



From dark to smart fiber: Adopting MOFN for the AI era

White paper

Transport networks are evolving to meet the growing demands associated with artificial intelligence (AI) traffic and cloud computing services. This has created a paradigm shift in the business model for network operators, as data centers must be located closer to end users and in regions with sufficient electrical power to sustain the computing resources required for AI training and inference workloads.

This shift requires hyperscalers to rethink how they can address the growing demand with new infrastructure while reducing costs and accelerating time to market. It opens an opportunity for hyperscalers and communications service providers (CSPs) to collaborate by adopting a business model that efficiently meets both their needs.

Managed optical fiber networks (MOFNs) have emerged as an architectural and commercial hybrid between traditional managed bandwidth and dark fiber private builds. MOFNs offer hyperscalers the ability to influence the architecture and network design while ensuring timely and reliable connectivity. They offer CSPs new customers and consistent revenue streams while leveraging their skills and knowledge in managing networks.

This paper explores how the MOFN model can be used to meet demands from hyperscalers and elevate services with “smart” network management for the new AI infrastructure era.

In addition, the paper provides architectural insights, real-world use cases and a high-level description of a typical MOFN that can be used by CSPs and hyperscalers that want to prepare their telecom infrastructure for an AI-centric future while maximizing economic and operational efficiency.

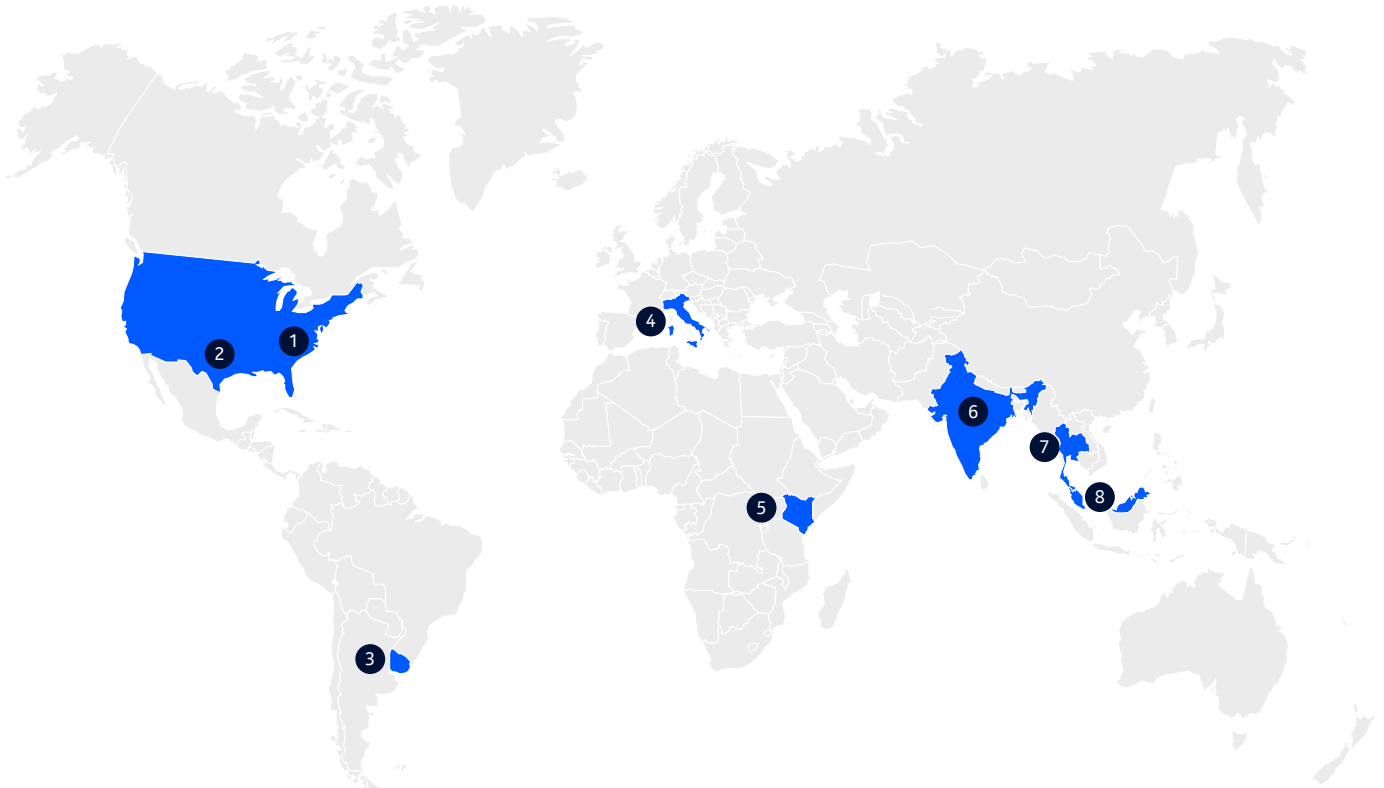
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Introduction

The AI era has catalyzed the need for tremendous high-capacity network connectivity. As data volumes surge and latency requirements tighten, hyperscalers must ensure their infrastructure can meet the demands of intelligent applications. To date, hyperscalers have invested heavily in building facilities to host these applications across the world, as shown in Figure 1.

Figure 1. Deployments of data centers worldwide by hyperscalers



- 1 Alphabet to invest \$US3.3 billion for two data centers in South Carolina (Reuters, 26 September 2024)
- 2 Meta to invest \$US1.5 billion in Texas (Reuters, 15 October 2025)
- 3 Google to open second data center in Latin America, to invest over \$US850 million (Reuters, 30 August 2024)
- 4 Microsoft invests €4.3 billion to boost AI infrastructure and cloud capacity in Italy (Reuters, 2 October 2024)
- 5 Microsoft and G42 announce \$US1 billion comprehensive digital ecosystem initiative for Kenya (Microsoft, 22 May 2024)
- 6 Google to invest \$US15 billion over 5 yrs in India (Reuters, 14 October 2025)
- 7 Google will invest \$US1 billion in Thailand to build new infrastructure for AI and cloud computing (Fortune Asia, 1 October 2024)
- 8 Google invests \$US2 billion in first Malaysian data center (IT Brief Asia, 3 October 2024)

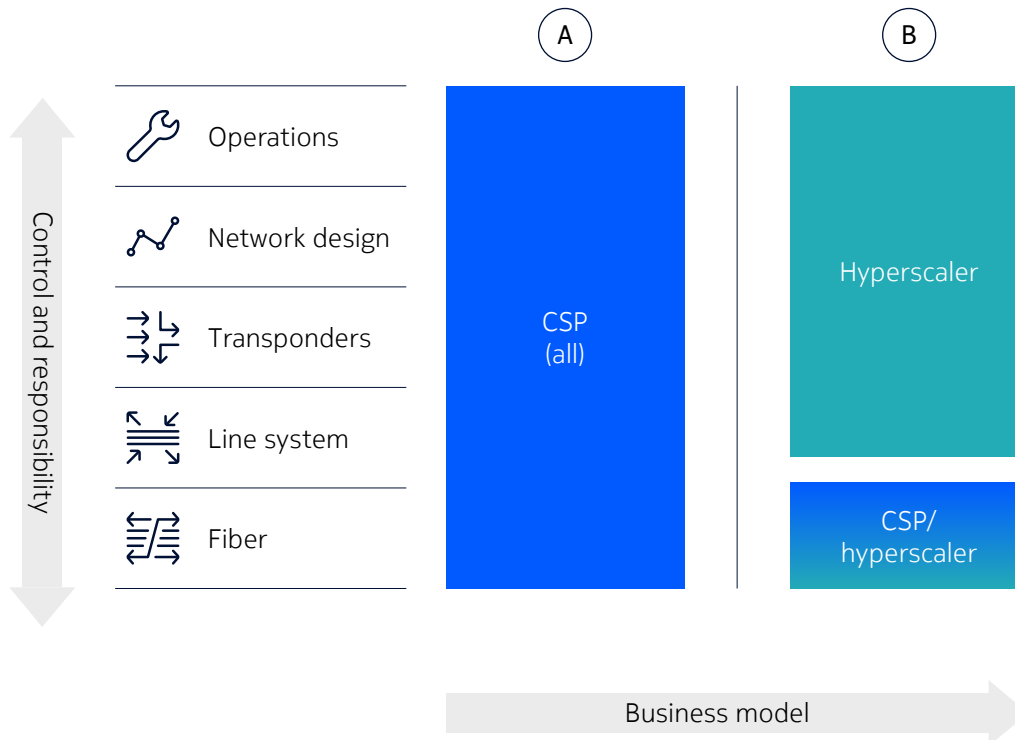
In attempting to connect data centers, CSPs and hyperscalers have pursued multiple business models to address the service connectivity demands for their optical transport networks:

- A. Managed bandwidth: Hyperscalers lease one or multiple optical services (100G, 400G and beyond) from CSPs across a metro or regional territory, or across a submarine network. The CSPs invest in the full optical network (line system infrastructure and coherent transponders) required to propagate optical channels carrying these services between any endpoint locations where capacity is needed.

B. Private build with or without leased dark fiber: Hyperscalers can interconnect their data centers using dark fiber pairs—optical fiber cables that are already installed but currently sitting idle. They can lease fibers from CSPs or source, buy and install their own fibers. The most adopted approach is leasing the dark fiber from a CSP given its availability. These interconnections require the hyperscaler to then build, deploy, manage, and operate its own optical network equipment (line systems and transponders).

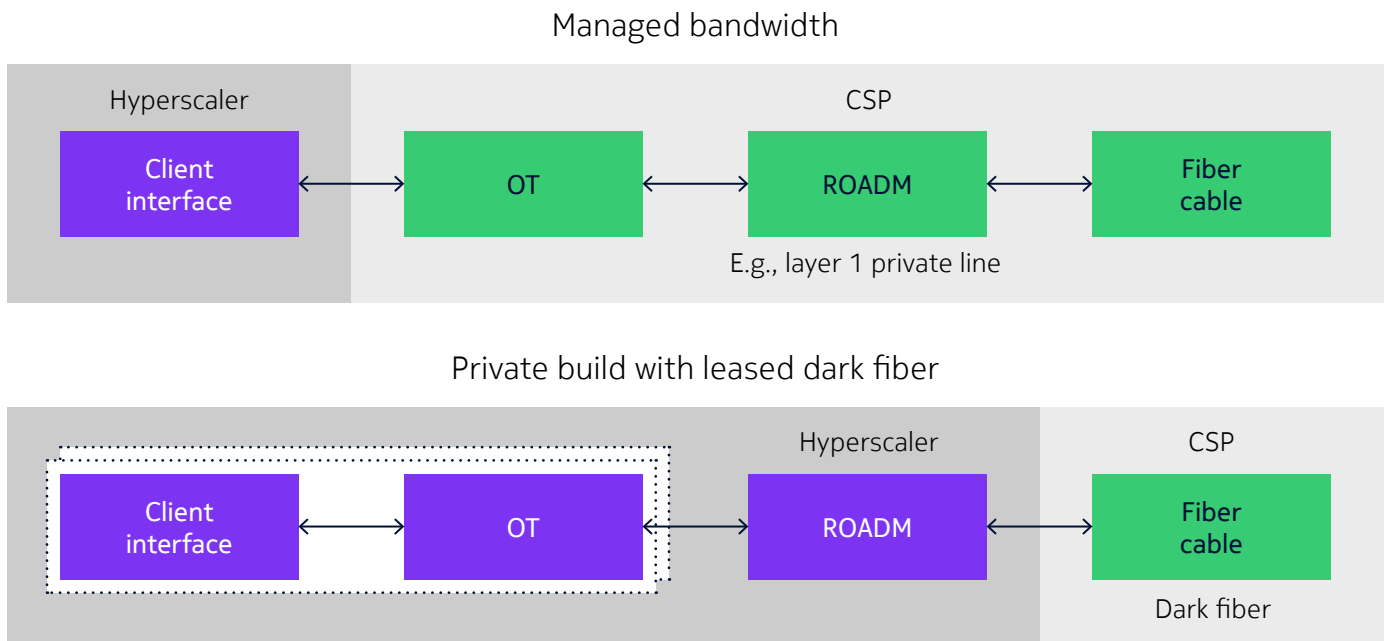
These approaches are summarized in Figure 2.

Figure 2. Network business model adopted to connect data centers



For CSPs, the selection of the network business model translates to different optical connectivity service models, as depicted in Figure 3.

Figure 3. Service business models for CSPs



There are advantages and disadvantages to the CSP for each of the service models, as highlighted in Table 1.

Table 1. Advantages and disadvantages of CSP service models

Service Business Model	Advantage	Disadvantage
Managed bandwidth	<ul style="list-style-type: none"> Simple and well defined for the hyperscaler. Fiber availability is high given it is already deployed and installed across regions of interest. Delivers long-term reliable incremental revenue. CSPs have built networks to adapt, protect and restore routes when planned or unplanned events occur in the network. 	<ul style="list-style-type: none"> Hyperscalers can't self-manage on-demand changes in capacity requirements. Changes can take weeks or longer to be implemented by CSP.
Private Builds with and without leased fiber	<ul style="list-style-type: none"> Provides managed private network build using an entire fiber pair and associated photonic infrastructure, with net capacity to scale to over 38.4 Tb/s for to a single hyperscaler using the latest 1.2 Tb/s coherent technology in the C-band and double if L-band is adopted. Dedicated fiber route to a single hyperscaler. Hyperscalers have flexibility to select the optical network infrastructure or transponder technology as they see fit. Hyperscalers gain speed and scale at a lower cost point without having to run a network. 	<ul style="list-style-type: none"> The cost of purchasing or leasing a whole fiber pair may be prohibitively high. Higher OPEX and CAPEX associated with planning, building, operating and maintaining the optical network. Regulatory constraints may prohibit the introduction of new fiber across regions inland, which adds cost and delays time to market.

Several other factors, some which are depicted in Table 1, play into architecture choices for hyperscalers, such as:

- The availability of dark fiber.
- Country regulations that also prevent hyperscalers from operating as CSPs.
- The availability of an internal workforce skilled in telecommunications networks.
- The cost of optical waves for large bandwidth requirements.
- The availability of electrical power required to support the network equipment.
- Time-to-market constraints to capture business demand from end consumers (or subscribers).

Managed optical fiber networks

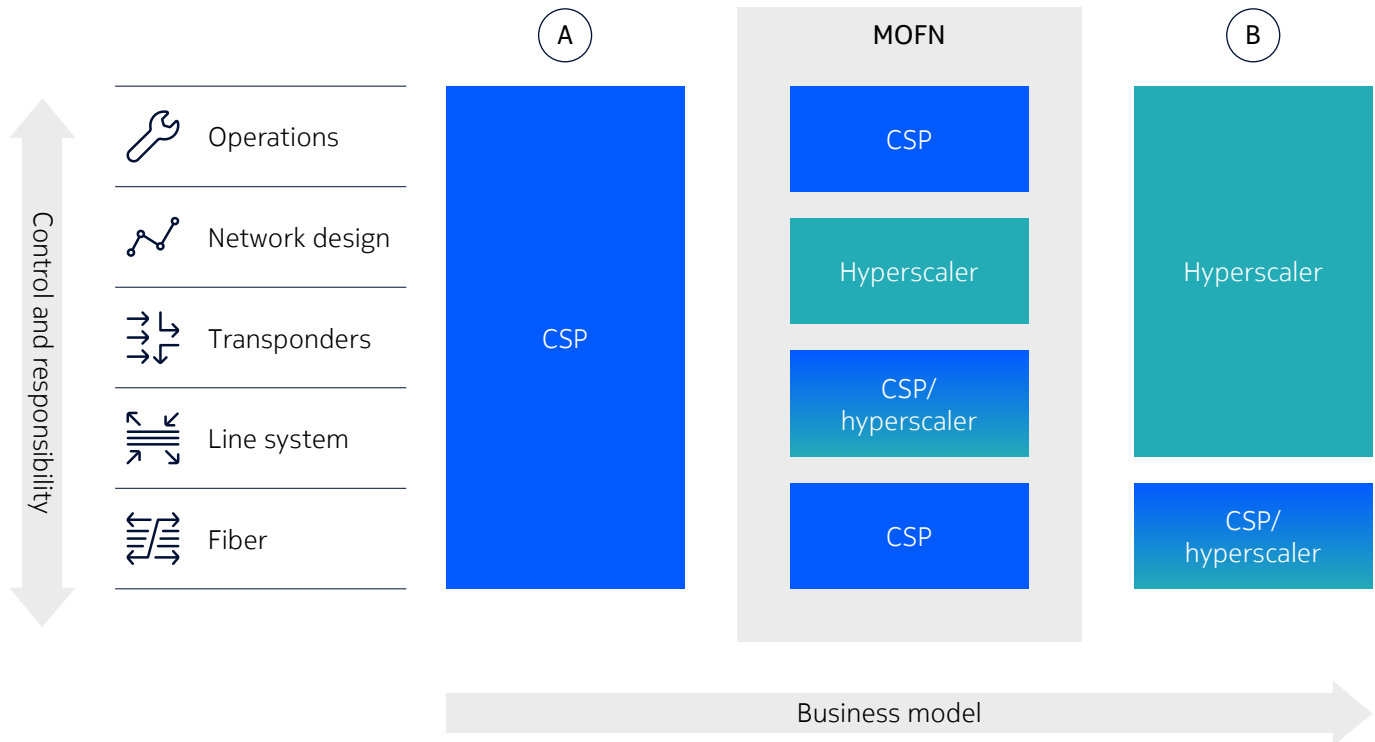
MOFNs have emerged as a hybrid approach between managed bandwidth and dedicated private networks. They are becoming increasingly common for three key reasons: regulation, resources and risk. In some geographies, such as India, regulatory requirements may prevent a hyperscaler from acting as a transport network operator. In other cases, a hyperscaler may lack the right resources or qualified optical networking personnel to take on the added responsibility of running an optical transport network. Additionally, a hyperscaler may be entering a new market or a new country and may want to reduce its risk by leveraging the skills, experience and relationships of an in-country incumbent service provider. But the hyperscaler may still want to influence the network design and the type of optical equipment deployed.

This hybrid business model enables a hyperscaler to enter into a partnership agreement with a local CSP to build an optical network that is architecturally designed to transport and meet its performance and traffic capacity requirements exclusively. The MOFN business model provides an efficient alternative for interconnecting transport sites and meeting the hyperscaler's growing need for infrastructure.

As shown in Figure 4, responsibilities are split between the hyperscaler and the CSP.

In this model, the fiber is typically owned by the CSP, and the CSP and hyperscaler agree on the equipment vendor for the line system and transponders. The optical transport sites to be interconnected and the network optical design are defined by the hyperscaler to address the precise locations, capacity connectivity and performance requirements desired between each site location.

Figure 4. MOFN business model



In the MOFN model, the CSP is responsible for end-to-end network operations and management. This may limit the hyperscaler's visibility into the transport system. Hyperscalers can't access performance data, alarms or traffic metrics, so they must trust the CSP to route traffic correctly. This reliance can cause issues if connectivity problems arise after deployment.

To address this problem, an enhancement to the MOFN business model (see Figure 5) is introduced to enable hierarchical oversight of the managed network. Hyperscalers require better visibility into the network resources even when they don't own the physical network from end to end, or if they decide to own and control only certain network elements, such as the transponders (see Figure 6). The latter scenario provides hyperscalers with flexibility and future technology readiness, which are essential as these technologies evolve and mature over time.

In either case, a detailed system-level view that can help expose potential SLA impacting events within the entire network provides high value to the hyperscaler and reduces the risk involved in adopting this business model approach. Consequently, by adding an MOFN insights monitoring layer, the hyperscaler can be granted read-only access to visualize the topology of the network, review the state information from the topology and associated performance monitoring key performance indicators (KPIs) and alarms so it can make informed planning and business decisions about the network's current operational state. This provides the assurance metrics, at both the physical level of the network and the service level, needed to ensure optimal service delivery.

With monitoring and operations layers in place, hyperscalers gain visibility into various aspects of the transport network—including information about their physical assets—without the responsibilities of operating the CSP-owned network. This provides great value to hyperscalers as they scale their business.

Figure 5. MOFN insights monitoring

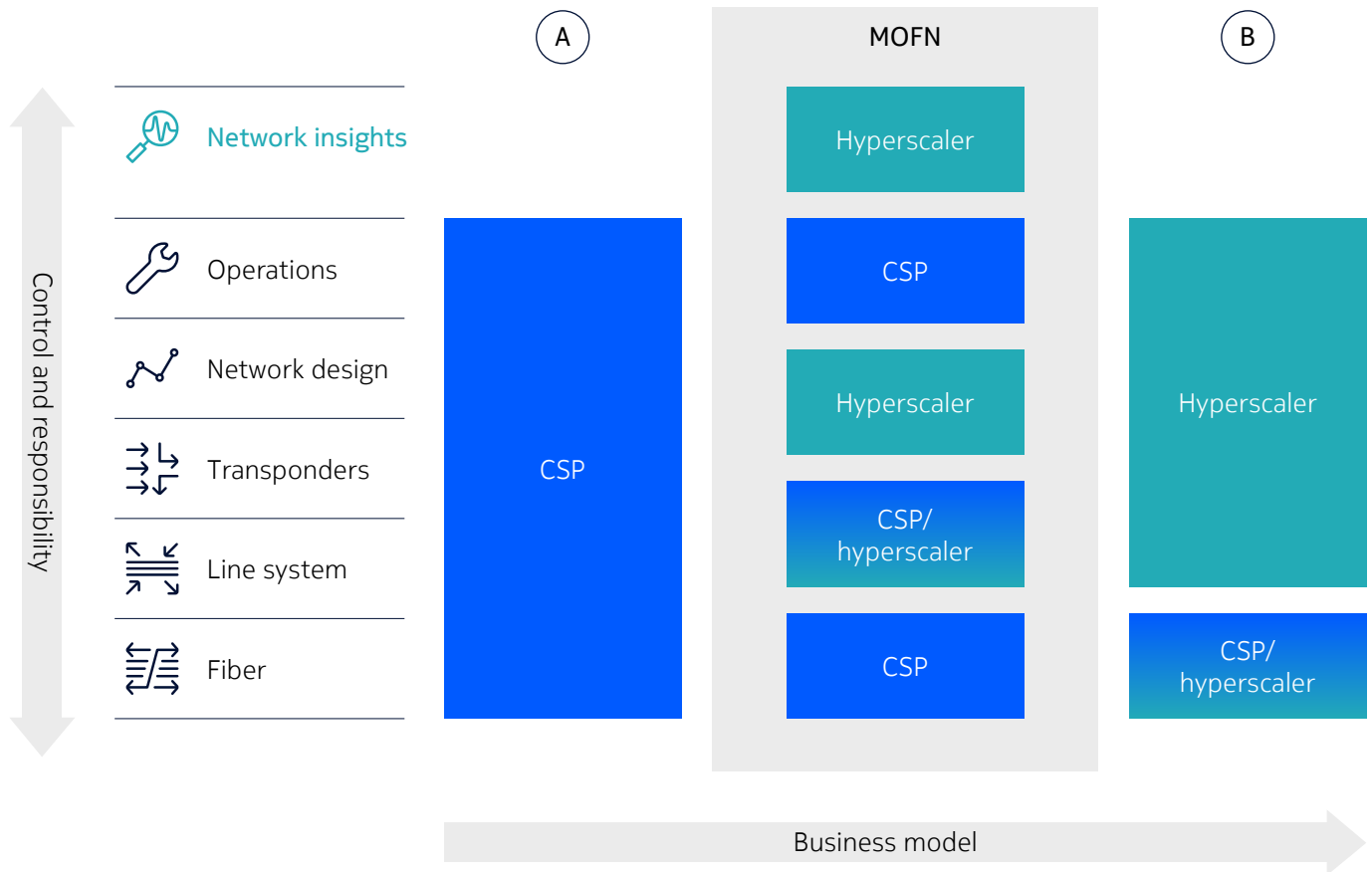
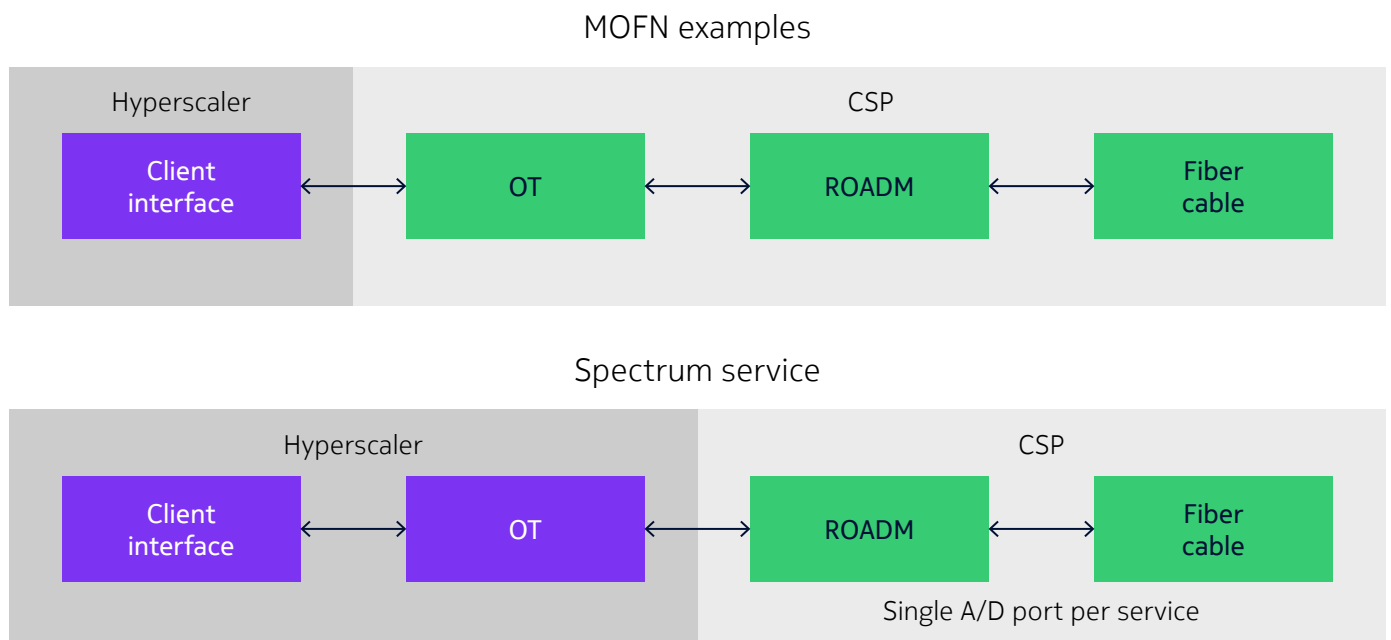


Figure 6. MOFN service models



MOFN business deployment use cases

Cloud providers that are implementing MOFNs also must consider the various deployment models associated with them. This section describes some typical MOFN deployment scenarios.

Hyperscalers monitoring multiple MOFNs from various CSPs

One strategy adopted by hyperscalers is to diversify their choice of CSP partners within the same country or region. This strategy aims to keep pricing competitive and delivery times short, while avoiding vendor lock-in.

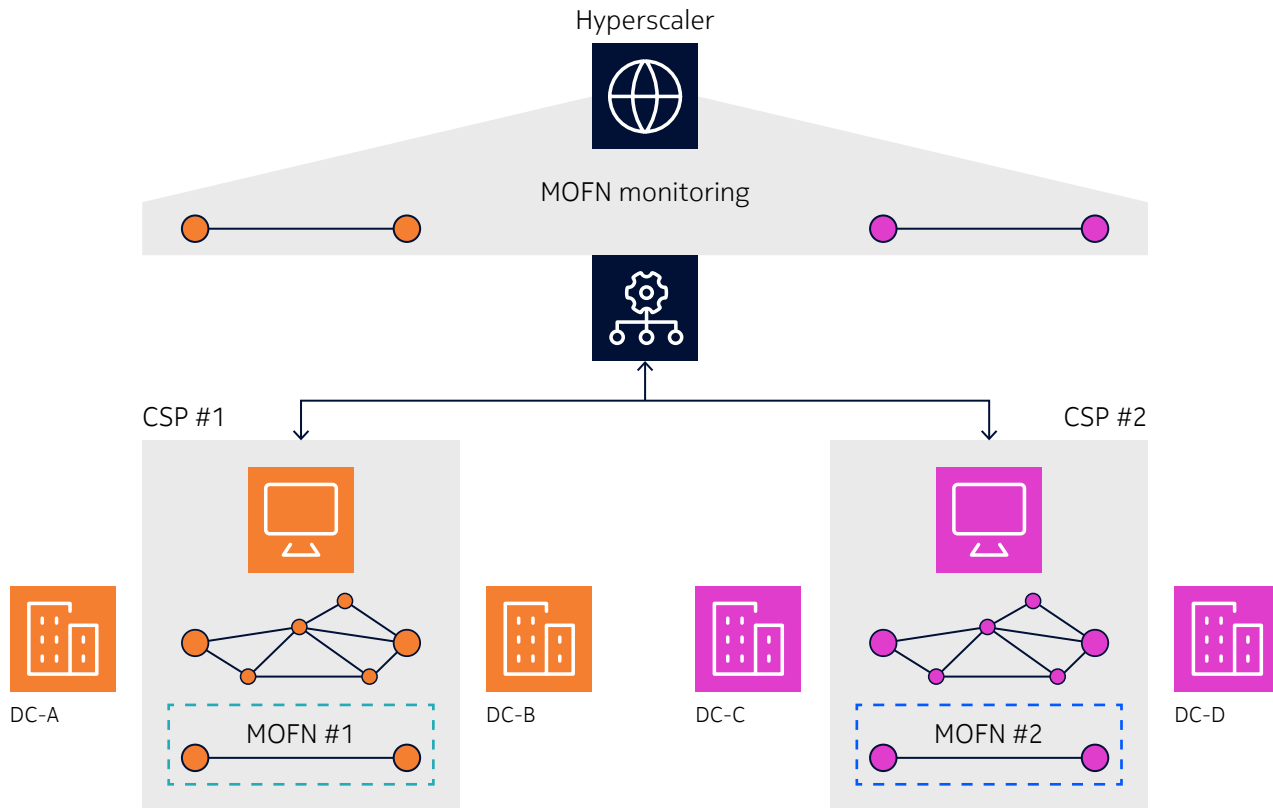
In this case, a hyperscaler partners with multiple CSPs (e.g., CSP #1, CSP #2 in Figure 7) to build dedicated optical networks to connect their data centers (e.g., DC-A, DC-B, DC-C, DC-D).

One of the challenges for hyperscalers using multiple CSP partners is how to effectively monitor each of its MOFN deployments for additional network insights to better quantify their service metrics based on network connectivity performance.

In the management platform of each of the CSPs networks, creating dedicated user accounts is a common approach, but it is not scalable, since hyperscaler personnel would have to log in to multiple platforms, potentially from different optical vendors using different credentials. This approach also tends to be rejected by CSPs because of the security risks associated with sharing direct access to their private network operations ecosystems.

To enable centralized monitoring and overcome the need to log in to multiple platforms, a hyperscaler can rely on a hierarchical management solution that connects to each CSP's management platform, extracts the pertinent MOFN service deployment information and consolidates it under a single pane of glass. This solution also addresses the security risks mentioned above, as shown in Figure 7.

Figure 7. Hyperscaler operating multiple MOFNs



To visualize the various MOFN subnetworks that may be either resource partitioned for the hyperscaler or built specifically for the hyperscaler, each CSP creates network access domain partitions, whereby the required portion (or all partitions in the case of a dedicated build) can be authorized with user-specific access policies to isolate the subnetwork dedicated to carrying hyperscaler traffic from the rest of the network (MOFN #1 and MOFN #2 in Figure 7).

The hyperscaler then uses a vendor-neutral multi-network hierarchical management approach to import and synchronize the specific network elements and topology from each of the subnetwork management layer instances operated by the CSP. This enables the hierarchical management solution to discover and view only the MOFN resources and network topology associated with the individual hyperscaler's businesses.

As a result, the hyperscaler can simplify monitoring all its MOFN deployments across multiple CSPs, a common challenge particularly when the networks are spread across different countries or regions.

Hyperscalers configuring connectivity across multiple networks

Optical transport networks have become increasingly important as a means to connect data centers for the purpose of training and inferencing models. However, they are challenged by the need to deploy these data centers in geographically diverse locations to increase resiliency, address proximity to end users and ensure reliable access to energy sources.

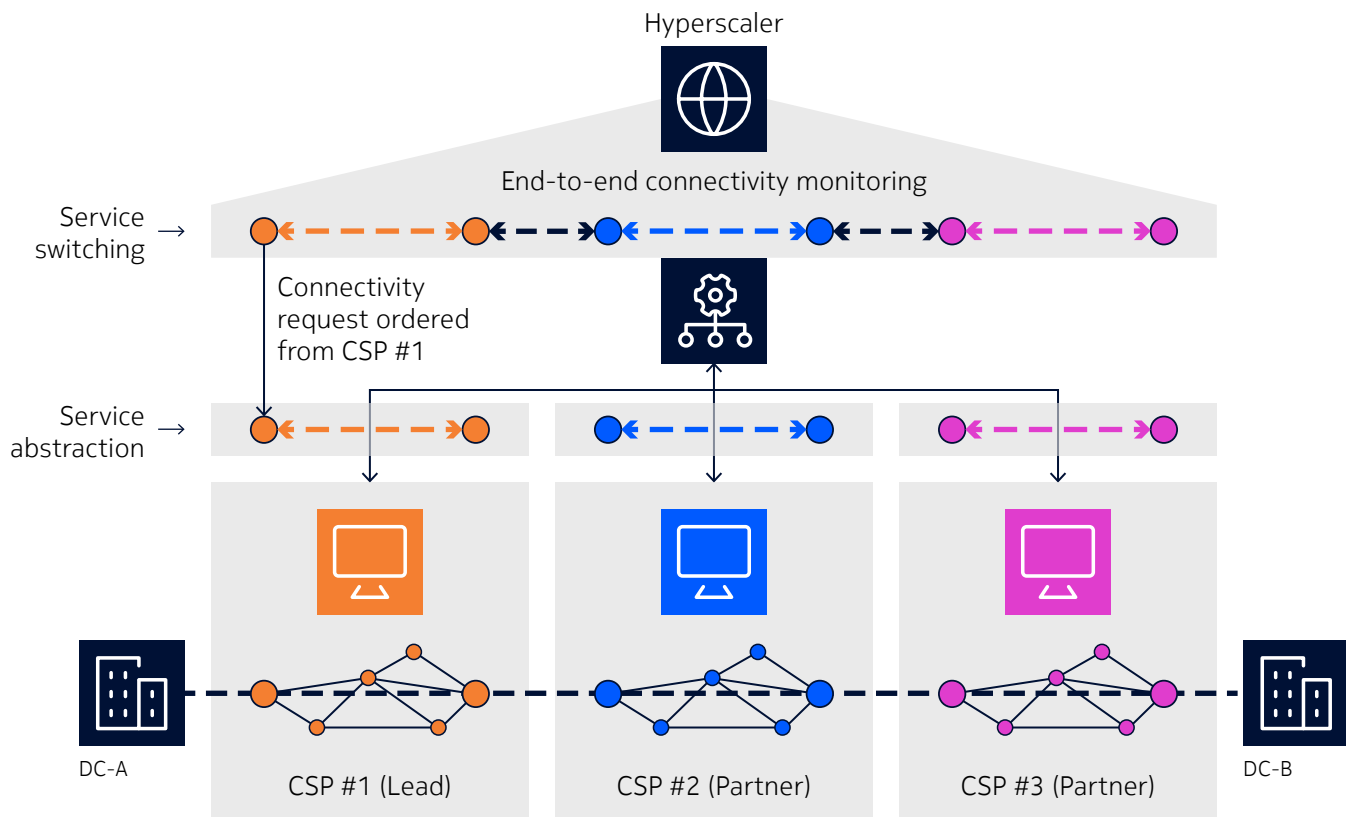
For example, some hyperscalers are considering building AI data centers close to nuclear plants because of their high energy requirements. This limits potential data center construction locations but the requirement for connectivity remains.

With the increasing variety of geographical endpoint locations and service requirements, connectivity cannot be achieved by using a single CSP network. Instead, the connectivity must traverse multiple networks, possibly operated by multiple CSPs (Figure 8).

Hyperscalers typically approach one of the CSPs, which assumes the role of “lead” (CSP #1 in Figure 8), to request end-to-end connectivity between data centers. In turn, the lead CSP partners with other CSPs as required to deliver the end-to-end connectivity, which they alone cannot provide. These new CSPs assume the role of “partner.”

The end-to-end connectivity across these links is achieved through each CSP delivering partial connectivity within its own network. Each of these networks is then interconnected, either using ENNI-based connectivity services to the next CSP through black and white or WDM colored interfaces, or through ROADM-to-ROADM connections for larger transmission capacity.

Figure 8. End-to-end connectivity across multiple networks



The challenge for hyperscalers when using multiple CSP partners is to gain the ability to monitor several partial connections through a single view. Conversely, on the CSP side, the challenge is often the additional effort required to expose the partial connection without revealing the entire network to the hyperscaler and violating its service agreements with other end subscribers.

These challenges can be addressed through a combination of service abstraction and service stitching solutions.

- **Service abstraction** allows CSPs to export a simplified view of an optical service, limiting the data exposed to information such as service labels, endpoints, signal rate and protection types.

- **Service stitching** allows CSPs to build end-to-end connectivity from partial optical services and inter-domain links. Inter-domain links connect two different networks together through ENNI-based connectivity or by using the ROADM-to-ROADM interconnections.

These two functions can be accomplished using a hierarchical management and service automation solution, respectively.

Hyperscalers requiring spectrum slices from a CSP network

Unlike traditional managed bandwidth services, the MOFN business construct lets hyperscalers leverage their existing transponder assets while having CSPs offer and deliver another form of managed-bandwidth services—either through fragmented optical spectrum offerings on existing shared line system infrastructure, or via contiguous spectrum slices on dedicated line system infrastructure. By using spectrum sharing, CSPs can allocate resources more efficiently and accelerate deployments for hyperscalers without the need to build a new private network.

Spectrum sharing is an emerging concept aimed at optimizing the use of the optical spectrum. It enables multiple services to coexist on the same physical infrastructure shared among several users (e.g., multiple hyperscalers). This provides a middle ground between a high-capacity/high-control solution offered by dedicated fiber pair and dark fiber and a low-capacity/low-control solution offered by private lines.

Through spectrum sharing, CSPs have access to a “virtual fiber pair” and are free to turn up, tear down or rearrange wavelengths as required. A spectrum slice is a multitenant construct that represents a range of optical spectrum assigned and reserved for use by a specific end subscriber between a pair of point of presence endpoints via its spectral width. Spectral slicing, which is also a part of spectrum sharing, provides a high degree of capacity between two endpoints for hyperscalers and is often required for AI data center interconnect.

The spectrum slice is configured throughout the entire routed layer 0 topology of interest, along with the ROADMs between these endpoints. This spectrum slicing and sharing opportunity enables the CSP to monetize the total available spectrum from both the C-band and L-band on a single fiber pair to help offset the CAPEX investment of the deployed line system infrastructure while reducing the bottleneck of dark fiber scarcity for the hyperscaler. For example, CSPs can exploit this value-added service monetization offering in their terrestrial networks, especially in cases where the hyperscaler subscriber requires connectivity directly into a submarine landing point and points of presence that fall under the jurisdiction of another operator. This is typically the location where there is a massive amount of inbound submarine traffic from the hyperscalers.

This spectrum slicing is a new service business model delivered using optical spectrum services (see Figure 9), which provides other benefits to the CSP and hyperscaler, along with a few other challenges as described in Table 2.

Figure 9. Spectrum service model

MOFN: Managed bandwidth using spectrum sharing

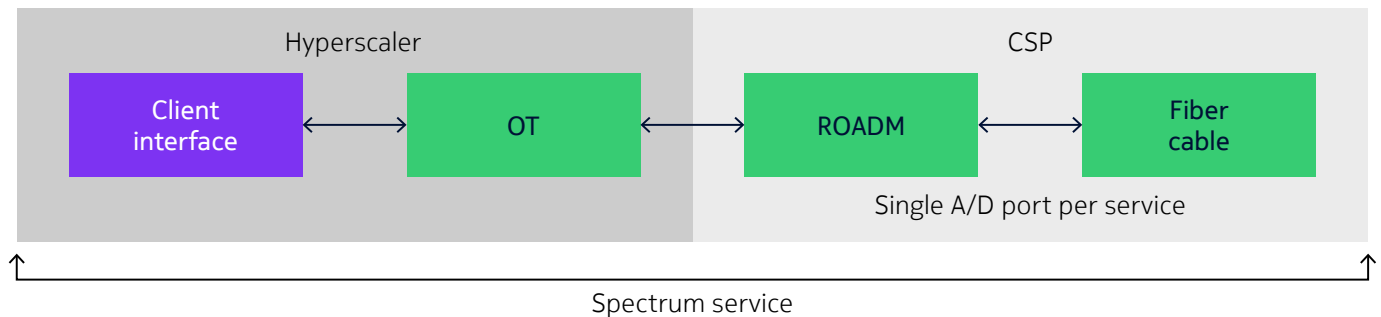


Table 2. Advantages and disadvantages of spectrum services.

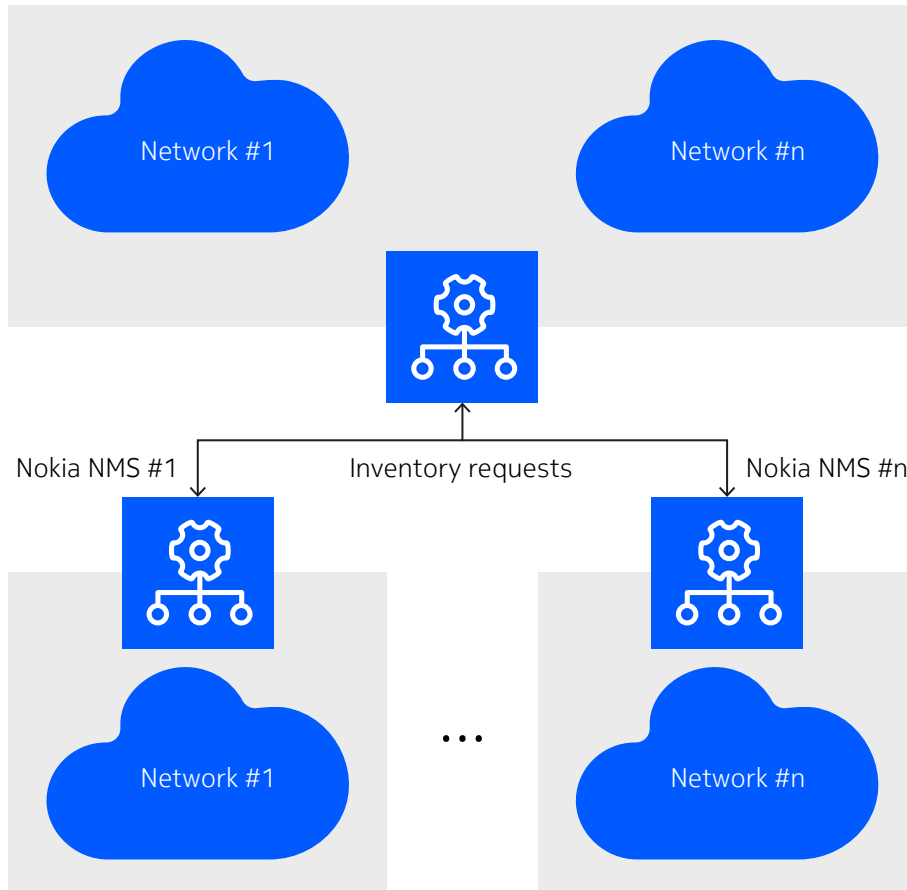
Service business model	Benefits	Challenges
Spectrum service	<ul style="list-style-type: none"> Provides a single spectrum service to enable capacity for a variety of services, (e.g., layer 1 private line over a DWDM line system infrastructure). Gives hyperscalers the flexibility to purchase and use preferred coherent transport technology while maintaining ownership of their transponder. Allows hyperscalers to differentiate with accelerated time to market because there is no need to source infrastructure or terminal resources. Enables hyperscalers to monetize services through a premium offering that exposes both C-band and L-band spectrums as spectrum services. Provides hyperscalers with improved service visibility, including spectrum service slice inventory, channel consumption per slice, service topology and service performance within each spectrum service slice. 	<ul style="list-style-type: none"> Hyperscalers can't self-manage on-demand changes in capacity requirements. The configured service type is challenging to validate. CSPs could incur spectral fragmentation, which impacts spectral efficiency and transport capacity.

Nokia multi-network management solution

The Nokia hierarchical network management solution is designed to consolidate and display information from multiple base network management systems into a centralized system (Figure 10).

Figure 10. Multi-network management

Hierarchical management



Nokia WaveSuite and Transcend offer an efficient and scalable hierarchical management solution for large, distributed networks. This solution provides centralized oversight, ensuring network management is consistent, secure and proactive across various network domains and aligns with hyperscalers' network visibility requirements for end-to-end connectivity.

The solution's hierarchical management capabilities provide the following advantages:

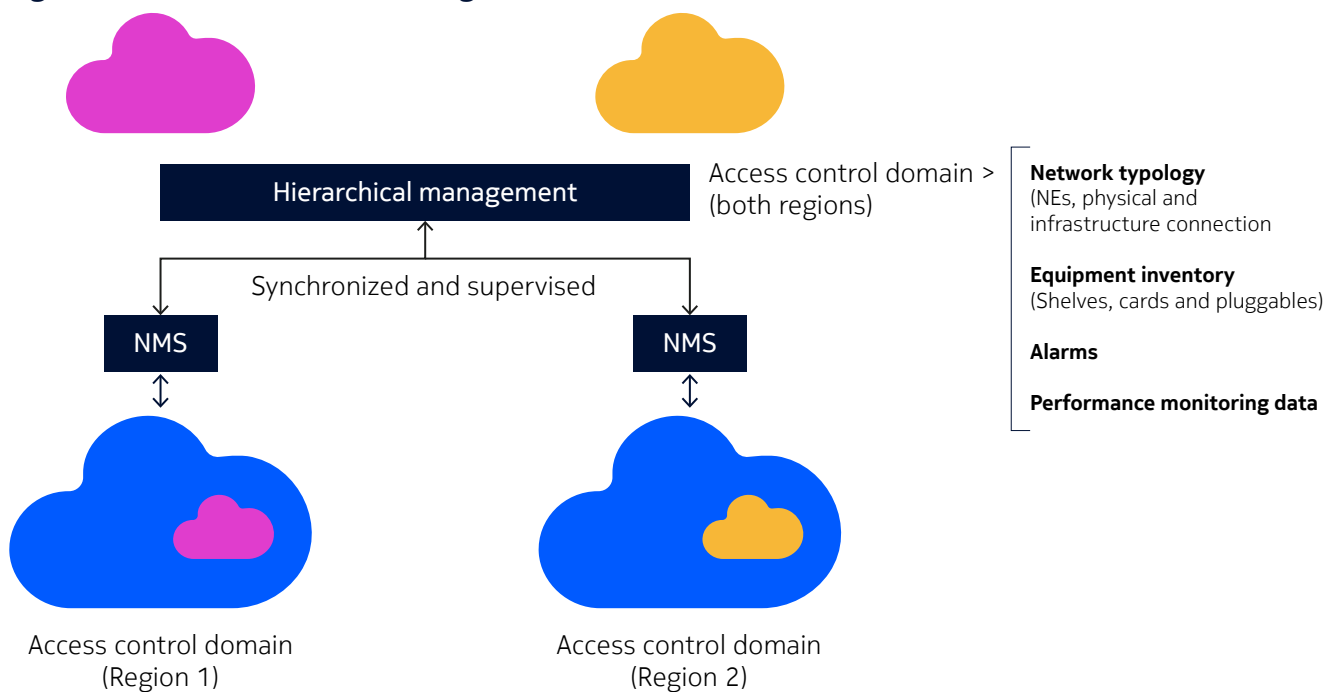
- They act as a centralized hub for viewing data across multiple base management systems owned by the CSP or across CSP partners.
- They aggregate topology and equipment inventory data from all management systems to deliver a unified, comprehensive view of the entire network through intuitive charts and dashboards.
- They aggregate alerts and alarms from all base management systems to provide centralized fault detection. They also consolidate performance data, providing a holistic view for tracking key metrics across the entire infrastructure, enabling hyperscalers to retain historical information from the network for root-cause reporting.
- As the network expands, additional base management systems can be integrated seamlessly and monitored by the existing CSP or partner CSPs.

- They enable CSPs to operate in compliance with regional laws and regulations, address data security and privacy concerns, and facilitate data connectivity across territorial boundaries to overcome challenges that previously existed.

The hierarchical management solution can be used to aggregate network information from different network systems without any data filtering. This type of network management solution is referred to as multi-network management and aims to streamline CSP operations while also addressing the MOFN business model.

In addition, the hierarchical management solution can be used to aggregate sub-network information. CSPs can create a network partition to be exposed for aggregation. This solution is referred to as multi-subnetwork management and is well suited to addressing MOFN deployments and other scenarios where a CSP is required to control the data exported to this hierarchical management layer (see Figure 11). The proposed solution helps to remove the traditional customer concerns regarding the end-to-end management of desired capacity from the hyperscalers, since each of the sub-network domains provides the same level of troubleshooting management and exposes areas of interest that have impacts on SLAs or network performance.

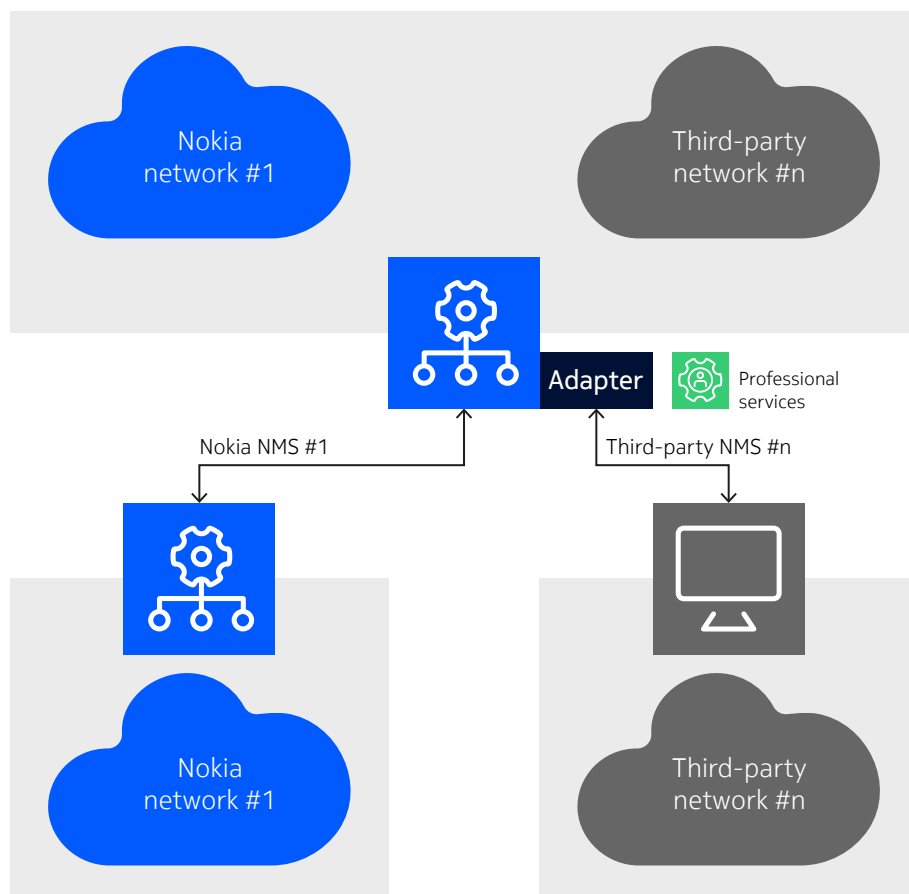
Figure 11. Multi-subnetwork management



The hierarchical management solution can be extended to address multivendor networks with the use of standard interfaces, and common data models in a seamless manner (see Figure 12). Nokia optical professional services provides optional support for integrating multivendor controllers or management systems for open line systems. This support can include integration, validation and software release maintenance against third-party systems to ensure rapid time to market within the same hierarchical architecture. Open interfaces with well-defined models such as ONF Linux T-API support programmatic abstraction of the underlying network to reduce the complexity of integration. They also provide a common structure for delivering notifications on real-time changes in the network state.

Figure 12. Multi-network, multivendor management

Hierarchical management



Nokia service automation solution

The Nokia WaveSuite service automation solution provides tenant-based hierarchical service abstraction that can address service lifecycles for CSPs and service stitching for each of the various service business models. The solution offers a means to define service specifications that end subscribers can order based on the characteristics of a specific service instance.

Spectrum service

In this scenario the hyperscaler will enter a contract phase with the CSP to order a spectrum slice that details how much spectrum and what locations are required. In a scenario where the hyperscaler owns the transponder or coherent pluggable optics hosted in its router, the contract will also specify the optical channel information such as transmitted optical power and the overall link feasibility between the endpoint locations.

By leveraging the Nokia WaveSuite automation platform, CSPs can publish the available service connections. Hyperscalers can execute add, modify or delete operations to increase or decrease their requested connectivity. The connectivity fulfillment process solution ensures the add/drop port

assigned within each point of presence locations is reserved and provisioned along with the desired spectral slice width, as shown in Figure 13. The service slice reservation can be established as a set of individual or contiguous bands of spectrum service consumption, expressed in terms of spectral width in gigahertz (GHz). This gives the hyperscalers the large quantities of reserved capacity they need, with planned engineered performance.

Figure 13. Connectivity fulfillment process

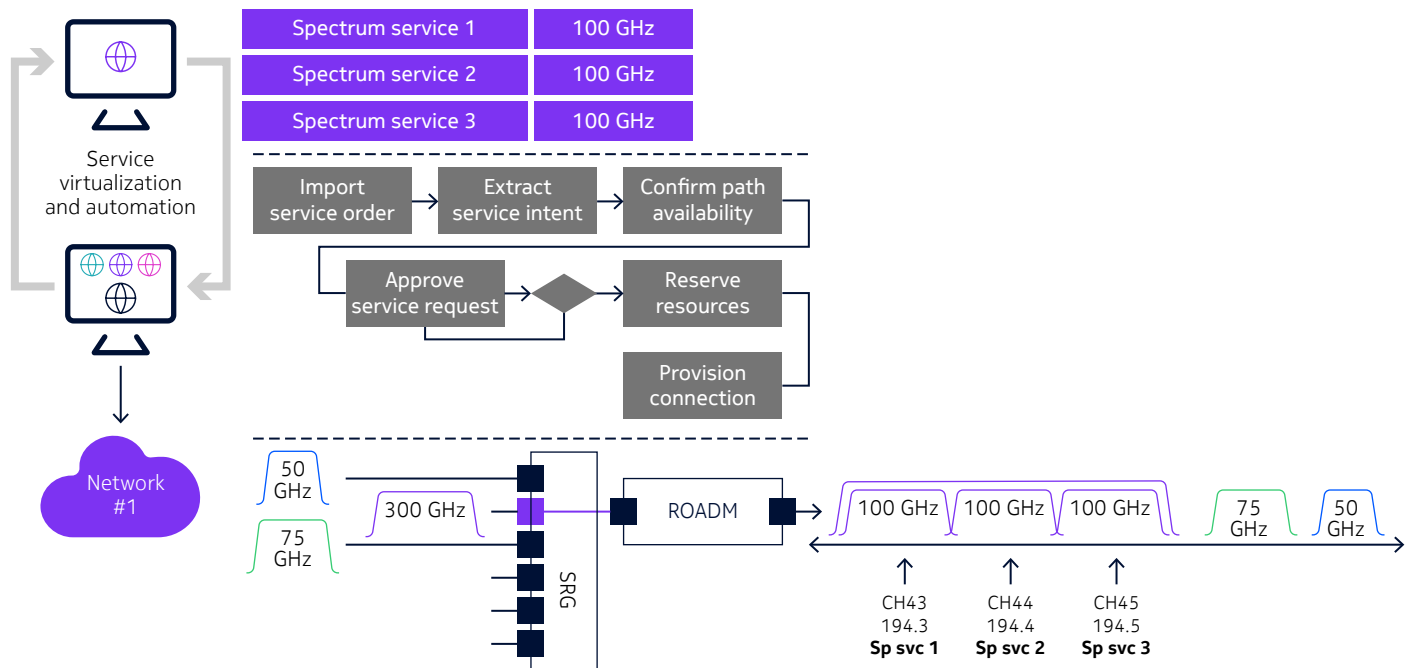
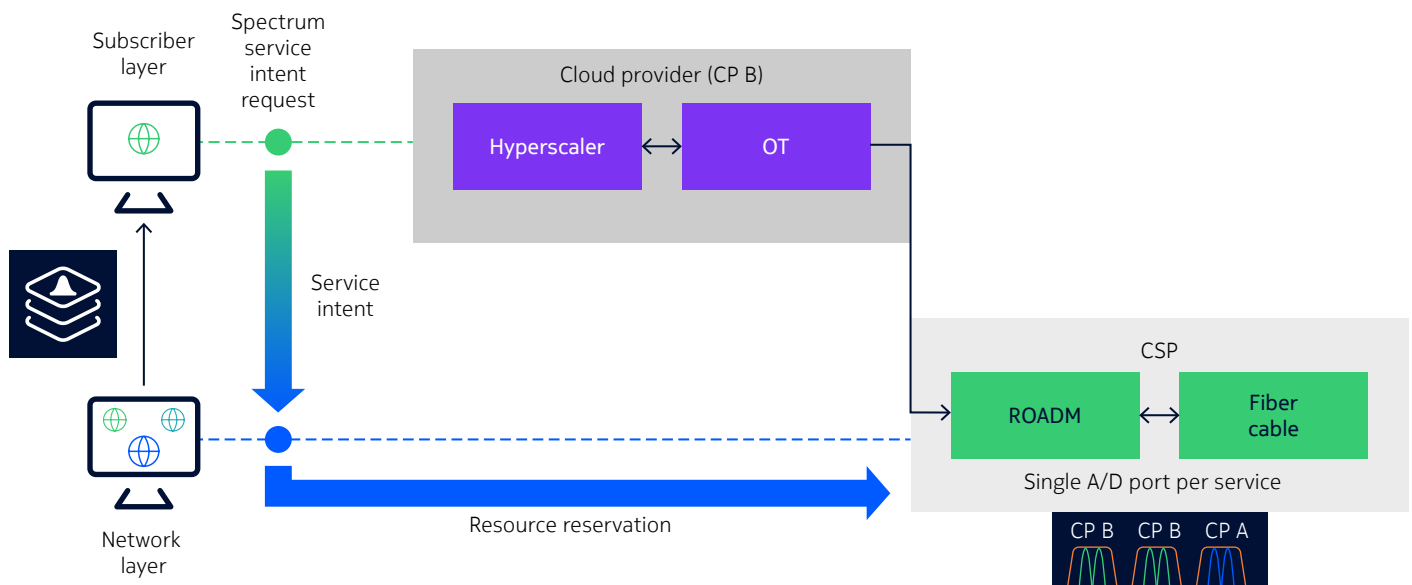


Figure 14. Spectrum service fulfillment automation



Service stitching

To accommodate service stitching across multiple regional networks owned and independently managed by the same CSP or multiple CSPs, an elected CSP can also provide end-to-end service connectivity between these networks using inter-domain links based on layer 1 ENNI-type links, or ROADM-to-ROADM links.

The Nokia service automation solution can accommodate service stitching between these network domains. Leveraging the hierarchical management solution, the elected CSP will create the connection between network element endpoints and instantiate layer 1 ENNI or ROADM-to-ROADM interconnection between each of the different network domains. Through the service stitching mechanism, the elected CSP can also offer several service characteristics as added value, such as latency to ensure the lowest cost path for the service is routed across each network domain, or provide the diversity or protection needed based on the SLAs with the chosen hyperscaler. This type of solution provides seamless connectivity between endpoints while ensuring hyperscalers can access performance metrics across the entire link.

Conclusion

Nokia provides network software solutions that help redefine the MOFN model by introducing an additional monitoring layer, while also providing seamless abstraction capabilities to easily automate connectivity fulfillment. This is accomplished through a centralized, scalable and secure solution tailored to the evolving demands of hyperscalers and CSPs. With this innovative solution, hyperscalers get end-to-end visibility and assurance across their fiber networks, and can unlock greater accountability and operational efficiency. As the digital landscape becomes increasingly data-driven, smart MOFN management will be essential for meeting future connectivity challenges.

Abbreviations

AI	artificial intelligence
CSP	communications service provider
DWDM	dense wavelength-division multiplexing
ENNI	external network-to-network interface
MOFN	managed optical fiber networks
NE	network element
NMS	network management system
ONF	Open Networking Foundation
OT	operational technology
ROADM	reconfigurable optical add-drop multiplexer
SRG	Shared Risk Group
T-API	Transport API
WDM	wavelength-division multiplexing

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