APPLICATION NOTE

ICE-X Point-to-Multipoint Optics in Infinera Metro DWDM Networks

Bringing point-to-multipoint economics and coherent single-fiber working to metro access and aggregation networks

The optical networking industry is on the cusp of several exciting architectural changes that offer the opportunity to radically evolve the way networks are designed, deployed, and operated. The most significant of these changes are the move from rigid point-to-point optical architectures to more flexible and dynamic point-to-multipoint architectures and the development of intelligent pluggable optics that bring high-performance coherent DWDM capabilities directly into third-party host devices such as switches, routers, and even servers and access devices such as 5G radios.

The introduction of high-performance XR optics, which supports both point-to-point and point-to-multipoint DWDM architectures, validates both innovation trends. The technology also introduces the opportunity to optimize traditional Xponder-based DWDM access and aggregation networks using digital subcarriers. Specifically, XR optics creates two major optimization opportunities for these networks: overall network cost reduction and the ability to support single-fiber infrastructure with coherent DWDM, the latter of which is typically a major challenge for the industry. Over time, these networks may also evolve further with the use of XR optics directly in third-party client devices, enabling the initial network to act as a stepping stone to a full XR optics architecture.

XR Optics Overview

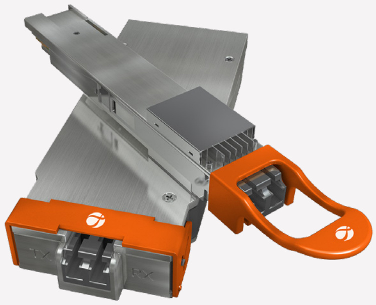
Since the inception of optical networking, there has been a significant misalignment between actual network traffic patterns and the technology used to transport that traffic. Network traffic patterns, particularly in metro networks, are overwhelmingly hub and spoke, with numerous endpoints consuming traffic that is aggregated by a small number of hub locations. In contrast, optical connectivity solutions have been implemented using strictly point-to-point technology, where each end of the connection is required to operate at the same speed (1G, 10G, 25G, 100G, etc.). The result is an extremely inefficient transport architecture that requires large numbers of bookended transceivers, as well as numerous intermediate aggregation devices to "up-speed" traffic flows.

XR optics is the next major inflection point in optical transceiver technologies. XR optics utilizes digital signal processing to subdivide the transmission and reception of a given wavelength spectrum into a series of smaller-frequency channels called digital subcarriers. These digital subcarriers can be independently managed and assigned to different destinations, enabling the industry's first scalable point-to-multipoint, direct low-speed to high-speed optical transceiver connectivity. A single 400G XR optics hub module generates 16 x 25 Gb/s digital subcarriers. Digital subcarriers can be assigned to a specific destination individually or in multiples to provide the required bandwidth.

In addition to a significant reduction in CapEx and OpEx, XR optics enables a multi-generational network architecture. The unique ability for low-speed transceivers to communicate directly and simultaneously with a high-speed transceiver at the hub eliminates the situation where a single-site upgrade triggers the need for a network-wide upgrade.

BENEFITS OF ICE-X IN INFINERA METRO DWDM NETWORKS

- **Reduce metro network capital expenditure by over 30%** using point-to-multipoint optics to reduce the number of coherent optics and intermediate aggregation devices
- **Reduce metro network operational expenditure by over 30%** with reduced power, cooling, and space requirements
- **Support coherent optics over single-fiber working infrastructure** using digital subcarrier-based DWDM
- **Automate network capacity upgrades** with software-provisionable bandwidth
- **Evolve to a full XR optics architecture** with XR optics modules directly hosted in third-party devices



It is widely known that network-wide upgrades, which involve all nodes and links, require a significant capital investment, are labor-intensive, and often result in inefficient utilization of bandwidth, where sites that consume low bandwidth are provided with capacity significantly in excess of actual demand. For the first time in the industry, XR optics decouples node upgrades from network-wide upgrades, enabling certain spans/links or nodes (hubs or spokes) to be upgraded to higher capacity while the rest of the network remains unimpacted, thus aligning CapEx with actual capacity demands.

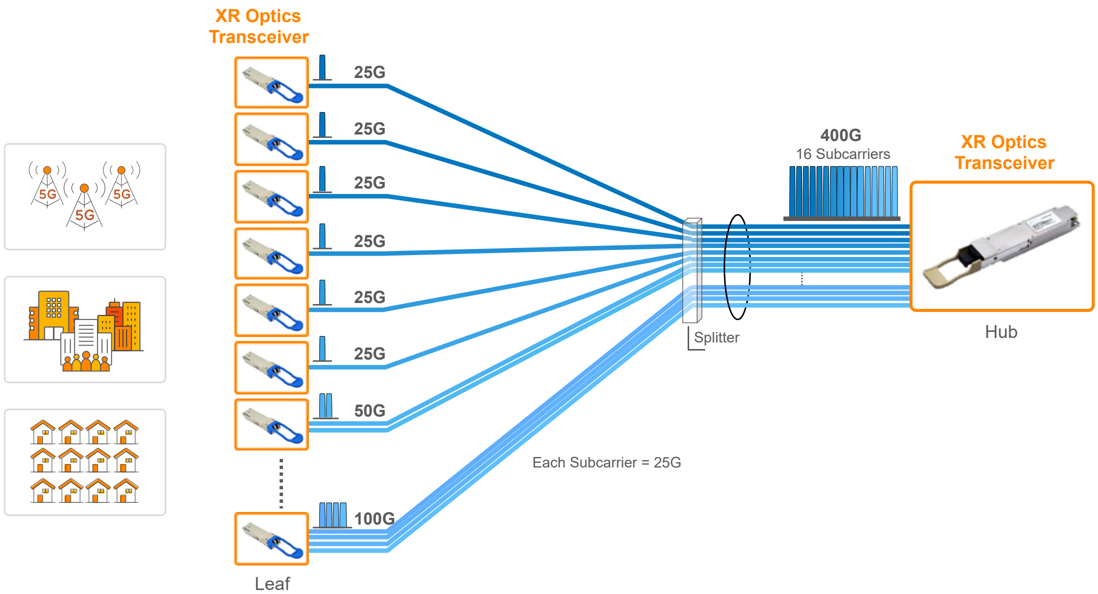


Figure 1: XR optics in action

Infinera is implementing the XR optics architecture via a range of digital subcarrier-based ICE-X intelligent pluggable optics modules, demarcation devices, and management software. This application note outlines architectures enabled by subcarrier-based XR optics, such as ICE-X point-to-multipoint optics, within Xponder-based DWDM networks, as well as the benefits these architectures can bring to network operators.

Major Challenges in Optical Transport Networks

Optical networks underpin virtually all communications networks, and therefore their primary purpose is to provide the most economical data transport for the higher-level services within the operational bounds of the network. These operational bounds include factors such as required reliability/availability, latency constraints, support for anticipated bandwidth growth, and any application-specific requirements, such as synchronization transport for mobile xHaul networks. Once those bounds are met, the main objective of the network is to transport the required bandwidth in the most economical manner on day one and as the capacity of the network grows. Overall, network total cost of ownership (TCO) and cost per transported bit are key.

A further constraint on the operation of the DWDM-based optical transport network is the availability of resources to operate the network. Most DWDM networks run over existing infrastructure, which includes ducts, fiber cables, and buildings that may have limited space and power. Removing the need for networking hardware within the network, such as intermediate aggregation nodes, can have a very positive impact on network TCO and can also help networks operate when space and power are limited. Two areas of optical infrastructure availability that are sometimes a major challenge are the availability of fiber within a network and the prevalence of single-fiber networks at the edge of the optical network. As fiber networks expand ever closer to the end user, most optical access networks use passive optical network (PON) technology and single-fiber infrastructure. PON is highly suited to single-fiber working (SFW), and overall, this approach provides the best economics for optical access networks targeting residential and small/medium enterprise customers.

However, as network capacity grows, DWDM-based transport networks are getting pushed closer to the edge of the optical network and often into single-fiber domains originally planned for PON. SFW is easily supported by lower-speed direct-detect DWDM, typically operating at 10G or perhaps 25G per wavelength. But as capacity demands increase further, this SFW infrastructure presents a significant challenge for higher-capacity coherent DWDM networks operating at 100G+ per wavelength. While the direct-detect DWDM optics can easily use two different wavelengths over the fiber – one per direction – modern coherent optics are challenged over SFW infrastructure as they use the transmitter laser as a local reference oscillator for the receiver, thereby locking both directions to the same wavelength. This capability is a benefit in normal dual-fiber networks but a real challenge in single-fiber infrastructure for higher-speed coherent DWDM optics. Using digital subcarrier-based XR optics, and Infinera's ICE-X specifically, network operators can address both these challenges – overall network TCO and deploying coherent DWDM over SFW infrastructure.

Addressing Overall Network TCO

Most metro access and aggregation networks are designed to aggregate lower-speed services from a wide array of access locations into a smaller number of higher-speed services for transport and handover to the core/long-haul network. As described above, this must be achieved with the best overall network TCO and utilization of resources. The point-to-multipoint DWDM capabilities of ICE-X present network operators with the opportunity to address this challenge through the removal of unnecessary aggregation devices and a reduction in the number of required optics across the network.

The full XR optics architecture takes advantage of the move to intelligent pluggable optics by hosting XR optics directly in third-party devices such as routers, switches, servers, or access devices. However, traditional Xponder-based DWDM networks can also take advantage of XR optics to reduce network TCO with lower equipment requirements and lower associated operational costs. A simple example is shown in Figure 2, where the number of coherent transceivers is halved from eight to four and the intermediate 400G Xponder is no longer required.

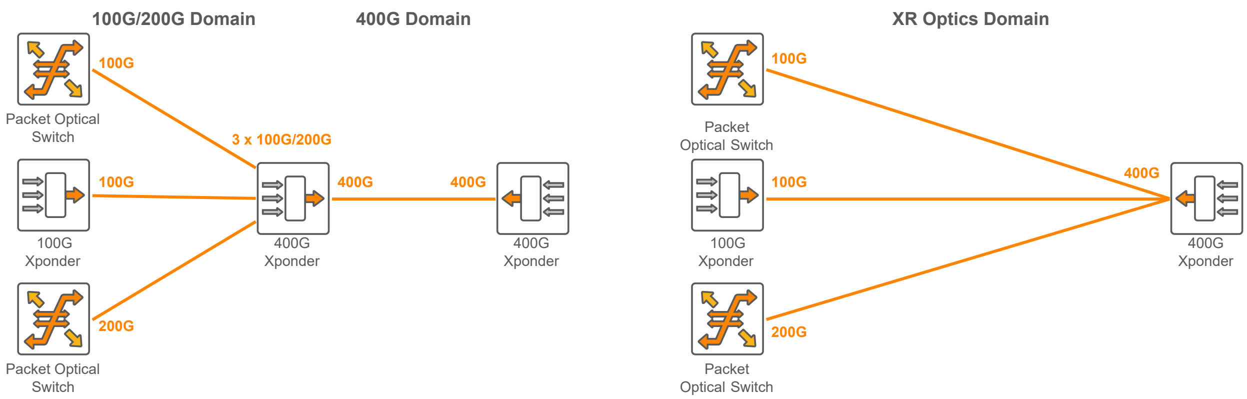


Figure 2: XR optics reduces the need for intermediate aggregation devices and reduces the number of coherent optics in the network

These networks still provide grey handover to the connected client equipment and are totally separated from client systems from a management perspective. This means that from an external perspective, they are identical to conventional DWDM networks in terms of management, operations, and service demarcation. They simply use the benefits of XR optics to reduce the TCO of the optical network. Over time, with the integration of XR optics into client systems and network management, these networks can be migrated further and provide a stepping stone to eventual full implementation of the XR optics architecture, with intelligent coherent optics directly mounted in the client systems.

Supporting Single-fiber Working Infrastructure

As shown in Figure 3, the fundamental principle of SFW support within XR optics is to avoid the challenge of using the same wavelength for both directions of traffic on the single fiber by using individual subcarriers on a per-direction basis. This approach avoids the challenge outlined in the introduction of this application note where, unlike direct-detect optics at 10G or 25G, coherent optics are unable to use different wavelengths in each direction to support SFW as the transmit laser is also used as a local oscillator for the receiver, thereby locking both directions to the same wavelength.

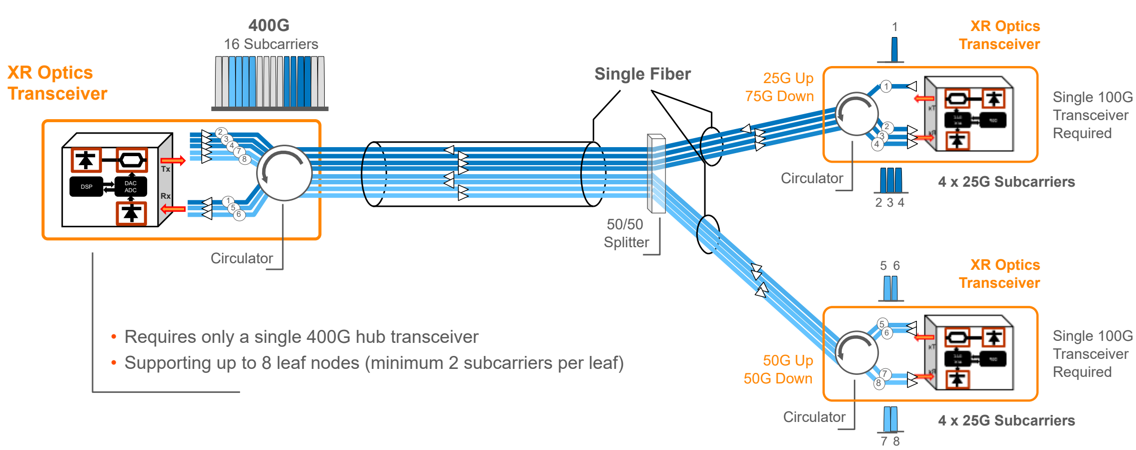


Figure 3: XR optics operation over single-fiber working infrastructure

Figure 3 also highlights the three main benefits that the XR optics architecture generally provides over single-fiber infrastructure:

- Support for coherent optics over SFW using individual subcarriers per direction to avoid the challenges associated with standard coherent optics over SFW
- Support for both point-to-point and point-to-multipoint architectures, with subcarriers being routed to one or more leaf locations (note: two leaf nodes are shown in Figure 3, but this can be any number from one to eight with 400G hub optics)
- Support for asymmetrical traffic flows, with the possibility of a differing number of subcarriers per direction

Metro DWDM platforms that extend their existing coherent optics capabilities to also support XR optics can utilize these capabilities to support SFW infrastructure for both traditional point-to-point optics architectures and new point-to-multipoint optics architectures.

Components of ICE-X Metro Networks

Infinera's ICE-X portfolio comprises several key components that together enable network operators to migrate to point-to-multipoint xHaul architectures:

Figure 4: Infinera ICE-X metro networking components

ICE-X Point-to-Multipoint Pluggable Optics

As outlined earlier, the cornerstone of the ICE-X point-to-multipoint architecture is a range of intelligent pluggable optics built around a digital subcarrier technology that allows optics with differing speeds to communicate with each other. Infinera's initial range of ICE-X intelligent pluggable optics will include CFP2-DCO and QSFP-DD modules that support flexible operation from 25G to 400G using between one and 16 digital subcarriers. Over time, the range of ICE-X intelligent pluggable optics will be extended, for example, to include higher-capacity 800G optics supporting 32 digital subcarriers.

ICE-X Network Demarcation Unit

The ICE-X Network Demarcation Unit (ICE-X NDU) is designed to provide an effortless translation of ICE-X point-to-multipoint pluggable optics into a standardized 100G QSFP28 as well as 25G through a 4:1 breakout configuration. This enables XR optics deployment in locations requiring 100G/25G grey optics handoff.

The ICE-X NDU enables simple extension of ICE-X pluggable optics and creates a demarcation point between 100G/200G ICE-X line optics (supporting from one to eight digital subcarriers) and 2 x QSFP28 100G client optical ports (each supporting from one to four digital subcarriers). Through the embedded virtual transport interface of ICE-X, bandwidth can be sliced in steps of 25G up to the full bandwidth of the client interfaces.

GX Series

The GX Series is a compact modular DWDM transport platform supporting end-to-end open optical networks from metro aggregation to ultra-long-haul and subsea applications. The GX Series will also support ICE-X CFP2 and QSFP-DD optics in a broad range of 100G, 200G, and 400G networking devices, including:

- CHM1R – Dual 400G transponder/muxponder supporting 10G, 100G, and 400G client services mapped into 2 x CFP2 ICE-X-capable line ports supporting dynamic bandwidth from 100G to 400G in 100G increments
- SPN2/SPN2C – 1.2T high-capacity OTN transponder/muxponder/aggregator supporting a broad range of lower-speed client services mapped into 4 x QSFP-DD ICE-X-capable ports supporting dynamic bandwidth from 100G to 400G in 100G increments
- UTM2/UTM2C – Flexible 400G OTN-based transponder/muxponder/add-drop mux supporting a broad range of lower-speed 1G to 100G client services mapped into dual ICE-X-capable 100G or 200G line ports

XTM Series

The XTM Series is a disaggregated metro/regional DWDM platform supporting packet optical applications ranging from hardened edge aggregation networks to flexible grid-based regional networks. The XTM Series supports ICE-X CFP2 optics in a broad range of 100G, 200G, and 400G networking devices, including:

- 400G Flexponder – 1 x 400G transponder or 4 x 100G muxponder for OTN and Ethernet services, supporting ICE-X in the 400G line port
- 200G OTN Muxponder – OTN muxponder supporting a broad range of lower-speed client services mapped into ICE-X-capable 100G or 200G line ports
- EMXP440-Q and -X variants – 440G Layer 2 packet optical transport switches supporting 10G/100G client ports and ICE-X-capable 100G/200G line ports
- EMXP XH800 – Hardened 960G Layer 2 packet optical transport switch with supporting 10G/25G/100G client ports and dual ICE-X-capable 100G/200G line ports optimized for demanding transport applications such as 5G xHaul

Optical Line System

Both the XTM Series and GX Series contain a broad range of optical line system (OLS) components to support ICE-X optics over conventional DWDM fixed-/flexible-grid ROADM-based OLS architectures. The XTM Series and GX Series also provide a range of splitter-/coupler-based options for point-to-multipoint ICE-X broadcast networks.

Network Management

The ICE-X options for both the XTM Series and GX Series are fully managed by the Transcend Software Suite in exactly the same way as any other Infinera network. The Transcend Network Management System (TNMS) fully supports point-to-multipoint optical architectures within XTM Series and GX Series networks, whether as standalone deployments or hybrid deployments alongside conventional point-to-point optical architectures.

Note: XTM Series and GX Series support for ICE-X point-to-multipoint optics is an ongoing development process. Please contact your Infinera sales representative for full roadmap details.

ICE-X Metro Network Case Studies

This section evaluates three case studies that address network evaluation exercises where current and/or future XTM Series and GX Series support of ICE-X optics was considered as a deployment option.

Case Study 1 – XTM Series TCO Reduction Using ICE-X Point-to-Multipoint Optics

This first case study evaluates a European network operator's plan to expand metro aggregation capabilities with high-capacity aggregation rings in major cities within the operator's territory. The new aggregations rings collect traffic from leaf nodes across the city into single or dual hubs that are then connected to the existing long-haul intercity core network. Each ring differs in terms of number of hub and leaf nodes, as shown in Figure 5.

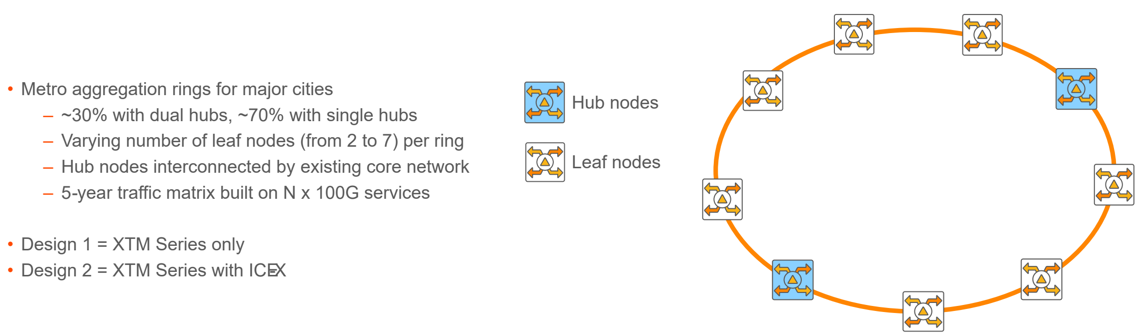


Figure 5: XTM Series with ICE-X case study

Two network designs were created to evaluate the economic and operational benefits of introducing point-to-multipoint optics. Both designs provided grey handoff to the client systems in the leaf nodes and the aggregation routers in the hub nodes. Both designs were also fully managed as standalone networks, meaning there was no operational difference between the two network designs. Table 1 explains the key design elements of the two design approaches.

Design Element	Design 1 – Standard XTM Series	Design 2 – XTM Series Including ICE-X

Optical Layer	▪ Standard fixed-grid FOADM-based OLS architecture
	▪ 75 GHz grid to support 400G wavelengths
	▪ Terminal filters in hub nodes and four-channel add/drop filters in leaf nodes for scalability
	▪ Conventional XTM Series single-slot EDFA
	▪ Additional monitoring capabilities with OTDR and optical channel monitor modules
		▪ Splitter-/coupler-based broadcast OLS architecture
		▪ Fixed 75 GHz filters in hub nodes to support 400G wavelengths (colorless configuration also possible)
		▪ Two types of colorless drop-and-continue LEAF nodes
		  ▪ Type A: with 4+4 colorless add/drop ports
		  ▪ Type B: with 2+2 colorless add/drop ports
		▪ Standalone pizza-box EDFA for bulk amplification and offline booster QSFP-DD amplifiers housed in ICE-X NDU as needed
		▪ Additional monitoring capabilities, including OTDR

Wavelength Capacity	400G wavelengths with all optical devices running at 400G	Subcarrier-based 400G wavelengths with 400G optics (16 subcarriers) in hub nodes and 100G optics (four subcarriers) at leaf nodes, scalable to 200G if required (eight subcarriers)
Hub Node Devices	Enhanced 400G Flexponder (FXP400G-E) supporting 4 x 100G client signals and a 400G line signal	Enhanced 400G Flexponder (FXP400G-E) supporting 4 x 100G client signals and a 400G ICE-X-based line signal
Leaf Node Devices	Dual back-to-back FXP400G-E cards enabling drop or continue of N x 100G client signals, initially dropping 1 x 100G service but scalable to 4 x 100G through network reconfiguration (requiring on-site visit)	Dual ICE-X NDU devices for east/west services using digital subcarriers, initially dropping 1 x 100G service but scalable to 2 x 100G through remote allocation of subcarriers

Table 1: XTM Series with ICE-X case study design comparison

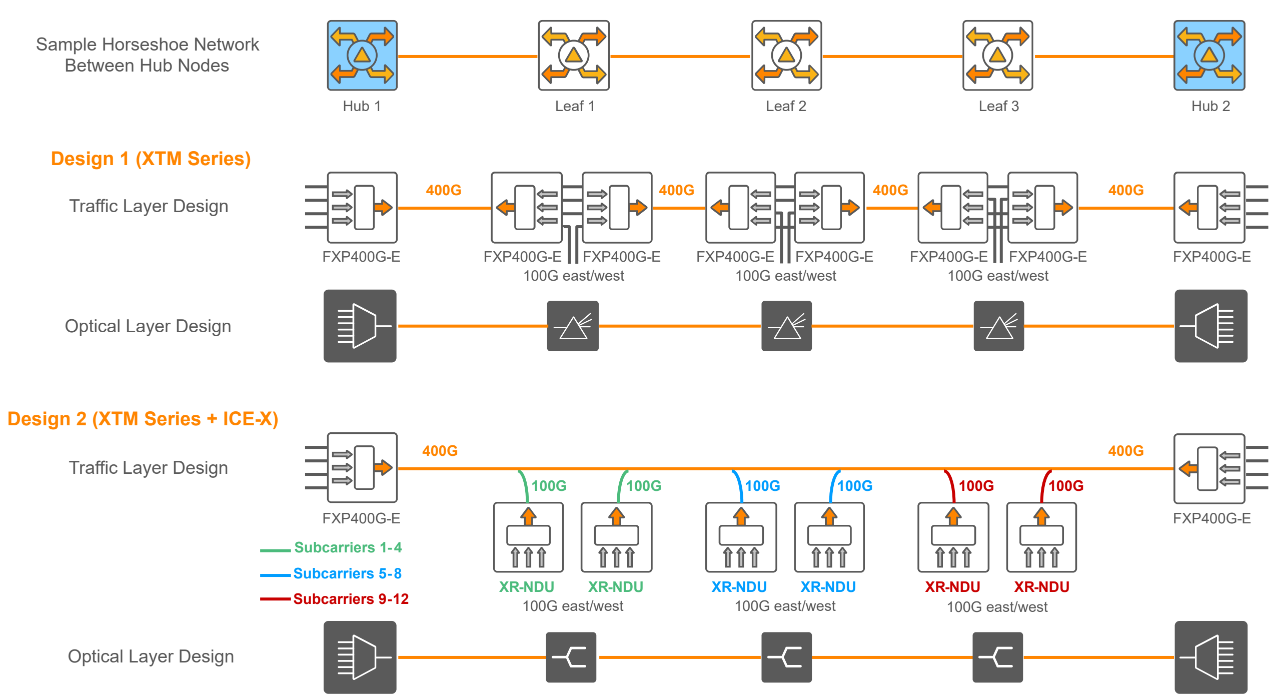


Figure 6: Case study 1 design comparisons

Figure 6 shows a simplified version of the two designs for a sample horseshoe span connecting two hub nodes. In both designs, a single 400G wavelength is required for the initial capacity requirements within the span. Each leaf node has dual 100G circuits for protected east/west connection to the hub nodes, with the optical network providing diverse connectivity and the IP layer providing the necessary protection mechanisms. In an aggregation ring with a single hub node, the horseshoe closes on the hub node for protected east/west connectivity from each leaf to the hub. In horseshoes or rings that have more than four leaf nodes between the hub node(s), a second 400G wavelength is deployed in both designs to provide connectivity to leaf nodes 5 to 7. Similarly, as capacity grows in the network over time, additional wavelengths are added to the span as needed.

Design 2 greatly simplifies leaf nodes with reduced hardware requirements and a much more scalable and flexible design. As all wavelengths and subcarriers are available at all leaf nodes, there is total flexibility to allocate any wavelength/subcarrier combination to any subtended ICE-X optic and ICE-X NDU, within the obvious constraint that each specific ICE-X optic uses a contiguous block of four subcarriers per 100G service. As capacity scales in the network, traffic can be remotely allocated much more simply and flexibly than in the more rigid FOADM-based design 1. The network now provides ROADM-like flexibility without the additional cost.

Overall, the benefits of including point-to-multipoint ICE-X optics within the XTM Series design can be summarized as follows:

- Reduced CapEx:
    - Reduction in the number of optics required or the speed requirements of the optics. Many XR optics designs can reduce the number of optics required in the network, although in this case study the number of optics remains the same, but the requirements are reduced. The example horseshoe span in Figure 6 shows the change from 8 x 400G optics to 2 x 400G and 6 x 100G/200G optics, which is a considerable cost reduction. To put this savings into perspective, 200G optics are approximately 30% cheaper than comparable 400G optics.
    - Reduced hardware requirements. Again, XR optics designs can reduce the need for aggregation devices, although in this case study the number of devices remains the same, but the requirements are reduced. The example horseshoe span in Figure 6 requires six of the eight devices to be changed to the much simpler and significantly lower-cost ICE-X NDU. To put this savings into perspective, the ICE-X NDU is less than half of the price of the FXP400G-E. In addition to the simplification and cost reduction of hardware, additional savings are related to the requirement for fewer chassis slots to house Xponder cards.
    - Increased OLS requirements. While the optical components of the OLS are simpler and cheaper, due to the higher insertion loss of the splitter-/coupler-based broadcast architecture of the OLS in design 2, there is an increase in the required number of optical amplifiers, which increases the cost of the OLS in design 2. However, it should be noted that in this comparison, the base case OLS is a very simple design, if the comparison had been against a ROADM-based OLS, the ICE-X-based design 2 would have shown considerable savings.
    - Overall, these savings combine to give a CapEx reduction of **over 30%** for this case study when the network is optimized through the introduction of ICE-X point-to-multipoint optics within the XTM Series design.
- Lower OpEx:
    - Lower space requirements. Both design options require 1RU of rack space for OLS components in leaf nodes, but the space required for active components is reduced from 3RU to 1RU, meaning overall space requirements in leaf nodes are halved from 4RU to 2RU.
    - Lower power consumption over time. Day one power consumption of the two designs is comparable due to the increased number of amplifiers in design two offsetting the lower power requirements of the other active components. Over time as capacity grows, leaf node power requirements can be reduced by up to approximately 25% for capacity expansion requirements.
- Increased network flexibility and simplified network operations through dynamic allocation of subcarriers. Both designs are fully managed via TNMS and allow for remote management of traffic. However, traffic changes and additions with design 2 are greatly simplified as all ICE-X optics are fully tuneable across all wavelengths and fully tuneable at the subcarrier level. Using the broadcast-based OLS, design 2 offers increased flexibility and simplified traffic moves or additions.

In summary, the introduction of ICE-X optics into this customer case study shows that point-to-multipoint optics bring significant TCO savings and more flexibility to the network, while the network interfaces to third-party devices and management environments are maintained in exactly the same way as the non-XR-based option. Over time, this network design can be migrated to the full XR optics architecture, with ICE-X optics mounted directly into suitable third-party equipment to further increase the TCO savings of the network.

Case Study 2 – GX Series TCO Reduction Using ICE-X Point-to-Multipoint Optics

The second case study also addresses a Tier 1 network operator's plan to scale its metro aggregation rings and evaluates the optimization that can be achieved with the introduction of ICE-X point-to-multipoint optics. In the first case study, the hub node design was largely unchanged, and the savings were all created by simplifying the leaf nodes. In this second case study, ICE-X was again able to show considerable TCO savings, although this time largely through simplifying and cost-reducing the hub node design. This evaluation addressed a large national metro aggregation network with multiple aggregation networks connecting metro aggregation nodes to metro core hub nodes, as shown in Figure 7.

- National network with over 1,000 metro aggregation (leaf) nodes and ~100 metro core (hub) nodes
- Sample network for case study:
  - ~40 dual-homed leaf nodes with diverse point-to-point links to 2 hub nodes
  - Another ~30 leaf nodes as part of WDM chains between the same 2 hub sites
  - The chains consist of either 2, 3, or 4 leaf nodes between the 2 hub sites
  - 5-year traffic matrix built on N x 10G and N x 100G services
- Design 1 = GX Series only
- Design 2 = GX Series with ICE-X

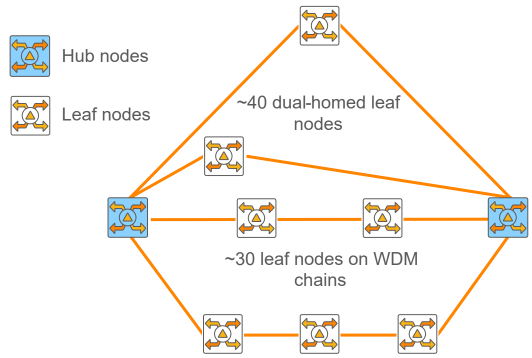


Figure 7: GX Series with ICE-X case study

Two network designs were created to evaluate the economic and operational benefits of introducing point-to-multipoint optics. Both designs provided grey handoff to the client systems in the leaf nodes and the aggregation routers in the hub nodes. Both designs were also fully managed as standalone networks, meaning there was no operational difference between the two network designs. Table 2 explains the key design elements of the two design approaches.

Design Element	Design 1 – Standard GX Series	Design 2 – GX Series Including ICE-X
Optical Layer	Standard fixed-grid FOADM-based OLS architecture with similar details to case study 1	Splitter-/coupler-based colorless OLS architecture with similar details to case study 1
Wavelength Capacity	Design support for 100G-400G wavelengths, with all optical devices running at 100G/200G initially	Subcarrier-based 400G wavelengths with 400G optics (16 subcarriers) in hub nodes and 100G optics (four subcarriers) at leaf nodes, scalable to 200G if required (eight subcarriers)
Hub Node Devices	N x UTM2 100G/200G multi-service muxponder supporting 10G/100G services	SPN2 high-capacity OTN aggregator supporting 10G/100G services and up to 2 x 400G ICE-X-based line signals
Leaf Node Devices	Dual UTM2 100G/200G multi-service muxponders for east/west 10G/100G services	Dual UTM2 100G/200G multi-service muxponders for east/west 10G/100G services using digital subcarriers

Table 2: GX Series with ICE-X case study design comparison

Figure 8 shows a simplified version of the two designs for a sample chain span connecting two hub nodes. The GX Series design 1 uses 100G/200G wavelengths between UTM2 muxponders to deliver 10G and 100G services between leaf and hub nodes, depending on the total add/drop capacity requirement for each leaf node. As capacity grows in the network over time, additional wavelengths are added to the span as needed.

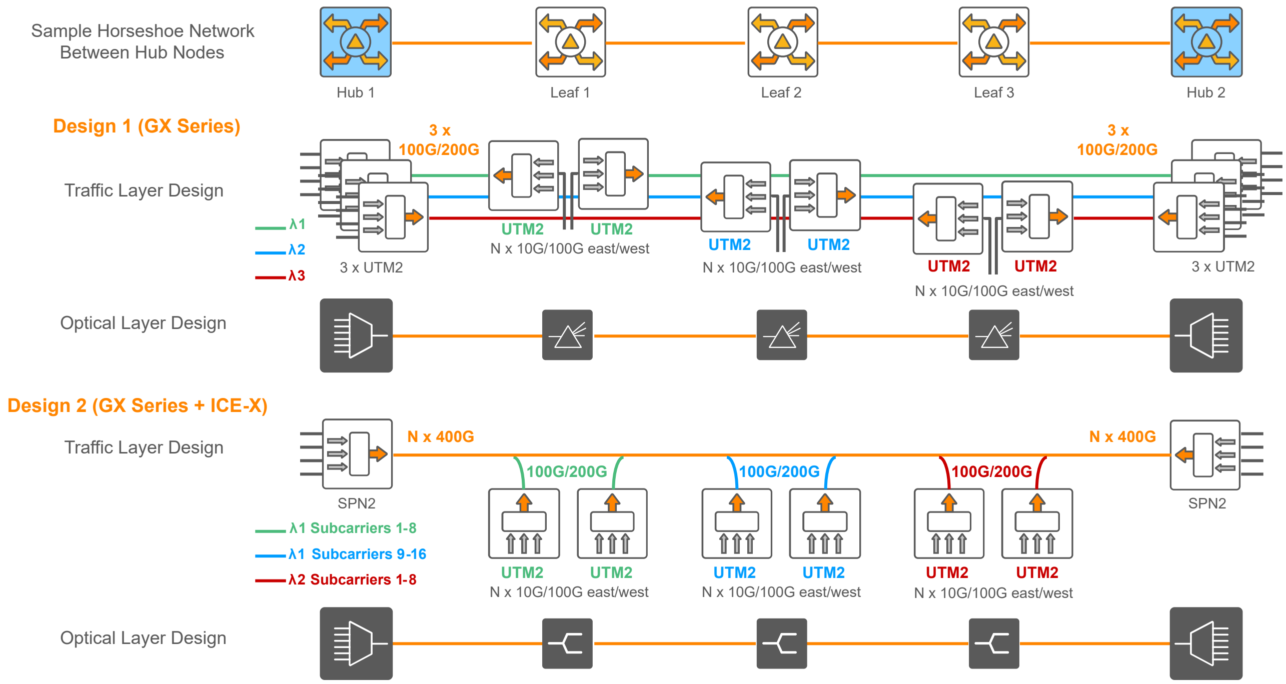


Figure 8: Case study 2 design comparisons

Design 2 greatly simplifies hub nodes with reduced hardware, space, and power requirements and a much more scalable and flexible design. As all wavelengths and subcarriers are available at all leaf nodes, there is total flexibility to allocate any wavelength/subcarrier combination to any subtended ICE-X optic and UTM2, within the obvious constraint that each specific ICE-X optic uses a contiguous block of four or eight subcarriers per 100G/200G capacity requirement. As capacity scales in the network, traffic can be remotely allocated much more simply and flexibly than the more rigid FOADM-based design 1. As with the previous case study, the network now provides ROADM-like flexibility without the additional cost.

Overall, the benefits of including point-to-multipoint ICE-X optics within the GX Series design can be summarized as follows:

- Reduced CapEx:
  - Reduction in the number of optics required. As with many XR optics designs, there is a reduction in the need for pluggable optics in this network. The example chain span in Figure 8 shows the change from 12 x 100G/200G optics to 2 x 400G and 6 x 100G/200G optics, which is a considerable cost reduction.
  - Reduced hardware requirements. There is also a reduction in the need for aggregation devices in this network. The example chain span in Figure 8 simplifies the hub node design so the initial requirement for three devices per hub node is reduced to a single device in each. In addition to the reduction in hardware, additional savings are related to the requirement for fewer chassis slots to house Xponder cards.
  - Increased OLS requirements. As with case study 1, the original OLS design is a very simple FOADM-based OLS. While the optical components of the design 2 OLS are simpler and cheaper, due to the higher insertion loss of the splitter-/coupler-based broadcast architecture, the OLS there has a small increase in the required number of optical amplifiers, which slightly increases its cost. However, it should be noted that if the comparison had been against a ROADM-based OLS, the ICE-X-based design 2 would have shown considerable savings.
  - Overall, these savings combine to give a **CapEx reduction of over 20%** for this case study when the network is optimized through the introduction of ICE-X point-to-multipoint optics within the GX Series design. This is primarily achieved through optimization of the hub nodes, where the specific CapEx savings is over 50%.
- Lower OpEx:
  - Lower space requirements. Both design options require similar rack space for OLS and leaf node components, but the space required for hub nodes is reduced by approximately 50% on day one and by up to 67% over the case study period.
  - Lower power consumption. The power consumption of the hub nodes is reduced by approximately 60%, and this reduces **overall network power consumption by 25%** once the OLS and leaf nodes are also factored in.

- Increased network flexibility and simplified network operations through dynamic allocation of subcarriers. As with case study 1, both designs are fully managed via TNMS and allow for remote management of traffic. However, traffic changes and additions with design 2 are greatly simplified as all ICE-X optics are fully tuneable across all wavelengths and fully tuneable at the subcarrier level. Using the broadcast-based OLS, design 2 offers increased flexibility and simplified traffic moves or additions.

In summary, the introduction of ICE-X optics into this customer case study also shows that point-to-multipoint optics bring significant TCO savings and more flexibility to the network, while the network interfaces to third-party devices and management environments are maintained in exactly the same way as the non-XR-based option. Over time, this network design can be migrated to the full XR optics architecture, with ICE-X optics mounted directly into suitable third-party equipment to further increase the TCO savings of the network.

Case Study 3 – Supporting Single-fiber Working Infrastructure with ICE-X Optics

This third case study is slightly different from the previous two case studies as it addresses a network application that simply would not be possible with modern conventional coherent DWDM optics. This third case study addresses another large metro network project that included numerous SFW spans with capacity demands that required 100G/200G coherent DWDM.

As a quick reminder, the challenge with coherent optics and SFW is that the vast majority of modern coherent optics use the transmitter laser as a local reference oscillator for the receiver, thereby locking both directions to the same wavelength. This is particularly the case in digital coherent optics that include the digital signal processor (DSP) and optics within the same package, either a pluggable optics module, such as ZR, ZR+, or XR optics pluggables, or a higher-speed embedded optical engine, such as Infinera's ICE6. This implementation saves on the cost and space/power of the second laser. Lower-speed 10G or 25G direct-detect optics do not need a coherent DSP or local reference in the receiver circuitry and can easily support SFW by using two separate wavelengths for the bidirectional channel.

The third case study addresses another network operator that was evaluating potential upgrade scenarios for the operator's metro access and aggregation networks. Most of this network was based on conventional dual-fiber infrastructure, but some of the spans in the access network only had single fibers available, requiring SFW in the DWDM network design.

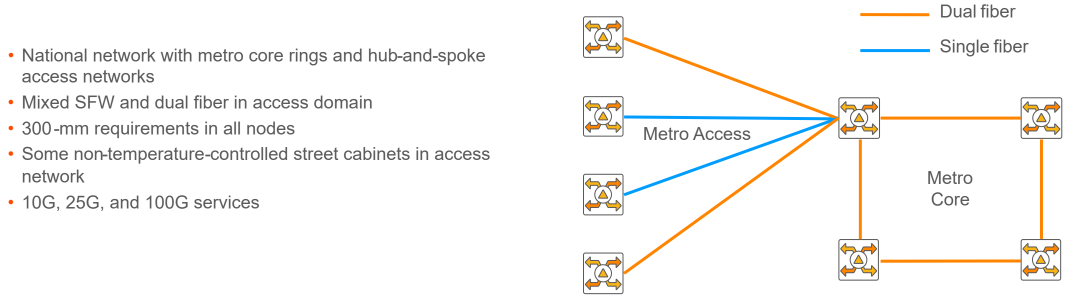


Figure 9: Case study 3 network requirements

The XTM Series provided an excellent technical solution for the case study, with support for 10G, 25G, and 100G services via the EMXP XH800 packet optical transport switch. The EMXP XH800 is a temperature-hardened 1RU pizza-box device with two 100G/200G uplinks and 24 client ports supporting 1G, 10G, 25G, and 100G services. Using ICE-X subcarrier-based optics in the 100G/200G uplinks enables this solution to support both the dual-fiber and single-fiber domains with a common architecture, as shown in Figure 10. As there is no design 1/design 2 alternative option with case study 3, the optical layer design has not been shown in this case study.

Figure 10 outlines the available XTM Series options within the metro access network for nodes that require coherent 100G+ optics due to high capacity demands. Leaf 1 is supported by conventional dual-fiber coherent DWDM at 200G. In leaf 2, the ICE-X optics provide the capability to support up to 200G point-to-point connectivity over SFW with eight subcarriers per direction. Leaf nodes 3 and 4 require only 100G over SFW, and this enables point-to-multipoint capabilities over SFW with the 16 available subcarriers supporting 200G on the hub node interface and 100G per leaf node via four subcarriers per direction per node.

The main advantage that ICE-X subcarrier-based optics bring to this case study is the ability to support higher-capacity coherent optics over SFW links that otherwise could not be supported. In addition to standard point-to-point DWDM links over SFW, point-to-multipoint links are also possible.

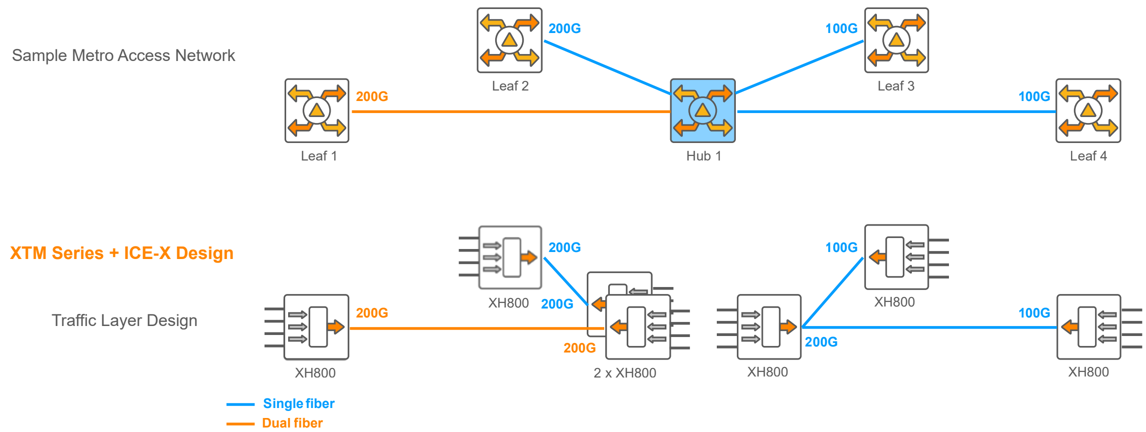


Figure 10: Case study 3 metro access network options

The SFW architecture supports unamplified spans of approximately 50-60 km depending on fiber quality, which supports all the access node requirements within this case study. If required, additional amplification can be added to support spans of over 100 km. The use of the XTM Series EMXP XH800 also supported the case study requirement for hardened solutions in sub-300 mm for street cabinet deployments.

Without the support of coherent optics over SFW spans, the operator in this case study would have to keep the SFW spans as 10G direct-detect spans. This would use considerably more wavelengths at a higher cost per bit and use much more space and power within the nodes. Some older first- or second-generation 100G coherent platforms with embedded optics could support SFW as they did not have the same level of integration as current platforms. These may have used separate lasers in the transmitter and local oscillator in the receiver circuitry, which would potentially enable SFW support. Most of these platforms are now end-of-life and are no longer commercially available. If a suitable platform was available, then it could potentially also support these SFW spans, although the platform would not be economical across the rest of the network and would use considerably more space and power. Furthermore, it is very unlikely that any of these older platforms would support hardened street cabinet deployment.

Overall, this case study proved that the XTM Series with ICE-X optics can support high-capacity coherent transmission over the entire sample network, enabling the network operator to benefit from increased capacity and better network economics, even though the network contained SFW spans in the access domain.

Additional ICE-X Metro Network Use Cases

Beyond the three case studies outlined above, there are numerous other use cases where the introduction of ICE-X point-to-point or point-to-multipoint capabilities is enabling a change of approach or additional customer benefits:

Improved Point-to-Point Optical Performance

ICE-X optics deliver leading optical performance in point-to-point applications with better reach performance than conventional ZR+ optics. This is made possible by the higher 0 dBm launch power coupled with the low out-of-band noise of the optics due to the indium phosphide photonic integrated circuit. Using ICE-X optics in DWDM metro networks, network designers have been able to close challenging optical links at 400G 16QAM rather than having to downspeed 400G ZR+ optics to 200G QPSK.

This enables network operators to achieve a lower cost per bit and achieve higher overall capacity over these demanding spans.

Extending OLS Lifespan and Deferring OLS Upgrade Costs

In this use case, the network operator had an older 50 GHz-based line system that was reaching capacity with 100G wavelengths. The operator needed to move to 200G wavelengths or higher but had a choice:

- Move to 32 Gbaud 16QAM 200G wavelengths now and defer the OLS upgrade needed for 64 Gbaud 16QAM 400G to a later date but then have a higher overall cost, with multiple transponder upgrades from 100G to 200G and then ultimately to 400G transponders when the OLS was upgraded to become a flexible-grid 400G-capable OLS
- Move to more modern 64 Gbaud 16QAM 400G transponders now with higher capacity but also an expensive flexible-grid OLS upgrade at the same time
- Use ICE-X subcarrier technology to enable 400G optics running at 200G over the existing 50 GHz-based line system and defer the OLS upgrade until a later date

ICE-X in the GX Series gave the network operator the additional subcarrier-based option. This enabled the network operator to select an upgrade path with new 400G-capable transponders running at 200G initially over the existing 50 GHz-based OLS. Later, when network capacity requirements exceed those available with 200G wavelengths, the operator could take the final step of upgrading the OLS to flexible grid. But the operator can reuse the existing transponders and optics at 400G, avoiding another transponder upgrade cycle and deferring the OLS upgrade cost until it is absolutely necessary.

This is possible by using ICE-X optics in transponders where the subcarrier-level granularity allows for 200G wavelengths using just the middle eight 4 Gbaud subcarriers running at 16QAM. This total aggregated signal is 32 Gbaud using just 32 GHz of spectrum and therefore supported by the 50 GHz OLS. In this example, the customer selected the GX Series with SPN2 Xponders to initially support 200G over the existing OLS, with the ability to simply increase the number of subcarriers to 16 in the future to support the full 400G once higher network capacity is required and the OLS upgrade has taken place.

The competitive vendors in this opportunity could not offer this capability due to the overall network requirements requiring them to offer their 32 Gbaud 200G generation solutions. Overall, the Infinera approach offered the network operator the most cost-effective transponder upgrade cycle and deferred the costly OLS upgrade to a much later date.

Mixing IPoDWDM and DWDM Transport

The network applications in this application note have focused on cases where ICE-X optics can bring benefits within conventional DWDM metro networks. Other documents cover the full XR optics IPoDWDM architecture, with XR optics modules hosted directly in third-party devices such as routers, switches, servers, or access devices. However, there are also some hybrid cases where some nodes use IPoDWDM and other nodes use DWDM transport platforms, especially for field deployments that also contain older legacy equipment. In these cases, hybrid networks can be considered, where the ICE-X NDU or DWDM hardware from the XTM Series or GX Series can be deployed to support legacy sites.

For example, a generic PON backhaul architecture might include XR optics hosted in PON optical line terminal (OLT) devices in remote access nodes and in routers in aggregation nodes. For access nodes with legacy OLT devices, the ICE-X NDU can provide a low-cost ICE-X demarcation point, and for hub nodes with legacy routers, the XTM Series 400G Flexponder or GX Series CHM1R devices can provide a 400G ICE-X hosting function. The management environment for ICE-X optics supports this hybrid environment with a mix of classic DWDM nodes using ICE-X and IPoDWDM nodes using ICE-X and links, with one end hosted in third-party devices and the other end hosted in a DWDM transport device.

Conclusions

This application note has outlined how XR optics technology, and specifically Infinera's implementation of the architecture, ICE-X, can bring substantial TCO benefits and enable support over SFW infrastructure that otherwise could be considerably challenging for network operators in the modern coherent DWDM era.

Case studies 1 and 2 both addressed network simplification and cost reduction through the introduction of point-to-multipoint capabilities within the DWDM transport network, although the two examples showed how XR optics can optimize networks in differing ways depending on the network requirements and the functionality of the particular DWDM platform. Case study 1 did not change the number of optics or DWDM devices in the network but brought considerable savings through the use of lower-speed optics and the simplification/cost reduction of networking hardware. Case study 2 was more like the classic XR optics case study, with a reduction in the number of optics and devices required within the network. Both case studies simplified the internal DWDM network design while providing the same external interfaces as conventional designs in terms of client interfaces and operational network management/orchestration. Both examples reduce TCO through both CapEx and OpEx reductions and increase network flexibility.

Case study 3 highlighted an example where high-capacity coherent optics were required in SFW environments at the edge of a large metro access and aggregation network. Alternatives were possible using older technologies, but these substantially changed the economics of the design and forced the SFW spans to be designed and operated differently from the rest of the network. The introduction of ICE-X into the DWDM platform enables the operator to meet the required capacity demands in both the single-fiber and dual-fiber domains, with the same platform delivering the lowest cost per bit and flexibility through subcarrier-based coherent optics anywhere in the network.

The additional use cases also showed additional applications where XR optics, and Infinera's ICE-X optics modules specifically, can bring further benefits to network operators.

Overall, this application note has highlighted the economic and architectural benefits of using ICE-X point-to-multipoint optics within the XTM Series and GX Series DWDM platforms. Over time, these networks can evolve further to also support ICE-X optics directly hosted in third-party platforms such as routers, switches, compute platforms, or access devices, including PON OLTs or 5G RAN devices, to further optimize the network.

Further Reading

XR Optics Solution Brief

XR Optics in 5G Transport Networks Application Note

Hardened DWDM for Demanding Transport Network Applications Application Note

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