WHITE PAPER

OPTICAL LAYER PLUGGABLES: THE END OF HARD CHOICES IN THE METRO?

Examining Three Optical Layer Architectures

Internet video, enterprise cloud, and Data Center Interconnect (DCI) are driving unprecedented traffic growth and unpredictable traffic patterns in metro networks. At the same time, network operator budgets are constrained in terms of both CapEx and OpEx as this traffic growth has not been matched by corresponding top line revenue growth. This environment has – until now – forced network operators to make hard choices:

- The low start-up cost of fixed WDM – or – the flexibility and operational savings of ROADM
- The flexibility of a DWDM system with separate modules for each function – or – the compact footprint and installation simplicity of a system-on-a-blade architecture

This white paper looks at a new approach to building the metro optical layer based on miniaturizing optical layer functions (e.g., amplification, monitoring, wavelength selective switching, and optical supervisory channel) into compact pluggables that enables network operators to avoid these hard choices. After first explaining the evolution of optical layer functions to compact pluggables, this white paper examines the benefits of pluggables and provides comparisons with traditional approaches including individual modules and system-on-a-blade architectures as well as fixed WDM and ROADM. Finally, example applications and use cases are described for optical layer pluggables.

BEFORE OPTICAL LAYER PLUGGABLES: HARD CHOICES IN THE METRO

Metro networks are experiencing tremendous traffic growth. Access bandwidth speeds are increasing rapidly with the adoption of technologies including G.fast DSL, NG-PON/NG-PON2, and DOCSIS 3.0/3.1 in fixed networks and the evolution to LTE and LTE-Advanced in mobile networks, with 5G just around the corner. Applications are making the most of these increased access speeds with Internet video and cloud services driving rapid increases in bandwidth use. DCI bandwidth between the data centers hosting these video and cloud services is experiencing even faster growth.

However, these increases in bandwidth are not being matched by top line revenue growth. This is leaving network operators the challenge of having to support this traffic growth in a CapEx-constrained environment and facing some hard choices regarding optical layer technology in the metro.

Before the advent of a pluggable optical layer option, metro network planners had to choose between two primary options for the metro optical layer.

	FIXED WDM	ROADM
Advantages	Lower Upfront CapEx Smaller Footprint Lower Power Consumption	Flexible Add/Drop Future-Proof Simplified Planning Low Operational Costs

TABLE 1 – Fixed WDM vs. ROADM

The first option was fixed WDM which offers the lowest upfront CapEx together with a compact footprint and low power consumption. On the other hand, fixed WDM offers limited flexibility in network topology and wavelength patterns. It also has higher operational costs with the need to manually balance power levels on a regular basis and the complex wavelength planning that comes when using fixed filters for non-trivial channel plans.

The other option was ROADM. With its flexible add/drop and ability to perform optical layer express, ROADM offers a flexible and future-proof solution with simplified planning and lower operational costs. However, the ROADM advantages come at the expense of higher upfront CapEx and a potentially larger footprint and higher power consumption, at least for the initial deployment. Metro network planners, therefore, had to choose between the low upfront costs of fixed WDM or the more flexible and future-proof ROADM. That is until the advent of a pluggable optical layer.

A SHORT HISTORY OF COMPACT PLUGGABLES

Compact pluggables are nothing new to telecoms and networking. The first compact pluggable was the GBIC (Gigabit Interface Converter), providing Gigabit Ethernet and Fibre Channel, which was first proposed in 1995 and was commonly used in networking equipment in the 2000s, until it was made obsolete by SFPs, at the time also referred to as mini-GBICs, which were first defined in 2000. Later came XFPs for 10G, CFPs for 40G and then 100G, and SFP+ for a more compact 10G option.

In terms of optical transport equipment, these pluggables were initially used on the client side to provide flexibility for protocol and reach while also delivering cost, space, and power savings. On the DWDM side, fixed WDM XFPs were first introduced in 2006 and tunable XFPs in 2008. This was followed by the first fixed WDM SFP+ in 2011 and the first tunable SFP+ in 2013.

This transition from non-pluggables to pluggables has helped to significantly drive down the cost of WDM transceivers over the past decade. However, until now the optical layer itself has been largely untouched by pluggables.

INTRODUCING COMPACT OPTICAL LAYER PLUGGABLES

This evolution to compact pluggable form factors that occurred first for client side/grey transceivers and then for line side WDM transceivers is now starting to happen to the optical layer.

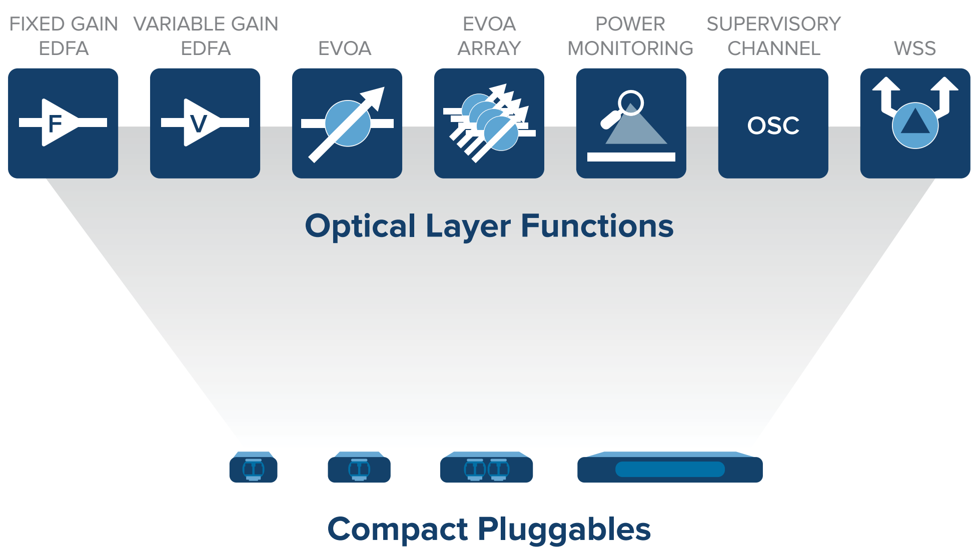

FIGURE 1 – Optical Layer functions evolving to compact pluggables

Optical layer functions evolving to compact pluggables based on SFP, XFP, or other pluggable form factors include:

- Fixed gain Erbium Doped Fiber Amplifiers (EDFAs)
- Variable gain EDFAs
- Electronically Variable Optical Attenuators (EVOAs)
- Optical Per Channel Power Monitoring (OCM)
- Optical Supervisory Channel (OSC)
- Wavelength Selective Switches (WSS) for broadcast and select ROADM
- Optical Time-Domain Reflectometer (OTDR)

In the longer term, even more advanced optical layer technologies, such as route and select ROADM and Raman amplification, also have the potential to move to compact pluggable form factors.

Additional technology enablers for this new optical layer include compact banded filters with low insertion loss, transceivers with expanded ranges and tighter launch power tolerances, EVOAs with integrated photodiodes, and power tone for automatic amplifier gain management. Compact low loss filters and improved transceivers enable extended passive architectures and more complex channel plans in fixed WDM networks. EVOAs with integrated photodiodes simplify operations with automatic attenuation without the need for per channel power monitoring and WSSs. Likewise, power tone provides a highly cost-effective solution for automatically setting the gain of variable gain EDFA-based amplifiers.

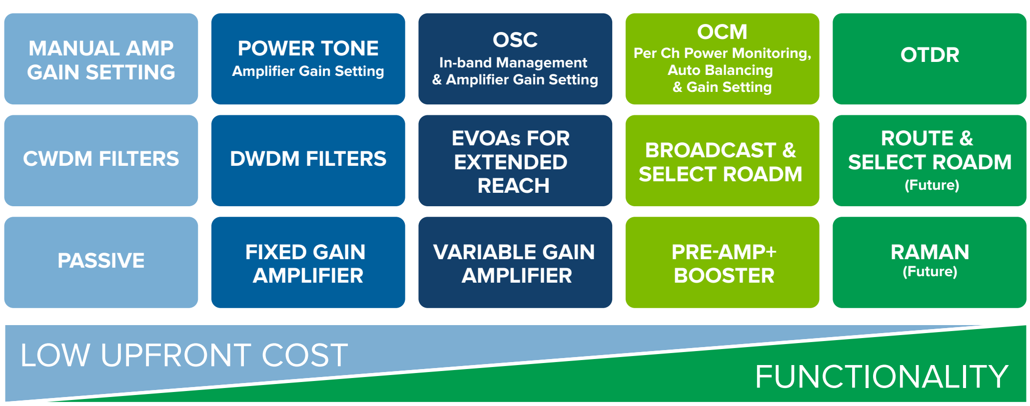

FIGURE 2 – Pluggable Optical Layer: Mix and Match Functions as Needed

Together, these technologies enable metro network planners to select the exact set of technologies and functions they need, when they need it, making the optimal trade-off between low upfront costs and functionality for their network, with the ability to add more functionality later if and when it is needed – incrementally and while protecting earlier investments.

For example, in its simplest form an operator could deploy an entirely passive solution based on CWDM filters. Fixed gain amplifiers could be combined with DWDM filters for a point-to-point application with extended reach. Variable gain amplifiers could be used for more complex topologies, more channels, and/or longer distances. Operational choices would include manual gain setting, power tone for low cost automatic gain management, OSC for amplifier gain management and in-band communications (i.e., to adjacent Optical Line Amplifier nodes), and OCM for the most accurate automated gain setting and per channel power monitoring.

In complex extended topologies, EVOAs can be used for power balancing. Alternatively a WSS could be used in conjunction with the EDFAs and OCM to create a broadcast and select ROADM with full add/drop flexibility and all the other benefits of ROADM. Advanced functionality could include OTDR for identifying the location of fiber cuts, route and select ROADM with support for cost-effective colorless and directionless add/drop, and even Raman amplification to support extra long spans.

THE BENEFITS OF A PLUGGABLE OPTICAL LAYER

So what are the benefits of using a pluggable optical layer?

PLUGGABLE OPTICAL LAYER BENEFIT 1: REDUCED CAPEX

The first benefit of a pluggable optical layer is reduced costs – more specifically capital costs – which can be up to 30% lower than traditional alternatives. The first way in which a pluggable optical layer enables cost reductions is the ability to choose exactly the optical layer functionality needed without having to pay for unneeded functionality. If a network operator does not need an OSC or per channel power monitoring, they do not need to pay for this functionality. Additional cost advantages of compact pluggables include reduced footprint, which can eliminate the need for additional shelves and common equipment such as systems processors. In addition, low loss filters and improved transceivers can enable extended passive architectures, reduce the need for amplification, and reduce the need for channel equalization. Reducing the need for channel equalization can eliminate the cost of EVOAs/WSSs used for attenuation and the cost of the OCM for power monitoring.

PLUGGABLE OPTICAL LAYER BENEFIT 2: REDUCED OPERATIONAL COSTS

A pluggable optical layer can reduce operational costs in multiple ways. The first and easiest to quantify are footprint and power consumption, with savings of up to 70% and 50% respectively relative to traditional solutions based on individual module per function or system-on-a-blade architectures.

However, perhaps the biggest impact of the pluggable optical layer on operational costs is on the less easy to quantify aspects related to installation, operations, and maintenance, relative to traditional fixed WDM solutions.

Improved filter and transceiver technology can enable extended network designs without the need for per channel equalization and balancing, thus avoiding many of the scenarios in traditional fixed WDM networks that would typically require sending out engineers to manually balance power levels on a regular basis. Power tone provides a cost-effective solution for automatic gain management of the amplifiers. Where balancing is required, it can now be enabled cost effectively by EVOAs with auto-attenuation. Furthermore, advanced functionality such as per channel power monitoring and equalization, which would previously have required more expensive ROADM-based solutions, can now be provided cost effectively without the need to pay for the full functionality of a ROADM-based system. Even advanced functionality, such as OTDR to quickly locate fiber cuts, can be supported within the concept of a pluggable optical layer.

PLUGGABLE OPTICAL LAYER BENEFIT 3: FLEXIBILITY

A third key benefit is flexibility. A pluggable optical layer enables a wide range of applications, including CWDM, passive fixed DWDM, amplified fixed DWDM, optical line amplifiers, and even ROADM, with the set of functions tailored to each network's requirements. A wide range of topologies, distances, and traffic patterns can be supported by combining passive components such as mux/demux filters and band splitters with different amplifier combinations and by using EVOAs or WSSs and per channel power monitoring for balancing.

PLUGGABLE OPTICAL LAYER BENEFIT 4: INVESTMENT PROTECTION

As a fourth benefit, a pluggable optical layer offers a future-proof solution that maximizes investment protection. For example, it is possible to start with a fixed DWDM network and then evolve to a ROADM-based network, as traffic patterns and needs evolve, by adding WSS pluggables while protecting earlier investments in amplifier pluggables, power monitoring pluggables, and other hardware.

Furthermore, over time more advanced optical functions can evolve to compact pluggables, including multi-degree ROADM, route and select ROADM, colorless and directionless add/drop, OTDR, and Raman amplification, which enables the pluggable optical layer approach to expand to support a wider application set and to evolve with network operator needs.

COMPARISONS WITH TRADITIONAL APPROACHES

PLUGGABLE OPTICAL LAYER VS. INDIVIDUAL MODULES AND SYSTEM-ON-A-BLADE

To date there have been primarily two architectures available for building the optical layer. The first basic architecture is to put each function (EDFA, OCM, OSC, WSS, etc.) on its own individual module, though in some cases, functions may be combined on a single module.

For example, many amplifiers integrate an OSC. This architecture is still most common in long haul equipment.

A second traditional architecture has been to integrate all the optical layer components into a single module, a system-on-a-blade, typically a ROADM-on-a-blade. This can result in significant footprint and power savings and to a lesser extent cost savings. The integrated single module approach simplifies installation and commissioning with no need for cabling between individual modules, which also reduces the risk of human error during installation and commissioning. This architecture has been most widely adopted in the metro where footprint and power consumption are typically key considerations.

Where does a pluggable optical layer fit within the network compared to the two traditional architectures?

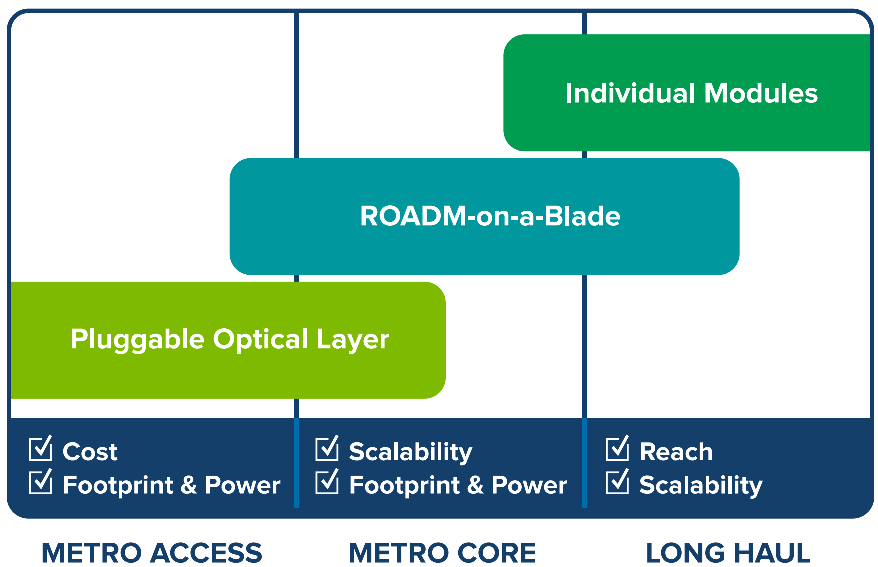

FIGURE 3 – Sweet Spots for Pluggable Optical Layer, ROADM-on-a-blade, and Individual Modules

Each of these three architectures has a sweet spot in different parts of the network where different priorities of cost, footprint, power, scalability, and reach dominate. Individual modules will typically provide the best fit for long haul where reach and scalability dominate. ROADM-on-a-blade is likely to be in the metro core where a combination of scalability together with a small footprint and low power consumption are high priorities. The pluggable optical layer provides the best fit for metro access applications where low cost, small footprint, and low power consumption are high priorities. In addition, each of these architectures may find a role in a neighboring part of the network based on the priorities of individual network operators.

	INDIVIDUAL MODULES	SYSTEM-ON-A-BLADE	PLUGGABLE OPTICAL LAYER
Footprint & Power	✓	✓✓	✓✓✓
Flexibility (to mix & match components)	✓✓	✓	✓✓✓
ROADM Scalability (Degrees, Channels)	✓✓✓	✓✓✓	✓ (Future Improvements)
Advanced ROADM Add/Drop	✓✓✓	✓✓✓	✓ (Future Improvements)
Performance/Reach	✓✓✓	✓✓	✓
Ease of Installation	✓✓	✓✓✓	✓✓
Cost of Replacing Failed Hardware/Sparing	✓✓✓	✓	✓✓✓

TABLE 2 – Individual Modules vs. System-on-a-blade vs. Compact Pluggables

Table 2 compares these three architectures in more detail. In terms of footprint and power consumption, the system-on-a-blade architecture with the ability to provide a full ROADM degree in a one slot module has a distinct advantage over individual modules, which require multiple modules per degree. Likewise, a pluggable optical layer can have a significant footprint advantage over even a single slot ROADM-on-a-blade because the compact pluggables can provide multiple degrees in the same footprint. As an example of potential power consumption savings, XFP-based EDFAs draw only a few watts, compared to multiple tens of watts for traditional EDFA-based amplifiers.

If flexibility is defined purely in terms of the ability to select functions and mix and match different components such as amplifiers, individual modules have an obvious advantage over system-on-a-blade. However, as functions become combined (i.e., amplifier and OSC) even in the individual module architecture, a pluggable optical layer will have the advantage as it maintains disaggregated functions without compromising footprint.

For ROADM scalability, defined in terms of the number of degrees and channels, both individual modules and ROADM-on-a-blade architectures can support up to 16 degrees and 96 channels per degree or more channels per degree with flexi-grid. Optical layer pluggables will be limited to two or four ROADM degrees at least in the short to medium term, though there is the potential for pluggable ROADM scalability to increase over time.

Likewise, advanced ROADM add/drop options, including colorless, colorless/directionless, and colorless, directionless, contentionless (CDC), are supported in the individual modules and system-on-a-blade architectures, while for the pluggable optical layer, these add/drop options remain medium to long-term evolution options.

In terms of reach, both individual modules and system-on-a-blade architectures have advantages and disadvantages. With individual modules, a wider selection of amplifiers can be used to optimize for the span distances in the network. On the other hand, the system-on-a-blade architecture benefits from not having to lower the power of the amplifiers to meet safety standards for external connections. While the system-on-a-blade architecture can, therefore, have an advantage with spans within a narrow range close to the sweet spot for maximum reach (i.e., 60km~80km), the flexibility of the individual modules usually wins out as the fiber conditions become more challenging with a mix of span lengths and fiber types. In the metro space that is the target for pluggable optical layer architectures, reach is not a top priority.

Finally, the integrated system-on-a-blade architecture also has an ease of installation advantage without the need for external cabling between functions. On the other hand, the individual module and pluggable optical layer have the cost advantage of replacing failed hardware and, to a lesser extent, sparing. The sparing advantage is most likely seen in smaller networks with diverse requirements as the ability to spare each function individually could result in lower quantities compared to sparing different types of system-on-a-blade architecture.

PLUGGABLE OPTICAL LAYER VS. FIXED WDM AND ROADM

<table>
<tr><th></th><th>FIXED WDM</th><th>ROADM</th><th>PLUGGABLE OPTICAL LAYER</th></tr>
<tr><td>Lower Upfront CapEx</td><td>✓</td><td></td><td>Depends on Functionality Selected</td></tr>
<tr><td>Smaller Footprint</td><td>✓</td><td></td><td>✓</td></tr>
<tr><td>Lower Power Consumption</td><td>✓</td><td></td><td>✓</td></tr>
<tr><td>Future-Proof</td><td></td><td>✓</td><td>✓</td></tr>
<tr><td>Flexible Add/Drop</td><td></td><td>✓</td><td>With WSS Option</td></tr>
<tr><td>Simplified Planning</td><td></td><td>✓</td><td rowspan="2">Ability to Select ROADM Features</td></tr>
<tr><td>Low Operational Costs</td><td></td><td>✓</td></tr>
</table>

TABLE 3 – Fixed WDM vs. ROADM vs. Pluggable Optical Layer

Depending on the options selected, the pluggable optical layer can combine many of the benefits of fixed WDM with many of the benefits of ROADM. A pluggable optical layer can deliver equivalent or lower cost compared to a traditional fixed WDM solution for equivalent functionality, together with equivalent or lower power consumption and footprint. As advanced functionality gets added, the upfront cost of a pluggable optical layer solution will increase. However, a pluggable optical layer enables metro network planners to only pay for those functions that will give them a substantial operational or other benefit.

A pluggable optical layer can also support selected functions that are typically only found in ROADM systems up to and including full ROADM functionality leveraging pluggable WSSs. This capability enables a pluggable optical layer option to provide a flexible and future-proof solution without a high upfront CapEx investment.

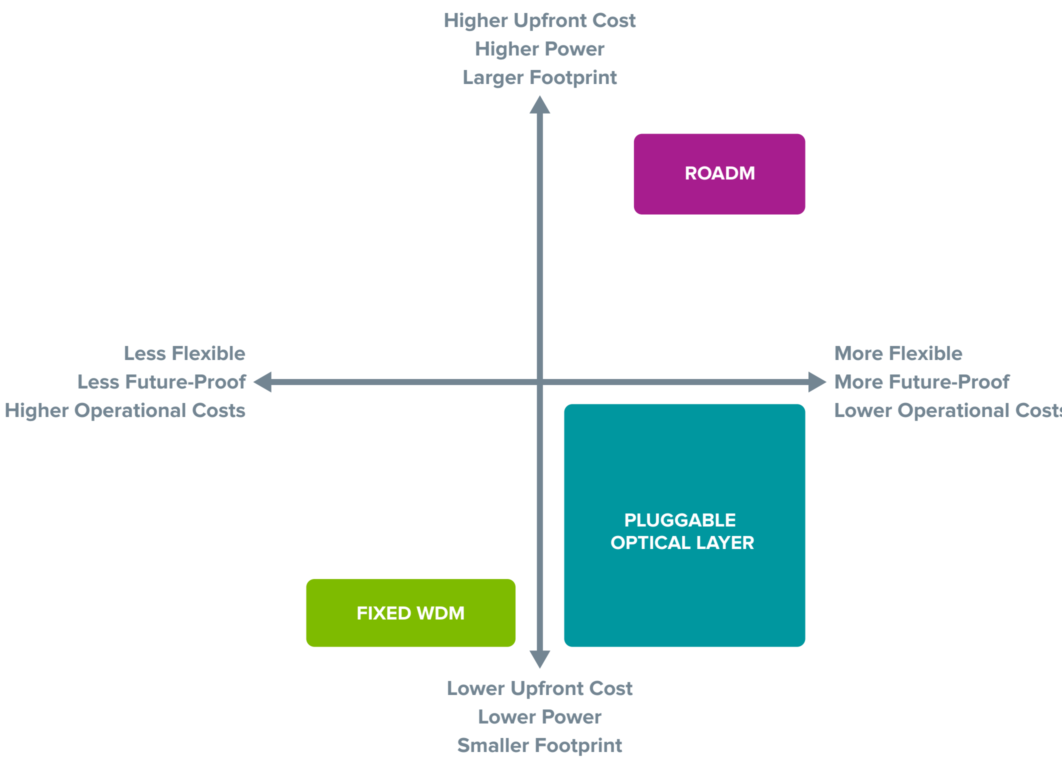

FIGURE 4 – Pluggable Optical Layer: The Best of Both Worlds

As shown in Figure 4, a pluggable optical layer solution bridges the gap between the cost, footprint, and power consumption benefits of fixed DWDM and the flexibility, investment protection, and low operational costs of ROADM, offering, to a large extent, the best of both worlds.

USE CASES AND APPLICATIONS

Targeted at metro access networks, the Infinera Pluggable Optical Layer is ideal for point-to-point topologies, ring/chain topologies, and spurs and arcs off an existing ROADM-based infrastructure.

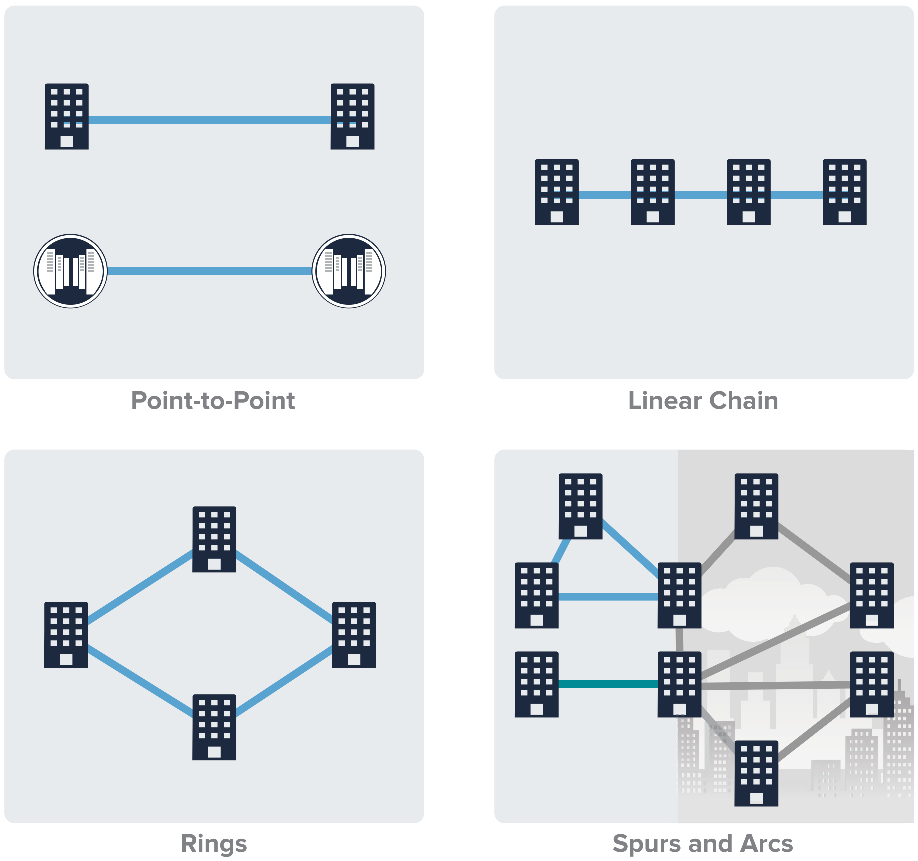

FIGURE 5 – Pluggable Optical Layer Applications

POINT-TO-POINT

Options for point-to-point WDM include passive CWDM, passive DWDM, amplified DWDM with low channel counts, and amplified DWDM with up to 96 channels, currently to distances of up to 120km and span losses of up to 30dB. Key applications for point-to-point WDM include metro data center interconnect and private enterprise networks. XFP-based EDFAs can also be used to provide a compact and cost-effective solution for very high loss/long spans, currently up to ~40dB/160km, for single channel point-to-point 10G or 100G.

CHAINS AND RINGS

The Pluggable Optical Layer can support more complex topologies including rings and chains. Passive rings/chains are supported with the aid of low loss compact filters. Variable gain amplifiers with transient control can be used for extended distances with spans of up to 30dB. While many metro networks built with the Pluggable Optical Layer will not require EVOAs, larger networks with extended optical express can be supported with the aid of EVOAs for power balancing. Applications include metro fixed WDM networks, ROADM rings, private enterprise networks, and mobile backhaul.

SPURS AND ARCS

The Pluggable Optical Layer can also be used for extending one or more 10G or 100G lambdas to a customer site from a ROADM edge node without OEO and without the need to dedicate scarce and relatively expensive ROADM degrees on individual enterprise customers. The Pluggable Optical Layer can also be used for extending ROADM-based metro DWDM networks more cost effectively into the access network.

OTHER: ALIEN WAVELENGTHS

An additional application for the pluggable amplifiers is boosting the power levels of alien wavelengths at the ingress and/or egress to the WDM network.

SUMMARY

The evolution to compact pluggables that helped drive significant declines in the cost of WDM transceivers over the last decade is now set to have a similar impact on the optical layer itself. With functions including EDFA-based amplifiers, EVOAs, Optical Per Channel Power Monitoring, OSC, and WSS moving to compact pluggables, the new Infinera Pluggable Optical Layer solution enables metro network planners to mix and match optical layer functions to optimally meet the requirements of their networks in the short term, while still being able to add functionality over time as needs evolve. The Pluggable Optical Layer also enables network planners to benefit from many of the operational benefits of functions that were previously only available in ROADM-based systems, without incurring the full cost of a ROADM-based system.

Targeted primarily for metro access applications including point-to-point, chain/ring, and spur/arc topologies, the Pluggable Optical Layer has the potential to significantly lower CapEx and OpEx (including footprint, power consumption, operations, and maintenance), while at the same time offering a level of flexibility and investment protection that has, until now, only been available from ROADM-based systems.

Infinera®