

Solutions for IP Optimized Optical Transport

The Cisco Routed Optical Network



Executive summary

Service provider traffic continues to be overwhelmingly IP services, and consequently:

- Next-generation network architecture should be optimized for the transport of the majority IP services
- Legacy non-IP TDM service volumes are small and transient and should not define the transport architecture in next-generation networks

Current service provider network infrastructure is not optimized for transport of IP services and is challenged with high TCO attributed to:

- Layered and siloed infrastructure relying on large volumes of line cards for traffic hand-off between networking layers
- Overlapping and redundant resiliency schemes in each networking layer, resulting in high costs and poor network resource utilization (poor monetization)
- High complexity due to multiple overlapping and independent switching points, control and management planes associated with each network layer
- Layered and siloed architecture which requires manual service stitching across network domains, posing challenges to end-to-end cross-loop automation required for automated operations (remediation) and shorter service lead times

In order to address these pain points and allow networks to scale effectively to meet traffic projections, Cisco is advocating a new Routed Optical Networking architecture to bring about simplification in order to drive higher scale and lower TCO for IP services:

- Savings of up to 40% compared with TCO of current layered network architectures
- Lower TCO solutions for IP aggregation for mobile backhaul applications based on coherent DWDM interface integration into IP aggregation devices, offering savings of up to 45% in CapEx and 60% in OpEx

The Cisco Routed Optical Network architecture features:

- Integration of 400G coherent transponders function into routing devices: Convergence of IP routing and coherent DWDM by leveraging new advances in silicon photonics to realize 400G coherent transport within a highly compact QSFP56-DD on high-scale routing platforms to enable service line cards that are not compromised in terms of routing port density nor capacity relative to grey optical counterparts
- Assimilation of private line/OTN services and photonic switching into a single converged IP/MPLS network layer: Service consolidation for IP, OTN, and private line services into a single IP/MPLS network layer (single forwarding plane and single control plane) that can leverage Segment Routing for sub-50ms service resiliency for all failure scenarios
- Massive network simplifications and higher fiber utilization by leveraging H2H IP Core architecture that avoids the complexities associated with contentionless ROADMs and reduces the exposure to compromise in fiber resource utilization (maximize optical network monetization) and reduces the need for costly regeneration imposed by Shannon's Limit
- Removes barriers for realizing automated network infrastructure via closed-loop automation framework across single converged IP and optical infrastructure for service path computation, activation, orchestration, remediation, and optimization

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Traffic is overwhelmingly IP

Service providers are facing challenges in addressing the exponential traffic growth on their networks with flat Average Revenue Per User (ARPU). Traffic will continue to grow from video, gaming, and virtual/augmented reality as well as from the promises of mobility with 5G and future technologies. Service providers need to continue meeting the demand for this new capacity, while also rolling out new revenue generating services and lowering their costs. Looking at forecasts, a service provider will need to move 11 times more traffic per \$1 of infrastructure investment in 2022 than in 2012.

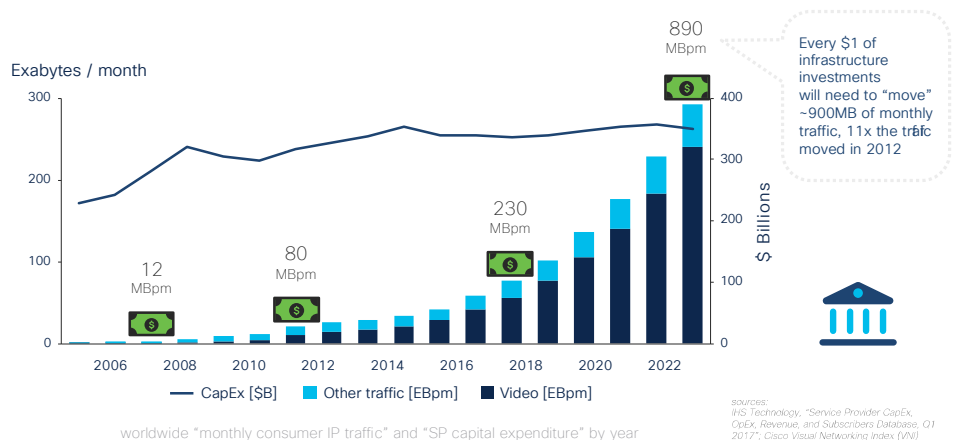


Figure 1 - Cisco Visual Networking Index (VNI) vs SP Network Investment

Internet traffic has seen a compounded annual growth rate of 30 percent or higher over the last five years because more devices are connected, and more content is being consumed¹.

Service providers recognize that the bulk of the services consuming this capacity are increasingly lower ARPU which is not commensurate with the cost of building the network infrastructure that can scale to support the capacity growing at an exponential rate. Technology continues to evolve following Moore's Law, and we continue to push Shannon's Limit. From operations we see a strong drive to leverage automation, Software-Defined Networking (SDN), telemetry, machine learning, and artificial intelligence to lower operational costs. From a network architecture perspective, we continue to see investments in individual network layers, from packet to Optical Transport Network (OTN) to Dense Wavelength Division Multiplexing (DWDM), with each layer evolving around capacity and flexibility in a siloed manner. This contributes to the cost and complexity of the overall network infrastructure.

As the tried and tested solutions to address these pain points have proven to be ineffective, a more disruptive approach is necessary to bring about the required level of network scale and efficiency to accommodate the anticipated huge exponential traffic growth. This transformative approach must be taken to:

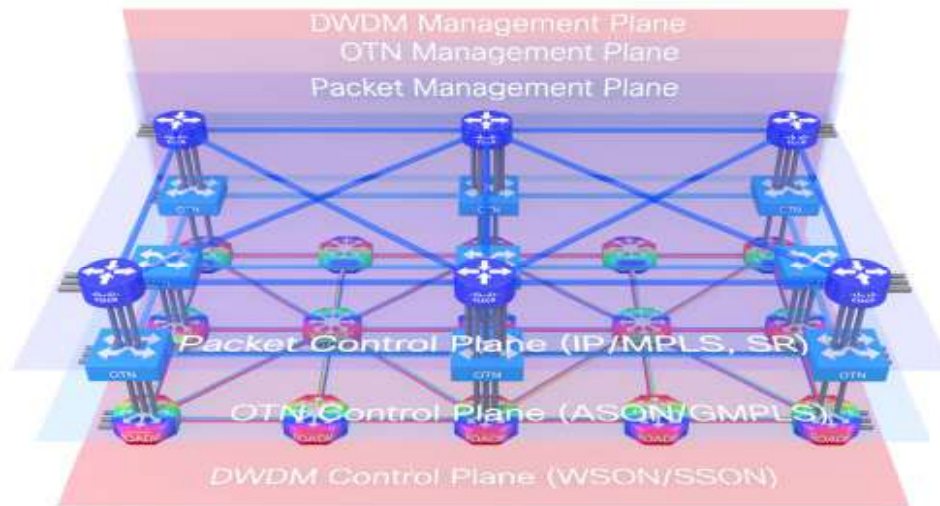


Figure 2 – Traditional Network Architecture

- Radically transform the network operations to focus on speed and efficiency in services delivery by leveraging network automation and orchestration toolkits
- Re-architect the network specifically for IP traffic by simplifying and removing redundant legacy network layers. We acknowledge that legacy services exist in most service providers' network infrastructure, however they are transient and at relatively low volumes, so any influence they exert on the architecture of the next generation network should be proportionately minimal

This objective of this paper is to provide details on these transformative network architectures and solutions that form part of Cisco's Converged SDN Transport initiative to facilitate efficient network growth for IP services. The Routed Optical Networking architecture is one component of the Converged SDN Transport Framework.

Routing Optical Networking architecture

Traditional network architectures are comprised of networking layers that relied on line cards for service hand-off between the layers. This kind of layered architecture is highly inefficient as it consumes too much line card Capital Expenditure (CapEx) resources and relies on manual operations for service hand-off between the layers. Moreover, each networking layer has its own control and management planes associated with it, which operate independently from each other. This creates huge complexities in service assurance, fault correlation, path optimization in terms of network utilization, as well as network planning and optimization. These complexities represent challenges to service

providers' aspirations towards achieving service driven end-to-end, closed-loop automation across the entire network infrastructure. The Total Cost of Ownership (TCO)² associated with this network architecture is prohibitively high and will not allow service providers to scale their network to meet the capacity demands of IP services in a cost-efficient manner.

Cisco is committed to addressing these challenges by applying simplification through key technology that brings about true convergence of the IP and optical domains. Network simplification is aimed at removing complexities inherent to the infrastructure in order to allow service providers to leverage their assets more effectively through:

- Transformational changes applied to the transport network architectures
- Coherent pluggable modules which offer reach and performance at the right cost points and power profiles

These initiatives are embodied in the Routing Optical Networking architecture which is a key enabler for the realization of Cisco's vision for the [Internet for the Future](#). This new approach transitions networks from the siloed infrastructure to a new architecture that relies on a single control plane based on IP/MPLS in a converged Hop-to-Hop (H2H) IP and optical network. This drives significant simplification and cost savings. It addresses the complexities and redundant networking layers that present bottlenecks to scalability and enables end-to-end automation in the service provider network infrastructure through:

- Assimilation of any OTN switching infrastructure required to address any legacy

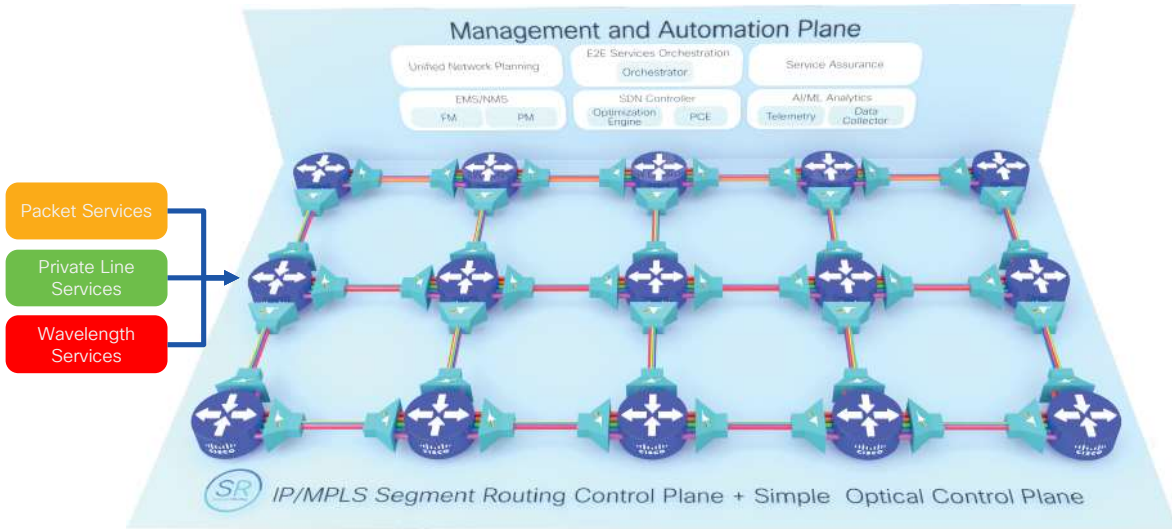


Figure 3 - Cisco Routed Optical Networking Architecture

- Time-Division Multiplexing (TDM) services
- Direct integration of high capacity optical interfaces (for both grey and coherent) directly on the routing devices without the compromise of the deloading of the IP fabric that was present in Cisco IP over Dense Wavelength-Division Multiplexing (IPoDWDM)
- Full core H2H IP routing architecture characterized by a single networking/switching layer in the IP domain and simple point-to-point optical infrastructure without the cost and complexity of Colorless Directionless Contentionless (CDC) Reconfigurable Optical Add-Drop Multiplexers (ROADMs)
- Single, unified transport SDN across IP/routing and optical transport infrastructure for:
 - Unified capacity and network planning

- Path optimization
- Service assurance, inventory and element management
- Closed-loop automation

Transformative architectural changes are often disruptive to the present operational constructs of many service providers and thus involve a phased introduction. Service providers would take different paths to reach the envisioned Routing Optical Networking architecture based on the level of change they are willing to operationalize at Day 1.

Solution components of the Routed Optical Networking architecture can interwork with the ROADM-based optical network architectures that service providers have in their network infrastructure today. For example, the

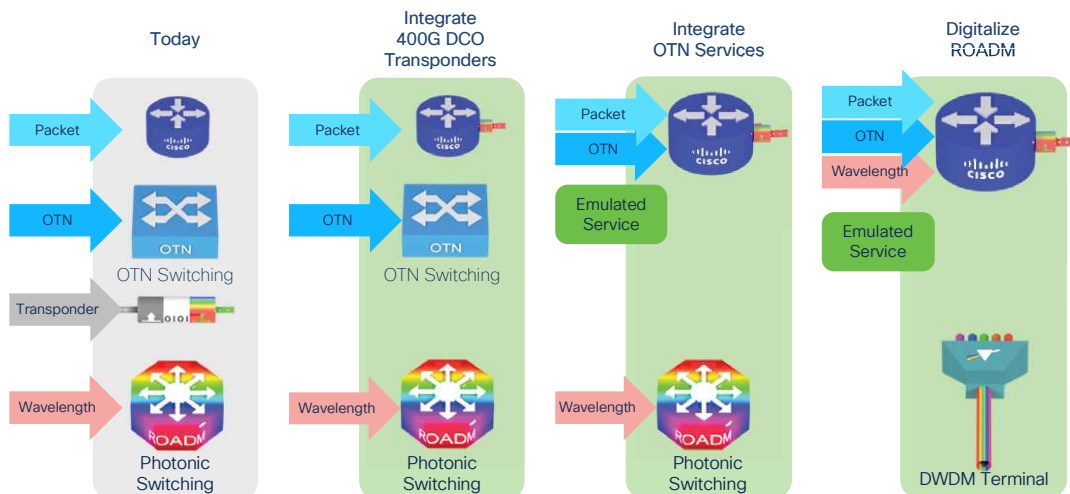


Figure 4 - Routed Optical Network Architecture Transformative Solution Components

coherent DCO optics already supported on the current IP aggregation devices may be leveraged in ROADMs-based infrastructure today. The Routed Optical Networking architecture is defined by two initiatives which address key inefficiencies in the network architectures of today:

1. Integration of 400G transponders function
2. Service convergence via the integration of:
 - a. OTN aggregation and switching functions
 - b. Photonic switching

Routed Optical Networking architecture for service convergence

Many service providers today are focused on the layer of the network to deliver a service rather than on the service itself. The focus on networking layers is largely driven by the assumption that specific Service Level Agreement (SLA) targets could only be achieved in specific networking layers where transport infrastructure could only leverage TDM services that required a distinct independent network silo/overlay. This essentially meant that:

- Private-line services were a challenge that could only be addressed with dedicated resources
- Bi-directional, deterministic services could only be provided via a network layer
- OAM was provided from a network layer perspective
- SLAs were based on layered rather than service availability

Fundamentally, service providers were forced into a position of building layered networks rather than an ideal service-focused network. Multiple efforts are underway to shift away from this model by leveraging technological and organizational enhancements, resulting in:

- CO modernizations led by Cisco where legacy TDM traffic is carried over the packet network with new efforts around high speed private line and OTN services also carried over packet networks with matching SLAs. This modernization effort has been adopted by many of the largest service providers around the world.
- Routing capacity is increasing multifold. We can now achieve greater than four times the largest platforms in a fraction of the footprint and power, as demonstrated by our new single Rack Unit (RU) 14.4TBps router providing unmatched scale: 36³x400Gbps DWDM interfaces compared to 3.6TBps today.

- Universal line cards are used where it is possible to mix and match grey and colored (400GbE ZR/ZR+) optical interfaces by leveraging innovation in optics to realize 400GbE clients in a QSFP56-DD form-factor. This greatly reduces exposure to port density trade-off commonly associated with IPoDWDM line systems and facilitates integration on the service-routing platform.
- Increased flexibility is realized, with multiple set points and multiple degrees of freedom on the optical front. Integration provides the operator with tools that offer assurances for connectivity and performance with an ability to focus root-cause alarms on a problem, whether it be in the router (transceiver), line terminating equipment, intermediate amplifier, or in the outside plant fiber itself.
- Simplified and streamlined operational models enabled by automation and life-cycle management toolkit allow the network to be treated as one rather than as many stitched together.

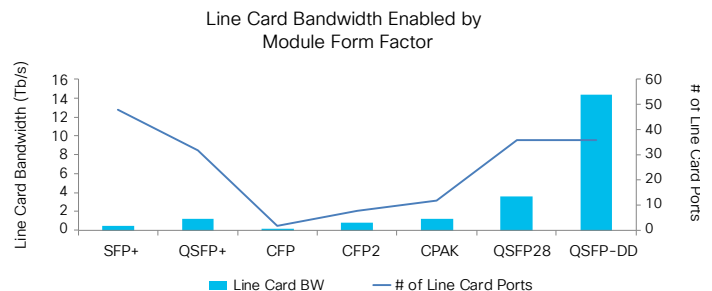


Figure 5 - Routing Line Card Bandwidth Enabled by Optical Pluggable Modules

Architectural changes are required to bring about these benefits by reducing complexity, maximizing capacity, and avoiding inefficient networks. One might argue that SDN is built to address this complexity and hide from the operator; however, the complexity that SDN must overcome is directly related to the inherent complexity within the system. CDC ROADMS have delivered on networking flexibility in the photonic layer, but this flexibility comes at a cost of complexity in Operating Expenses (OpEx). Multi-layer networks add an additional dimension of complexity from an operational lifecycle perspective of planning, protecting, and managing systems.

In order to address the current pain points faced by service providers, we leverage the following principles as guidelines for building the next-generation networks:

- Eliminate Layers:
 - Simplify operational lifecycle
 - Reduce power and footprint
- Advanced circuit emulation for legacy services and high-speed private line and OTN services:
 - Network simplification with single-layer network
 - Meet existing SLAs
 - Provide dedicated Bandwidth (BW) and predictable paths
- Integrate optics at significantly reduced port-density trade-off:
 - 400G price points are changing the game
 - Smaller form factors enabling huge reductions of up to zero density trade-offs relative to grey optical line card port density
 - Path to gain even greater capacity
- Move from a ROADM-based architecture to H2H architecture:
 - Gracefully transition from bypass to H2H networks
 - Provide optimal capacity by shortening end point distances
 - Operational simplification
 - Simplify lifecycle management

simplification. This is accomplished by the collapsing of layers with reduced port-density trade-off optics and eliminating the complexity and redundant nature of layers that add unnecessary switching complexity to a network.

A fundamental impact requirement of optical bypass featured in both the Hollow Core (HC) and the Optimal Bypass (OB) architectures is that it requires leveraging ROADM switching elements in the optical network infrastructure to establish direct routes between routing devices (e.g. direct Provider Edge (PE) device to Provider (P) device) in order to avoid H2H optical connectivity between adjacent routing devices (e.g. PE to PE). This optical bypass feature leverages optical transit on ROADM elements as well as high performance coherent DSP. This ensures optical reach performance to establish feasibility for optical connections between routing devices over challenging (due to distance or quality or both) long-haul fiber infrastructure. This means the HC architecture is much more reliant on leveraging the most powerful coherent DSPs in order to bridge the gap between Moore’s Law and Shannon’s Limit⁴. As many service providers are aware, this trade-off leads to low fiber utilization (monetization). This is due to lower channel count and high network costs attributed to large volumes of regeneration introduced as necessary measures for maintaining performance over large distances. Having the large volumes of required regeneration defeats the primary purpose of the HC architecture, which is to minimize the use of routing line cards as a transport function. In this case, the regeneration function is merely transferred from the routing device to the optical transponder line cards.

The Routed Optical Networking architecture takes advantage of the technology advancements and new capacities being made available to deliver a network optimized around the service. It enables true network capacity optimizations while providing network

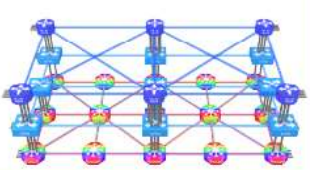
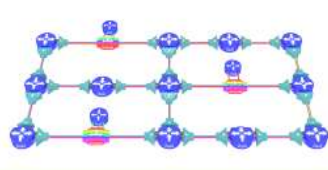
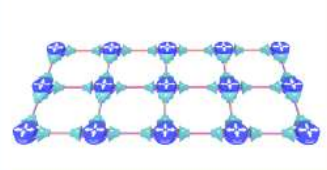
			
Architecture	Hollow-Core	Optimal Bypass	Hop-to-Hop
Distance vs. Capacity	Non-Optimal	Non-Optimal	Optimized
CapEx	High	Medium	Low
OpEx	High	Medium	Low
Scalability	Low	Medium	High

Table 1 – HC to OB to H2H architecture comparison

In contrast to the HC architecture, H2H architecture seeks to avoid the challenges posed by the trade-off between channel capacity vs. performance characterized by Shannon's Limit. It avoids the need for optical connectivity between routing devices over long distances by advocating optical connectivity only between adjacent routing devices.

The H2H approach shows relative savings of 40% over a HC network and an approximate saving of 34% over an OB network. It is true that more interfaces are required, but the advantage of H2H architecture in a Routed Optical network is the ability to leverage lower cost, with capacity optimized interfaces to offset the cost of additional interfaces while simplifying the operational lifecycle.

The Cisco Routed Optical Networking architecture takes advantage of advanced technology and features available today to build a new architecture that scales with technology, enabling a network that will:

- Decrease costs:
 - Models have shown as much as 40% savings
 - Reduction in power consumption and equipment footprint via integration and elimination of redundant network layers
- Network simplification featuring:
 - Single layer H2H network
 - Simplified planning, design, activation, management, and troubleshooting
- Meet and exceed existing SLAs:
 - Circuit emulation to address legacy TDM and private line services
 - Reduction in components, increasing availability and mean time between failure
- Improvement on time to market of new revenue-generating services enabled by:
 - Service-focused network architecture
 - Integrated automation and telemetry functionality
- Optimize fiber capacity utilization via:
 - Less exposure to Shannon's Limit by decreasing the un-regenerated distance and increasing the spectral efficiency (transported bit per symbol)

OTN and private line service emulation

With recent advances in packet switching silicon, Field Programmable Gate Array (FPGA) technology and

stagnating innovation in the space of OTN framers, bit-transparent transport services are better delivered using emulation technology over a high capacity, scalable, and cost-effective packet network infrastructure. This solution, referred to as Private Line Emulation, allows bit-transparent point-to-point connections between a wide range of client ports which include OC-48, OC-192, 1GbE, 10GbE and 100GbE. It also allows for transparent Optical channel Data Unit (ODU-k) connections for Optical channel Transport Unit (OTU-k) client ports.

The connections are established using pseudo-wires in accordance with the Pseudo-Wire Emulation (PWE3) architecture and are leveraging an MPLS or Segment Routing (SR) underlay. This architecture can leverage SR transport with enhancements for circuit-style services to realize flexibility, efficiency gains, and simplicity of SR. This flexibility allows for a single, common SR/ MPLS switching layer for private line services and any other carrier ethernet or IP service offering, reducing networking layers, complexity, and cost.

Topology Independent-Loop Free Alternatives (TI-LFA) is used to provide fast reroute protection to services for failure scenarios including link, node, and local Shared Risk Link Group (SRLG) by leveraging the post-convergence path. TI-LFA relies on SR to build a protection mechanism based on proven (IP-Fast Re-Route) IP-FRR concepts to extend sub-50ms protection to private line services, similar to the 1+1 protection schemes that are commonly reliant on being served from an OTN switching network layer.

Network automation framework

There are two main concepts driving changes in the Routed Optical Networking architecture:

- Direct integration of digital coherent WDM interfaces in the router
- Photonic infrastructure simplification by reducing/eliminating reliance on ROADMs

The direct integration of digital coherent WDM interfaces in the router eliminates the traditional manually intensive service hand-off across the demarcation between the optical transport and packet domains. The result is a single network infrastructure that can be planned, designed, implemented, and operated as a single entity.

Network automation is a key element to plan, optimize, manage, and maintain all the network functions to enable

a true SDN and drive network intelligence on an end-to-end basis. The real-time information of node state and condition is coupled with pre-determined trigger mechanisms for managing and optimizing service routes. The path computation, orchestration, and management toolkits that form the automation ecosystem are open, programmable, modular, operationally ready, and consistent with existing practices.

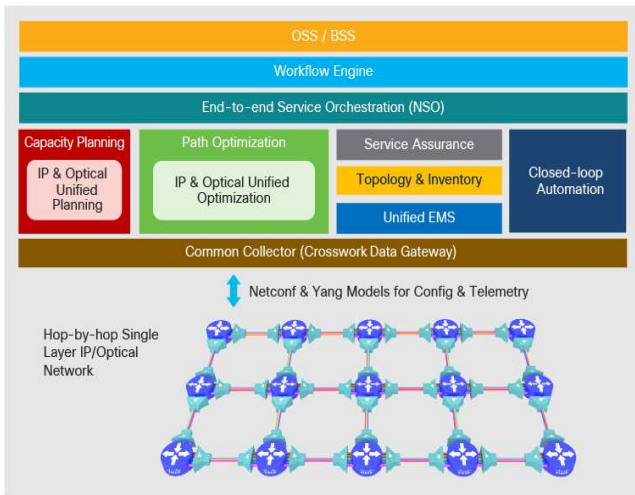


Figure 6 - Network Architecture Enabled Network Automation

The automation architecture includes unified capacity planning, path optimization, and element management for both IP and optical layers. It also includes topology and inventory visualization, service assurance, and closed-loop automation for proactive remediation powered by an end-to-end service orchestration and workflow engine.

IP/optical convergence through optical transponder functions integration

In the past, direct termination of DWDM interfaces on the routing device to eliminate transponders required a coherent DSP to be implemented on the router line card, which occupies real estate on the line card. This resulted in reduced port density and capacity on the router line cards. With the new pluggable coherent optics that incorporate the coherent DSP on the optical pluggable modules instead of the host line card, the maximum router capacity can be maintained with little to no density tradeoffs.

A key pillar of the Routed Optical Network is the integration of the coherent pluggable modules. As router port densities increase, the CapEx spend transitions from the line card ports to the pluggable optics. A key enabler for the scale envisioned in the Internet for the Future is the 400GbE line rate. 400GE coherent optics leverage a multi-vendor Quad Small Form-Factor Pluggable (QSFP) with standardized specifications, which allows interoperability for easier adoption and gains of scale. Previous implementations relied on proprietary Digital Signal Processors (DSPs) on router line cards that were not interoperable or subject to standardization.

400GbE will be featured in the next generation routing line cards which can realize up to 14.4TBps on a single blade. In order to ensure full flexibility, these line cards will support both coherent and grey optical interfaces (or a combination thereof) in the form of QSFP56-DD form-factor pluggables. The use of QSFP56-DD for both coherent and grey optical interfaces can be leveraged

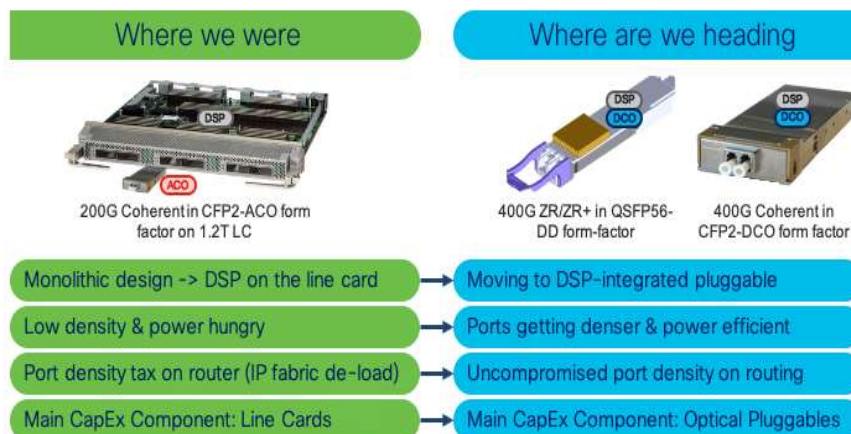


Figure 7 - Evolution of Pluggable Coherent Optics

to limit any tradeoff in terms of port densities and IP fabric capacity commonly associated with coherent optics on routing platforms (previously referred to as IPoDWDM). This means that a specific line card required to host coherent DWDM optical interfaces will no longer be required. A universal line card which can be flexibly deployed to support the termination of coherent DWDM, or grey optical line interfaces, can be realized. While the maximum number of 400G ZR/ZR+ ports (via QSFP56-DD) on a single coherent line card is limited by the optical power budget and characteristics associated with the line, the 400G ZR/ZR+ line card can still support significantly higher port densities than what is feasible on the previous generation CFP2-DCO-based coherent DWDM line cards.

QSFP form-factor has been widely leveraged in the industry and Cisco has been a key contributor in promoting QSFP-DD Multiple Supplier Agreement (MSA) through the Optical Internetworking Forum (OIF) as well as other standards organizations. QSFP56-DD is strategic in the realization of 400GbE and specifically for 400GbE ZR+. It is capable of dissipating the heat associated with the ZR+ interface as it incorporates the coherent transmission required to establish longer distance optical reach at the 400G line rate.

Evolution of Digital Coherent Optics

In the IP aggregation application space, IP/optical integration can already be served by leveraging IP aggregation devices which feature Modular Port Adapters (MPA) and Digital Coherent Optical (DCO) pluggable modules. The integration of DCO modules allows the direct termination of coherent DWDM interfaces directly into the IP aggregation devices without incurring the cost and complexity of optical transponder line cards. While the integration of CFP2-DCO modules into routing devices has already been leveraged to address key networking pain points in the IP aggregation space, the port densities associated with CFP2-based optics are too low compared with the QSFP pluggables employed in their grey optical line card counterparts to offer the similar TCO savings. This is primarily because in the IP aggregation space, typically a small number of 100G/200G line interfaces are terminated at each aggregation site which does not lead to significant deloading of the IP fabric. However, in the case of core/edge applications, the volume of traffic is significantly

higher and therefore core/edge aggregation devices leveraging current DCO line cards are more prone to IP fabric deloading arising from lowered port density.

Current port densities on core/edge routing devices are in the order of 3.6TBps per line card⁵. This level of port density scale on grey interface port line cards is a challenge to match with coherent line cards because current ACO/DCO implementations are limited to the CFP2 pluggables. These pluggables require a larger footprint compared with the QSFP modules leveraged in the grey interface line cards. Therefore, the use of CFP2-ACO/DCO line cards for the termination of significant volumes of traffic in core/edge applications could introduce significant levels of IP fabric deloading. This remains a temporary issue as we transition from the use of DCO interfaces from a CFP2 form-factor to one leveraging QSFP56-DD which offers a much smaller footprint that can also be leveraged for grey client interfaces.

Learn more

Visit cisco.com/go/optical

Endnotes

- ¹ [Cisco Annual Internet Report \(2018–2023\) White Paper](#)
- ² *Cost considerations commonly associated with the Capital Expenditures (CapEx) as well as the Operating Expenses (OpEx) of owning and operating the network*
- ³ *This is the maximum number of coherent 400Gbps channels that can be accommodated on a single line card. The actual number of coherent DWDM ports that can be accommodated is determined on the optical power budget imposed on the optical channels terminating on the line cards.*
- ⁴ *Moore's Law vs. Shannon's Limit: Moore's Law is a representation of the service capacity growth trends in a service provider's network whereas Shannon's Limit defines the upper limit with regards to the capacity of the optical transport network to carry the service. An implication of Shannon's Law is the trade-off between optical performance (reach characterized by optical signal to noise ratio) and error-free digital capacity that can be transported over the optical network; the shorter the optical reach (distance), the higher the digital channel capacity.*
- ⁵ *Cisco NCS 5500 36x100GbE Service Line Card*