



## **Benefits of OTN in Transport SDN**

## Introduction

Today's telecom service providers require higher capacity and more dynamic network infrastructure to meet the needs of the cloud and mobility. They recognize that their static and manually provisioned networks are not capable of delivering the services that are being requested. For example, business customers are using both public and private clouds, requiring a network that can meet the needs of elastic on-demand computing and storage. Taking a page from the datacenter industry, telecom service providers are actively exploring Software-defined Networking (SDN) to manage the challenges of the cloud and mobility. In a recent survey, 97% of telecom service providers indicated they plan to deploy SDN<sup>1</sup>, and 81% indicated they will deploy SDN for multi-layer transport and optical transport.

This whitepaper discusses the requirements for Optical Transport SDN and how Optical Transport Network (OTN) architectures supporting OTN Switching add flexibility to deliver the dynamic network infrastructure that enables the full potential of transport SDN.

## Extending SDN into Transport

The general principles of SDN are:

- Separation of data and control plane
- Flow/circuit oriented data plane
- Centralized management and control
- Hardware abstraction and virtualization
- Network programmability
- Open Standard-based

The centralized management and control nature of SDN promises to provide the following benefits:

- Faster service provisioning
- More informed network management decisions resulting in more efficient use of network resources
- Optimized, global view of the network
- Technology independence
- Powerful new services that provide greater flexibility and control to the customer

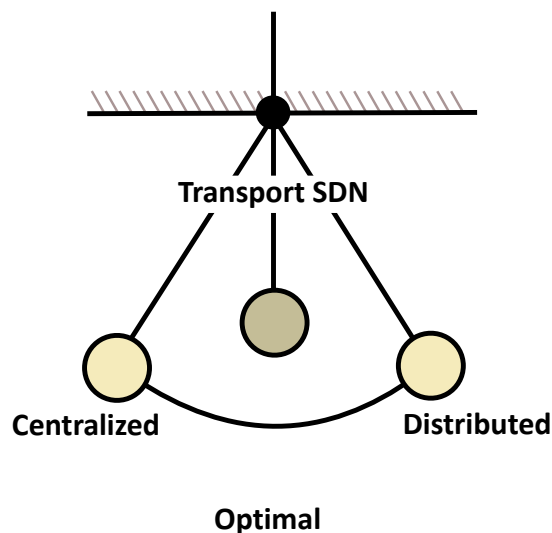
SDN was originally conceived for packet-based networks, where the management, control and forwarding/data plane operations are performed locally at the node and each node operates autonomously to forward packets. For packet-switched network domains like Metro Ethernet or China's Packet Transport Networks (PTNs), SDN provides tremendous value—telecom service providers like China Mobile will be deploying SDN-based PTNs as early as 2015.

Transport networks have evolved differently from packet switched networks over time. Historically, such networks have always had a centralized management plane consisting of the Network Management System (NMS). In addition, most network service providers have adopted the Automatically Switched Optical Network (ASON) architecture using the Generalized Multi-Protocol Label Switching (GMPLS) protocol as their optical transport control plane. This control plane logically sits between the management plane and the transport data planes. The optical control plane consists of a set of applications located on each transport network element (NE) that enable functions such as path computation and the discovery of network topologies, resources, and capabilities. As a result, each transport NE has access to the complete network topology and resources availability to support the end service. Based on ASON and GMPLS, optical transport's distributed control plane provides the following benefits:

- Survivability
- State accuracy
- Fast Recovery

Depending on the protection and restoration scheme deployed, optical transport networks can generally achieve as low as 50ms or better protection switching times or up to 100-200ms restoration times in a meshed network using GMPLS. A distributed control plane tightly coupled to the underlying NE is needed to achieve this level of performance. Therefore, most telecom service providers today are in agreement that they do not expect or want complete centralization of the optical control plane. In fact, leading telecom service providers such as Verizon have said that they want their supply chain to continue to innovate at the control layer within the vendor's equipment domain.

**Figure 1 • A Blend of Control Architectures is Optimal for Transport SDN**



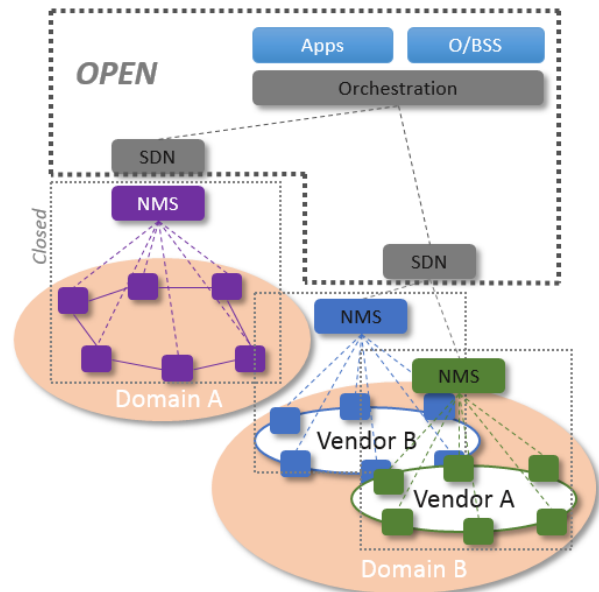
<sup>1</sup> Infonetics SDN and NFV Strategies: Global Service Provider Survey, March 2014

From a control plane perspective, by moving from GMPLS to SDN, service providers seek interoperability between multiple vendors in heterogeneous transport networks and across multiple networking layers to reap the benefits of multi-layer co-ordination and optimization. Therefore, for Transport SDN, service providers likely will leverage the proven performance of distributed control while borrowing the hierarchical nature of the SDN architecture with its open north- and south-bound interfaces and an orchestration layer to enable end-to-end path provisioning across multiple vendor domains and across multiple network layers.

Service Providers like China Mobile<sup>2</sup>, China Telecom<sup>3</sup> and Verizon<sup>4</sup> and industry bodies like Open Networking Forum (ONF)<sup>5</sup> have all proposed an architecture where OEM domain controllers will manage the optical transport NEs within each vendor's own domain while providing open northbound interfaces to a common network orchestrator (a parent "super" controller). The network orchestrator will abstract the details of the optical transport layer while enabling end-to-end provisioning of services by providing open interfaces to client SDN applications (i.e. OSS/BSS, network optimization, etc.). The orchestrator will facilitate individual OEM domain controllers to essentially communicate with each other in the east-to-west direction, allowing for multi-vendor interoperability.

With this architecture, it is also feasible to have multiple technology controllers per domain to take advantage of converged packet optical equipment (i.e. P-OTPs). So an L2/MPLS-TP controller can control the packet capabilities of P-OTPs while an optical/L1 controller can control the WDM/OTN aspects of P-OTPs within a domain. The orchestrator would be able to interface to these different technology controllers and enable multi-layer optimizations and interoperability.

**Figure 2 • Hierarchical SDN Architecture for Optical Transport**



This hierarchical SDN architecture for optical transport will enable telecom service providers to leverage best of breed choices while taking a pragmatic approach to achieving:

- Network programmability while leveraging the installed base/investments
- Simplified Multi-layer control
- Commonality in heterogeneous NE deployments
- End-to-end application awareness
- Better network efficiency

Ultimately, these achievements lead to an abstraction of the physical optical networking resources for enabling optical network virtualization—*Optical Transport Network as a Service*.

<sup>2</sup> ACTN Use-cases for Packet Transport Network, Weiqiang Cheng, China Mobile, IETF, Jul 2014

<sup>3</sup> Perspectives of Beyond 100G, Dr. Yiran Ma, China Telecom, OFC 2014

<sup>4</sup> Verizon readies its metro for next-generation P-OTS, Gazettabyte, June 2014

<sup>5</sup> Multi-technology and Multi-domain Network Orchestration Use Case, Ricard Vilalta (CTTC & ONF) and Victor Lopez (Telefonica)

## Use Cases Driving Telecom Service Providers Toward Transport SDN

While numerous Transport SDN use cases have been conceived, discussed and written about by different industry forums and standards working groups, Telecom Service Providers are focusing on ones that can deliver new monetization opportunities for the cloud connectivity market and ones that solve pressing needs, like maximizing their network efficiency in order to reduce CAPEX and OPEX. These early use cases include:

- Bandwidth-on-Demand
- IP and Optical Multi-Layer Optimization
- Virtual Transport Network

**Bandwidth-on-Demand** – A new breed of cloud services such as Amazon’s Virtual Private Cloud<sup>6</sup> and applications such as VMware’s Distance VMotion<sup>7</sup> are driving increasingly large amounts of data in and out of geographically dispersed data centers. These cloud services and applications are driving new network traffic patterns that are different from traditional steady data replication or traffic load balancing.

As a result, inter-data center traffic bandwidth can often exceed the mean by as much as 20x<sup>8</sup>. Purchasing a fixed leased/private line service for peak bandwidth is wasteful and not economical. Transport SDN enables a telecom service provider to offer optical transport bandwidth-on-demand services, allowing enterprise customers to establish and dynamically re-size the connectivity between their data centers temporarily or permanently as required and only pay for the actual bandwidth used.

*Service Provider benefits:* Allows flexible new services and associated revenue opportunities. On-demand connections at the optical layer would be established by a central SDN controller interacting with a bandwidth broker application.

*Physical Network Requirements:* The underlying physical transport network needs to be capable of dynamically adjusting and switching capacity at both the wavelength and sub-wavelength levels.

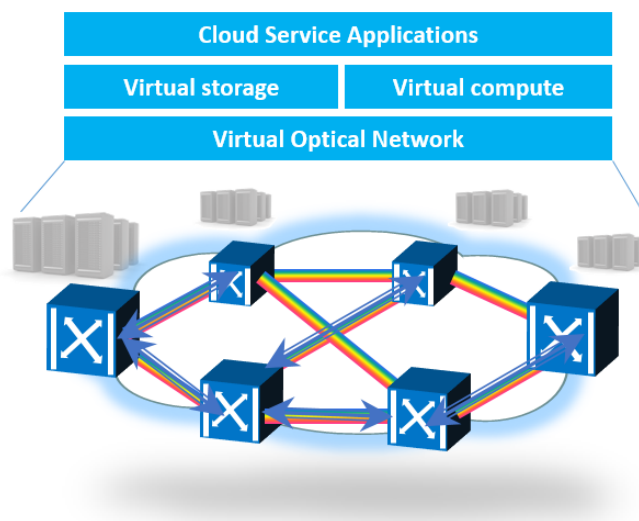
**IP and Optical Multi-Layer Optimization** – For most telecom service providers, IP/MPLS and transport are still operationally run as separate layers of the network with very little to no coordination between them other than IP/MPLS as a client of the transport layer. This is largely due to separate provisioning processes between routers and optical transport equipment with different NMSS. As a result, the transport layer is assumed to be a static layer by the IP/MPLS layer (IP over dumb pipes).

IP/MPLS traffic may be 1+1 protected, resulting in no more than 40% efficient IP networks.<sup>9</sup> Transport SDN addresses these challenges by providing a solution that can use either a single multi-layer controller interfacing to both router and transport NEs or separate IP and transport domain controllers interfacing to routers and transport NEs respectively with an orchestration layer above them for path computation and restoration management. In the latter case, the north bound interface from each of the IP and transport controllers would be based on open APIs and would provide detailed topology, provisioned services and performance information to the orchestration layer in order to find more efficient routes or create express/low latency routes, etc.

*Service Provider Benefits:* IP/MPLS and transport optimization translates into CAPEX reduction (by reducing the need for over-provisioning), higher network availability and quality (because traffic is routed and protected on the most optimal layers), and interoperability across different network domains and between different router and transport vendors.

*Physical Network Requirements:* IP and optical multi-layer optimization further drives the need for flexible sub-wavelength network channelization and opens up the possibility of converged multi-layer transport platforms.

**Figure 3 • Virtualization of the Network**



<sup>6</sup> Amazon Virtual Private Cloud, <http://aws.amazon.com/vpc>

<sup>7</sup> VMware VMotion, <http://www.vmware.com/products/vsphere/features/vmotion>

<sup>8</sup> ONF Solution Brief: OpenFlow-enabled Transport SDN, May 2014

<sup>9</sup> Ibid

**Virtual Transport Network** – The transport network is strategic to many enterprises for interconnecting either different offices or different data centers for cloud-based virtual computing and storage. The vast majority of enterprises cannot afford to build out their own private optical networks (procuring their own optical transport equipment, leasing dark fiber and hiring dedicated skilled-teams to maintain and operationalize the network). So, there is an opportunity to extend the concept of IP/MPLS VPNs to the transport layer with optical VPN services.

However, this service is not easily realizable today due to vendor-specific NMSs, network elements from different vendors across an end-to-end path, and the lack of configurability for the end-user through the application portal. Transport SDN enables a telecom service provider to overcome these challenges by creating abstracted views of the physical network through network virtualization.

Transport SDN extends the OpenFlow architecture to allow a telecom service provider's physical transport network to be partitioned into multiple virtual transport networks. This is achieved with the control data plane interface (CDPI) and control virtual network interface (CVNI) OpenFlow extensions<sup>10</sup>.

With these extensions, a service provider can create virtual slices of their physical network for each user. In addition, the multi-layer, multi-vendor aspects of the network can be hidden through these virtual topologies and the user can self-manage and control their end-to-end virtual optical networks. User control and management of their own network slice can be done through a portal or by a user's own controller.

**Service Provider Benefits:** Virtual transport networks allow service providers to share physical network resources easily to offer new value-added services like dynamic, self-managed optical VPNs to both internal and external users.

**Physical Network Requirements:** The optical transport network needs to support provisioning of optical circuits at the wavelength and sub-wavelength levels with rich OA&M for each circuit and support mechanisms to dynamically scale the end-to-end bandwidth of circuits up and down.

There is a common theme among the use cases presented: the requirement for greater flexibility at the photonic and electrical layers of the next-generation optical transport network. Without greater flexibility, the use cases have limited value for the telecom service provider.

## SDN Requirements at the Optical Transport Layer

To enable software programmability and realize Transport SDN use cases, optical transport networks need to be more flexible than they have traditionally been. Key network requirements to achieve the needed flexibility at both the photonic and electrical layers include:

- Flexible CDC ROADMs
- Flex-grid and Super-channels
- Adaptive Rate Modulation
- OTN Switching
- L2 Packet-Optical integration

**Flexible CDC ROADMs** – Colorless Directionless Contentionless (CDC) Reconfigurable Optical add-drop Multiplexers (ROADMs) overcome the three major limitations imposed on the optical network by 1<sup>st</sup> generation ROADMs. “Colorless” allows the automation of assigning add/drop wavelengths such that any wavelength/color can be assigned to any port entirely by software control. “Directionless” allows any wavelength to be routed in any direction at a given ROADM node entirely by software control, eliminating the directional dependency and manual rewiring of add/drop pairs and transponders and their outgoing direction. “Contentionless” solves the 3rd limitation of 1<sup>st</sup> gen ROADMs by enabling an architecture that allows non-blocking of wavelengths (multiple copies of the same wavelength) at a given add/drop structure. Therefore wavelengths cannot “bump” into each other during a reconfiguration. CDC ROADMs enable a more flexible photonic layer in concert with another ecosystem component, Flex-grid.

**Flex-grid and Super-Channels** – Flexible WDM grid (“Flex-grid”) is a solution to greatly increase the existing fiber capacity by flexibly allocating optical spectrum in the network for 100Gbps and beyond wavelengths. Traditionally, ITU-T has defined the WDM grid in 50GHz channel spacing, and this served the industry well for 10Gbps, 40Gbps and initial 100Gbps optical channels. Flex-grid re-defines the WDM grid with finer 12.5GHz spacing to “pack” more channels densely together on existing fibers. For example, the latest generations of best-in-class 100Gbps Coherent solutions can be compressed to occupy only 37.5GHz of spectrum. As a result, Flex-grid allows the service provider to increase overall fiber capacity by 33% from 8.8Tbps to 11.7Tbps<sup>11</sup>. An aggregate of Nx12.5GHz channels is referred to as a super-channel, and can be flexibly defined by different number of optical carriers and modulation schemes for different data rates. For example, a 400Gbps optical data rate channel may be flexibly defined as a two-optical-carrier DP-16QAM modulated super-channel or as a four-optical-carrier DP-QPSK modulated super-channel depending on the reach requirement.

<sup>10</sup> OIF Workshop, Lyndon Ong, ONF Optical Transport Activities, March 2014

<sup>11</sup> Gazettabyte, <http://www.gazettabyte.com/home/2012/3/8/latest-coherent-asics-set-the-bar-for-the-optical-industry.html>, March 2012

### Adaptive Rate Modulation for Coherent Wavelengths –

Different coherent wavelength modulation techniques can be utilized to achieve different transmission rates while trading off spectral efficiency (fiber capacity) and overall optical reach (OSNR). For example, the industry standard for 100Gbps is DP-QPSK, which has a 2 bit/symbol spectral efficiency and can support transmission reaches of more than 2000km.

Higher-level modulation techniques like DP-MQAM can support much higher transmission rates and achieve much greater spectral efficiency but come at the expense of maximum optical reach before requiring regeneration. For example, 200Gbps can be supported by DP-16QAM modulation with a 4 bit/symbol spectral efficiency (doubling the fiber capacity compared to DP-QPSK), but can practically only support reaches of 600-800km.

With DP-8QAM, 150Gbps can be supported with reaches greater than 1000km. The next generation of Coherent DSPs will allow the service provider to software-configure many different modulation techniques to flexibly support different transmission rates depending on network reach, spectral requirements and client rate service requests.

While these requirements increase the flexibility of the optical transport network, they by themselves are not enough. For example, focusing on just achieving flexibility in the photonic layer means only coarse bandwidth granularity is possible when trying to realize virtual transport networks or deliver bandwidth-on-demand.

## Benefits of OTN Switching for Transport SDN

Historically, OTN has been the de facto protocol for management of DWDM networks, but has been limited to a framing protocol for FEC and OA&M functionality. It was only recently defined and utilized as a deeply channelized and switchable networking layer. As a networking layer, OTN plays a few key roles:

- Grooming, Switching and Bandwidth Adjustment
- IP/Packet and Multi-Service Convergence
- Protection

### OTN Grooming, Switching and Bandwidth Adjustment –

While SDN is not a prerequisite for the deployment of OTN switching, an optical transport network architected with OTN switching adds more flexibility for Transport SDN. While the deployment of 100G in the transport network solves the overall bandwidth problem, the majority of clients feeding into the transport network remain largely 10G or less<sup>12</sup>.

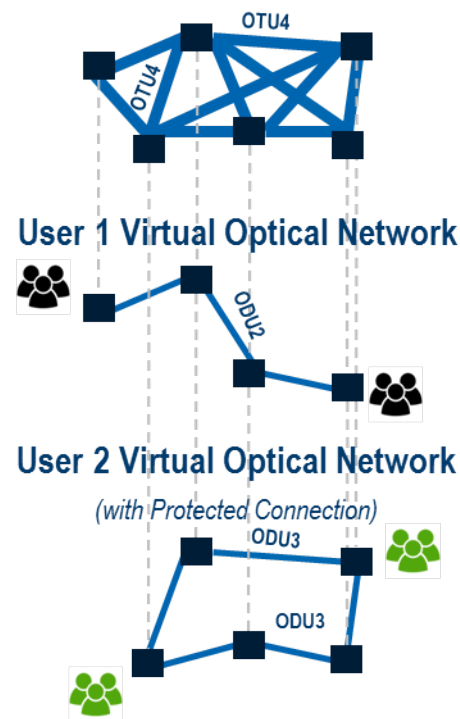
As a standards-based networking layer, OTN provides an equivalent of up to 80 “virtual” sub-wavelength circuits per 100G physical wavelength. These virtual optical circuits can

support their own independent network timing (asynchronous to each other) and have independent OA&M to enable carrier-grade, deterministic bandwidth services.

When it comes to provisioning, these sub-wavelength circuits can be truly “virtual” as they are created and monitored from an end-to-end “path” perspective, independent of the WDM network topology, wavelength segments or rates they are carried over. These virtual circuits can each be provisioned in granularities as small as 1.25Gbps (an ODU0 circuit) and up to the full bandwidth of a 100G wavelength (an ODU4 circuit).

**Figure 4 • Virtualization of Optical Resources with ODUK Circuits**

### Physical OTN Switched Network



In addition, once these circuits are provisioned, they can be scaled up or down in increments of 1.25Gbps (an ODUflex circuit), and if necessary even without any traffic hit occurring (G.HAO – Hitless Adjustment of ODUflex). The standards-based mechanics to dynamically ramp up or down the bandwidth of each circuit is the real value of G.HAO. Modern P-OTPs are now deployed using 3<sup>rd</sup> generation OTN processors on the line cards, which have integrated support for G.HAO in hardware and software.

So every P-OTP node will be able to participate in supporting switchable and scalable virtual optical circuits across the entire transport network. Transport SDN can leverage these OTN

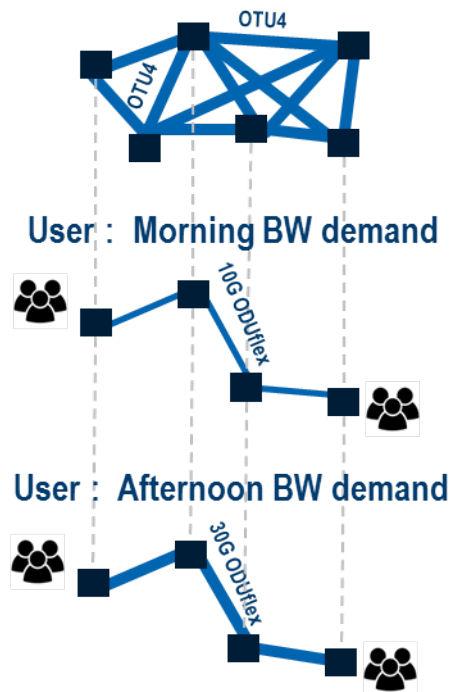
<sup>12</sup> Ovum 2012 Managed Service Mix Survey



capabilities to realize both bandwidth-on-demand and virtual transport network use cases.

**Figure 5 • Bandwidth-on-demand with ODUflex and G.HAO**

### Physical OTN Switched Network



**IP/Packet and Multi-Service Convergence** – OTN as a networking layer is designed to transport any client service type transparently through the network. From the client service perspective, this means it is transported end to end without the client being aware of a transport layer. OTN natively supports the transport of Ethernet (up to 100G), SONET/SDH (up to OC-768/STM-256) and Constant Bit-Rate (CBR) clients such as FC and Video.

In addition, because modern P-OTPs are capable of switching IP packets, OTN is used to deliver IP services directly, without the need for an Ethernet MAC encapsulation layer. IP packet flows can be mapped directly into adjustable virtual circuits (ODUflex) using the Generic Framing Protocol (GFP), which allows client packets of variable length to be carried over deterministic circuits.

By eliminating the need for Ethernet MAC encapsulation, IP services can be transported much more bandwidth efficiently. This is especially true for large IP packet flows that exceed 10Gbps or 40Gbps. Mapping directly into OTN overcomes the inefficiency with Ethernet Link Aggregation (LAG) over multiple 10G or 40G Ethernet links.

GFP mapping of IP into OTN circuits serves as the adaptation function to interwork between the IP/MPLS and optical

domains in support of Transport SDN's multi-layer optimization use case. So it is no surprise that many telecom service providers around the world are deploying OTN switched networks using P-OTPs and leveraging OTN as a convergence networking layer for IP, Ethernet, SONET/SDH and multi-service traffic.

**Packet-Optical Integration** – Modern Metro and Core optical transport platforms have been architected at the hardware level to support both packet and OTN processing/grooming and switching capabilities. While there are many different Packet Optical Transport platforms (P-OTPs) available on the market from different OEMs, the most common platform architecture relies on a central packet-based switching fabric capable of switching packets or ODUk streams, with pluggable line cards that support OTN multiplexing/mapping or Packet processing.

OTN streams are packetized using the industry standard OTN over Packet Fabric (OPF) protocol before they are switched. In addition, the line cards generally all support integrated WDM optics. Combined with system level software, P-OTPs provide a flexible integrated platform to deliver L0 (photonic), L1 (OTN) and L2-L3 (Ethernet & IP/MPLS) capabilities for network service providers. By supporting these three capabilities in a single transport NE, service providers can benefit from the flexible use of different network layers to achieve cost, bandwidth and protection optimizations.

**Protection** – Transport networks based on OTN switching provide greater network survivability. For example, protection at the OTN layer provides very fast circuit switching (sub 50ms) while protection at the photonic layer can often exceed 200ms<sup>13</sup>, and protection at the IP packet layer (like MPLS Fast Reroute) can be less deterministic and slower to recover. In addition to supporting linear protection (1+1, 1:N, etc.), OTN also supports shared meshed protection, which leverages meshed network architectures to share protection and restoration resources to minimize cost.

<sup>13</sup> Oclaro WSS PR, <http://investor.oclaro.com/releasedetail.cfm?releaseid=652644>

## Summary

Telecom service providers must transform their optical networks from static, manually provisioned architectures into dynamic, software programmable platforms while leveraging their large installed base of equipment as well as equipment investments they are making over the next 24 to 36 months. Most telecom service providers are looking to Transport SDN to achieve this goal. However, simply adopting Transport SDN to abstract their networks does not mean those networks are now programmable platforms. Programmability needs to come from the underlying optical and networking layers, which must be flexible.

Network elements with OTN switching are being deployed by telecom service providers around the world to add flexibility to the network layers of their Metro and Core networks while increasing overall bandwidth efficiency, especially as 100G rolls out. OTN switching enables the creation of virtual sub-wavelength end-to-end optical circuits and supports on-demand adjustment of bandwidth. Therefore, architecting and deploying OTN switching in the transport infrastructure ensures maximum network flexibility to enable programmability for Transport SDN in the near future.

## Transport SDN, OTN Switching and Microsemi

Microsemi is the semiconductor and software solutions market leader for OTN framing, grooming, mapping and switching — *OTN processing*. With four generations of OTN processors spanning support for Ethernet and Multi-service client protocols from 100Mbps to 100Gbps, Microsemi is delivering highly integrated and flexible platform solutions that optical transport OEMs can leverage to rapidly build out their portfolio of line cards.

Microsemi's latest OTN processor, the DIGI-G4, delivers the industry's 1<sup>st</sup> single-chip 400G solution with unparalleled integration to enable the lowest power line cards for OTN switched network deployments. As a member of Open Networking Forum (ONF)'s Transport SDN workgroup, Microsemi is taking a leadership role in ensuring our OTN solutions provide the necessary forwarding/data plane capabilities to support the SDN era.





**Microsemi Corporate Headquarters**  
One Enterprise, Aliso Viejo,  
CA 92656 USA

Within the USA: +1 (800) 713-4113  
Outside the USA: +1 (949) 380-6100  
Sales: +1 (949) 380-6136  
Fax: +1 (949) 215-4996  
E-mail: [sales.support@microsemi.com](mailto:sales.support@microsemi.com)

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