OPEN NETWORKING FOUNDATION

OpenFlow-enabled Transport SDN

ONF Solution Brief

May 27, 2014

OpenFlow™

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Executive Summary

Wide area network (WAN) traffic continues to double every 18 to 24 months, with individual service flows now exceeding 1Gbps and inter-site aggregates reaching tens to hundreds of gigabits per second. Simultaneously, mobility networks and cloud-based services are causing traffic patterns to become ever more dynamic and unpredictable. In the face of these realities, today's static and manually configured transport networks operating in their own silos are woefully inadequate. Transport networks need to become more flexible and dynamic to support end-user demands.

OpenFlow-based Software Defined Networking (SDN) initially enabled open, application-driven, programmatic control of packet forwarding among a set of packet switches. However, not all services are packet-based, and very few WANs are constructed with packet switches directly connected by fibers as may be the case in data centers. Most deployed WANs employ SONET/SDH or OTN sub-wavelength and wavelength circuit-switching elements—technologies that are not currently supported by OpenFlow. These elements provide reliable, efficient transport services directly to end users or to client packet nodes (e.g., IP/MPLS routers) that, in turn, provide packet services to end users.

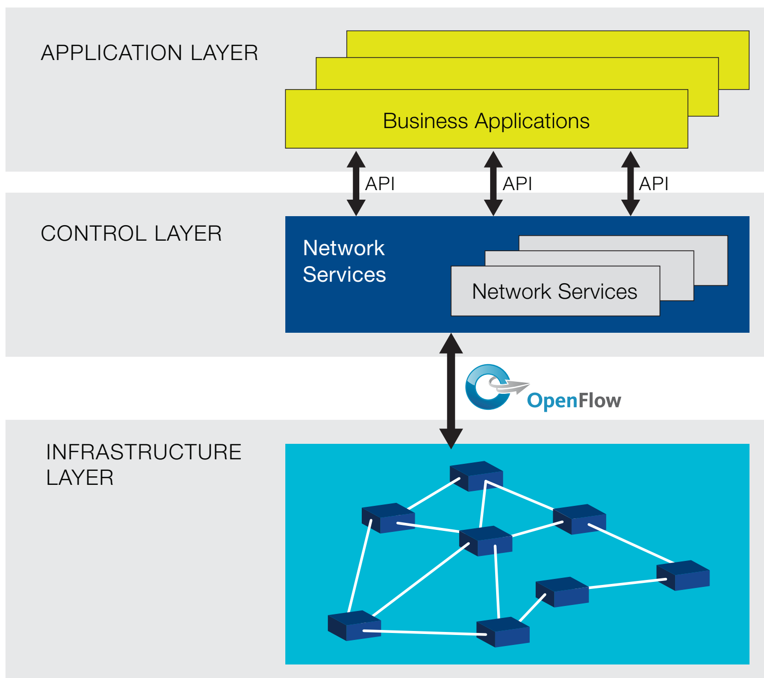
Recently, packet transport technologies such as MPLS-TP have been incorporated with optical transport, resulting in more cost-effective packet-optical transport systems (P-OTS). Based on Heavy Reading's March 2013 Metro P-OTS survey[1], revenue of such P-OTS elements in metro networks already exceeds that of SONET/SDH nodes and is projected to outpace that of pure DWDM systems by 2015.

This solution brief addresses how OpenFlow can enable open, application-driven, programmatic control of optical and packet-optical transport elements. It also offers several illustrative use cases, including bandwidth on demand, private optical networks, optical VPN services, and IP/MPLS plus Transport optimization.

SDN Overview

Software Defined Networking is a new architecture that has been designed to enable more agile and cost-effective networks. The Open Networking Foundation (ONF) is taking the lead in SDN standardization, and has defined an SDN architecture model as depicted in Figure 1.

FIGURE 1
ONF/SDN architecture



The ONF/SDN architecture consists of three distinct layers that are accessible through open APIs:

- **The Application Layer** consists of the end-user business applications that consume the SDN communications services. The boundary between the Application Layer and the Control Layer is traversed by the northbound API.
- **The Control Layer** provides the logically centralized control functionality that supervises the network forwarding behavior through an open interface.
- **The Infrastructure Layer** consists of the network elements (NE) and devices that provide packet switching and forwarding.

According to this model, an SDN architecture is characterized by three key attributes:

- **Logically centralized intelligence.** In the ONF SDN architecture, network control is distributed from forwarding using a standardized southbound interface: OpenFlow. By centralizing network intelligence, decision-making is facilitated based on a global (or domain) view of the network, as opposed to today's networks, which are built on an autonomous system view where nodes are unaware of the overall state of the network.
- **Programmability.** SDN networks are inherently controlled by software functionality, which may be provided by vendors or the network operators themselves. Such programmability enables network configuration to be automated, influenced by rapid adoption of the cloud. By providing open APIs for applications to interact with the network, SDN networks can achieve unprecedented innovation and differentiation.
- **Abstraction.** In an SDN network, the business applications that consume SDN services are abstracted from the underlying network technologies. Network devices are also abstracted from the SDN Control Layer to ensure portability and future-proofing of investments in network services, the network software resident in the Control Layer.

Trends and Challenges

Transport networks are under pressure. Demand for bandwidth continues to grow rapidly with no apparent end in sight. Traffic patterns are seismically shifting due to the adoption of cloud services, the dramatic increase in video usage, and the emergence of mega-sized data centers.

At the same time, device mobility and an "Internet of things" has changed where and how bandwidth is being consumed. Self-serve, on-demand infrastructure, and applications based on virtualized compute and storage, have changed customer expectations of the WAN. Utilization is dynamic, and the network needs to support that dynamism. Traditional L2/L3 VPN services provide the necessary flexibility, but not the level of determinism or control required. High peak-to-average and/or transient bandwidth demands between certain locations require transport services that can be turned up, modified, and torn down in near real time.

Current transport networks cannot effectively address these pressure points, as they are generally static and operated separately from the client layers and applications they serve. Traditional transport services can take weeks or months to turn up and must be contracted for periods of months or years—a reflection of the planning and provisioning effort currently endured. Because of the lengthy process to turn up new services, many customers cancel orders before they become operational.

To support the highly dynamic environment mentioned above, connectivity services must be turned up in minutes or seconds and be modifiable by client users or software applications without operator intervention. Orchestration is required to manage connectivity services over a network covering potentially multiple network domains, through multiple layers of networking technology, and across multiple vendors' equipment.

Enhancing Transport Networks with OpenFlow

Transport SDN, which is being defined under the umbrella of ONF's Optical Transport Working Group (OTWG),[2] provides the architecture and mechanisms to address these trends and challenges. In March 2013, ONF chartered the OTWG to extend the OpenFlow standard to support transport networks . The OTWG has liaised with peer standards bodies such as the OIF, ITU-T, BBF, and TMF to reach alignment on the target use cases, architectural proposals, and information model.

Through automation and logically centralized intelligence, OpenFlow-based Transport SDN simplifies operators' complex, rigid, and multi-vendor environments and enables the introduction of new transport network services to better monetize the network.

Until recently, the OpenFlow standard focused on the packet-oriented Layers 2 and 3. Transport SDN extends OpenFlow to support Layer 0 (photonic) and Layer 1 (SONET/SDH, OTN) networks, allowing the same support for logically centralized control and independent software and hardware development. Fundamentally, extensions are added to OpenFlow to program switch ports and fabrics that operate on fibers, wavelengths, and timeslots as well as packet headers, while retaining the same simple model of match and action tables across these multiple layers.

To address the specific requirements for transport networks, OpenFlow is also being extended to support protection, performance monitoring, and other critical operations, administration, and maintenance (OAM) capabilities. Such performance monitoring information (e.g., bit error rate) could be used for consequential dynamic service control. See Figure 2 for a summary of Transport SDN extensions.

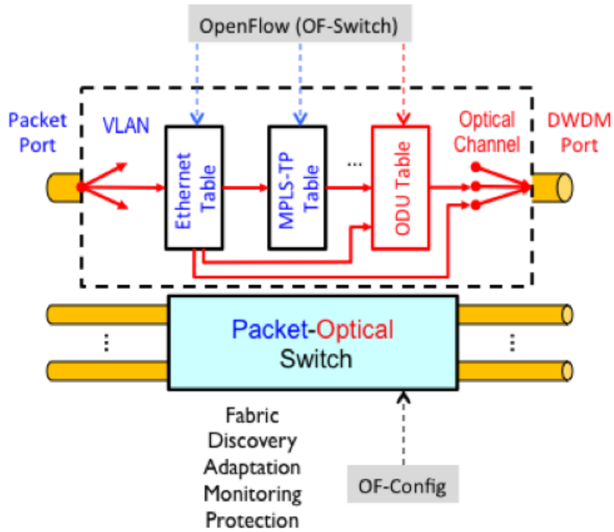


FIGURE 2
Target multi-layer OpenFlow logical switch model

EXTENTIONS

– L0/L1-capable port descriptions
  - Including neighbor discovery / ID
– Match table capable of matching/changing L0/L1 "fields", adding MEPs
– Match & Group tables supporting NE-based protection and OAM
– Dynamic multilayer control of switching and adaptations, e.g.
  - Ethernet > ODUk > Optical Channel
  - Ethernet > ODUj > ODUk > Optical Channel
  - Ethernet > MPLS LSP > ODUk > Optical Channel

The application of these L0/1/2 OpenFlow extensions, as elucidated in the use case sections below, includes:

- Packet-optical integration (POI) to support logically centralized control of multi-layer and/or multi-technology networks, resulting in optimized network utilization.
- Open transport network control programmability to spur greater network innovation.
- Real-time application-driven provisioning of the transport network.

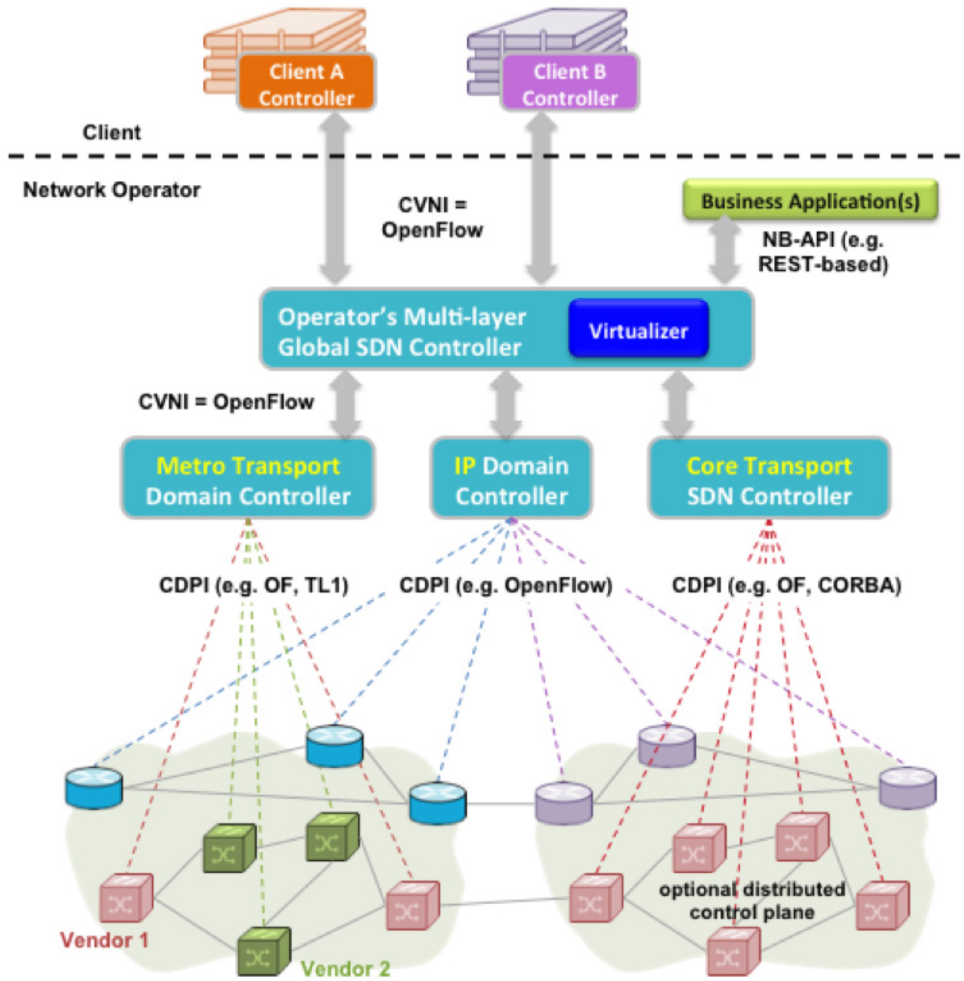
An important architectural innovation is the introduction of transport network virtualization, whereby the operator's physical transport network can be partitioned into multiple virtual networks. Each virtual transport network is allocated certain virtual network elements (V-NEs) and interconnecting virtual links (VLs) that are under the control of the respective clients through their client controllers.

The ONF Transport SDN model defines two interface points where OpenFlow can be applied:

- The CDPI (control data plane interface), originally defined in an ONF white paper[3], where there is a direct interaction between the network operator's SDN controller and the transport network elements.
- The CVNI (control virtual network interface), where the client controllers use OpenFlow to interact with the provider's controller that offers a virtualized view of each client's slice of network resources.

A client controller can belong either to an internal customer (e.g., the operator's own content distribution network), or to an external customer (such as an enterprise or another operator). The scope of the client's visibility into their resources is still under definition, but may vary from completely abstracted to completely specific depending on the policy set by the provider, which is generally a function of the trust relationship with the client.

FIGURE 3
Hierarchical control architecture



The hierarchical controller structure illustrated in Figure 3 enables control to be explicitly partitioned across the physical network resources. Hierarchy further provides a means for coordinating multiple domains in an operator's network for greater scalability and for integration across different layers or technologies. The use of CVNI also may ease the migration process or coexistence between legacy transport networks and OpenFlow-based transport networks. The control plane under the CVNI could be anything, including distributed control planes such as GMPLS. A mediation application to translate to traditional transport management interfaces (e.g., TL1 or CORBA) can be introduced to allow legacy transport domains to operate in an SDN environment.

In addition to greater network resource and operational efficiencies, Transport SDN allows network programmability for the rapid deployment of new transport services, enabling operators to better differentiate and monetize their infrastructures. Examples of such offerings are tiered recovery, customized path selection, and various applications that will make the transport network aware of packet (client) layers and their dynamic requirements in terms of bandwidth, latency, geography, and time span.

Use Case: Bandwidth on Demand

The increases in big data, cloud networking, and ad hoc inter-enterprise collaboration result in inter-site bandwidth peaks that can exceed the mean by 10x, 20x, or more—and can last anywhere from tens of minutes to several hours or even longer. Contracting for a private line or committed information rate (CIR) sized to accommodate such peaks is at best wasteful—and for some, prohibitively expensive. Research[4] shows that approximately 35% of key industry verticals such as finance, manufacturing, media and entertainment, and others are very interested in dynamic services that address this conundrum.

OpenFlow-based Transport SDN enables carriers to offer bandwidth on demand (BWoD) services that allow customers to dynamically establish and subsequently resize connectivity between their sites as necessary—and to pay only for the network resources that they actually use.

These services require access from each customer site to a dedicated port at the edge of the carrier switched network (either at customer premises or backhauled over a fixed access segment). In either case, the UNI is typically Ethernet (e.g., 10/100GbE) or OTN (e.g., OTU2/3/4), though others are possible. Forwarding from the UNI may be physical port-based or logical sub-port–based, in which case customer traffic is mapped to its respective BWoD “switched virtual leased line” (SVLL) by matching ingress VLAN ID, MPLS label, SONET/SDH AU-4/STS-1 time slot, OTN OPUk tributary slot, or wavelength frequency slot. Inter-site switching of the SVLL will be OTN ODU or wavelength-based.

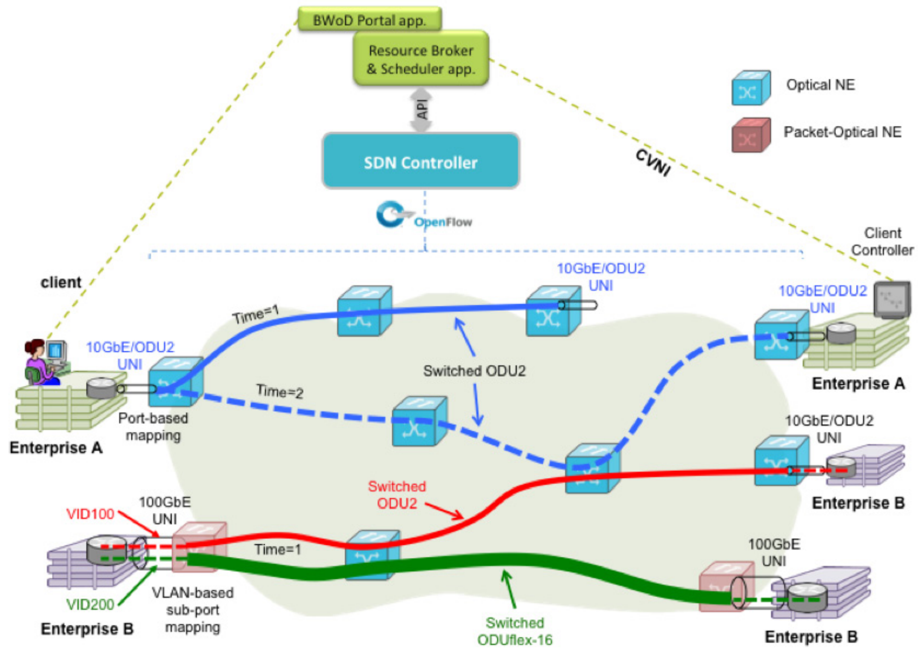


FIGURE 4
BWoD service illustrating port-based (above) and sub-port based (below) forwarding

On-demand connections are established by the customer interacting with a bandwidth broker/scheduler application hosted on an SDN controller. Requested connection parameters are communicated through a portal or over a northbound API (NBI). The northbound API allows operations users, customer clients, and applications to request SDN communications services directly from the Control Layer. Connection parameters may include source and destination UNIs, bandwidth, maximum latency, protection tier (e.g., unprotected, 1+1, 1:1, or mesh restorable), and sub-port mapping identifiers (e.g., VLAN ID), if applicable. In addition, the connection request may be for immediate instantiation or a specified scheduled time in the future, and for an indefinite or specified duration.

The broker/scheduler application first validates the request against the customer's contracted policy (e.g., endpoints or maximum aggregate bandwidth) and then invokes the path computation element (PCE) to determine whether a viable path exists. If so, it proceeds to instantiate the connection—either immediately or when scheduled—via the SDN controller. The SDN controller again uses the PCE to identify the best path and issues OpenFlow commands to the transport NEs to establish the bi-directional connection, including the mapping from client port to connection origination point (e.g., ODUj/k), the hop-by-hop ODU and/or wavelength cross-connects, and the connection termination point to client port de-mapping. Multiple sub-port connections can be supported by the UNI simultaneously, and the resources of released or decremented connections are immediately available for other connections.

Transport SDN–enabled bandwidth on demand provides benefits to end customers and network operators alike. End customers can receive high bit-rate, deterministic capacity on a temporary basis when and where they need it, without the cost burden of over-provisioned private lines with long-term contracts. Priced intelligently, the network operator increases overall revenues by increasing their addressable market to those who can't afford such contracts. At the same time, the operator increases return on assets by selling capacity several times over per month and for higher value per time unit than a flat monthly fee yields.

Use Case: Private Optical Networks

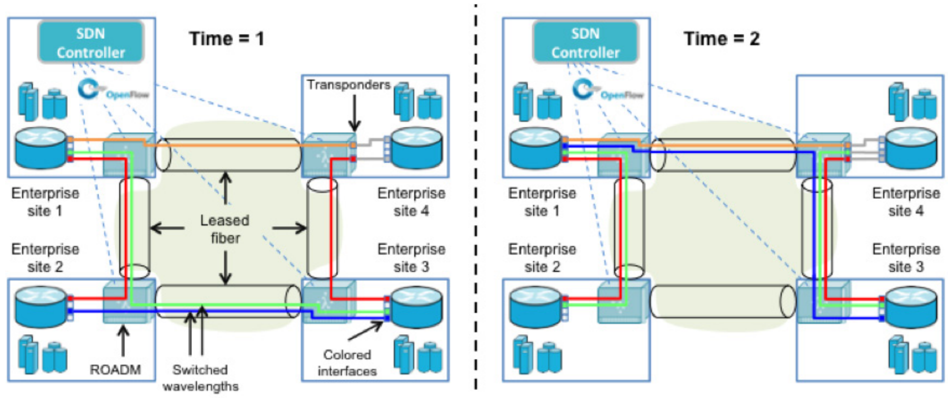
There have always been enterprises for which the network is such a strategic part of their business that they have chosen to build and manage their own private optical networks. Such enterprises directly procure networking equipment and connect their locations with leased dark fibers.

An enterprise private optical network is often a microcosm of the public network. Some enterprises connect large offices and data centers for cloud-based virtual compute and storage. Some enterprises support mobile users. These enterprises experience high peak-to-average inter-site bandwidth demands, and require rapid capacity reallocation driven by applications such as cloud orchestration systems. Consequently, enterprises running private optical networks may also benefit from Transport SDN.

SDN's logically centralized control provides a network-wide perspective to optimize the use of all resources through the network. SDN also enables service automation to simplify and accelerate provisioning and reduce potential for human errors. With Transport SDN, enterprises can switch wavelengths to allocate bandwidth among sites as needed by their applications (see Figure 5). For example, they can:

- Redirect wavelengths through ROADMs.
- Retune transceivers on optical transponders/muxponders or colored interfaces on OpenFlow-enabled switches/routers to a new wavelength.
- Activate new connections and deactivate old connections.

FIGURE 5
Private optical network with reconfigured wavelengths



Until dynamic optical services become widely available from local providers, Transport SDN enables enterprise IT departments to function as their own service providers. Such in-house capability enables them to manage connectivity and allocate bandwidth between sites in minutes rather than waiting weeks or months for today's typical local provider to fulfill their fixed-line change order. Instead of ordering fixed bandwidth services sized for the peak, an enterprise managing a private optical network has the flexibility to manage their network and orchestrate capacity shifts among their locations where and when they are needed.

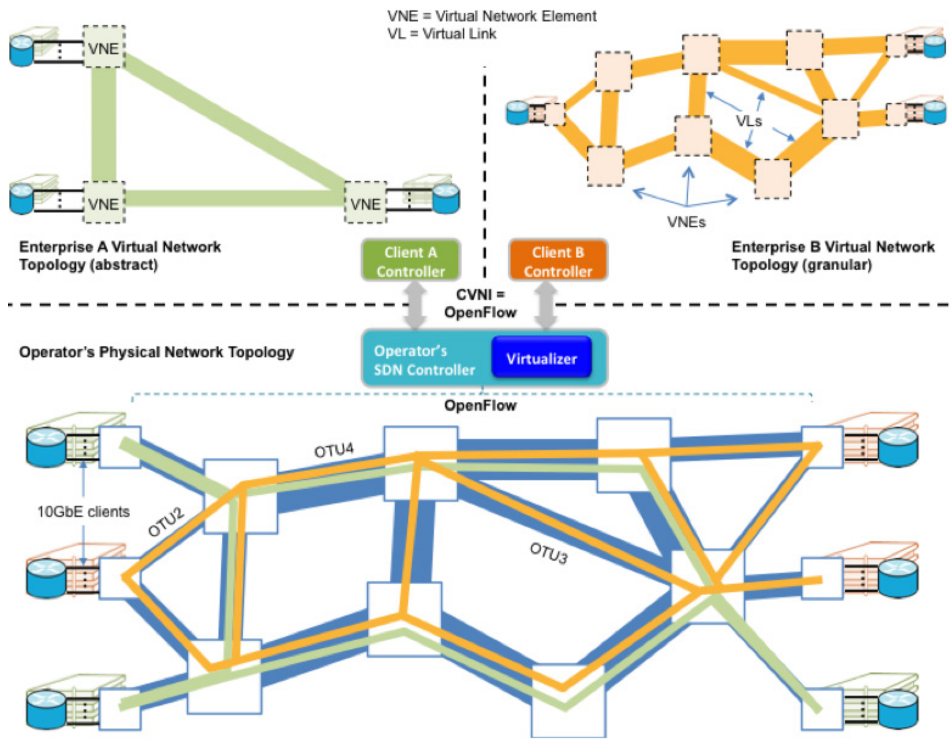
Use Case: Optical Virtual Private Networks

While many enterprises are interested in the benefits of private optical networks, not all can afford the dedicated equipment and leased fibers of a bespoke network operated by a service provider, or have the in-house expertise to manage a fully private optical network on their own. Such enterprises are prime candidates for optical virtual private network (O-VPN) services. Extending the concept of VPN to the optical layers is not an entirely new concept. There are commercial solutions available today; however, most are based on sophisticated, vendor-specific management systems and only allow end users to provision wavelength or sub-wavelength connections across their VPN resources through a portal.

The key challenge for IP/MPLS VPN services is to provide deterministic performance. Optical network-based services are circuit-based and inherently deterministic. However, there are two challenges with O-VPNs: providing independent control and management across the end-to-end service, and provisioning the O-VPN services across various layers and vendor network elements. Both of these challenges are addressed by Transport SDN.

Using Transport SDN, O-VPN service is made possible through network virtualization (described above) that allows a network operator to create virtual slices of the network that deliver dedicated capacity and provide the client with self-managed control of their end-to-end virtual networks. With O-VPN, the client can allocate capacity as if it were their own private network.

FIGURE 6
Common optical network supporting multiple O-VPNs



OpenFlow-enabled Transport SDN allows network operators to expose the underlying multi-layer, multi-vendor network as a virtual topology. The visibility and performance information (e.g., latency) of this topology over which connections can be created can be further controlled for full or partial view. For example, Figure 6 shows an optical network that supports multiple O-VPNs with different levels of virtual network granularity.

The connection creation can be achieved either through a client portal or from a client's controller over the CVNI by specifying connection details, including end points, size, explicit path, resiliency, protection path, and more. This results in a dynamic VPN that allows clients to develop their own algorithms to manage connection paths in support of their unique requirements.

For example, a distributed, multi–data-center cloud operator could use Transport SDN to orchestrate capacity turn up and tear down between specific data centers to support bulk VM migration or the synchronization of large databases. Based on the ebb and flow of bandwidth demands, portions of the same O-VPN capacity could be reallocated to a different application or a different pair of data center locations as needed.

The key benefit that Transport SDN provides for O-VPN end users is access to a deterministic network at a much lower cost. For network operators, the key benefits are reduced costs due to sharing network elements, fiber, and wavelengths across multiple internal and external customers, and higher profits based on the introduction of new value-added services with higher revenue and better margins than simply leasing dark fibers.

Use Case: Multi-vendor IP/MPLS Plus Transport Optimization

Presently, IP/MPLS services deliver most application-based, content-rich services. Because it is inefficient to interconnect routers with dedicated fibers, operators have deployed Layer 0/1 transport networks to deliver and manage capacity. With the traffic growth and dynamic patterns described in this solution brief, transport networks must become more dynamic. This use case describes coordinating multi-layer IP/MPLS and transport provisioning and restoration to address shifting aggregate IP flows.

In network parlance, the IP/MPLS routers are clients and the transport nodes are servers. Presently, most IP/MPLS topologies assume a static transport layer. Physical router topologies and transport connections are sized based on 6- to 12-month traffic forecasts, worst-case source-to-destination peaks, and allowances for extra capacity to recover from link or IP/MPLS node or port failures. The IP/MPLS traffic is 1+1 protected, and the transport network provides two diverse optical paths to the routed network. The result is IP/MPLS networks that are no more than 40% efficient.

This is largely a byproduct of the fact that current IP/MPLS plus transport networks typically have disjoint provisioning processes and network management systems. IP/MPLS services and transport services are independently provisioned using separate workflows. Path computation and traffic engineering are employed at each layer of the solution separately. Control plane information for each layer is also held separately in the IP/MPLS routers and the transport nodes.

Transport SDN provides the mechanisms for a dynamic transport layer and defines an architecture to enable the IP/MPLS and transport layers to be controlled synergistically. Typical adaptation between domains includes either IP/MPLS pseudowire or MPLS-TP tunnel to GFP-F to ODU to DWDM physical port, and could be performed on a router with colored interfaces or a packet-optical transport node.

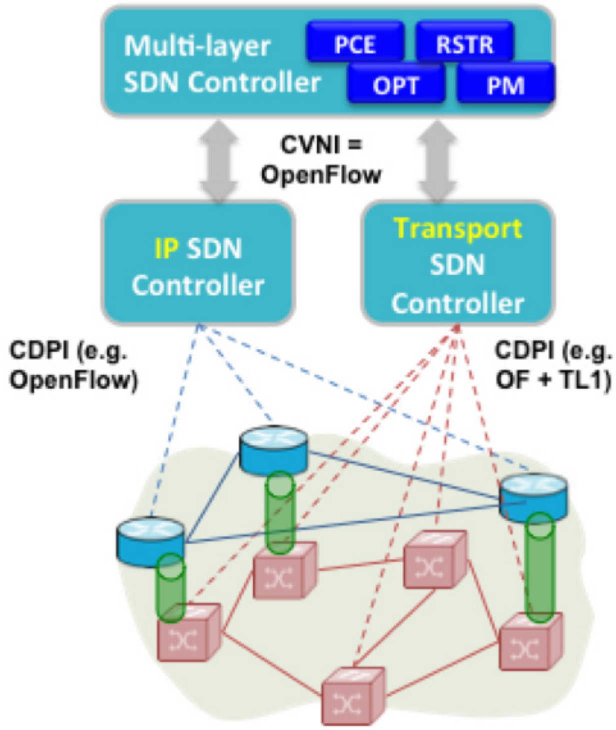


FIGURE 7
Multi-layer IP/MPLS plus transport control

The solution may use a single multi-layer controller interfacing directly to both IP/MPLS and transport elements, or separate domain controllers and a multi-layer orchestrator/controller, as illustrated in Figure 7. In this approach, each domain controller provides detailed information about topology, latency, provisioned services, and performance to the multi-layer controller for path computation and restoration management. When bandwidth shortfalls are anticipated, a failure occurs, or more efficient routes are possible, the multi-layer controller can orchestrate changes to the IP/MPLS and transport layers through the respective domain controllers, by allocating or reallocating router ports and transport capacity, rerouting transport connections, or creating express routes.

This multi-layer IP/MPLS + transport optimization achieves many network benefits, including:

- CapEx reduction, by reducing the need for over-provisioning of the network to support demand shifts and protection/restoration.
- Increased service availability (e.g., coordinated protection and restoration) and service quality (e.g., latency-optimized multi-layer provisioning).

- Multi-layer control and optimization across separate IP/MPLS and transport vendors.
- OpEx reduction and simplification through automation to reduce manual processes and associated configuration errors.
- Increased revenues, by leveraging network intelligence to monetize the network based on a broad list of programmable path and service level parameters, such as end-to-end latency of an IP/MPLS service.

Key Benefits of Transport SDN

OpenFlow-enabled Transport SDN provides several benefits to optical and packet-optical networking, including:

- **Speed and automation.** Programmatic APIs and logically centralized control streamline operations compared to manual order entry and NMS-based provisioning.
- **Operator innovation.** A standardized information model and open northbound APIs allow network operators to develop their own service models and constraint-based connection routing algorithms to differentiate their services.
- **Efficiency.** Using OpenFlow for conjoint control of packet, circuit, and photonic transport resources enables multi-layer path computation and optimization to intelligently aggregate and express traffic to minimize stranded capacity.
- **Multi-vendor networking.** Standard OpenFlow enables common connection provisioning commands across any compliant NE, allowing the choice of different vendors for different layers and/or geographical or operational domains.

Conclusion

In this era of intense competition, high bandwidth demand growth, and unpredictably shifting traffic patterns, operators need their transport networks to become dynamically programmable in order to offer new services and to match capacity to traffic demand without over-provisioning network resources. Transport SDN, as defined by the ONF, provides the architecture and mechanisms to enable programmatic and dynamic control driven by the revenue-generating services that consume network capacity. This linkage, governed by policy management, will enable network operators to transform their transport networks to simultaneously reduce capital and operational expenses while increasing revenue opportunities and operational agility.

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