WHITE PAPER

Infinera®

Future-proof Open Line Systems for Cloud Scale Networks

1 Summary

Network operators with large-scale optical transport networks have traditionally relied on a single optical transport supplier to provide end-to-end optical systems within each domain of their network, such as a long-haul backbone or a metro core. In these networks, the optical line system is tightly integrated and managed with the dense wavelength-division multiplexing (DWDM) transponders and terminal equipment to optimize end-to-end capacity and performance and minimize operational complexity, from planning and commissioning to maintenance and troubleshooting. In such networks, the optical system supplier can serve as the “one neck to grab” for problem resolution across the entire system.

While integrated optical systems have demonstrated advantages in maximizing performance and minimizing operational complexity, network operators have also explored various forms of optical disaggregation to introduce greater flexibility and competition into their choice of subsystem technologies and suppliers. In particular, "alien wavelength" implementations, which enable one supplier's line system to carry optical wavelengths from another supplier's transponders, have been tried in a variety of networks for years, but such implementations have had limited market success.

Today there is a renewed interest in optical system disaggregation, driven by multiple factors:

- The newest large-scale network operators, the hyperscale cloud and internet content providers (ICPs), have brought a different mindset to information technology (IT) and networking technology, and they are now applying it to optical transport. ICPs have led the trend toward optimizing the components of their networks, which in many cases has meant disaggregating traditionally integrated systems and building their own systems tailored to their narrower requirements. ICPs started this trend by disaggregating servers into slimmed-down central processing units (CPUs) and disk drives, and have begun to apply the same thinking to networking equipment.

- Optical technologies are evolving at different rates and with different life cycles. New generations of coherent DWDM transponder technologies are arriving at an increasing rate, with significant improvements in cost, capacity and reach being achieved every two to three years. Meanwhile, line system technologies, while improving continuously, can have much longer useful lifespans in the field, and the cost of replacing them in a deployed network can be much higher. Because of this, network operators would like to be able to deploy multiple generations of transponders, potentially from multiple suppliers, over a single generation of line system.

- Emerging models for controlling disaggregated optical systems promise to improve the ability to ensure end-to-end performance and reliability in a multi-supplier environment. Using software-defined networking (SDN) principles with open application programming interfaces (APIs) and standardized information models, a network operator could in principle build a disaggregated optical system with sufficient end-to-end control to mitigate the increased complexity and risk.

As a result, the trend toward open line systems appears to be growing, and this in turn motivates an examination of the requirements for an open line system that will meet the most advanced needs of network operators today while offering future-proofing for tomorrow.

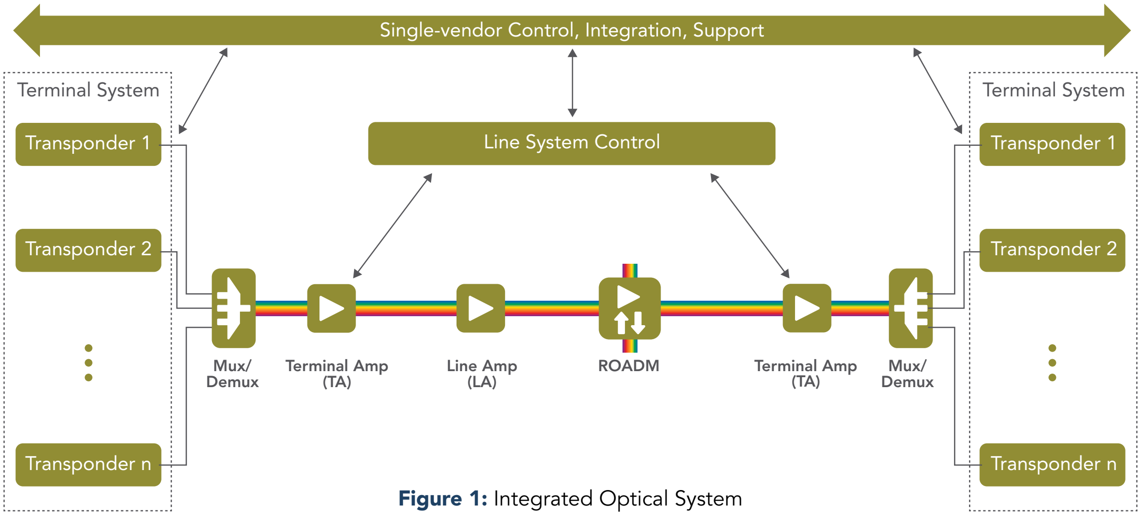


Figure 1: Integrated Optical System

2 Introduction to Optical Disaggregation and Open Line Systems

Figure 1 shows a simplified view of an end-to-end optical system including both the terminal systems, which incorporate optical transponders, and the optical line system, which includes various types of multiplexing, amplification and related optical functions. The components are all drawn in the same color to indicate a single supplier is responsible for all components, including the management and control systems, and end-to-end integration and support.

Figure 2 shows an open line system, with all line system components (in green) supplied by a single supplier, while the terminal equipment and transponders are supplied by multiple suppliers (including the line system supplier), as indicated by the multiple colors. In this figure, the line system controller is shown as supplied by the line system supplier, while control of the

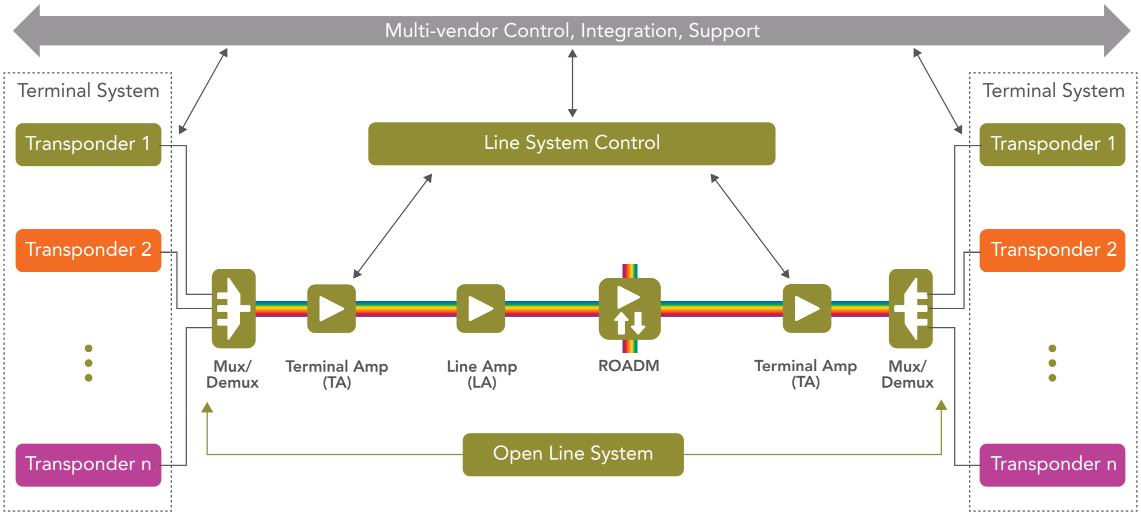


Figure 2: Open Line System

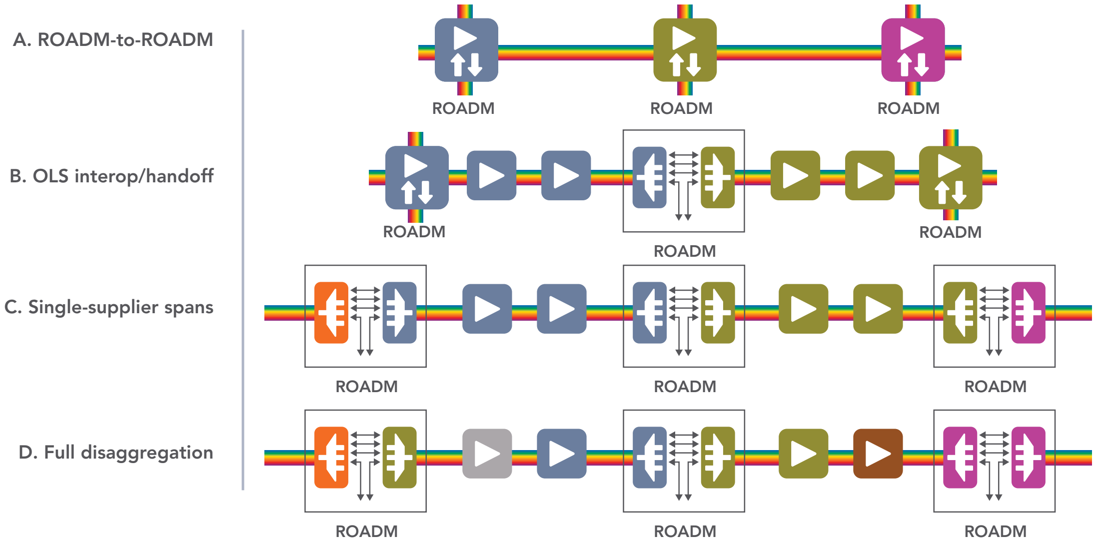


Figure 2a: Disaggregation Options for Open Line Systems

transponders and the end-to-end system is provided by others. In principle, however, with the definition of open APIs and information models, the line system controller could also be provided by a supplier other than the line system supplier.

Some network operators have expressed a desire for further line system disaggregation into subsystems or components from multiple vendors. At present, there are several alternative approaches under consideration, and industry consensus on the best approach may take some time to achieve. Figure 2a shows a few of these approaches, with different suppliers indicated by different colors. Option A envisions reconfigurable optical add-drop multiplexers (ROADMs) from different suppliers interoperating across an optical span without any intermediate amplification. This is representative of the initial target architecture of the OpenROADM project. Option B envisions an alternative point of interoperability, with two open line systems from different suppliers connected by splitting a ROADM into components from both vendors. In Section 4.3 below, we propose this type of interoperability as a minimum requirement for all open line systems. This model is extended in Option C, preserving single-supplier control of individual spans while allowing arbitrary concatenation of multiple spans. Option D shows full disaggregation, with components from different suppliers mixed and matched in any configuration.

Integrated Optical System	Open Line System	Disaggregated Line System
Single supplier for transponders/ terminals and end-to-end line system	Single supplier for end-to-end line system, enabling multiple transponder/terminal suppliers	Multiple suppliers for individual line system components, multiple transponder/terminal suppliers
Potential for advanced features and performance using proprietary capabilities	Features and capabilities may be limited by open interface standards and supplier interoperability	Features and capabilities may be limited by open interface standards and supplier interoperability
Clear supplier ownership of end-to-end performance assurance	Multiple models for end-to-end performance assurance (operator, supplier, integrator)	Multiple models for end-to-end performance assurance (operator, supplier, integrator)
Lowest operational complexity and risk	Added operational complexity and risk	Higher operational complexity and risk
Preferred approach for many service providers historically	Significant industry interest and activity, stated direction for many network operators	Some operator and supplier interest and activity

Table 1: Comparing Line System Architectures

Table 1 summarizes the characteristics of these different line system architectural approaches. As noted in the introduction, the integrated optical system approach has been predominant historically, while the open line system approach is gaining strong industry momentum. For the purposes of this whitepaper, we will focus on the requirements for an open line system provided by a single vendor, with the option of limited ROADM-to-ROADM interconnect between two open line systems (option B above). We will leave the requirements for other types of line system disaggregation for a future discussion.

3 Open Line System Evolution

Fixed-grid 50 gigahertz (GHz) line systems offering limited support for alien wavelengths have been used in a variety of networks for years, but such implementations have had limited market success and limited impact.

Many line systems have proven to be not entirely open. In some cases, important features and functions implemented for "native" wavelengths don't work properly in open line system mode. In other cases, proprietary features effectively prevent desired open line system use cases.

The other key limitation preventing widespread adoption of open line systems has been the complexity of end-to-end system operation and performance assurance, and the resulting challenge of allocating end-to-end operational responsibility.

As a result, most so-called "open" line systems are used primarily with transponders from the same vendor.

If open line systems are to become more widespread and successful, suppliers will need to address these existing issues. They also need to implement newer capabilities aligned to today's and tomorrow's requirements, which are outlined below.

4 Requirements for Open Line Systems

Looking ahead, open line systems must evolve beyond traditional expectations to accommodate a wider range of channel and carrier formats, support more sophisticated automatic power control mechanisms, support network-to-network optical interoperability and deliver all these capabilities via open APIs and information models that enable SDN-based control and orchestration for the end-to-end optical system.

The following sections discuss the technology and architecture drivers for each of these requirement categories and propose specific target requirements that will enable a range of network operators to realize the full benefits of open line systems.

4.1 Flexible Channel and Carrier Formats

As noted in the introduction, as new generations of coherent DWDM transponder technologies emerge, network operators should be able to deploy multiple generations of transponders, potentially from multiple suppliers, over a single generation of line system. Therefore, it is important to minimize restrictions on the optical channels that the open line system can support.

The most important restriction seen on many line systems today is fixed channel width, typically following the International Telecommunication Union standard grid spacing of 50 GHz. Over the past few years, an industry consensus has developed that a flexible grid – allowing for variable channel width and spacing – is critical to continued improvement in optical system capacity. There are several reasons for this:

1. Advances in digital signal processing (DSP) hardware and algorithms allow for improved spectral shaping and coherent detection, reducing both the required channel signal width and the required guard band between channels for a given channel capacity and distance. Flexible-grid systems that allow these techniques to be maximized can increase spectral efficiency by 25% or more when compared to fixed-grid line systems.

2. Fiber capacity for a given fiber route distance can often be improved by optimizing channel spacing in conjunction with other variable factors such as modulation, baud rate and optical power. For example, as shown in Figure 3, with a given modulation (8 quadrature amplitude modulation, or 8QAM), capacity can be traded off for greater reach by adjusting carrier spacing. Without this flexibility, in some cases, the network operator would be forced to use a lower-order modulation (e.g. quadrature phase-shift keying or QPSK instead of 8QAM) with a substantial reduction in capacity. For that reason, operators would like the ability to fine-tune

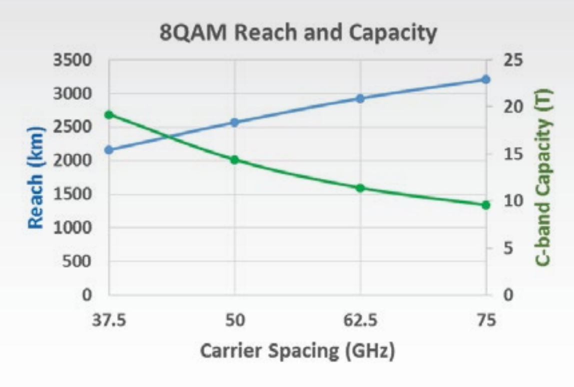


Figure 3: Capacity-Reach Trade-offs with Variable Carrier Spacing

channel width and spacing to achieve maximum capacity, and some are even exploring the value of enabling dynamic optimization in response to changing capacity usage patterns and other factors such as fiber aging or repairs.

3. New generations of coherent DSPs will allow for higher baud rates (number of symbols transmitted per time unit), which can improve transponder cost and power consumption for a given capacity. Operating at a higher baud rate, however, requires increasing the channel width per carrier. With baud rates increasing from around 32 gigabaud (Gbaud) today to around 64 Gbaud in the near future, and as much as 100 Gbaud within a few years, single-carrier channel widths will need to increase well beyond 50 GHz.

4. Multi-carrier optical channels, including super-channels, can enable both increased spectral efficiency and increased operational efficiency.[2] Multiple vendors have demonstrated super-channel transmission, and Infinera products have incorporated super-channels for several years. Dual-carrier coherent transceivers are now available from multiple component suppliers, and we expect to see more carriers in future multi-carrier implementations. As shown in Figure 4, open line systems must accept single-, dual- or multi-carrier channels and treat the multi-carrier channel groups as if they were single, wider channels. Channel width of course depends on the number of carriers and the carrier spacing. For example, some commercially announced products employ super-channels with 12 carriers at 37.5 GHz each, which requires a total super-channel width of 462.5 GHz including guard bands. To support a range of likely implementations, open line systems must support channel widths of at least 400-500 GHz now, and should allow even wider channel support with only software upgrades.

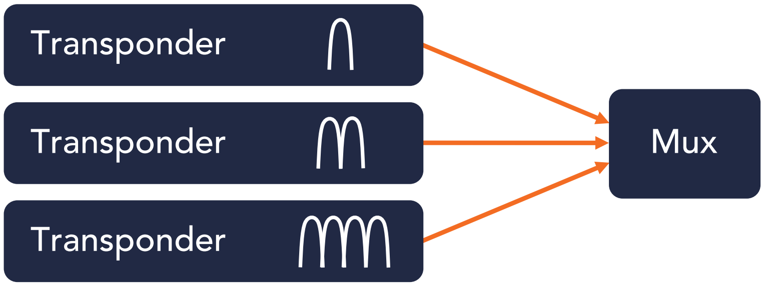


Figure 4: Single-, Dual- and Multi-carrier Channel Inputs to an Open Line System Multiplexer

OLS Capability	Target OLS Requirements
Variable channel width	18.75 GHz – 400+ GHz with ≤6.25 GHz granularity*
Variable channel spacing	18.75 GHz – 100 GHz with ≤6.25 GHz granularity*
Signal rate	15-100 Gbaud*
Externally multiplexed sources	Single-, dual- and multi-carrier (unlimited number of carriers within supported channel width)

*These ranges should all be expandable with only a software upgrade.

Table 2: Requirements for Flexible Channel and Carrier Formats

Based on all these factors, open line systems must support widely variable channel widths, channel spacing and signal rates, and must be capable of supporting multi-carrier channel groups. Table 2 summarizes the recommended minimum ranges that should be supported today for each of these parameters, and also recommends that these ranges be expandable in the future with only software upgrades as noted.

4.2 Automatic Power Control

Power control in any line system is critically important to ensure end-to-end performance and system availability. When optical carriers on a fiber are balanced at the same optical power level, fiber capacity and reach can be maximized. In an open line system, the power control problem becomes more complex than in an integrated system from a single supplier. Automatic power control must be able to cope with a variety of operational scenarios:

- Optical carriers and multi-carrier channels from different sources may be inserted into the system with varying formats, central frequencies, spectral shapes and optical power levels.

- Individual carriers or multi-carrier groups may disappear and reappear due to fiber cuts or equipment failures, disrupting the steady-state power balance.

To ensure fast response and robust operation, the open line system must be able to independently detect and adjust for these variables without relying on higher-level management and control or proprietary techniques.

Effective automatic power control requires several capabilities, which may be implemented differently by different suppliers:

- Fine-grained optical power monitoring
- Amplifier gain and tilt control
- Flattening algorithms
- Express auto-discovery
- Multiplex and demultiplex wavelength selective switch (WSS) control

These capabilities may be implemented in varying ways, but regardless of the implementation, the automatic power control must meet the requirements outlined in the following subsections.

In all cases, an open line system must be able to support these requirements for any carrier inserted into the system, without preference for native (same supplier) or alien (different supplier) wavelengths.

4.2.1 Fine-grained Optical Power Monitoring

A high-performance, fine-grained optical power monitor (OPM) is required to provide maximum openness and future-proofing. Benefits of such an OPM include:

- An OPM directly measures carrier power rather than relying on fixed and possibly erroneous assumptions or indirect measurements. This ensures that measurements are always accurate and allows for maximum openness, i.e. maximum ability to accept wavelengths from alien sources. By contrast, proprietary power measurement techniques that do not use direct OPM measurement create a barrier to alien wavelength insertion and make the line system closed.

- When the OPM is fine-grained, i.e. able to measure power at small increments of frequency, it will be capable of scanning and measuring individual carrier power levels accurately even in the presence of the many variables noted above. The OPM granularity should be no more than 50% of the channel width and spacing granularity to achieve this objective. A coarser measurement approach may misread individual carriers, leading to improper power balancing and reduced system performance.

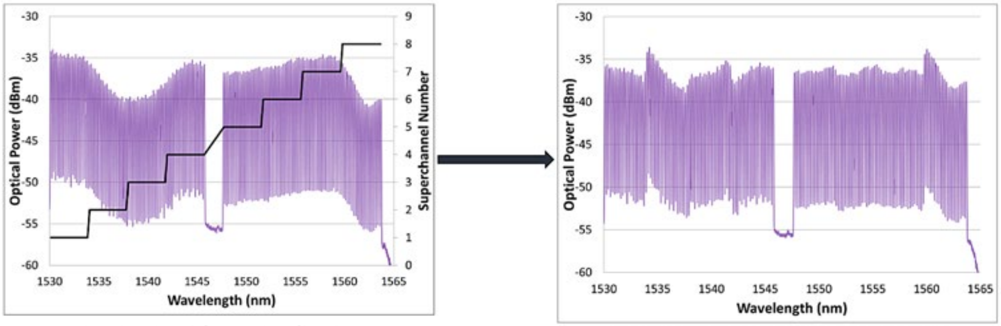
- A high-performance, fine-grained OPM can ensure future-proofing of the line system and guarantee compatibility with any future optical formats, including super-channel formats that may evolve faster than the line system.

4.2.2 Spectral Shaping and Flattening for Arbitrary Channels

Spectral shaping is required to achieve optimal transmission performance. Accurate spectral shaping is becoming increasingly important as higher-order modulation formats are being deployed in networks.

Naturally the open line system must support flattening for single-carrier optical channels. To fully support multi-carrier channels and super-channels, both interchannel and intrachannel flattening are required. As an example, this goal may be achieved by a process of intersuper-channel flattening followed by intrasuper-channel flattening.

Step 1: Intersuper-channel flattening (see Figure 5)
- Power balancing done at the super-channel level
- Flattens the average power to target value
- Uses power integrated over all spectral slices spanned by the super-channel
- Residual ripple remains within the super-channels



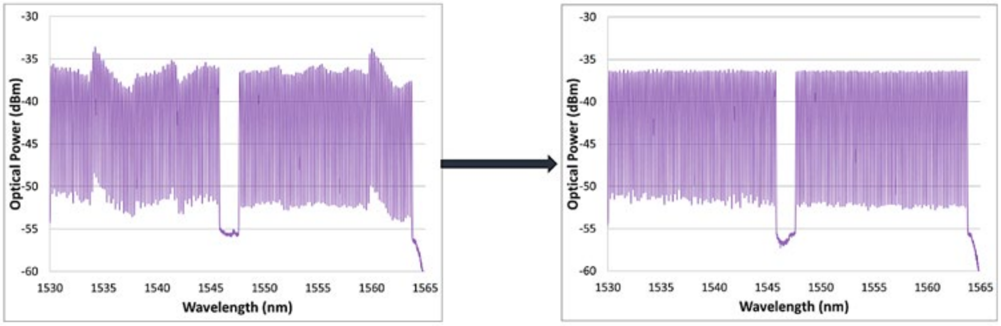
Spectrum without equalization

Spectrum with inter-SC equalization

Figure 5: Intersuper-channel Shaping and Flattening

Step 2: Intrasuper-channel flattening (see figure 6)

- Power balancing done at the carrier level
- Uses fine-granularity spectral scan within passband to quantify and negate carrier-to-carrier power variation



Spectrum with inter-SC equalization only

Spectrum with both inter- and intra-SC equalization

Figure 6: Intrachannel Shaping and Flattening

4.2.3 Channel-agnostic Detection, Shaping and Flattening

The spectral shaping algorithms of an open line system must be agnostic to the composition of a channel group:

- Number of carriers within the super-channel
- Spectral shape of carriers (e.g. shaped by digital-to-analog converter [DAC] vs. unshaped)
- Carrier location relative to the ITU G.694.1 flexible grid
- Carrier pitch

OLS Capability	Target OLS Requirements
Automatic power control	• Fully hands-free optical power control of any supported optical channel end-to-end • Fine-grained optical power monitor (OPM) with measurement granularity ≤3.125 GHz • Per-channel power balancing (gain, tilt, flattening) • Full support for native and alien channels • Automatic alien channel recognition • Arbitrary spectral shape, agnostic to composition of channel or super-channel

Table 3: Automatic Power Control Requirements

Table 3 summarizes the above requirements for automatic power control.

4.3 Network-to-network Interoperability

As noted in the Introduction, many network operators will choose to deploy open line systems from a single supplier in a particular domain of their network, and may not initially attempt to deploy fully disaggregated line systems. However, a specific case of multi-supplier line system interoperability may be required if operators choose different open line system suppliers for different domains and then interconnect them. In that case, the focus will be on a handoff at a single point of interoperability (or perhaps two points for additional reliability) using the approach described as "OLS interop/handoff" in Section 2. Open line systems must be able to support handoffs of an arbitrary arrangement of aggregated channels, including a mix of single-carrier and multi-carrier channels, as shown in Figure 7.

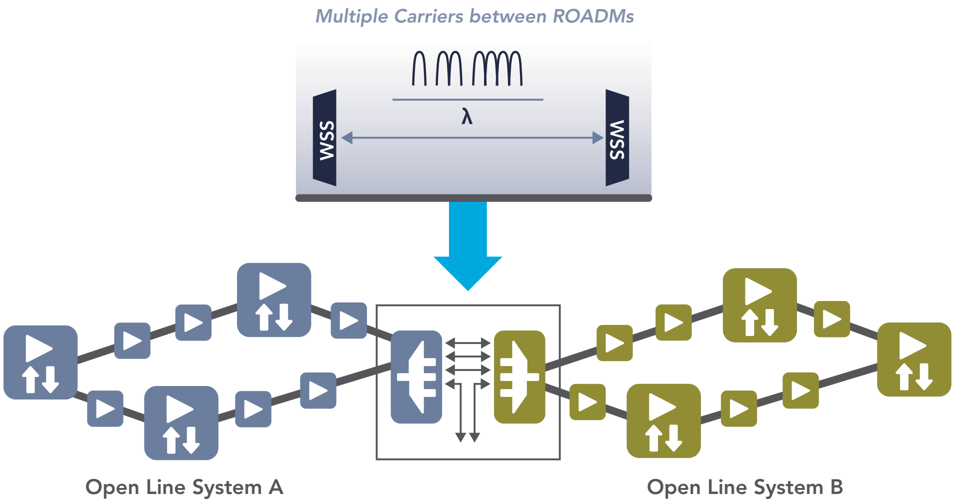


Figure 7: Enabling Multi-carrier Handoff Between Open Line Systems

OLS Capability	Target OLS Requirements
Network-to-network interoperability	• Flexible single-carrier or multi-carrier transmission between open line systems • No proprietary feature barriers

Table 4: Network-to-network Interoperability Requirements

Also important is that such line system interoperability is not impaired by one of the line systems' proprietary control or signaling features, such as the proprietary power control approaches mentioned in Section 4.2. Existing line systems that incorporate such proprietary features are not readily capable of interoperating in this network-to-network scenario.

Table 4 summarizes the network-to-network interoperability requirements.

4.4 Management and Control, Open APIs and Information Models

Management and control of open line systems may be achieved in multiple ways. This section covers two complementary approaches: traditional network management and SDN-based management and control using open APIs and information models.

4.4.1 Network Management

Open line systems have traditionally been implemented with independent network management systems (NMS) provided by each supplier, i.e. one NMS provided by the open line system supplier and a separate NMS provided by each supplier of transponder terminal equipment. Network operators who want to start deploying more advanced flexible-grid open line systems today can choose to start with this same management approach, and in that case, the open line system NMS should be able to support full provisioning, monitoring, troubleshooting and other operational functions for both native and alien wavelengths, aligned to the above requirements.

4.4.2 SDN-based Control with Open APIs and Information Models

Looking forward, network operators are expected to prefer new models for controlling disaggregated optical systems based on SDN principles with open APIs and standardized information models. This approach has the potential to allow easier integration of multiple suppliers into an end-to-end control and orchestration framework, and provides more options for network operators to use control systems sourced from different suppliers or developed in-house. This whitepaper addresses the requirements for open APIs and information models that can enable this approach, but does not attempt to specify the software architecture for SDN-based control and end-to-end orchestration.

It is important to acknowledge that the standardized definitions of open APIs and information models for optical line systems are still emerging and industry preferences may evolve. That said, it appears likely that many network operators will gravitate toward the following approaches:

Open APIs:

- NETCONF/YANG-based APIs are becoming widely accepted for the programmability and automation of all types of network elements, particularly in ICPs. It is highly likely that NETCONF/YANG interfaces will be required for line system programmability, configuration, and other operational functions. Some customers may prefer to use a simpler RESTCONF interface instead of NETCONF, so the ability to support both will be highly desirable.

- The gRPC protocol is emerging as a preferred vehicle for network monitoring and performance management. Leading network operators are eager to move away from traditional network management protocols toward gRPC with streaming telemetry, in which operational and performance data is continuously streamed from the network to the operations system.

Information Models:

- While YANG appears to be the consensus choice for representing information about open line systems, the specifics of the information models (how the data is structured and defined) are still under discussion in various industry forums. Initial deployments are likely to rely on YANG models that are somewhat supplier-specific, pending agreement on standardized models. Open line systems should implement YANG information models that are as aligned as possible with emerging standard approaches and then evolve the models to align to final standards.

It's important to note that open APIs *may* be provided directly on individual line system elements, and some operators may choose to require such direct interfaces, but many network operators will prefer to interface to an SDN controller provided by the open line system supplier or a third-party SDN controller of their choice, that can interface to all the line system elements, provide an abstracted representation of the entire open line system, and enable end-to-end provisioning through a single open API. This approach greatly simplifies the operator's job of integrating into higher-level management and orchestration systems.

Table 5 summarizes the network management, API and information model requirements.

OLS Capability	Target OLS Requirements
Network management	• OLS NMS supports full provisioning, monitoring, troubleshooting and other operational functions for both native and alien wavelengths
Open APIs and information models	• NETCONF, RESTCONF, gRPC • YANG information models (align to standards as developed)

Table 5: Management and Control, Open API and Information Model Requirements

4.5 Summary of Requirements

Table 6 below summarizes the requirements outlined in the preceding sections for easy reference.

OLS Capability	Target OLS Requirements
Flexible support for optical channel and carrier formats	
Variable channel width	18.75 GHz – 400+ GHz with ≤6.25 GHz granularity*
Variable channel spacing	18.75 GHz – 100 GHz with ≤6.25 GHz granularity*
Signal rate	15-100 Gbaud*
Externally multiplexed sources	Single-, dual- and multi-carrier (unlimited number of carriers within supported channel width)
Automatic power control	• Fully hands-free optical power control of any supported optical channel end-to-end • Fine-grained optical power monitor (OPM) with measurement granularity ≤3.125 GHz • Per-channel power balancing (gain, tilt, flattening) • Full support for native and alien channels • Automatic alien channel recognition • Arbitrary spectral shape, agnostic to composition of channel or super-channel
Network-to-network interoperability	• Flexible single-carrier or multi-carrier transmission between open line systems • No proprietary feature barriers
Network management	• OLS NMS supports full provisioning, monitoring, troubleshooting and other operational functions for both native and alien wavelengths
Open APIs and information models	• NETCONF, RESTCONF, gRPC • YANG information models (align to standards as developed)

*These ranges should all be expandable with only a software upgrade.

Table 6: Summary of Target Open Line System Requirements

This table represents an important subset of common requirements that will apply to many network operators. Naturally, individual operators will have additional requirements specific to their networks and operations environments.

5 Conclusion

Open line systems are poised to gain much wider acceptance and deployment over the next few years. However, the definition of what an open line system is must evolve to align to the underlying optical technology drivers and meet the architectural needs of network operators. This white paper has outlined a set of common requirements that apply across a range of operators, from web-scale cloud and content providers to integrated network service providers. With some suppliers already delivering open line systems that meet most or all these requirements, it's clear that the requirements are technically feasible and applicable to networks that are being deployed today, while also enabling future-proof open line systems that can accommodate optical technology advances expected in the coming years.

---

1 Gerstel, Jinno, Lord & Yoo, *"Elastic Optical Networking: A New Dawn for the Optical Layer?"*, IEEE Communications Magazine, February 2012

2 *"Super-Channels: DWDM Transmission at 100Gb/s and Beyond"*, Infinera Whitepaper

3 S. Kumar, R. Egorov, K. Croussore, M. Allen, M. Mitchell, and B. Basch, *"Experimental Study of Intra- vs. Inter-Superchannel Spectral Equalization in Flexible Grid Systems,"* in Optical Fiber Communication Conference/National Fiber Optic Engineers Conference 2013, OSA Technical Digest (online) (Optical Society of America, 2013), paper JW2A.05.

Infinera Corporation
140 Caspian Court
Sunnyvale, CA 94089 USA
Telephone: +1 408 572 5200
Fax: +1 408 572 5454
www.infinera.com

Have a question about Infinera's products or services?
Please **contact us**.

Document Number: 0183-WP-RevA-0519