A strategy for IP/optical integration

This paper outlines the platforms, tools, solutions and services required to integrate and interwork IP and optical technology domains in an evolutionary manner. Taking a step-by-step approach that recognizes the diversity of operator networks, this strategy optimizes the value of each technology, rationalizes cost across network layers, and reduces total cost of ownership by streamlining multi-layer management and control operations.
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>3</td>
</tr>
<tr>
<td>Control plane integration in three steps</td>
<td>6</td>
</tr>
<tr>
<td>IP/optical data plane integration</td>
<td>13</td>
</tr>
<tr>
<td>Converged IP/optical management</td>
<td>16</td>
</tr>
<tr>
<td>Multi-layer network modeling and design</td>
<td>17</td>
</tr>
<tr>
<td>Conclusion</td>
<td>17</td>
</tr>
<tr>
<td>Acronyms</td>
<td>19</td>
</tr>
</tbody>
</table>
Introduction

IP/optical integration enables the combination of state-of-the-art routing and optical transport technologies to provide a more agile, dynamic and integrated network with significant cost and performance synergies.

In the short term, IP/optical integration removes operational and technological barriers that currently inflate overhead costs. It will allow network operators to optimize the utilization of their IP routing and transport network assets to economically scale network capacity and reduce their day-to-day expenses by simplifying and streamlining multi-layer network operations.

In the long term, IP/optical integration provides the agility and programmability needed for innovative control paradigms based on software defined networking (SDN). SDN further improves network utilization with on-line traffic engineering and bulk optimization, which will allow to improve service velocity and dynamically adjust capacity to fluctuating demand. IP/optical integration addresses major disparities and disconnects at the management, control and data plane that make conventional routing and transport networks costly and cumbersome to operate (Figure 1, left side). Typically, legacy transport services are statically provisioned through the management plane. Manual intervention and elaborate workflows are needed to orchestrate cross-layer actions. Service provisioning is complex, time-consuming and error-prone. The operational infrastructure is for the most part too rigid, static and disconnected to adequately respond to fluctuating demands or to facilitate dynamic service control.

Figure 1. Transition to a dynamic, programmable and integrated network

State-of-the-art routing and optical transport technologies can provide a more agile, dynamic and integrated deployment model (Figure 1, right side).
The paper first discusses the three steps required to achieve control plane integration. It will then discuss integration of the data and management planes (Figure 2).

**Figure 2. Nokia IP/optical integration strategy**

The following summarizes an evolutionary approach to IP/optical integration and introduces the topics that will be addressed in more detail.

**IP/optical control plane integration**

There are three main aspects to be considered in IP/optical control plane integration. They can be conducted in parallel with management and data plane integration as each plane addresses different issues and offers complementary integration benefits.

- **Add a Generalized Multiprotocol Label Switching (GMPLS) control plane** to the optical transport layer for a more agile optical network. Dense wavelength division multiplexing (DWDM), optical transport network (OTN) and reconfigurable optical add-drop multiplexers (ROADMs) offer flexible and cost-efficient grooming and transport for IP/Ethernet and SDH/SONET payloads. GMPLS protection and dynamic restoration features leverage this flexibility to efficiently protect services and improve network utilization.

- **Extend dynamic transport control capabilities to the routing layer through a GMPLS user-network interface (UNI).** GMPLS UNI integration closes the loop between the routing and transport control planes and establishes a unified multi-layer control plane to efficiently coordinate cross-layer operations.

- **Expose an SDN abstraction layer with programmatic SDN interfaces**¹ to help monetize the multi-layer network as virtualized, cloud-consumable services. SDN control elements, such as the path computation element (PCE), help optimize capacity usage with dynamic traffic engineering and bandwidth calendaring.
Each control plane integration step delivers immediate cost and efficiency benefits. It also contributes to creating an open and programmable multi-layer control plane, which will facilitate dynamic SDN control and improve service velocity.

**IP/optical data plane integration**

Tunable router optics and integrated packet transport help to achieve cost-effective interworking of IP routing and optical transport at 10Gb/s, 40Gb/s, 100Gb/s, 200Gb/s and 400Gb/s speeds (and higher in the future). Total cost of ownership (TCO) benefits come from reduced optical-electrical-optical (O-E-O) conversion costs for packet transport. This is a more economical use of router ports and a better utilization of transport resources.

**Converged IP/optical management and SDN control**

The Nokia 5620 Service Aware Manager (5620 SAM) enables end-to-end and cross-domain management of routing and transport assets to simplify and speed up complex operations, reduce operations support system (OSS) integration costs and ultimately improve service performance. The Nokia Network Services Platform is a carrier SDN solution that enables service automation and network optimization of IP/optical networks.

**Multi-layer network planning and optimization**

Properly designing a multi-layer network for optimal cost and performance requires a comparison of different network topologies to reveal the advantages of the various layer technologies in terms of improved cost, resource utilization, performance and availability. Nokia provides professional services to help network operators evaluate and make the best implementation choices for their network.

The objective of the Nokia IP/optical integration strategy is to establish a multi-layer routing and transport infrastructure with an integrated control plane and programmatic SDN support interfaces. While the strategic objectives and integration approach are clear, there is no single solution for integrating IP routing and optical transport that is applicable for every network and all operators. There are multiple options with different costs and benefits that may apply, depending on prevailing deployment conditions and operational requirements. Thus, a multi-faceted and adaptable approach to the complexities of an operator’s current network is required. A step-by-step approach is evolutionary in that it recognizes the operational realities of today’s networks.

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1 Notable interfaces are OpenFlow, BGP-LS and the PCE Communication Protocol or PCEP (RFC 5440).
Control plane integration in three steps

Agile optical networking and a GMPLS control plane

As we will discuss in the section on integrating the IP/optical data plane, today's optical networks are becoming more flexible. The key to getting the most out of this flexibility is an integrated IP/optical control plane. The first step is to establish a GMPLS control plane.

**Generalized Multiprotocol Label Switching**

A GMPLS control plane lays the foundation for a converged multi-layer transport network that is optimized for packet and cloud services. GMPLS is the natural evolution of MPLS to circuit-oriented transport networks (SDH/SONET, OTN, DWDM), and provides the following functions:

- Dynamically sets up connections in multi-layer transport networks
- Multivendor and cross-technology (IP, Ethernet, SDH, DWDM, OTN)
- Combines the benefits of optical transport and IP/MPLS routing

GMPLS enables the transport network to dynamically route or reroute traffic around failures or onto optimal paths based on network utilization and/or service level agreement (SLA) constraints. The GMPLS UNI lets routers dynamically signal transport paths with support of various service protection options. Protection and restoration options are applicable to optical segment (UNI-N to UNI-N), end-to-end (UNI-C to UNI-C), or both (Figure 3).

**Figure 3. GMPLS protection and restoration options**

<table>
<thead>
<tr>
<th>Protection Type</th>
<th>Description</th>
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<tr>
<td>1+1 Protection (SNCP)</td>
<td>Classical 1+1 self-healing segment protection, Fast recovery from single failure but full redundancy</td>
</tr>
<tr>
<td>1+1 Protection and Restoration Combined (PRC)</td>
<td>Improved 1+1 self-healing protection by using dynamic restoration to protect against multiple failures</td>
</tr>
<tr>
<td>Dynamic Restoration Source Based (SBR) and Guaranteed Restoration (GR)</td>
<td>Slightly slower failure recovery than 1+1 protection but more cost-efficient sharing of protection resources</td>
</tr>
<tr>
<td>Unprotected with SRLG constraints</td>
<td>To establish a backup path that is physically disjoint from a primary path to avoid single points of failure</td>
</tr>
<tr>
<td>gLSP Full Rerouting Source Based</td>
<td>End-to-end protected gLSP (UNI-C to UNI-C) with dynamic restoration to protect point-to-point traffic</td>
</tr>
<tr>
<td>gLSP/gLSP group protection (1:1/1:N protection)</td>
<td>Cost-efficient 1:N protection of a group with gLSPs</td>
</tr>
<tr>
<td>gLSP tunnel group protection (1:N load-sharing)</td>
<td>Cost-efficient protection of gLSPs groups with use of OP interface hashing for transparent IP traffic restoration</td>
</tr>
<tr>
<td>Floating backup ports (protect router interconnect)</td>
<td>Cost-efficient 1:N port protection of the router port interconnections to the optical transport devices</td>
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</table>
The GMPLS protocol suite exchanges topology and resource information to communicate route decisions to involved network elements and sets up the corresponding paths. The GMPLS suite contains routing protocols (OSPF-TE), signaling protocols (RSVP-TE) and the link management protocol (LMP) and is fully standardized by the major routing, transport and management bodies.\(^2\)

The Nokia agile optical networking solutions are based on the 1830 Photonic Service Switch (PSS) product family. They all include an intelligent GMPLS control plane with multi-layer and multi-region network support. The 1830 PSS family also covers all access, metro and long haul transport needs, including a reconfigurable ROADM up to 20 degrees, with colorless, directionless, contentionless flexgrid (CDC-F) capabilities to carry any service over any wavelength in any direction without contention and with flexible grid spacing. The family also includes a scalable, universal OTN switching fabric to groom and switch any mix of client traffic including OTH ODUk, GigE and 10GigE, SDH/SONET up to STM-64/OC-192, and 40Gb/s and 100/200/400Gb/s signals.

**GMPLS application benefits**

The GMPLS control plane supports a rich toolkit of dynamic protection and restoration capabilities for OTN and DWDM transport services. These capabilities can complement IP/MPLS mechanisms in a multi-layer resiliency strategy that supports SLAs with different availabilities. Moreover, GMPLS can significantly reduce resource redundancy requirements for protecting traffic, leaving more capacity for revenue-generating traffic.

Figure 4. Implementing differentiated availability SLAs

Network operators can leverage a broad array of GMPLS protection and restoration options to balance service availability and cost objectives for an even more differentiated SLA offer. For example, both protection and

restoration can be leveraged for mission-critical services and high-revenue traffic, while less critical service categories can be cost-effectively protected using dynamic restoration.

GMPLS-based dynamic restoration mechanisms can recover from multiple failures and efficiently share backup resources by utilizing N+1 and N:1 redundancy models. Conventional 1+1 self-healing protection mechanisms reserve as much as 50 percent of provisioned capacity to recover from failures like fiber cuts. Besides being costly, they are often inefficient to protect IP service traffic:

• Traditional 1+1 protection mechanisms rely on a single, pre-provisioned backup path and thus are unable to take the actual failure location into account, whereas GMPLS dynamic restoration is able to create a local detour.

• 1+1 protection can only use a single path and restore only a single failure, whereas IP routing topologies have high degrees of connectivity with many alternate paths that can be leveraged to protect against multiple failures.

• As most IP traffic can tolerate brief outages and limited packet loss, rather than using dedicated 1+1 protected infrastructure to protect each path, it is possible to leverage alternate network paths (reroute) using a GMPLS control plane, which enables routers to dynamically trigger path restoration with N+1/N:1 redundancy.

A recent Bell Labs study shows that GMPLS protection and restoration can result in savings of up to 40 percent on router ports and optical transponders without compromising service availability requirements.

**IP/MPLS routing with GMPLS UNI support**

The second step in realizing an integrated control plane closes the loop between the routing and transport control planes by enhancing the IP/MPLS layer with GMPLS UNI (RFC 4208).

Figure 5. Leveraging GMPLS UNI to integrate routing and transport layers
The GMPLS UNI enables crossing the administrative boundary between routing and transport, allowing the IP routing layer to directly communicate resource requirements with the underlying transport network, without the need for operator intervention through network management systems (Figure 5).

The GMPLS UNI enables clients in the IP/MPLS routing overlay to acquire and control link resources from the underlying optical transport layer, without the need for operators to intervene or mediate in the process. The transport layer can also use GMPLS UNI to inform the IP routing layer about relevant events in order to monitor and more effectively use network resources.

Closing the control loop between IP routing and optical transport helps to

- Simplify and streamline complex operations
- Reduce the possibilities for human error
- Improve service performance and resource utilization

For example, consider a situation where a transport section must be temporarily down for maintenance. Ideally the IP routing layer is informed ahead of time so that it can make that section traffic free and avoid unnecessary service degradation or outages. Without IP/optical control plane integration, this task must be coordinated manually between the routing and transport teams, which consumes time and is error-prone.

With GMPLS UNI control plane integration:

- The optical transport layer can notify the impacted IP layer clients of impending maintenance actions or performance degradations through RSVP reservation or state notifications (Figure 6), whereupon the IP layer may choose to dynamically re-signal a transport path to avoid the impacted segment.
- The IP layer gains better visibility of the transport layer and can obtain shared risk link group (SRLG) information about established primary and secondary paths to ensure there is no single point of failure.

Figure 6. Simplified provisioning and maintenance
GMPLS UNI coordinates forwarding and protection services across network layers, and eliminates the need for redundant protection mechanisms across network layers. A cost-efficient and complementary use of routing and transport layer protection mechanisms can significantly reduce the resource redundancies required to meet SLAs.

Closing the loop between routing and optical transport enables a consistent use of network resources. This leads to improved network efficiency because it removes the need to touch each layer separately. It also helps to consolidate, coordinate and automate management activities across routing and transport layers with fewer touch points and less operator intervention. With GMPLS UNI, the IP layer can dynamically establish transport services with a variety of constraints such as bandwidth, latency and protection type, and trigger rerouting upon link performance degradation (Figure 6).

GMPLS UNI support is available for the following Nokia IP/MPLS products:
- Edge routing (7750 Service Router, 7450 Ethernet Service Switch)
- Core routing (7950 Extensible Routing System)

These products are powered by the Nokia-developed 400G FP3 network processor silicon and leverages the field-proven and feature-rich Nokia Service Router Operating System (SR OS) across all platforms.

SDN programmable control plane integration
The third step is to support the SDN control interfaces. The objective is to provide a powerful, open abstraction layer to allow multivendor SDN applications to directly tap into unified multi-layer control plane capabilities. Along with enabling dynamic resource management and bandwidth optimization, this abstraction layer will also allow monetization of IP/optical network infrastructure assets as virtualized, cloud-consumable services.

Notable programmatic interfaces:
- OpenFlow enables SDN controllers to define access control lists (ACLs) and do traffic steering.
- Network configuration protocol (NETCONF) provides mechanisms to install, manipulate and delete the configuration of network devices. It uses an extensible markup language (XML) - data encoding based on YANG for the configuration data and the protocol messages.
- BGP Link-State (BGP-LS) leverages Border Gateway Protocol (BGP) as a source of topology information and safely distributes Interior Gateway Protocol (IGP) information to entities outside of the usual IGP peering.
- Path Computation Element Communication Protocol (PCEP) is originally designed for offloading optimal path computation in MPLS-Traffic Engineering (MPLS-TE) networks to a path computation element (PCE).
Path computation element (PCE)

The PCE is a critical element for enabling dynamic network resource control and can be leveraged to introduce new, innovative services as well as improving network utilization. It supports dynamic path setup of multi-layer infrastructure with various constraints, such as bandwidth, latency and diversity, and enables online traffic engineering and optimization.

The PCE concept (RFC 4655) separates path computation and path signaling functions, which:

- Gives operators more control of their networks
- Adds the ability to apply network operator policies
- Addresses multivendor integration considerations

The PCEP (RFC 5440) defines the interface between PCE and PCE clients (PCCs). Clients can be network nodes, a network management system (NMS) or traffic engineering applications. For example, the GMPLS multi-layer routing engine (GMRE) in a transport node may call upon the PCE to assist in computing an explicit route (XRO) that takes into account specific constraints such as bandwidth, latency or physical diversity. The PCE can be embedded in a network node, in an NMS or operate as a dedicated entity. Multiple PCEs may exist in a hierarchy and collaborate to compute multi-domain paths. Path computation can operate as a centralized, distributed or collaborative process.

Figure 7. Path computation element
The general use case for a centralized PCE is to enhance distributed constraint-based shortest path first (CSPF) routing protocols in the network. A centralized PCE has far more compute and storage resources than a router to compute optimal routes. It can deploy sophisticated path computation algorithms such as Bell Labs Self-Tuned Adaptive Routing, which can accommodate over 20 percent more revenue-generating traffic by more efficiently routing path requests and balancing network traffic more evenly over available link capacity. Another use case is support of a segment routing control plane. Since this approach removes the Resource Reservation Protocol (RSVP) soft state from the network for better scalability, it consequently loses visibility of bandwidth usage in network nodes.

The PCE is then deployed in a stateful operation mode for:

- Path computation with bandwidth, latency, diversity and bi-directionality constraints
- Multi-area/domain path computation with constraints (admin-group, SRLG, max hop count, etc.)
- Bandwidth-on-demand and bandwidth calendaring

The PCE learns bandwidth resources and topology by receiving segment routing updates through IGP routing advertisements and BGP-LS. Figure 8 depicts a number of additional PCE use cases.

**Figure 8. Path computation element use cases**
The capability to make periodical adjustments to allocated capacity opens up various new revenue-generating opportunities that use bandwidth calendaring and off-peak/on-peak hour services. For example, database auditing or backup services could benefit from unused capacity during off-peak hours. Another option is to use the complementary peak hours of residential and commercial traffic to share a pool of common bandwidth resources on a periodical basis to meet peak capacity needs more cost efficiently.

The ability to make dynamic capacity changes enables bandwidth-on-demand and bandwidth bursting services through self-service portals. These two service capabilities are highly desired by business users. Applying SDN for dynamic load-balancing, on-line traffic engineering and bulk optimization can mitigate network hotspots and adapt to unexpected demand fluctuations with minimal capacity requirements.

**IP/optical data plane integration**

IP/optical integration at the data and forwarding plane can save costs by consolidating routing and transport requirements in fewer devices. Nokia offers a broad spectrum of system- and device-level integration options to address a wide range of deployment scenarios and operational requirements.

- Integrated transponders (IP with DWDM) allow routers to directly plug into the DWDM layer without requiring an optical transponder.

- Integrated packet optical transport in the transport system allows cost-effective grooming of IP/Ethernet traffic for better fiber utilization and saves overlay router ports.

**Figure 9. Data plane integration options**

As there is no single solution that works for every situation, it is important to have all options available. Integrated packet optical transport may be successfully deployed in the aggregation network, while the edge and core networks may leverage integrated DWDM optics, or a combination of separate routers and transport devices with IP/optical control plane integration.
Integrated DWDM transponders in routers

Integrated optical transponders enable routers to plug directly into the DWDM layer as an alien wavelength — a “colored” optical signal that originates from equipment not under the direct control of the transmission network operator (Figure 10). This saves employing a transponder on the DWDM transport system and allows the router to connect remotely over longer distances than standard gray optics allow.

Figure 10. Integrating tunable optics in routers

Integrated transponders also give routers direct visibility of optical transport performance, such as forward error correction (FEC).

Nokia supports the ITU-T Blacklink initiative (G.698.2) to develop multivendor interworking standards for colored 100G optical components and has performed pre-standard multivendor interworking field demonstrations.

The Nokia edge and core routing platforms support a variety of integrated DWDM transponders at 10G, 40G and 100G rates. Nokia recently also introduced the world’s first 400G DWDM transponder interface for its 7950 XRS core routing platform.

Integrated packet-optical transport

There are a number of advantages to an integrated packet-optical transport system (P-OTS). The present mode of operation in most networks is shown in Figure 11, on the left. It employs packet switching overlay on DWDM metro rings. There are several inefficiencies that can make such legacy overlay solutions costly to scale:

- They require two types of equipment to maintain and operate.
- They consume 2xN wavelengths and 2xN router ports and point-to-point transport connections.
- The fiber plant in the transport network has poor fill rates due to a lack of statistical multiplexing opportunities.
Figure 11. Application of integrated P-OTS

An integrated P-OTS solution as shown in Figure 11, at the right, offers the following advantages:

- It avoids the need for a separate packet switching overlay.
- Statistical multiplexing at each P-OTS node requires the allocation of fewer wavelengths and consumes fewer ports on the metro edge/core destination router.
- Statistical multiplexing fully benefits from complementary traffic patterns from residential, business and mobile users.


Integrated packet switching technology enhances the 1830 PSS with Ethernet, MPLS transport and QoS capabilities-in full compliance with Metro Ethernet Forum, Carrier Ethernet (MEF CE) 2.0 certified services, such as E-line, E-LAN and E-tree. Integrated packet switching capabilities on the 1830 PSS use the same operating system (SR OS) and management system (5620 SAM) as Nokia Ethernet switches and IP/MPLS routers.
Converged IP/optical management

Traditional network management systems take a single domain management approach across the optical and IP layers, which results in multiple operation teams managing different parts of the network. As a result, it is cumbersome to isolate faults that impact multiple domains and labor-intensive to coordinate efforts through trouble ticketing and work-flow management systems.

IP/optical management and SDN control integration enables operators to transition from operationally fragmented, technology-specific management silos to cross-domain automation and optimization of routing and transport infrastructure (Figure 12).

Figure 12. Cross-domain multi-layer management and SDN control.

Converged IP/optical management and control is an invaluable aid in orchestrating network and service operations spanning multiple network layers. Operators can optimize network resource allocations across IP and optical transport layers, and manage Key Performance Indicators from both network service domains.

The Nokia Network Services Platform is a carrier SDN platform that unifies service automation and network optimization for delivery of profitable, on-demand network services, provides operators with a more efficient way to define, provision, and activate network services across multiple layers, physical/virtual infrastructure, as well as equipment from multiple vendors.
Multi-layer network modeling and design

Designing a multi-layer network for optimal cost and performance can be a complex task to conduct without the proper tools and expertise. Nokia offers professional services to help in evaluating and making the best implementation choices for the network, based on unique requirements (Figure 13).

Figure 13. Designing and optimizing the multi-layer network

A multi-layer network assessment can compare different network topologies and reveal the advantages of the various layer technologies in terms of improved cost, resource utilization, performance and availability.
Conclusion

IP/optical integration is a multi-faceted topic with a significant bearing on network evolution. It has great potential to reduce networking cost and operational complexity. The evolution from operating separate optical and IP layers to operating an integrated multi-layer network maximizes the natural synergies between IP routing and optical transport technologies. IP/optical integration provides a control continuum between network layers that enables forwarding, protection and restoration of traffic at the most economical layer, based on traffic profile and requirements.

With the transition to all-IP and cloud-based services, many network operators are also considering how integrated IP routing and transport may help them reach their business goals. As well as reducing costs and complexity, it offers additional benefits to service innovation, reliability and performance.

Nokia’s approach to IP/optical integration strategy leverages state-of-the-art routing and transport technologies, platforms and operation practices. This approach establishes an integrated multi-layer routing and transport infrastructure with a unified control plane and programmatic SDN support interfaces.

Converged IP/optical management and control with the integration of routing and transport at the data plane contribute to meeting key business objectives. Converged IP/optical management support by the 5620 SAM efficiently coordinates cross-layer operations. Modular extensions to Nokia routing and transport platforms optimize network deployment and interworking costs. Professional services that design and optimize the multi-layer network complete the offer.

While the strategic objectives and integration approach are clear, there is no single solution for integrating IP routing and optical transport that is applicable for every network and all operators. There are multiple options with different costs and benefits that may apply, depending on prevailing deployment conditions and operational requirements.

Devising an optimal strategy requires a deep understanding of these integration options based on the specific operator network, service requirements and operational support infrastructure in place. Choosing from a range of integration options allows network operators the flexibility to select combinations that best fit their particular needs.

Nokia is a market and a technology leader that masters both IP/MPLS routing and optical transport. A Tier 1 equipment vendor of both IP/MPLS routing and optical transport, Nokia has the scope, skills and solutions required for a balanced and cost-optimized IP/optical integration strategy that leverages the complementary strengths of both technology domains.
Acronyms

ACL   access control list
AON   agile optical networking
BGP   Border Gateway Protocol
BGP-LS Border Gateway Protocol - Link State
CDC-F colorless, directionless, contention-less with a flexible grid
CSPF  constraint-based shortest path first
DWDM dense wavelength division multiplexing
ECMP equal cost multi-path
FEC   forward error correction
FRR   fast reroute
GE    Gigabit Ethernet
GMPLS Generalized Multiprotocol Label Switching
GMRE  GMPLS Multi-layer Routing Engine
IGP   Interior Gateway Protocol
IPT   integrated packet transport
LAG   Link Aggregation Group
LMP   Link Management Protocol
MPLS-TE MPLS - Traffic Engineering
MTTR  mean time to repair
NETCONF Network Configuration Protocol
NFV   network functionS virtualization
NMS   network management system
OAM   operation, administration and maintenance
O-E-O optical-electrical-optical
OSPF-TE Open Shortest Path First - Traffic Engineering
OSS   operations support system
OTN   optical transport network
P2P   point-to-point
PCC   PCE client
PCE   path computation element
<table>
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<tr>
<th>Acronym</th>
<th>Definition</th>
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<tr>
<td>PCEP</td>
<td>Path Computation Element Communication Protocol</td>
</tr>
<tr>
<td>P-OTS</td>
<td>packet-optical transport system</td>
</tr>
<tr>
<td>ROADM</td>
<td>reconfigurable optical add/drop multiplexer</td>
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<tr>
<td>RSVP</td>
<td>Resource Reservation Protocol</td>
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<tr>
<td>RSVP-TE</td>
<td>Resource Reservation Protocol - Traffic Engineering</td>
</tr>
<tr>
<td>SDH</td>
<td>Synchronous Digital Hierarchy</td>
</tr>
<tr>
<td>SONET</td>
<td>Synchronous Optical Network</td>
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<tr>
<td>SDN</td>
<td>software defined networking</td>
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<tr>
<td>SLA</td>
<td>service level agreement</td>
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<tr>
<td>SRLG</td>
<td>shared risk link group</td>
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<tr>
<td>SR OS</td>
<td>Service Router Operating System</td>
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<tr>
<td>UNI</td>
<td>user-to-network interface</td>
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<tr>
<td>XML</td>
<td>Extensible Markup Language</td>
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<tr>
<td>XRO</td>
<td>explicit route object</td>
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