discusses Nokia's approach for building smart and software defined network (SDN) fabrics that seamlessly blend IP and optical transport technologies to cost-efficiently meet the service delivery objectives for the digital era.

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Entering the digital era of 5G and the cloud

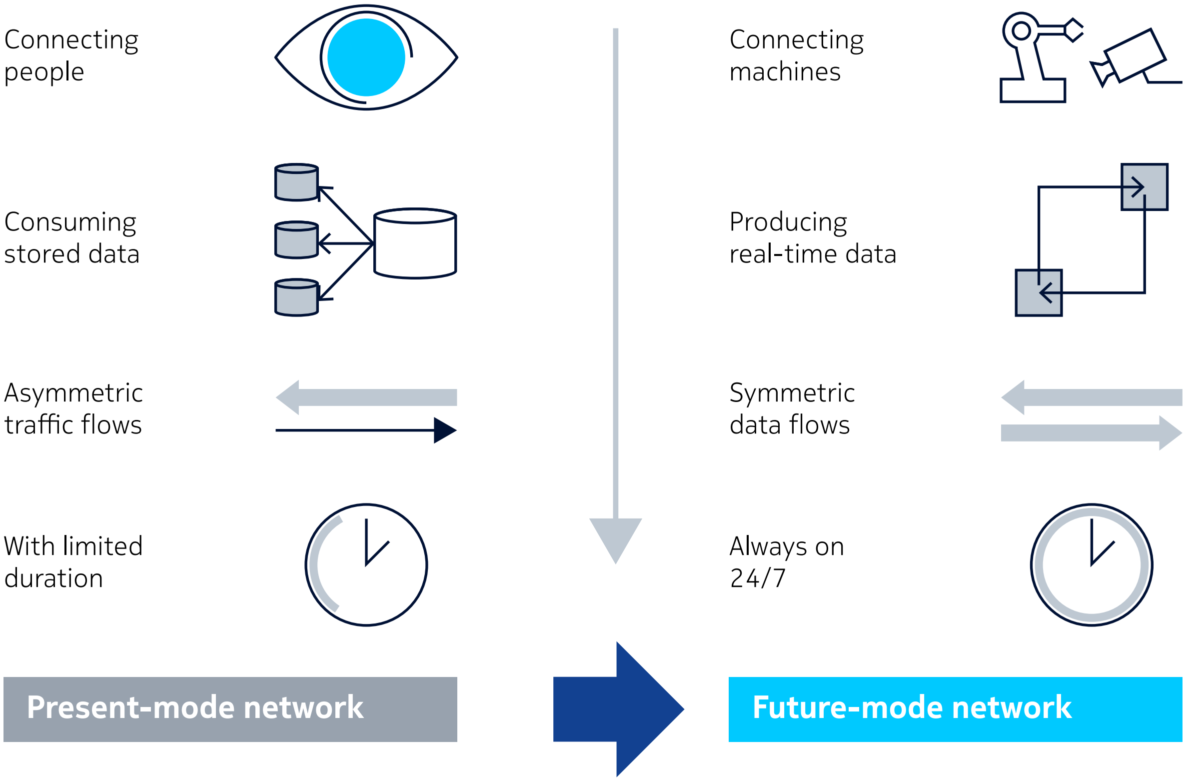
The digital era of 5G and the cloud triggers a new cycle of network investments that is needed to address the projected growth of existing markets and applications, such as consumer broadband, and emerging market opportunities from digital enterprises, Industry 4.0 and smart cities.

This next cycle of network investments will determine business outcomes for the next 5 to 10 years and presents a key opportunity to reflect and reassess the present network, its architecture and cost attributes to determine what changes are needed for the future mode of operation.

The IP/optical transport infrastructure plays a critical role in future networks because it carries all service traffic and greatly determines the quality, reliability and efficiency of the user experience. Interworking of IP routing and optical transport is essential to efficiently use their complementary roles and resources, and IP/optical integration is a prerequisite to maximize these cost synergies.

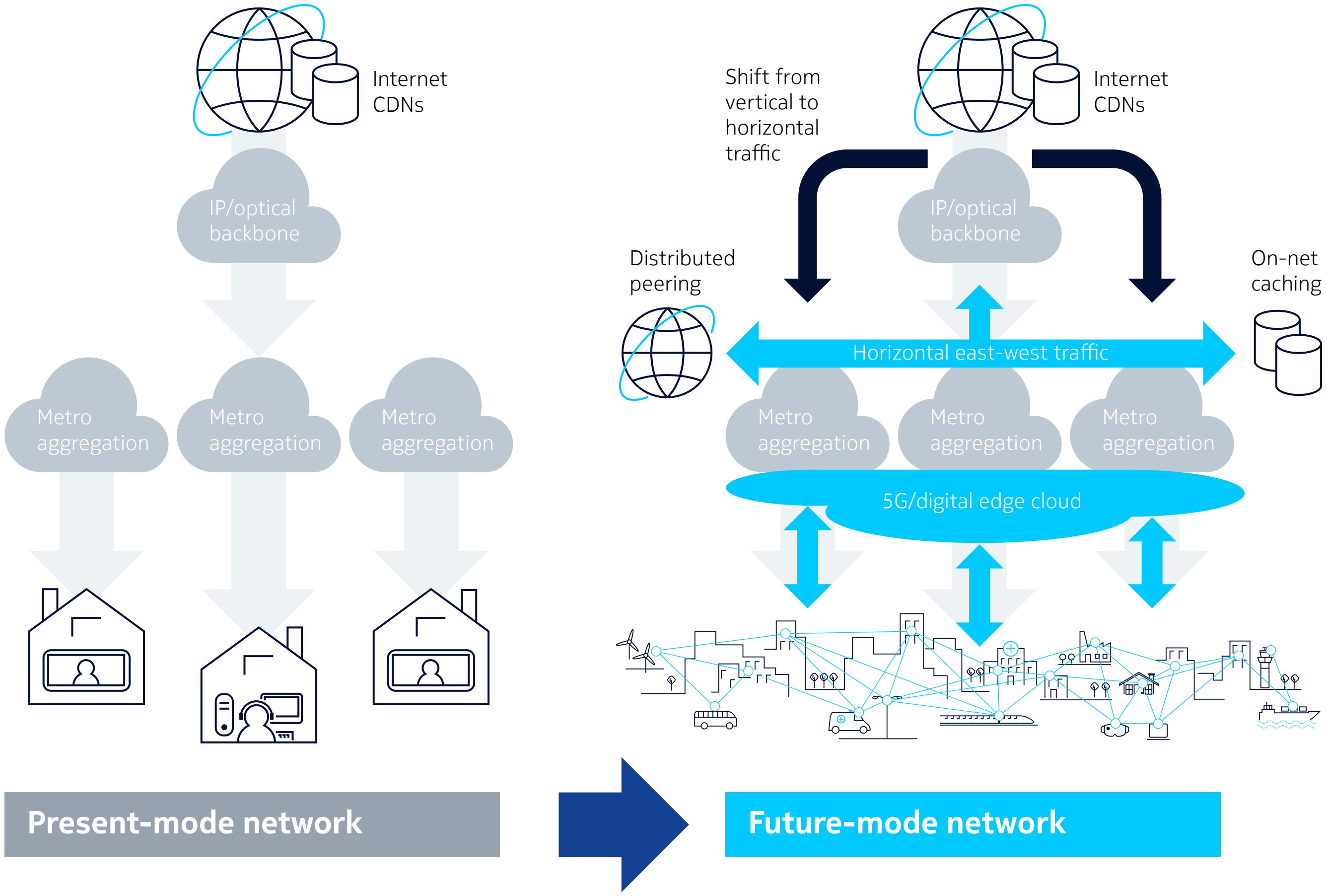
Looking ahead, capacity growth will be heavily driven by 5G mobile broadband applications for both business and consumers while future connectivity growth will be driven by 5G cell densification, the Internet of Things, and massive machine-type and mission-critical communication services that require ultra-reliable low latency transport. However, humans and machines have very different connectivity requirements and consumer behaviors (see Figure 1).

Figure 1. Evolving network characteristics and divergent traffic patterns



Future traffic patterns will diverge because connected machines are typically data producers that generate more symmetric any-to-any traffic on a 24/7 basis while people typically consume stored cloud content and generate highly asymmetric downstream traffic during prime-time peak hours. These changes will impact the present-mode networks that are designed and optimized for best-effort consumer broadband service aggregation such as internet video and social media, but are inefficient and not designed for delivering future-mode 5G and cloud connectivity services with stringent, deterministic latency guarantees and multiple failure recovery options (see Figure 2).

Figure 2. Traffic and network evolution



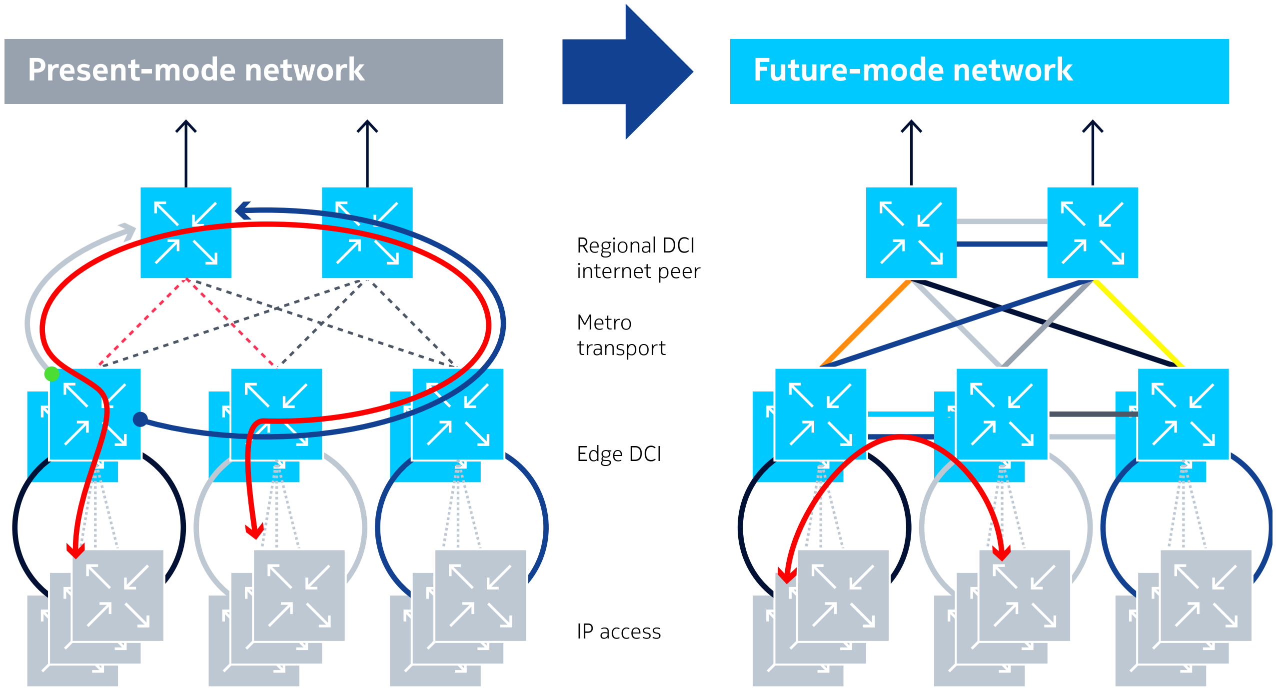
The future-mode network must efficiently scale to support incremental traffic growth of existing services and new growth of emerging applications. Distributed peering and edge caching improve cost and performance of multimedia broadband applications by inserting content closer to users. The emerging digital edge cloud meets the reliability and latency objectives of 5G machine-type applications by distributing compute and storage assets. As a result, traffic is shifting from a predominantly north-south flow in the present mode to more horizontal east-west and upstream flows in the future mode.

The following section discusses the present-mode network challenges to reliably and efficiently deliver the evolving mix of digital services on a common IP/optical infrastructure.

Present-mode network challenges

Considering the service evolution to 5G and the cloud, the first challenge is the emerging east-west traffic. Present-mode networks typically consist of a hierarchy of dual-homed IP aggregation routers that are interconnected by optical transport rings in a hub-and-spoke topology. While the present-mode design topology is optimal for aggregating north-south broadband traffic, it is inefficient for routing horizontal east-west and upstream traffic. Any-to-any traffic between sites in a distributed Industry 4.0 campus or data centers in the digital edge cloud needs to traverse up and down the IP hierarchy and all around the optical backbone ring (see the left side of Figure 3). A future-mode network design based on interconnected mesh topology is capable of efficiently routing all traffic (see right side of Figure 3).

Figure 3. Addressing present-mode network challenges



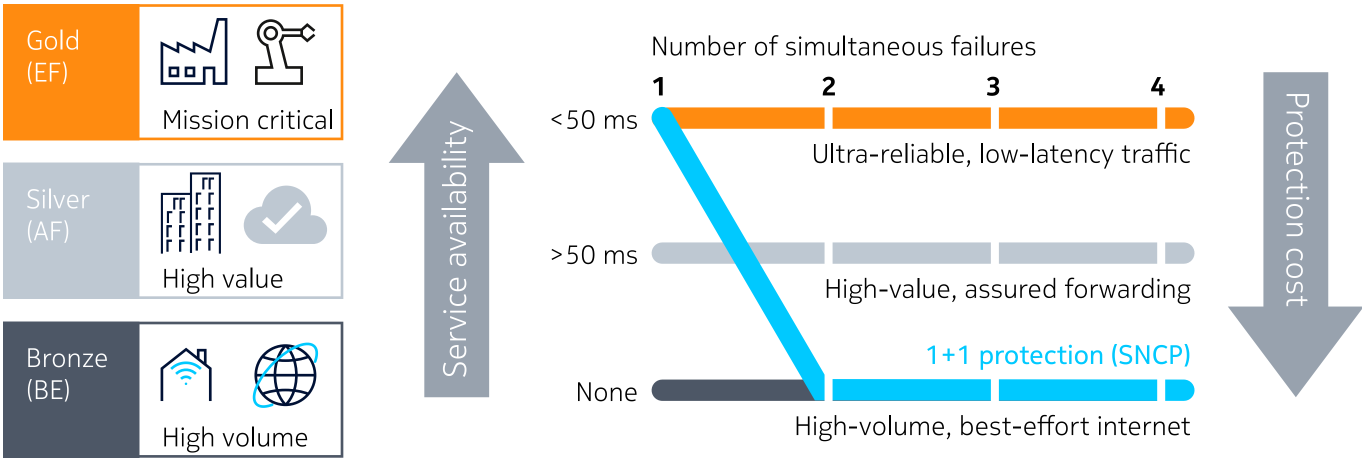
- Unmatched IP & optical topologies
- Inefficient any-to-any traffic routing
- Unable to deliver URLLC services

✓ Congruent IP/optical topology
✓ Optimized routing of all traffic
✓ Ultra-reliable, low-latency delivery

The second challenge is that the traditional 1+1 ring protection schemes found in many present-mode networks are a legacy of the past. These protection mechanisms were designed to protect voice telephony traffic, but they are unsuitable for future-mode optical mesh networks and ineffective for protecting emerging 5G and cloud traffic. The present-mode design is even suboptimal for delivering high-volume internet traffic due to the low resource utilization (1+1 protection implies 50% redundancy) and the large number of Optical-to-Electrical-to-Optical (OEO) transitions that occur.

Also, 1+1 connection protection (SNCP) can only recover from a single failure, after which there is no protection against subsequent failures until (manual) repairs have been made (see Figure 4). While the IP layer offers complementary recovery capabilities such as MPLS fast reroute, these mechanisms are not a cost-effective replacement of optical layer protection facilities as traffic volumes increase.

Figure 4. Differentiating service availability and cost requirements



The future-mode network requires a more differentiated strategy to meet the service-availability and cost requirements of high-volume internet traffic and emerging 5G and cloud applications.

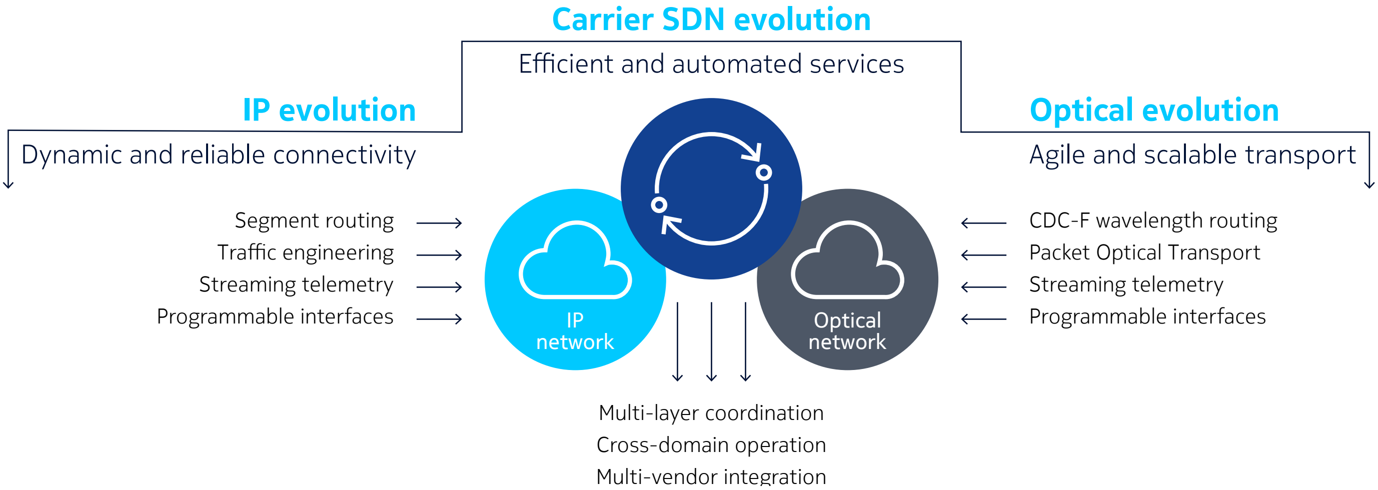
- Mission-critical management and control plane traffic and 5G ultra-reliable low latency communication (URLLC) applications must be protected against multiple simultaneous failures with extremely fast failure recovery to avoid triggering alarms and emergency shutdown procedures of mission-critical equipment. Latency must be low and deterministic, even in failure situations, which is a challenge in present-mode ring networks due to the variable length of working and protection paths.
- High-value enterprise and cloud IT applications such as Microsoft Office 365 typically need assured forwarding with protection against multiple failures but can tolerate fault recovery times in the order of a few hundred milliseconds by retransmitting lost packets.
- High-volume internet traffic should be protected against failures, but 1+1 redundancy is far too costly. Failure recovery within 50 msec is not required because most applications can easily recover from intermittent packet loss. To cost-effectively deliver internet services it is essential to maximize capacity utilization and efficiently load-balance traffic over all available paths. Routing protocols will reconverge when link failure occurs. Hierarchical QoS enables best-effort traffic to burst into unused link capacity reserved for higher priority applications.

The next section discusses the enabling technologies that are available to support the future mode.

Future-mode technology enablers

In recent years, IP routing and optical transport have gone through a significant technology evolution to address the connectivity and capacity needs of the digital era (see Figure 5).

Figure 5. Future-mode technology evolution



IP evolution

Segment routing (SR) enables support for dynamic and reliable IP connectivity with deterministic QoS that has far better scaling properties than RSVP-TE signaling approaches. SR is used for steering service flows along optimal routes, for on-line traffic engineering and for fast failure recovery. Streaming telemetry and model-driven interfaces are essential for multi-vendor integration and automation.

Optical evolution

State-of-the-art optical technology based on CDC-F (colorless, directionless, and contention-less flexible grid) ROADMs (Reconfigurable Optical Add-Drop Multiplexors) enables dynamic wavelength routing and restoration in ring and mesh topologies for cost-efficient and reliable transport of 5G any-to-any traffic. Leveraging a generalized MPLS (GMPLS) control plane, streaming telemetry and model-driven APIs enables the dynamic provisioning, optimization and assurance of optical transport services.

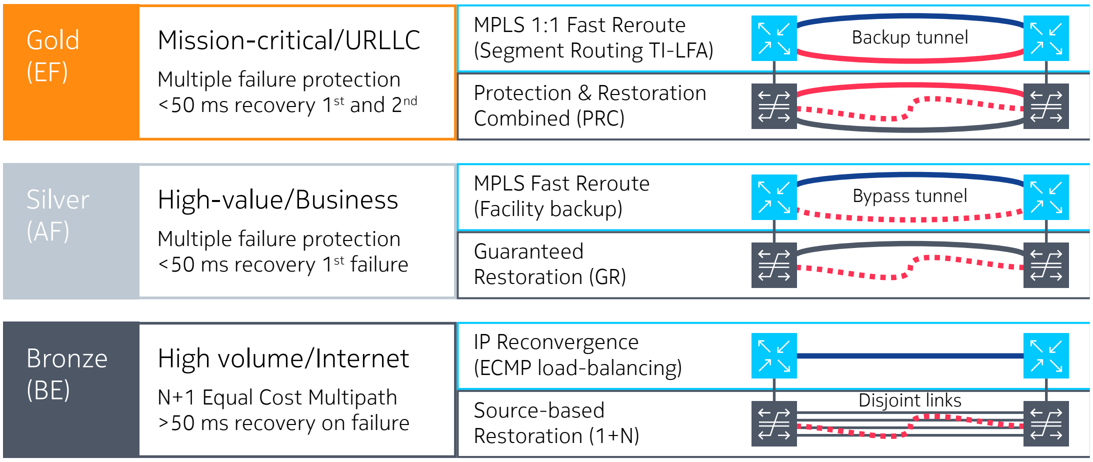
Carrier SDN evolution

Carrier SDN solutions have recently matured to the point where cross-domain operation and multi-layer coordination of IP and optical domains is achievable in multi-vendor environments. The interworking of next-generation IP and optical transport under a common SDN control layer helps to implement a smart and programmable next-generation network fabric with optimal cost synergies.

Architecture evolution

Evolving present-mode ring networks to a future-mode mesh network based on CDC-F ROADMs with a GMPLS control plane realigns the IP-routing and optical-transport topologies for cost-efficient routing of any-to-any IP traffic (i.e., both north-south and east-west traffic). It also addresses the service requirements of emerging 5G and cloud applications on a common network fabric (see Figure 6).

Figure 6. Adopting multi-layer IP/optical protection and restoration for differentiated Classes of Service



Gold (EF)	Mission-critical/URLLC Multiple failure protection <50 ms recovery 1st and 2nd	MPLS 1:1 Fast Reroute (Segment Routing TI-LFA)
		Protection & Restoration Combined (PRC)
Silver (AF)	High-value/Business Multiple failure protection <50 ms recovery 1st failure	MPLS Fast Reroute (Facility backup)
		Guaranteed Restoration (GR)
Bronze (BE)	High volume/Internet N+1 Equal Cost Multipath >50 ms recovery on failure	IP Reconvergence (ECMP load-balancing)
		Source-based Restoration (1+N)

The future-mode network combines complementary IP and optical-layer mechanisms to implement a multi-layer protection and restoration strategy that optimizes cost and performance (see Figure 5).

- Mission-critical and URLLC applications are protected against multiple failures with fast recovery by combining MPLS 1:1 fast reroute with GMPLS PRC at the optical layer.
- High-value business traffic with less stringent reliability and latency requirements is protected at the MPLS layer by fast reroute and at the optical layer by GMPLS Guaranteed Restoration.
- High-volume internet traffic with best-effort delivery is load-balanced over unprotected but physically disjoint 1+N redundant optical links. This approach maximizes resource utilization at the IP and optical layers and protects against single failures with minimal cost overhead.

To unlock these multi-layer cost and performance synergies[1] requires a multi-vendor, cross-domain, carrier SDN integration approach. The next section discusses the key use cases and benefits of an SDN-programmable IP/optical network based on the Nokia Network Services Platform (NSP).

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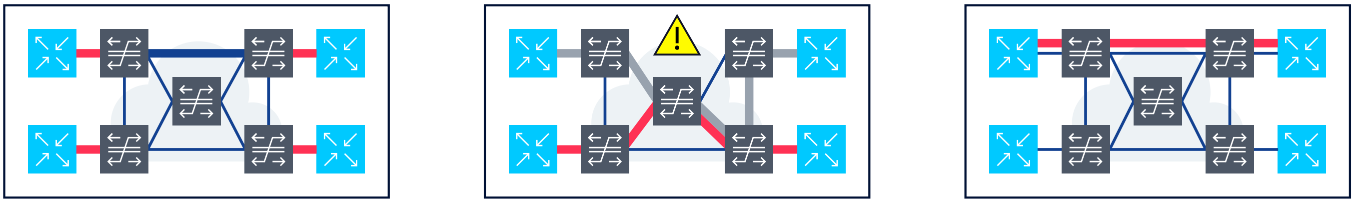
[1] Customer case studies conducted by Nokia Bell Labs indicate cost savings in the order of 25 % to 35%.

SDN programmable IP/optical interworking

Multi-layer carrier SDN allows operating a converged network fabric with visibility and control over both IP and optical domains to overcome the issues of siloed management approaches (see Figure 7).

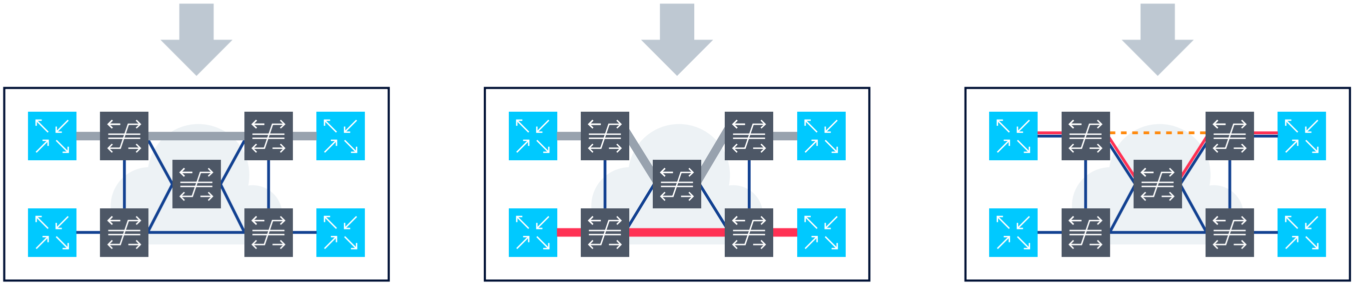
Figure 7. Multi-layer topology discovery, diversity analysis and maintenance coordination



Visibility of multi-layer topology

Verification of physical link diversity

Coordination of maintenance activities



Multi-layer topology discovery

Tracking IP and optical network topologies separately can easily lead to inconsistent information, making it difficult for operators to provision IP router links across the optical transport network. A multi-layer topology view can be created by discovering and correlating multi-layer connectivity through Link Layer Discovery Protocol snooping or by comparing traffic counts on ports.

Link diversity analysis

Link diversity is critical for ensuring that the working and protection paths of IP links are physically disjoint and protected against single failures at the optical transport layer. A multi-layer topology view helps to improve the reliability and cost-efficiency of network services by managing shared risk link groups (SRLGs), detecting single points of failure and automating the routing of physically disjoint backup paths.

Coordinated maintenance, assurance and troubleshooting

Coordinating maintenance activities between the IP routing layer and optical transport layer helps to avoid unplanned outages by automatically rerouting IP traffic away from transport resources that are flagged to undergo maintenance.

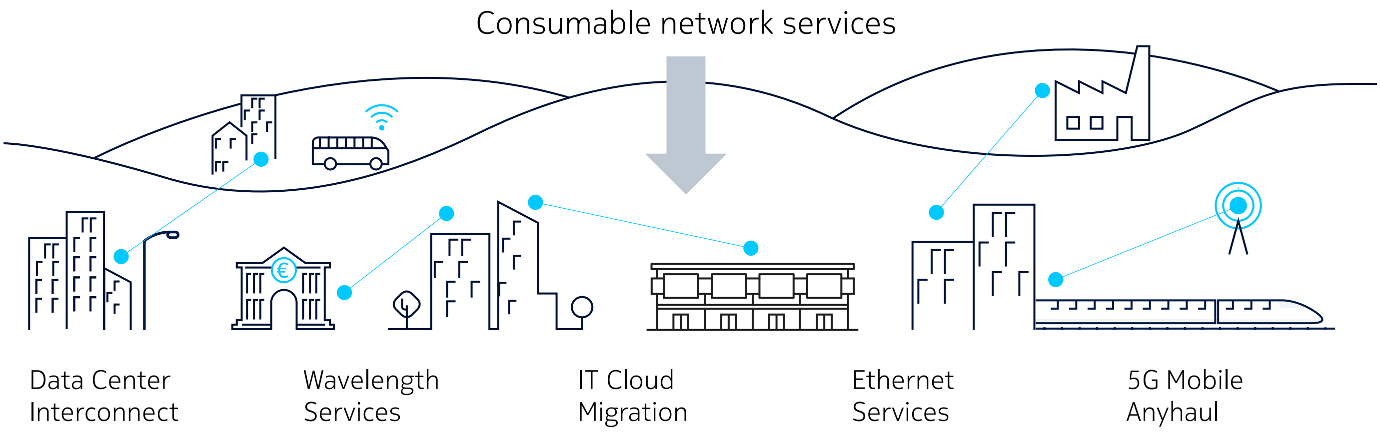
A single fiber cut can impact thousands of services at the IP layer, generating a flood of alarms that can easily overwhelm and confuse network operators and lead them to take incorrect actions. Cross-domain assurance and fault correlation with the assistance of artificial intelligence and machine learning will greatly reduce the time and impact of network outages by providing operators with actionable insight to identify the root cause of service-impacting failures and recommended actions to correct them.

Preventive maintenance goes one step further by automatically taking corrective actions before failures occur, for example due to laser degradation or fiber impairments. Collecting and analyzing streaming telemetry at the optical layer, such as pre-FEC bit error rates, allows automated monitoring of network health, extrapolation of performance trends to predict failures, and rerouting IP traffic away from impaired transport links before actual service outages occur.

Cross-domain connectivity management with multi-layer optimization

Emerging 5G network architectures are highly dynamic and programmable and contain a mix of both centralized core and distributed edge cloud infrastructures that are interconnected by a unified and smart IP/optical network fabric. This network fabric must be highly consumable and engineered to meet the stringent reliability, latency and throughput needs of 5G services (see Figure 8).

Figure 8. Delivering the network as a service



Cross-domain, multi-layer connectivity management is a prerequisite for building programmable network fabrics to deliver digital services at cloud speed with deterministic performance requirements. Cross-domain assurance and multi-layer optimization are also required to accomplish these goals effectively and cost-efficiently at the most economical network layer. Open, machine-programmable interfaces must be supported at all levels to support these use cases in real-world, multi-vendor network environments with a minimum of system integration effort.

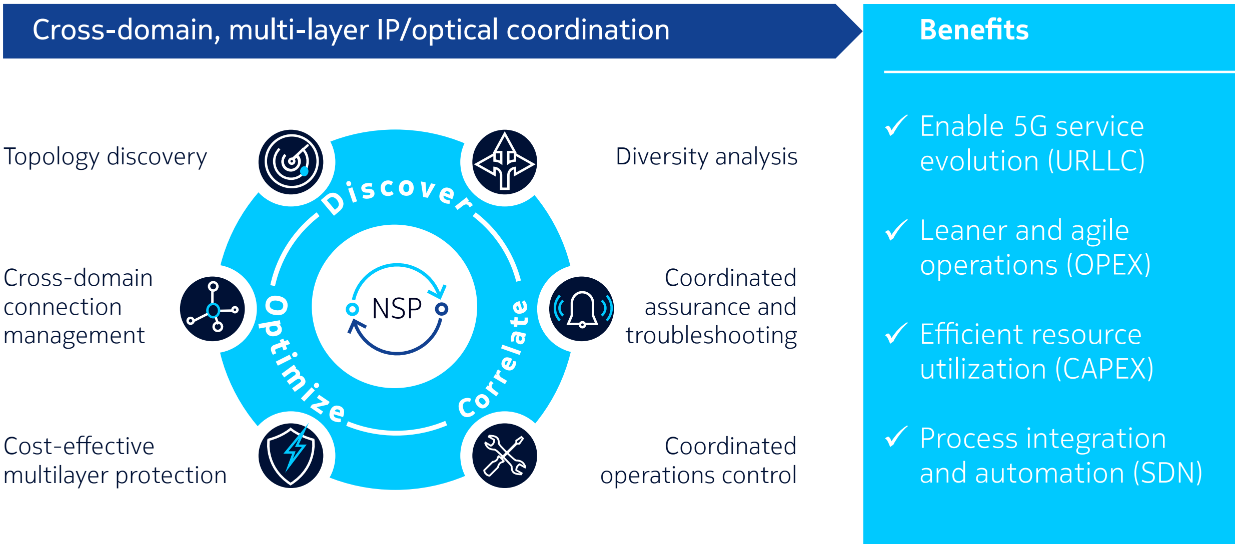
Building a smart network fabric with Nokia

The digital era of 5G and the cloud dramatically changes the scope and flow of network traffic and drives orders-of-magnitude-higher capacity, connectivity and efficiency needs:

- Extreme fixed/mobile broadband with 100 Mb/s to 10 Gb/s data rates for delivering a superior quality of experience with ultra-high definition video and immersive virtual/augmented reality
- Massive machine-type communications, anticipating a 10 to 100 times growth in connected devices and sensors on our person and in our homes, cars, offices, factories and public infrastructure
- Critical machine communications, providing ultra-reliable, low-latency communication services for self-driving cars, smart manufacturing and haptic feedback applications.

To efficiently deliver this expanding range of digital services in digital time requires an agile and programmable network fabric that is designed and optimized to meet stringent cost, throughput, reliability and latency objectives. Cross-domain carrier SDN integration (see Figure 9) is essential for establishing multi-layer visibility and control automation over IP routing and optical transport, and to optimize the inherent cost and performance synergies from their combined, complementary capabilities.

Figure 9. Building an SDN programmable IP/optical network fabric with optimal cost and performance synergies



The Nokia NSP addresses these needs with a multi-vendor carrier SDN solution to help network operators build and operate an agile, programmable and cost-efficient IP/optical network fabric that meets the new service delivery challenges of the digital era.

For more information about IP/optical interworking for 5G, visit our IP/Optical Integration web page.

References and resources

1. Nokia Network Services Platform. Application note.
2. Deploying SDN in IP/optical networks. Application note.
3. Solution profile. Nokia Network Services Platform. Appledore research report.
4. Network automation for the digital era. Executive summary.

Abbreviations

AF	assured forwarding
API	application programming interface
BE	best effort
CAPEX	capital expenditures
CDC-F	colorless, directionless, contentionless with flexible grid spacing
CDN	content delivery network
CoS	Class of Service
DCI	data center interconnect
ECMP	equal-cost multi-path routing
EF	expedited forwarding
FEC	Forward Error Correction
GMPLS	Generalized MPLS
IP	Internet Protocol
MPLS	Multiprotocol Label Switching
NSP	Nokia Network Services Platform
OPEX	operating expenditures
QoS	Quality of Service
ROADM	Reconfigurable Optical Add-Drop Multiplexor
RSVP-TE	Resource Reservation Protocol – traffic engineering
SDN	software defined network
SNCP	subnetwork connection protection
SR-TE	segment routing - traffic engineering
TI-LFA	Topology Independent - Loop Free Alternate
URLLC	Ultra-Reliable Low Latency Communication

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