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White paper

The role and importance of automation in converged SDN transport networks

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RESEARCH

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1. Executive summary

Consumers and enterprises continue to use innovative digital services that create increasing volumes of data traffic every day. As a result, service providers will need to redesign their network architecture to respond to customer demands for robust networks with high speeds and bandwidth, and reliable connectivity. Converged and automated transport networks could be a solution to simplifying network operations and optimising management workloads, therefore enabling service providers to rapidly launch new revenue-generating services and reduce network total cost of ownership (TCO).

Service providers are evolving their network architecture from traditional multi-layer networks to a converged transport network by integrating both optical and IP transport infrastructure to reduce complexity and cost of running separate network domains. These converged networks can be further enhanced by software-defined networking (SDN) capabilities to enable services such as network slicing and network-as-a-service (NaaS) to improve the agility, flexibility and scalability of converged transport networks.

Automating the fulfilment and assurance processes of the converged SDN network will enable use cases such as closed-loop automation of operational workloads, automated service provisioning and network resource management to help service providers to improve operational efficiencies. Furthermore, SDN controllers can be built upon AI/ML-driven advanced data analytics to provide near real-time telemetry and network visibility for service providers to gain deeper insights into network performance and hence configure services based on shifting network capacity and customer needs.

Service providers that deploy automated converged IP/optical networks will simplify the planning, designing, deployment and operating stages of the network lifecycle process, benefit from increased capex and opex efficiency, and deliver innovative use cases to accelerate digital transformation across enterprises and industries.

2. Service providers are preparing for the next big rise in data consumption driven by cloud, IoT and 5G

Service providers are in the midst of a transformation journey to modernise their business. Initiatives such as the move to digital channels, network convergence and cloudification, and network automation are top priorities for service provider CxOs. The COVID-19 pandemic has accelerated some of these initiatives. According to a report by Analysys Mason, service providers fast-tracked many of the existing transformation initiatives in 2020.[1] Our analysis is further supported by a report by McKinsey & Company, which concluded that COVID-

[1] For more information, see Analysys Mason's *The pandemic has not led to many strategy changes for operators, but some aspects require a rethink*.

19 had accelerated the digital transformation of many business functions across enterprises and industries by at least 3–4 years.[2]

2.1 Key market developments are reshaping service provider priorities

The proliferation of edge clouds, the rapid increase in the adoption of cloud-based services, the massive increase in the production and consumption of high-definition video, the increasing interest in IIoT and industrial automation, and the roll-out of 5G standalone technology will cause the volume of data to continue to surge in the next decade.

The role of the service provider network as the backbone of the modern internet supporting these services has never been more critical. Businesses and consumers expect service providers to continue to support these new-generation data-hungry services while improving on the quality of service, latency, service performance, and availability. On the other hand, service providers will be under significantly increased pressure to reduce the cost per bit and the total cost of ownership of their networks to stay profitable and meet customer expectations at the same time.

2.2 Service providers need to rethink how they will achieve significant network TCO reductions

Service providers have indicated that they plan to significantly reduce capex in the next 5 years on legacy networks and divert investments to modern networking technologies that will enable them to reduce total cost of ownership and increase revenue. Some of the new network investment areas include cloud infrastructure, software-defined control and management, next-generation transport and backhaul networks providing programmability and higher capacity, and white box routers and switches.

Service providers are also under pressure to reduce opex and protect margins as revenue growth slows and new competitors emerge. This has been challenging at a time when operators have needed to expand their networks and IT platforms just to support the existing revenue streams. Consolidation and the introduction of some efficiencies have driven opex down on a per-unit basis (per-subscriber or per-cell site, for instance) for some operators, but sustained reductions in absolute opex have proved elusive. Our research shows that absolute opex efficiencies will be achieved through a plethora of approaches, including asset sharing, deploying networks in more cost-effective way and through increased automation.[3]

3. IP/optical convergence with network automation paves the way to transforming network economics

Traditional high-bandwidth networks are based on a multi-layer multi-domain architecture consisting of separate optical and IP/MPLS networks. While this architecture has served the purpose well for many years,

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2 Refer to McKinsey & Company report: https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/how-covid-19-has-pushed-companies-over-the-technology-tipping-point-and-transformed-business-forever.

3 For more information, see Analysys Mason's report *Telecoms opex: worldwide trends and forecast 2017–2026*.

service providers think that the economics of running these as separate networks may not be sustainable as data traffic explodes with cloud and 5G.

There have been past attempts to combine the optical and IP networks, but technology limitations made it difficult to commercialise at scale. However, new innovations in the routing and optical technologies are presenting another opportunity to make converged IP and optical networks a reality. For example, the digital coherent optical modules have reduced in size and power consumption allowing the modules to be plugged directly into the routers. The latest routers with 400G ports offer significantly higher capacity and scale. In addition, routing technology innovations such as segment routing, path computation and the disaggregated control plane introduce network programmability for dynamic traffic management.

Telia Carrier announced in December 2020 that it plans to migrate away from a multi-layer to a converged IP-optical network. The much-simplified flat IP network will be built using 400G coherent modules plugged directly into routers. Telia said that this new simplified architecture enables them to drastically reduce capex and opex and prepares them to address the expected increase in demand for higher bandwidth in the coming years.

Source: Telia Carrier

With converged IP/optical networks, service providers can overcome some of the traditional drawbacks of deploying and operating a multi-layer network architecture. Some of these benefits are highlighted below.

- Create a lean organisation by collapsing departmental silos that have traditionally existed for IP and optical networks, including engineering, operations and architecture teams. Functioning as separate teams has led to longer lead times for planning, designing, deploying and operating these networks.
- Increase capex and opex efficiency by building highly simplified and cost-efficient networks, supporting them using a combined operations team and management systems.
- Collapse the separate control planes and benefit from the increased information sharing between the layers; standardise on open APIs that promote software defined control of multi-vendor networks.
- Deploy new generation management and control software to automate the converged network and simplify operations.
- Increase service and operations agility by improving the service turn-up times and reducing troubleshooting times caused by task duplication, process repetitions and inefficient operations.

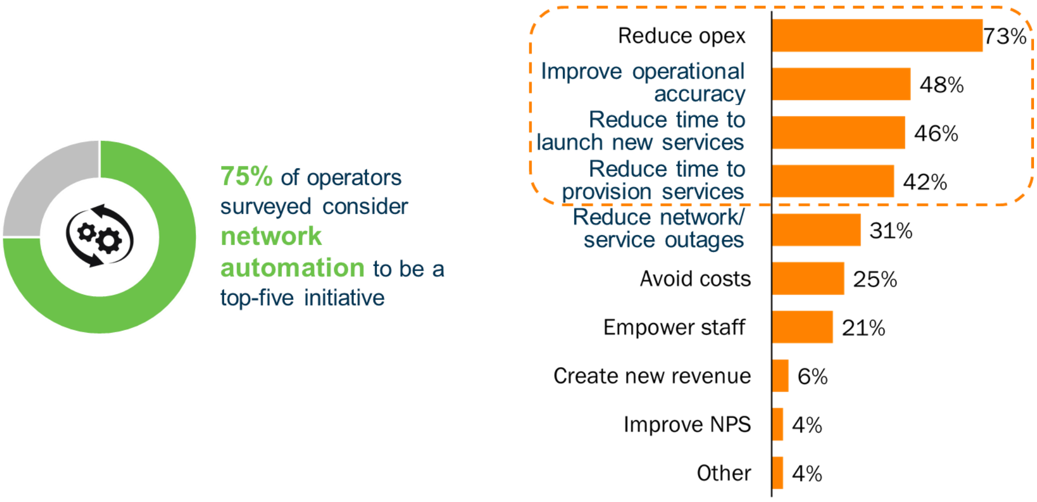
3.1 Network automation will be critical to deliver the operational benefits of network convergence

Many of the operational benefits discussed above cannot be achieved without a significant rethink of the management and control architecture, both in its current state and how it must evolve to support network convergence. Service providers that are on the path to IP and optical network convergence know that the full migration will take many years and will occur in a stepwise fashion rather than a ‘big bang’.

There is also broad consensus that service providers will need to continually automate the network management and operations processes to manage network complexity during the intermediate stages of the network evolution towards network convergence. The evolution of the management and control layer therefore must align with the network evolution and provide the most suitable automation capabilities depending on the stage of the evolution.

In an Analysys Mason survey on network automation, about 75% of the service providers noted that network automation is a top-5 business initiative. About 73% of the panel said that reducing opex was their primary aim for network automation, which is in line with the need to transform network economics. However, network automation is also critical to achieve service agility – about 46% of the service providers said they are using automation to reduce time to provision or launch new services, and we believe this is the new frontier for service providers as they look at new monetisation strategies in the 5G era.

Figure 1: Network automation is critical to achieve the benefit of network convergence



Source: Analysys Mason

Some of the key benefits of network automation in the context of converged IP/optical networks are discussed below.

- The automation of the highly manual processes such as network planning, service fulfilment and assurance can deliver opex savings, which can further boost the expected benefits from converged IP/optical networks. Service providers can reinvest the cost savings achieved by automating these processes back into the business to strengthen strategic initiatives such as network convergence. It also allows for the existing staff to be reskilled and reassigned to higher-value activities such as service design and innovation.

- Other network engineering and operational processes such as network discovery, creation and maintenance of network inventory and topology are highly sensitive to the quality of the network data. Automated network discovery of the converged networks and automated recording of the inventory and topology data prevents human error and increases the data accuracy, which can then be consumed during service fulfilment and assurance with a high level of confidence.

- Obviating manual interventions in processes such as provisioning a private-line service or a layer 3 VPN service in converged networks not only improves workforce productivity but also reduces the time to provision these services, in turn reducing the time to revenue.

- Automating native network processes such as traffic steering in a converged network based on near real-time policy enforcement and AI/ML-driven insights leads to efficient allocation of network capacity, and optimisation and utilisation of the network assets. It also reduces the need for overprovisioning bandwidth and allows service providers to 'sweat the assets' resulting in deferred capacity upgrades and efficient capex allocation.

- Open APIs and model-driven abstraction of the existing multi-layer, multi-vendor network provide a roadmap for network evolution to a converged IP/optical network with less risk of business disruption during the migration. It also allows service providers to avoid vendor lock-in to deploy a best-of-breed network and improve their ability to manage existing network complexity while preparing them for the network disaggregation with an increased use of software-based network control.

- Powering the converged network with programmability such as SDN controllers enables service providers to offer on-demand differentiated services based on network slicing and network-as-a-service (NaaS) capabilities, which allows faster, more-automated, and agile creation, delivery, modification, and termination of network services. Through these automated capabilities, service providers can meet the capacity and low latency demands of new services such as AR/VR, robotics and industry 4.0 use cases.

- Automation of the fulfilment and assurance processes of the converged network also enables service providers to provide a self-service experience to their customers, allowing enterprises to order, provision, monitor and modify their services on-demand through an easy-to-use online portal, much like the way enterprises consume cloud-based services such as infrastructure and software as-a-service today.

According to a quantitative study[4] conducted by Cisco, network automation can deliver significant time and cost savings by improving the efficiency of various business processes such as new customer adds, incident resolution, change requests, service disconnections, and network maintenance. The overall savings in time was estimated to be in the range of 60–70% with the related opex avoidance of 50–70%. In terms of real dollar value, the saving over 5 years was estimated to be in the range of USD3 million to USD16.7 million for smaller (Tiers 3 to 5) service providers, and as high as USD70 million for Tier 1 and 2 service providers.

4. A stepwise network automation approach for converged IP/optical networks

Service providers that are planning to roll out converged IP/optical networks need to assess the current state of their network control and management architecture and put in place a network automation roadmap to align with their network evolution strategy. Figure 2 illustrates an example of a roadmap that service providers can adopt. It starts with the automation of a given vendor domain and layer (for example, IP/MPLS), followed by automation of the multi-vendor network. Some of the benefits of such a roadmap are that it:

4 Source: Cisco; the quantitative benefits mentioned here are based on an ROI model developed by Cisco.

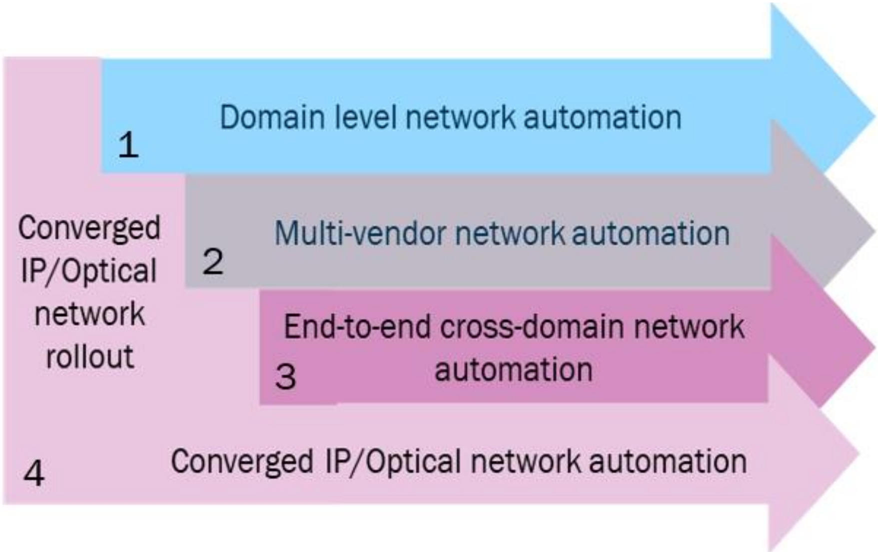
- alleviates the risks and avoids the common pitfalls of large transformation projects by enabling incremental automation of high-priority use cases that provide the best return on investment

- simplifies the management layer by introducing layered model-driven network abstraction and control through the use of standard data models and open APIs

  - decouples the underlying network from the higher-layer OSS, providing service providers with a high level of flexibility to execute network transformation (for example, by introducing a converged IP/optical network) and OSS transformation (for example, OSS modernisation), that are independent of each other.

The following sub-sections discuss the stages for the automation roadmap in detail.

Figure 2: Network automation roadmap for converged IP-optical networks

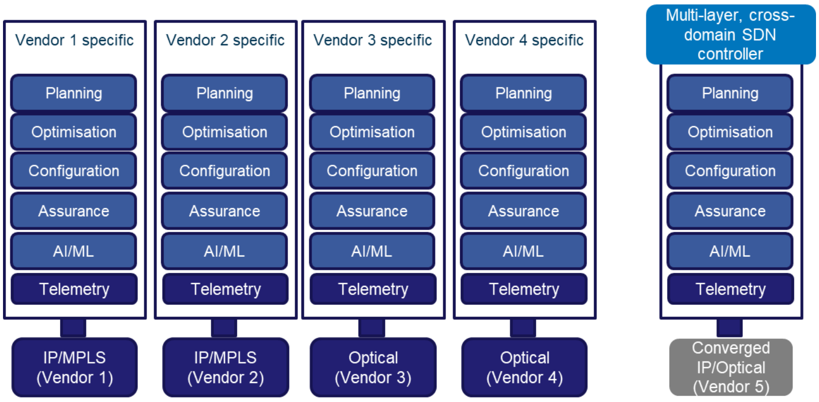


Source: Analysys Mason

4.1 Achieving domain-level network automation

Domain-level network automation provides the ability to fully automate the vendor-specific IP and optical domains, by combining all the management and control components needed for unified, closed-loop and self-sufficient operations of that domain (Figure 3).

Figure 3: Domain-specific automation



Source: Analysys Mason

Domain-specific network automation is achieved through SDN-enabled network management systems or an SDN controller, that includes capabilities such as dynamic traffic optimisation. Domain-specific SDN management and control tend to be vendor specific solutions that are engineered for a vendor's own IP or optical equipment and provides a straightforward migration path for service providers looking to make the transition to SDN.

The IP or optical domain SDN controllers are increasingly offering a plethora of network telemetry and AI/ML-based applications such as network planning, network health monitoring, optimisation, and closed-loop assurance, just to name a few. Most service providers that are on the path to network convergence are introducing domain specific SDN controllers as a first step in their network automation journey. This approach not only provides the basis for operationalising fully self-contained autonomous network domains but also acts as template for replicating easily across various domain before progressing to the next stages of the automation journey.

Furthermore, it allows service providers to gradually introduce the converged IP/optical network and treat it as just another domain for automation by following the same principles of telemetry based SDN control and management. However, in this case, service providers have an opportunity to make a big leap by deploying a multi-vendor, multi-layer cross-domain SDN control platform to future proof their network management and operations. The platform provides a highly simplified management architecture with out-of-the-box capabilities for managing a multi-vendor converged IP/optical network. Importantly, it also paves the way for a horizontal expansion of the platform to gradually take on the management of the existing silos as an overlay hierarchical SDN controller.

4.2 Achieving multi-vendor network automation

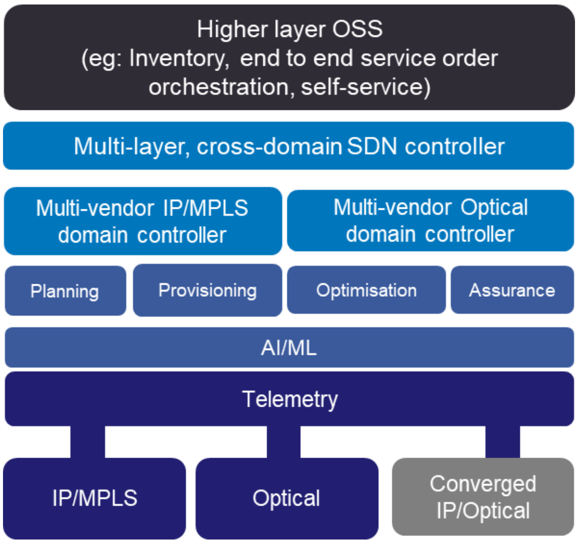
Multi-vendor network automation combines disparate vendor domains and enables service providers to rationalise and simplify the underlying silos with a common, programmable management and control layer. Standardisation of interfaces and service models are crucial to achieve this. To this end, vendors, standards bodies and service providers are closely working together to agree on a common set of standards. The multi-vendor network automation platform will not immediately replace the vendor-specific domain controllers, but it does provide a roadmap for full end-to-end automation (section 4.3), and offers a unified view of the entire domain (IP/MPLS or optical) by assessing the specific constraints of the relationships between the various vendor networks in that logical domain and converging their control and management with a multi-vendor centralised planning, optimisation, configuration, and assurance functions combined with AI/ML.

As service providers continue to make progress on consolidating the management layer for existing network domain silos, they can expand the scope of the umbrella multi-layer multi-vendor SDN controller if it was already introduced during the deployment of the converged IP/optical network.

4.3 Achieving end-to-end hierarchical cross-domain network automation

At this stage, the service providers should now be ready to extend the multi-layer SDN control platform to manage all of the existing IP/MPLS and optical network domains in addition to the new converged IP/optical network domains. The multi-layer SDN controller together with the multi-vendor domain SDN controllers introduces a hierarchical SDN controller architecture providing an end-to-end view (both horizontal and vertical) of the transport network combining the IP/MPLS and optical domains and providing an abstracted network view of the higher-layer OSS systems. The hierarchical network abstraction approach greatly simplifies service provider's transport network management allowing them to accelerate OSS transformation independent of the network evolution.

Figure 4: Hierarchical SDN controller architecture for converged IP/optical networks



Source: Analysys Mason

Use case-driven incremental approach to implementing end-to-end network automation

The transformation to an end-to-end cross-domain automation platform demands a steep learning curve and can be daunting at the start. To achieve success, service providers must treat the transformation as an incremental journey and execute it based on detailed use cases, supported by feasible business cases.

Service providers that are considering deploying converged IP/optical networks will be able to de-risk the transformation by considering a similar use case-driven incremental approach to end-to-end automation. Service providers can prioritise simple use cases to start with, and build the foundation for more advanced use cases, as listed below.

Figure 5: Use cases for hierarchical SDN controller

Simple automation use cases	Advanced automation use cases
Network and service discovery	Bandwidth on demand
Inventory and topology modelling	Closed-loop automation
Automated service provisioning	Real-time network optimisation
AI/ML-based monitoring and assurance	Network slicing
Service migration	Disaster recovery
Capacity management	Automated change management
CI/CD and DevOps	

Source: Analysys Mason

4.4 Standards-based interfaces will enable vendor-agnostic implementation of the hierarchical multi-layer transport network automation

Standards allow the key ecosystem stakeholders such as service providers, network equipment providers, software vendors and systems integrators to deploy highly interoperable networks and multi-vendor operational systems. This also allows rapid operationalisation of new products and services in production environments at scale and enables service providers to implement a best of breed networks and software systems. Industry bodies such as the IETF, LF Networking, MEF, ONF, ETSI and TM Forum, have worked towards defining interface specifications, service models and automation frameworks for SDN-enabled programmable transport networks. However, because of the sheer number of standards bodies involved and the lack of deep collaboration, the efforts have led to standards fragmentation, proprietary implementations, and slow overall progress.

More recently, there has been a concerted industry effort to collaborate and agree on a common set of standards for the hierarchical SDN control architecture. For example, the multi-vendor SDN domain controllers will communicate with the cross-domain SDN controller using standard northbound interfaces.

- The IP/MPLS SDN controller will use IETF-based standard APIs, and service models based on RESTCONF/YANG and OpenConfig provisioning models.

- The optical SDN controller will use the ONF Transport-API (T-API) and its associated common information model.

Another industry effort, led by communications service providers (CSPs) is underway. Six leading operators, Deutsche Telekom, MTN, Orange, Telefónica, Telia Company and Vodafone have teamed up as part of a new sub-group called MUST (Mandatory Use Case Requirements for SDN for Transport)[5] under TIP's Open Optical and Packet Transport project group. The key goal is to accelerate the adoption of SDN-based automation in IP/MPLS, optical and microwave transport technologies. At the heart of this initiative is the adoption of vendor-agnostic open and standardised APIs such as RESTCONF/YANG, OpenConfig and T-API, which allow CSPs to build a best-of-breed hierarchical SDN controller platform.

The consortium also focuses on driving incremental automation based on clearly defined use cases (as described in Figure 5) giving service providers the opportunity to achieve early success and realise the operational benefits in much shorter timescales. This is achieved through a well-defined process where the service providers

5 See https://telecominfraproject.com/6-major-operators-to-drive-sdn-for-transport-adoption-and-acceleration-through-telecom-infra-project/.

describe the use cases in a significant level of detail in specification documents, which are then used for the vendor RFP process and software implementation in production networks.

4.5 Key service provider stakeholders stand to benefit from implementing the hierarchical cross-domain SDN controller

Various service provider stakeholder departments can benefit differently from the hierarchical SDN controller, and the type of benefit can vary according to the stakeholder in question. A representative set of stakeholders and their benefits are discussed in Figure 6.

Figure 6: Benefits for different service provider personas

Persona	Benefits
Network engineer	• Unified one true source of network inventory and topology for IP and optical networks, reducing the time for capacity planning. • Real-time network optimisation across layers. • Zero-touch service provisioning.
Operations engineer	• Single pane of glass for IP and optical networks for monitoring alarms and faults reducing time to identify issues. • AI/ML-based root-cause analysis and troubleshooting reducing mean-time to resolution. • Closed-loop automation.
Network strategist and CFO	• Network decoupled from OSS enabling independent evolution of network (network disaggregation, virtualisation etc) with minimal dependency on OSS. • Reduced TCO due to better network capacity utilisation.
Operations strategist	• Centralised network automation platform for rapid feature introduction and application innovation. • Own and control the standards-compliant operational blueprint architecture enabling best of breed SDN control and management vendor lock-in

Source: Analysys Mason

5. The hierarchical SDN controller software must demonstrate five key capabilities

According to Analysys Mason, the hierarchical SDN control software and related professional services spending by service providers worldwide will grow from USD351 million in 2029 to USD2.7 billion in 2025, at a CAGR of 40%. From an architecture perspective, our research shows that the SDN controller software solution must demonstrate a set of key attributes (Figure 7).

Figure 7: Key capabilities of the hierarchical SDN control

Capability	Description
Multi-domain/multi-layer support	End-to-end, unified view, automated and policy-based control and management across multiple network domains (IP, optical and

Capability	Description
	microwave), regardless of which vendor supplies which network component.
Traffic steering/engineering	Near real-time computation of traffic paths and intelligent routing (for example, path computation engine (PCE) and segment routing (SR)) across multiple network layers to improve utilization, avoid congestion and provide differentiated SLAs.
Multi-vendor configuration	Automated distribution (and, if needed, rollback) of network element configuration using model-based abstractions and standard protocols (for example, YANG/NETCONF) or REST APIs.
Network lifecycle management	Network planning (supporting 'what-if' analysis and 'just-in-time' capacity management and optimisation capabilities), network management, monitoring, assurance, and provisioning.
AI/ML-based network analytics	Support for real-time telemetry with the ability to collect, consume and aggregate data from multiple sources and vendor devices using standard flow control protocols, IPFIX and gRPC. Support for AI/ML models and algorithms to achieve predictive operations and optimisation.

The hierarchical SDN controller combines the network control with OSS management functionalities. However, it is important for service providers to have clear separation of responsibilities between the control layer and the management layer; the control layer must be lightweight to meet the high-performance and near real-time requirements of network control such as PCE and SR, whereas the management layer can provide the offline functions such as network planning, provisioning, optimisation and assurance.

The decoupled nature of the control and management functions provides flexibility for service providers to deploy a best-of-breed multi-vendor SDN controller architecture. However, to achieve maximum benefits of such a deployment, service providers should also look for certain key solution characteristics (Figure 8).

Figure 8: Key features of the hierarchical SDN controller solution

Feature	Description
Modularity	The platform should be flexible enough to allow plug and play and swapping of modules at varying levels of granularity depending on the service provider's need, for example, the PCE or management applications (assurance and planning).
Openness	It should open northbound and southbound interfaces/APIs with minimal integration effort. Large ecosystem support with open APIs, SDKs and a developer community would provide additional value.
Standards- and model-based	Support for industry standard data modelling languages, protocols, and APIs such as those from MEF, TMF, IETF and ONF as well as compatibility with legacy SNMP/CLI-based operations.
Extensibility/gradual deployment	Service providers need a flexible and adaptable software solution to enable them to incrementally cover additional services and domains over time. This will also require legacy/backwards compatibility with existing infrastructure.
Cloud-native platform architecture	Built using a set of common and shared micro-services/functions to enable rapid onboarding of new features and functions to meet future requirements. It should also support various deployment models including on-prem and cloud-hosted and provided in a software-as-a-service (SaaS) licensing model.

Source: Analysys Mason

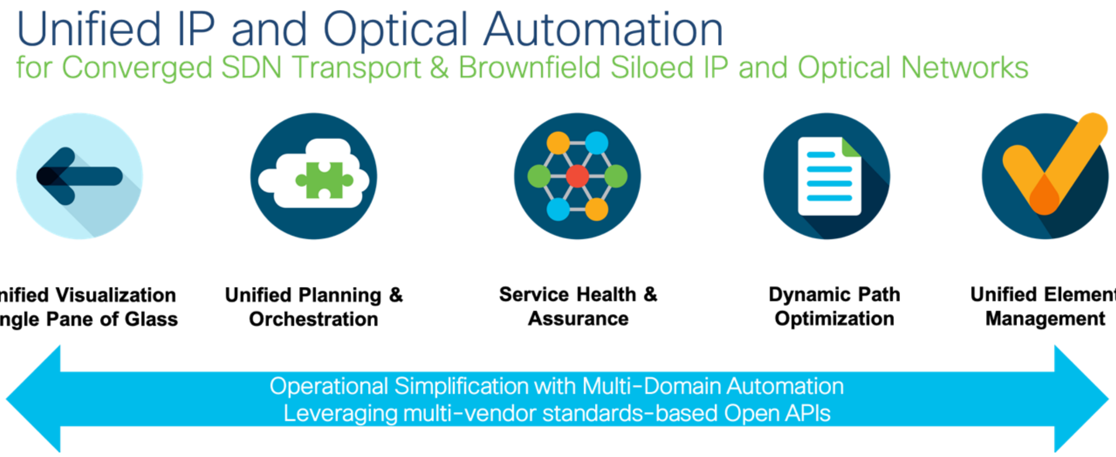
6. Conclusion

Service providers that deploy converged IP/optical networks will achieve important operational benefits of a simpler, more efficient network architecture. Deploying a hierarchical SDN controller will help those service providers to increase the level of automation, reducing the required manual labour and improving responsiveness to new requirements. Service providers should select and deploy a hierarchical SDN controller with the capabilities called out in this report to get the maximum benefit.

7. Cisco's network automation solution

Cisco's Converged SDN Transport automation solution focuses on delivering the key functions in Figure 9 to reduce the opex of managing IP and optical networks, optimize the capex spend and enable faster time-to-market by automating service roll-outs.

Figure 9: Cisco's Converged SDN Transport Automation key functions



Cisco's automation solution for converging the IP and optical layers closely follows the standards-based architecture described in this paper. It consists mainly of the following Crosswork automation components:

- A hierarchical controller – Cisco Crosswork Hierarchical Controller, powered by Sedona's NetFusion
- A multivendor IP controller – Cisco Crosswork Network Controller (CNC)
- An optical controller – Cisco Optical Network Controller (CONC)
- An element management for IP and optical – Cisco Evolved Programmable Network Manager (EPNM)
- A planning tool for IP and optical – Unified planning powered by Cisco WAN Automation Engine (WAE)

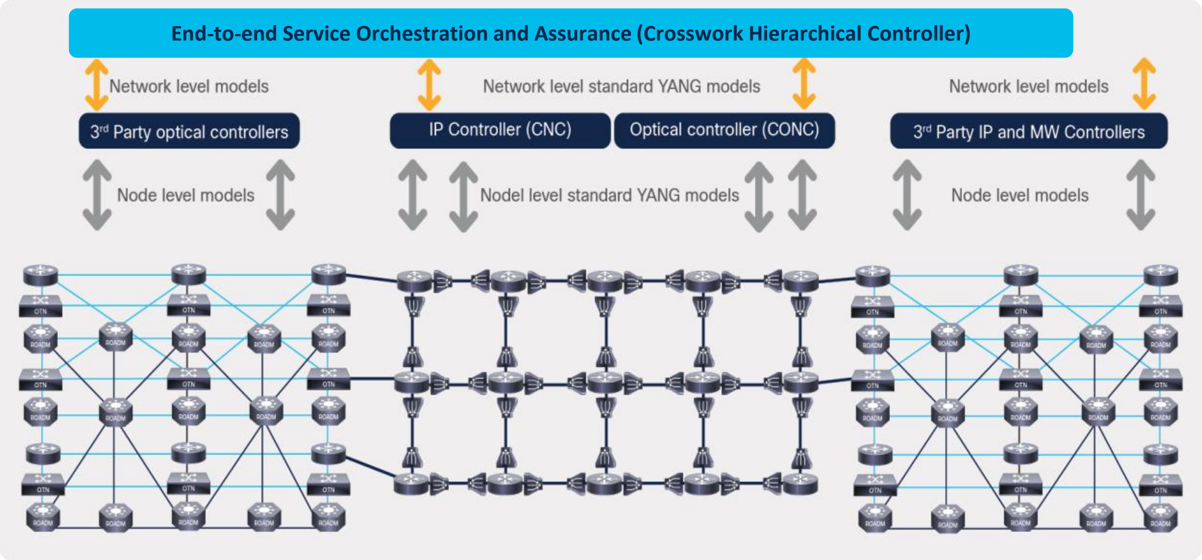
Crosswork Automation Solution Components

Crosswork Automation's controller architecture aligns to industry standards that define an IP domain controller, optical domain controller. and a hierarchical controller. The Crosswork controllers interact via standard interfaces based on IETF for the IP layer and Telephony Application Programming Interface (TAPI) for the optical layer, as shown in figure 10 below.

Hierarchical Controller

The operation of the Cisco IP + optical domain is performed through a single pane of glass provided by the Crosswork Hierarchical Controller. The Crosswork Hierarchical Controller provides a real-time replica of the entire network (aka "digital twin") to predictively understand any changes to the deployment, connectivity, and operations status of all network resources. This real-time view is leveraged to achieve optical path selection for new services as well as optimization of existing services.

Figure 10: Role of Cisco Crosswork Hierarchical Controller in the converged SDN transport architecture



Beyond the standard functionality expected from a hierarchical controller, Cisco Crosswork Hierarchical Controller goes the extra mile of simplifying the operation of integrated IP and optical networks. This is accomplished by simplifying the task of troubleshooting analog Dense Wavelength Division Multiplexing (DWDM) systems with the help of historical data and ML-based analysis of the data. It also provides easy-to-use assurance tools for services that reside on the network and allows customers to ask complex questions about network and service state via a simple query language. They can then use those results to build their own layer of reporting, analysis, and assurance tools around the solution.

A key distinctive attribute of the Cisco solution is the ability to tailor it to specific service provider needs. This can be done by implementing customer-specific service configuration models inside Crosswork Network Controller and Cisco Optical Network Controller, thanks to the use of Cisco Network Services Orchestrator (NSO) as the provisioning engine in these controllers. As the industry-leading service configuration tool, NSO brings the experience and richness of capabilities that do not typically exist in other, relatively new SDN controllers.

Last but not least, the simplicity of managing the Converged SDN Transport domain in a unified and consistent manner can be extended to the other domains by connecting the Cisco Crosswork Hierarchical Controller to their respective domain controllers.

IP Domain Controller

The Crosswork Network Controller is the multi-vendor IP domain controller in the architecture.

Cisco's Network Controller combines intent-based network automation to deliver critical capabilities for IP service orchestration and fulfilment, network optimization, service path computation, device deployment and management, and fault remediation. The Cisco Crosswork Network Controller realizes several outcomes:

- Visualize IP network and services inventory.
- Segment Routing (SR) and SRv6 policy provisioning with explicit intent (for example, bandwidth constraints, latency minimization, etc.) simplifying 5G network slicing.
- IP services provisioning (for example, L2VPN, L3VPN services with associated routing policy).

- Collect real-time performance information and optimize the IP network to maintain the service intent. Tactically optimize the IP network during times of congestion with bandwidth optimization service.
- IP service health and assurance for service visibility versus intent, dynamically tying KPIs and fault root cause analysis.
- Migration from legacy to new IP networks (for example, device migration to replace older network devices with newer ones, migration from RSVP-TE to SR-TE, etc.)
- Ability to build customer-specific IP services and applications leveraging the APIs and telemetry data.
- Automation of IP network Method of Procedure (MOP) for remediation and maintenance tasks.

Optical Domain Controller

The Cisco Optical Network Controller (CONC) is the Cisco optical domain controller. It collects optical data to provide network information in an abstracted format to the hierarchical controller to enable centralized control.

- Cisco Optical Network Controller supports a standardized TAPI model.
- It monitors the optical network, collects optical topology, and provisions/tears down optical circuits.
- Its Path Computation Element (PCE) service provides optical path computation.

IP and Optical Element Management

Crosswork Automation provides unified IP and optical element management via the Evolved Programmable Network Manager (EPNM). EPNM provides the below functions in a Converged SDN Transport architecture:

- Device Lifecycle Management: rich inventory configuration and visualization providing full device visibility, end-of-life reports for network audits, and interactive chassis views with deep device discovery.

- Software Image and Configuration File Management: configuration management, including backup of the configurations in a centralized database, software download and activation. It offers configuration compliance based on a golden network configuration for network audits and remediation.

- Monitoring Performance and Fault: performance metrics collection, correlation, and fault event processing, along with KPI monitoring and device-level alarm management with a single dashboard.

- Troubleshooting: device-level and service-level troubleshooting tools, MPLS OAM tools,Y.1731, Y.1564, and IP SLA for service testing and monitoring.

IP and Optical Planning

A key to managing converged IP and optical networks is having a unified IP and optical planning tool. The Crosswork unified planning solution for Converged SDN Transport is powered by the Cisco WAN Automation Engine (WAE). It provides the tools for capacity planning, failure analysis, and traffic engineering, as well as analysing network health and traffic trends.

Crosswork's unified planning enables service providers to improve traffic distribution, identify vulnerabilities, and mitigate risk. Used worldwide by network planners and engineers, its streamlined workflow and highly interactive interface enables providers to accurately model the network and quickly accomplish planning tasks to improve network efficiency and operational costs under different network stress conditions.

Cisco's automation solution for Converged SDN Transport focuses on simplifying the operations of converged IP and optical networks, while also allowing service providers to manage with the same stack existing brownfield networks that have siloed IP and optical domains to enable a seamless transition. The solution has open APIs and aligns to industry standards to manage multi-vendor, multi-layer, and multi-domain networks.

8. About the author

Anil Rao (Research Director) is the lead analyst on network and service automation research that includes the Network Automation and Orchestration, Automated Assurance and Service Design and Orchestration research programmes, covering a broad range of topics on the existing and new-age operational systems that will power operators' digital transformations. His main areas of focus include service creation, provisioning and service operations in NFV/SDN-based networks, 5G, IoT and edge clouds; the use of analytics, ML and AI to increase operations efficiency and agility; and the broader imperatives around operations automation and zero touch networks. Anil also works with clients on a range of consulting engagements such as strategy assessment and advisory, market sizing, competitive analysis and market positioning, and marketing support through thought leadership collateral.

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