Infinera has introduced a new transport network architecture, the Digital Optical Network, that leverages fundamental advances in both large-scale photonic integration and optical system architecture to create a disruptive shift in network architecture and economics. A Digital Optical Network enables carriers to deploy an optical service platform into metro, regional and long haul core transport networks to maximize service flexibility, minimize bandwidth costs, simplify network operations, and consolidate network architectures. This paper outlines the concept and benefits of an Infinera Digital Optical Network, including the ability to consolidate network architecture, maximize customer revenue capture, and reduce both capital and operating costs.
From Digital to Analog

The introduction of Wavelength Division Multiplexing (WDM) into core networks enabled significant growth in network traffic by reducing bandwidth costs by over 98% in the past decade. Before the advent of WDM, optical transport required the use of digital repeaters along the network to regenerate optical signals degraded during fiber transmission.

These digital repeaters performed Optical-Electrical-Optical (OEO) conversions of the signals so the digital data could be Re-amplified, Re-shaped, and Re-timed (leading to the term “3R” regeneration), and also provided bandwidth management and performance monitoring at each site. The digital data would then be re-transmitted back into the optical domain, and the process would continue across the network.

The economic benefits of WDM over the use of digital repeaters derived from two key attributes. Firstly, WDM provided the ability to significantly scale fiber capacity by multiplexing many optical channels along a single fiber. Second, WDM enabled a significant reduction in the number, and cost, of OEO’s used in repeaters by replacing these with optical amplifiers to increase optical reach and amortize costs across many channels.

In the process however, digital access to the data at repeater sites was lost, and optical transport networks became increasingly analog, relying on the amplification, manipulation and management of analog wavelengths, rather than of digital “bits” as used to be the case.

In becoming increasingly analog, optical networks lost their engineering simplicity while also introducing new cost pressures. Through the need to sustain “all-optical” transmission over extensive distances, system designers or carriers were required to move from the simple “plug and play” engineering of digital SONET/SDH repeaters to more complex measurement, engineering, and adjustment of analog optical transmission systems.

In addition, the need to compensate for optical transmission impairments required many special optical compensation elements, increasing system first-in-cost in the process. Finally, the manipulation of wavelengths, rather than digital bits, in an analog optical network significantly decreased network flexibility for functions such as traffic add/drop, bandwidth management, network diagnostics and SLA management. And when such functions were needed, WDM terminals with costly OEO conversions were required, thus negating the economic benefits of WDM in the process.

Introducing Digital Optical Networks

A Digital Optical Network redefines optical transport by providing the capacity of WDM with the traffic management flexibility and engineering simplicity of digital transport systems, and the network cost savings of large-scale photonic integration. This provides flexible access to the underlying digital data at any node, for the purpose of add/drop,
bandwidth management, performance monitoring, or other value-added manipulation.

In the process of providing frequent cost-effective digital access, a Digital Optical Network reduces the “analog” optical portions of the network to allow “plug and play” operation, and significantly simplifies network planning, engineering, installation and operation. Such a network concept provides a profit enabling optical network architecture for service providers to reach more customers, more cost-effectively, with better network performance, while unifying network architectures and simplifying operations.

The implementation of a Digital Optical Network is uniquely enabled through the development and use of large-scale Photonic Integrated Circuits (PICs) to bring to the industry what has long eluded it – ultra-low cost OEO’s.

Application of large-scale monolithic integration concepts to the photonic domain permits upwards of sixty or more discrete optical components to be consolidated onto PICs (see figure 1). This significantly reduces OEO costs, allowing network bandwidth to be cost-effectively converted to the digital domain at any.

In parallel, large-scale photonic integration brings “Moore’s Law” economics of semiconductor manufacturing to optical networking, allowing future optical transport cost reductions to be viably sustained on a cost curve defined by volume manufacturing efficiencies, greater functional integration, increased device density, and manufacturing yield enhancements.

Building the Digital Optical Network

The fundamental building block of a Digital Optical Network is the Digital Node, which provides high capacity WDM optical transport and digital add/drop flexibility. A Digital Node utilizes PIC technology to provide ultra-low cost OEO access to the WDM bandwidth, allowing the optical signals to be converted into the electronic domain for value-added processing using silicon electronics and software, before conversion back into optics (see figure 2).
Optical bandwidth transiting through a digital node can therefore be easily and cost-effectively managed to maximize service flexibility, enable rapid network reconfigurability, and simplify network engineering, turn-up, growth and operations.

**A Digital Node provides cost-effective “digital” access for:**
- signal clean-up
- digital PMs
- sub-\(\lambda\) grooming
- muxing and add/drop

**Digital Node**

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**Digital signal clean-up and performance monitoring (PM)** provided through frequent access to digital wrapper or SONET/SDH overhead provides valuable information on service SLA’s and network performance, and enables faster and more accurate fault identification and trouble-shooting. Optical system performance is improved through frequent 3R regeneration by applying the performance gains of Forward Error Correction (FEC) and Electronic Dispersion Compensation (EDC) technologies more widely across the network. Value-added system software automates system turn-up, adjustment and operation, and significantly simplifies all aspects of ongoing system operations.

**Digital multiplexing, grooming and add/drop** capabilities enable sub-wavelength bandwidth management at each node. This reduces the need for external bandwidth management within the core of the network, and allows both line-side and client-side traffic to be added/dropped, multiplexed, groomed, or protected. A Digital Node can be equipped with a wide range of SONET, SDH or Ethernet service interfaces for connection to new and existing customers. Finally, the application of a GMPLS control plane enables automated end-to-end service provisioning and topology auto-discovery across a Digital Optical Network, and provides a service platform for enabling the introduction of Intelligent Optical Networks.

The feature richness, flexibility and cost-effectiveness of a Digital Node enables the use of a common system platform across a wide range of core backbone applications in metro, regional, long-haul and ultra-long haul networks. Thus a Digital Optical Network...
can be implemented by deploying Digital Nodes anywhere carriers desire to provide “on-net” access to their networks. These can then be interconnected in a “building block” fashion using simple to engineer Digital Links using optical line amplifiers to extend the optical reach between Digital Nodes.

Migration to a Digital Optical Network can be implemented incrementally on a route-by-route basis where required due to capacity exhaust or geographical expansion and to reduce the cost of add/drop sites. The Digital Optical Networks can then be extended as required by network growth, or to cost-effectively increase the carrier’s by increasing the number of “on-net” sites on the network (see figure 3).

![Figure 3: A Digital Optical Network lowers the cost for add/drop, simplifies optical link engineering, and enables carriers to cost-effectively deploy more “on-net” locations to increase markets served.](image)

**Digital Optical Network Benefits**

By exploiting the architecture simplicity and operational flexibility of a Digital Optical Network, carriers can significantly reduce OpEx costs of operating a network while increasing service flexibility and revenue-generating “On-Net” network footprint. In addition, a Digital Optical Network provides the opportunity to significantly improve carrier networks by simplifying architectures, consolidating transport and bandwidth management, enabling flexible add/drop, and providing end-end service management.

**Simplify Network Architecture**

The cost-effectiveness of Digital Optical Network enables carriers to avoid the compromise between minimal network cost and maximum customer access imposed when using existing WDM systems. In such cases, a regional or “collector” network is often deployed to maximize “on-net” access in all target markets, at the expense of high per channel cost for any end-end circuit. To lower end-end circuit costs, carriers can deploy an overlay ultra-long haul or “express” network which provides network access only at major cities, but minimizes OEO cost for end-end circuits.

Finally, separate metro WDM systems are often deployed to connect carrier central
Digital Optical Networks provide a common, cost-effective core network platform for metro, regional, long haul and ULH applications.

offices (COs), data centers, and carrier hotels in large metropolitan areas. Such overlay network architectures, although a justified compromise given today’s WDM technology options, impose unnecessary capital and operating costs while increasing network architecture complexity.

By comparison an Infinera Digital Optical Network can be cost-effectively deployed to address both the needs of frequent network access along high-density regional routes, long-haul transport on express routes, and metro core connectivity requirements (see Figure 4.) In this case network equipment and capacity are deployed in a manner more closely correlated to capacity use, avoiding the need for duplicate capital expenditures to build both “collector” and “express” networks, both of which will initially operate at only a portion of their maximum capacity.

Figure 4: The cost-effective deployment of a Digital Optical Network enables customer access and low cost from a single network architecture.

By provisioning customers’ services over a common transport backbone, a Digital Optical Network reduces backhaul traffic between “collector” and “express” networks, and creates a flatter network which reduces inter-network connections at junction nodes, thereby reducing the need for Optical Cross-Connect (OXC) to manage capacity at junction nodes.

The use of a common Digital Optical Network deployed for metro core, regional and long-haul applications reduces the number of system technologies, simplifies network engineering, and reduces costs for installation, sparing, training, documentation, space allocation, power consumption, network management, and maintenance.

Consolidate Transport and Bandwidth Management

Leveraging low-cost OEO access at each Digital Node, a Digital Optical Network provides flexible sub-wavelength bandwidth management within the optical transport layer, and eliminates the “point-to-point” and “back-to-back” architectures of typical WDM systems. This allows nodal architecture simplification by managing the high-capacity circuits of core backbones within a single Digital Optical Network layer (see figure 5).
Thus pass-through or “transit” traffic can remain within the Digital Optical Network, thereby eliminating the operational and service turn-up inconvenience typical of manual back-back interconnections between point-point WDM systems. Trunk circuits originating or terminating at a Digital Node are connected to local service platforms, thus allowing SONET/SDH OXCs or add/drop multiplexers (ADMs) to provide maximum value by grooming and multiplexing lower-rate services at the edges of the network.

A Digital Optical Network therefore simplifies nodal architecture by consolidating digital transport, flexible multi-service add/drop, and multi-wavelength capacity into a common Digital Node for core networks, complementing local SONET/SDH and data service platforms.

**Figure 5:** Digital Optical Network architecture consolidates digital transport, WDM capacity, bandwidth management, and multi-service add/drop.

**Maximize Add/Drop Flexibility**

By combining flexible electronic add/drop of sub-λ services at any Digital Node with a standards-compliant GMPLS control plane, a Digital Optical Network unifies optical service transport and management across a single network layer. This provides carriers the ability to implement “point-and-click” end-end service management, and enables automated circuit provisioning, topology self-discovery and system turn-up.

This improves management of customer circuits, increases speed of service provisioning, simplifies service and performance management, and allows carriers to easily turn-up transport capacity between any Digital Nodes within the network, irrespective of topology (see figure 6).

In addition, the grooming capability of a Digital Node provides efficient line side optical transport (at 10G per wavelength) while simultaneously providing sub-lambda add/drop and bandwidth management to enable customer signals on different wavelengths, or originating from different locations, to be combined and add/dropped to the same client interface card or switched to different wavelengths.
End-end and automated service provisioning and management is enabled by a GMPLS control plane.

This provides carriers with significant simplification in the planning, engineering, and activation of new services compared to the manual connection of costly back-to-back transponders at WDM terminal nodes, or complex wavelength planning rules, banding constraints, and wavelength contention common in Optical Add/Drop Multiplexers (O-ADMs). In addition, the flexible add/drop architecture of a digital node provides equipment savings and simplifies operations over solutions that tie add/drop of services to a specific wavelength, as is the case with WDM terminals or O-ADM implementations.

The ubiquitous access to the underlying digital data at each Digital Node also significantly extends the flexibility to add and drop customer traffic where and when required, without requiring extensive pre-planning or reconfiguration. A Digital Node can be initially deployed to pass-through traffic transiting that location, and upgraded in-service to provide add/drop access to a new customer. This is accomplished simply by adding tributary interfaces and cross-connecting the client service from/to the already active wavelengths via an electronic switch within the system.

This ability to rapidly activate a new customer circuit across more “on-net” locations without complex manual provisioning operations will reduce back-haul or access charges, shorten provisioning lead times, increase customer satisfaction, and accelerate “time to revenue” for carriers.

Expand Network Access and Increase Revenue Capture

By permitting the cost-effective deployment of an Infinera Digital Optical Network anywhere customer access is required in the network, carriers can lower the business case threshold required to connect customers, thus increasing potential revenues. In contrast, with today’s WDM technology, carriers face the dilemma of either minimizing network cost by minimizing OEOs (and thus the number of add/drop sites) or maximizing customer revenue, but not both (see Figure 7). A Digital Optical Network eliminates the need to make such a compromise.
Greater service presence enabled by a Digital Optical Network maximizes revenue potential and improves service competitiveness.

Figure 7: A Digital Optical Network enables optimization for both lowest network cost and customer network access, enabling carriers to deploy more “on-net” locations and maximizing revenue potential of the network.

Leveraging the ultra-low cost OEOs enabled by photonic integration to provide unconstrained add/drop, a Digital Optical Network can provide carriers with the opportunity to maximize “Revenue Capture” for top-line growth. By providing cost-effective add/drop, carriers can deploy Digital Nodes more frequently in their networks to provide service in more markets, including secondary markets that may have previously been bypassed. By increasing the “on-net” footprint of their networks, carriers can benefit from several important benefits, including:

- Extend network connectivity to customers with geographically extensive service requirements;
- Increase addressable market by providing “on-net” access in under-served markets or those with historically limited choice of service providers;
- Maximize “Revenue Capture” from their network to increase top-line growth;
- Increase margins by reducing reliance on leased back-haul circuits;
- Improved pricing competitiveness by reducing the cost of “on-net” access;
- Increase service offerings by offering lower bit rate services where previously only wholesale wavelength services might have been justified;
- Maximize service responsiveness to new demands, changing customer connectivity, or new service requirements.

Implementing a Digital Optical Network

A Digital Optical Network defines a new network architecture concept that integrates the robustness, flexibility and end-end service management of digital transport with the capacity of WDM and economics of large-scale photonic integration. The implementation of a Digital Optical Network provides carriers with significant architecture benefits, including simplified metro, regional and long-haul architectures, consolidated transport and bandwidth management for simpler and more flexible
add/drop, and the ability to cost-effectively increase their network’s “on-net” footprint.

Carriers facing “span-by-span” capacity exhaust of legacy WDM systems can begin deployment of a Digital Optical Network on those portions of the network to gain immediate CapEx savings, and subsequently extend the Digital Optical Network architecture over time to more fundamentally re-shape their network economics and architecture. For carriers planning geographical network expansions or overbuilds, a Digital Optical Network can be seamlessly integrated to existing SONET/SDH and WDM systems to allow carriers to transition away from an operational cost structure burdened by legacy WDM systems.

Finally carriers seeking to evolve their network architecture and service offering in response to changing market conditions can deploy a Digital Optical Network to maximize their market presence and service competitiveness to meet today’s, and tomorrow’s, market requirements.
Have a question about Infinera’s products or services? Please contact us via the email addresses below.

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