The New Packet-Optical Core for a Software-driven World

The Cloud-driven Transformation of the Network
Over the past decade, IT infrastructure has seen a dramatic shift from local resources to those located in a third-party facility. Whether we receive them at home or on our mobile phones, the hardware-free services offered by service providers reside somewhere on the network, including storage of our personal files, streaming of personal and commercial video and, of course, photo albums and email. The acceleration of Cloud adoption, as evidenced by the tremendous growth of Infrastructure, Platform and Software-as-a-Service (IaaS, PaaS and SaaS) offerings among technology providers, is having a profound impact on IT and network architectures.
As a result, the traditional layered network model of a hierarchical, functionally heavy, ring fenced network comprising several layers of devices is being replaced by a simplified model of **Layer C**, Cloud Services, and **Layer T**, Intelligent Transport.

Cloud Services or Layer C, consisting of the upper layers (Layers 4-7) of a network, is growing at a phenomenal rate. The compute, storage and network functions in a single Point of Presence (POP) site are expanding to five to 10 such Cloud central office (CO) locations. As a result, operators need to scale, simplify and increase flexibility in their networks. In addition, they are constantly seeking efficient ways to reduce their IT complexity. As depicted in Figure 1, Network Function Virtualization (NFV) enables operators to migrate services like Security, Voice, CPE, and BRAS from standalone devices to software services on X86 hardware within Cloud datacenters. Longer term, even complex Layer 3 services like L3 VPN at the provider edge will likely be destined for migration to Layer C.

Meanwhile, transport functions at the lower layers are converging as operators encourage vendors to drive to the most cost-effective network elements, giving rise to an intelligent transport layer, Layer T. It combines MPLS and Ethernet packet services, digital functionality of OTN switching, and optical transmission and switching with WDM and ROADM functionality. Software Defined Network (SDN) technology can abstract these services and functions of Layer T and present standardized application programming interfaces (API) such that control can be offloaded to Layer C. This approach is manifested in Infinera’s **Intelligent Transport Network** architecture, which is a judicious mix of packet, digital and optical functions on a single, scalable, flexible and programmable platform exposed to virtualized control and network applications via open APIs using SDN.

### The Evolution of Core Transport

The fundamental requirement of the transport network is to move ever-increasing amounts of traffic from point A to point B. All traffic growth is packet based, so one can mistakenly build a network with only Layer 3 packet functions like routers everywhere, and use Layer 0 optical functions directly as fixed links. However, this quickly becomes expensive. Whether the traffic
is inter-datacenter, multicast video, or superhighways of traffic between major Internet POPs, there is a pattern in packet networks, which should be exploited to reduce costs. The pattern comprises deterministic connections like elephant flows, perhaps between datacenters, and mice flows destined for the Internet. This knowledge of data flows eliminates the need to use more costly routers everywhere until the data reaches the Internet gateway or peering points where Layer 3 intelligence resides. Between these points in the transport core, operators are increasingly using Layer 1 digital OTN switching for economical, fast and reliable performance.

In a recent survey of global operators, Infonetics Research found that more than 90% of them currently use or plan to use OTN switching in the core within the next couple of years (Source: Global Service Provider Survey Excerpts: OTN, MPLS, and Control Plane Strategies by Infonetics Research, Inc.). Let’s examine why this is so.

Traffic flows in the network vary in many different ways – by duration, size, time of day, bursty or deterministic nature and more. The flows can be handled by several technologies across the multi-layered network such as optical super-channel/wavelength connections, digital OTN circuits, and packet Ethernet/MPLS circuits. It is important to match the technologies to the traffic flow and ultimately to the end-user service. Also, these technologies are not necessarily exclusive. For example Ethernet/MPLS packets use the lower layers of digital OTN circuits and/or optical super-channels to send data over the transport media via multiplexing (or packing in a container that is headed in a common direction). Meanwhile, switching is essential for flows to be shunted along in different directions depending on the destination at an intermediate node (akin to a traffic junction for cars).

As seen in Figure 2, the techniques of matching, multiplexing and switching are key tenets of good design, and planners rely on available technologies of their transport solution to arrive at the optimal network state for their business. The choice of solution could limit the extent of achievable optimization, and sometimes the transport solutions are poorly engineered, not having the right mix of performance and features to achieve an architectural balance.

![Figure 2: Network Techniques](image-url)
Figure 3 shows the impact of a mismatch in client-service data rates versus the line-side long haul wavelengths that carry them. In this case the only option to support sub-wavelength client data rates is to use a multiplexing transponder (muxponder). This is, of course, a trivial example, but it shows the possibility for massive inefficiencies in a network architecture comprised of only routers and pure optical wavelength-level switching and muxponders.

The vast majority of services in core networks today are made up of sub-wavelength services – often 1GbE and 10GbE that are now being carried over 100G long haul wavelengths. Of course we are seeing an increasing number of high capacity 40GbE (also sub-wavelength), and 100GbE services. But at the same time long haul “wavelengths” are moving toward flexible grid super-channels that are not intended to be optically de-multiplexed, i.e., the entire super-channel is effectively treated as a single unit of capacity. In other words, even 100GbE is a “sub-wavelength” service.

To make matters worse, even if an efficient traffic matrix could be established when the network is turned up, typical core networks experience approximately 25% annual churn (Source: an Infinera analysis of actual customer databases over time to identify trends/rates of circuit addition and deletion). In a muxponder approach it is impossible to reroute or groom a sub-wavelength service without sending an engineer to unplug cables, and without causing a significant service outage.

By integrating Layer 1 OTN switching with Layer 0 WDM, service providers benefit from an elegant and robust solution to all these problems. OTN switching is capable of processing traffic flows at a highly granular level. The emergence of ODUflex (with 1.25Gb/ps granularity) allows IP/Ethernet client services (which are sub-wavelength) to be matched efficiently to digital traffic containers, which can then be multiplexed and switched. These digital OTN traffic containers are transported at Layer 0 using WDM super-channels. Also, OTN contains powerful provisioning protocols, excellent performance monitoring tools, highly efficient protection mechanisms, and precise mechanisms for fault location. When churn occurs it’s possible to provide a seamless rerouting of capacity without requiring either truck rolls or cumbersome physical/cabling procedures.
The use of a functionally heavy packet MPLS core for all transit traffic (with direct optical connections bypassing digital functionality) incurs significant penalties in terms of operations, resiliency and need for expertise, ultimately resulting in higher costs. Digital OTN switching mitigates these penalties and provides the additional benefit of enhanced revenues when it is enabled with Ethernet/MPLS packet intelligence.

**Enhancing Core Transport with Simplified Packet**

The transport core should allow matching, multiplexing and switching with a thoughtful mix of the multi-layer technologies of optical, digital and packet. Until around a decade ago core transport platforms offered only optical multiplexing, which created nailed-up circuits with time-division multiplexing. Advancements in photonics and electronics then enabled operators to add optical switching and digital layer functionality with matching, multiplexing and switching. The leading platforms offered terabits of capacity in the digital OTN layer. Today these platforms are capable of WDM scalability using super-channels with uncompromised performance in digital OTN switching. **Super-channels** combine multiple, coherent carriers in a single line card and are brought into service in a single operational cycle. Super-channels are seen as a seamless, aggregate unit of capacity by the DWDM line system, and the upper layer of OTN switching views this capacity as a pool of bandwidth resource. In addition, the platforms add sophisticated control plane functionality with GMPLS for automated network-wide operations and protection. For the latter, **Shared Mesh Protection (SMP)** emerged as a viable technology for meshed transport networks to recover from multiple local and network-wide failures. It also lowered costs by avoiding the need to dedicate backup bandwidth for every active circuit. Leading platforms use a purpose-built hardware acceleration chip for SMP, guaranteeing a sub 50ms recovery end-to-end across the network, even in the face of multiple failures. SMP combines the best attributes of disparate network protection techniques in the optical, digital and even packet layers. Additionally transport platforms are opening up their data-path/forwarding capabilities for control in the Cloud based on SDN. All these features ultimately led the transport solution to become more intelligent and capable, a far cry from the days of just optical multiplexing.

The next stage of transport evolution is to enhance these core platforms with simplified packet layer functionality. This is possible by making the digital OTN layer aware of and able to process packet client traffic flows directly. Ethernet is the client interface or port of choice for all providers today.

Within this interface, traffic flows can be identified using VLANs or MPLS Label Switched Paths (LSPs). These traffic flows are statistically multiplexed, the underlying characteristic of packet networks. The flows vary by duration, size, time of day, bursty or deterministic nature and more.
This is more pronounced closer to the end-user in an operator network and begins to smooth out toward the core. VLANs and LSPs pack traffic with similar characteristics in aggregate flows toward the core while retaining the benefits of statistical multiplexing. In the new Intelligent Transport architecture as shown in Figure 4, the core optical transport platform adds simplified packet functionality to its existing optical and digital capabilities. As a result, this architecture can handle the traffic flows individually with VLANs or LSPs, deeper than the interface/port level, and with service differentiation being achieved using QoS techniques of priority queuing and scheduling.

As depicted in Figure 5, the core optical transport platform can look inside the Ethernet port for individual traffic flows and then match them to the highly granular OTN layer services. ODUflex provides 1.25Gb/s granularity, sufficient to match the aggregated traffic flows toward the core. Thus the Intelligent Transport platform with packet capability can consolidate all the traffic flows onto a single Ethernet port that is VLAN and MPLS-TP LSP enabled.
This new simplified packet for transport offers the following new levels of network efficiency:

- Packet aggregation over OTN circuits: Traffic from several lower speed interfaces is forwarded over an ODUflex circuit, which provides oversubscription gains by statistical multiplexing. This use-case replaces aggregation routers/switches, potentially realizing CapEx savings.

- Fractional Ethernet: This enables more efficient point-to-point connections using ODUflex.

- Port consolidation: This consolidates transport ports to the central router as shown in Figure 5, reducing the number of interconnects and devices.

Additionally, this packet-enabled OTN core platform can now have direct interface to customers who require high-capacity Carrier Ethernet business services with packet QoS and SLAs. All this functionality can be controlled using the traditional approach of NMS or SDN. Now planners have the requisite design tools across packet, digital and optical layers in a single, converged platform to achieve the most efficient transport network possible.

**Augmenting Revenues with High-Capacity Packet Services**

As the packet capabilities of the transport network evolve, significant new revenue opportunities arise for network operators via converged Ethernet services. By hosting these in an OTN-based transport platform the service provider retains all the advantages of a carrier-grade system with highly resilient features. Network operators can provide high-capacity business Ethernet services directly from these platforms. The services vary by application, ranging from private-line connectivity to multi-point links for video distribution. The MEF (Metro Ethernet Forum) has standardized these services in a Carrier Ethernet 2.0 portfolio, and end-user adoption is growing rapidly. It is forecasted that **high-capacity MEF services will grow at a CAGR of 32% through 2018**. This translates to the growing use of converged Packet-Optical Transport Systems (P-OTS) to deliver these services; 84% of operators plan to deploy P-OTS by 2017, tripling the number of systems in use today.
The traditional approach to designing a network for this opportunity is to use multiple layers of switch/routing devices that aggregate end-user services and then connect them to the WDM transport layer. The hub location requires multiple ports between the central router and the transport node as depicted in Figure 6.

The new approach of simplified packet transport provides Ethernet aggregation with the attendant QoS features directly from the transport platform. This packet optical transport solution offers high bandwidth MEF CE 2.0 certified services such as E-Line (EPL and EVPL). Furthermore, the solution offers a rich set of advanced CE 2.0 compliant services directly from the P-OTS – E-LAN, E-Tree, and E-Access.

While CE 1.0 focused on service delivery within a single provider’s domain and did not attempt to standardize interconnection between providers, it did provide consistent service delivery to all regional and branch offices via local or regional service providers implementing standardized CE network connections. The result was a ubiquitous global service that simplified enterprise application delivery, reduced development cost and greatly sped availability to new locations.

For the enterprise and business user, CE 2.0 interconnect makes it look like a single service-engineered network, avoiding costly, complex delivery and support problems. It adds clear demarcation points for user-network (UNI) and network-network (NNI) with new management features. In short **CE 2.0 brings the benefits of application differentiation** and distance-oriented performance objectives to the next generation of SLAs.

*Figure 6: Network Architecture for MEF Services*
For large enterprises, CE 2.0 provides sophisticated application-oriented performance attributes delivered over multiple Ethernet virtual connections, each with multiple classes of services. Some popular applications include Internet access, enterprise-class Cloud-based applications, distributed imaging/storage networks, VoIP, video distribution, and wholesale interconnect. The CE 2.0 portfolio is a matrix of four port-based and four VLAN-aware services. Figure 7 outlines the CE portfolio with relevant applications that can be fulfilled by the Ethernet/MPLS Packet-enabled OTN architecture.

<table>
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<tr>
<th>Private Service Port-based</th>
<th>Virtual Service VLAN-based</th>
<th>Typical Applications</th>
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<td>All to One Bundling</td>
<td>Service Multiplexing</td>
<td>Internet Access, Backhaul</td>
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- E-Line (Point-to-Point EVC) UNI-UNI SPs to Users
- EPL (Eth Pvt. Line)
- EVPL (Eth Virtual Pvt. Line)

- E-LAN (Multipoint-to-Multipoint EVC) UNI-UNI SPs to Users
- EP-LAN (Eth Pvt. LAN)
- EVP-LAN (Eth Virtual Pvt. LAN)

- E-Tree (Rooted-Multipoint EVC) UNI-UNI SPs to Users
- EP-Tree (Eth Pvt. Tree)
- EVP-Tree (Eth Virtual Pvt. Tree)

- E-Access (Point-to-Point OVC) UNI-ENNI Operators to SPs
- Access EPL
- Access EVPL

**Summary**

The overall economic impact of this new software-driven world led by the Cloud is estimated to be up to $6.2 trillion by 2025 as per McKinsey’s 2013 report on disruptive technologies. Transport is fundamental to the Cloud as well as the Internet, and building an efficient packet-optical core network is vital to keep the bits flowing smoothly.

The old model of a hierarchical, functionally heavy, siloed packet and optical transport core is now being replaced by the new Intelligent Transport Network, which is built on three key principles,

- **Scalability**: DWDM super-channels, digital OTN and packet Ethernet/MPLS granularity
- **Optimized Convergence**: Simplified multi-layer packet-optical switching
- **Programmability**: Open software-defined APIs, hardware-accelerated resiliency

Figure 7: MEF Services
Simplified packet transport introduces the benefits of statistical multiplexing to the transport layer. It provides the right level of granularity to match packet services from clients with highly efficient and resilient transport circuits. It enables high capacity Ethernet (MEF) services to be provisioned directly from the transport layer, improving revenue streams. In addition, it allows operators to create a rich portfolio of packet and transport services: VLAN-, port- or circuit-based in point-to-point and multi-point configurations with carrier-grade QoS for a variety of enterprise and wholesale applications.

Network and Cloud operators can now build a highly flexible packet-optical transport infrastructure that is optimized for today’s software-driven world.

Appendix

Abbreviations, Terms, Icons

BRAS = Broadband Remote Access Service
CE = Carrier Ethernet
ENNI = External NNI
EVC = Ethernet Virtual Connection
IaaS = Infrastructure As a Service
LSP = Label Switched Path
MEF = Metro Ethernet Forum
MPLS = Multi-Protocol Label Switching
NNI = Network to Network Interconnect
ODU = Optical Data Unit
OTN = Optical Transport Network
OVC = Operator Virtual Connection
PaaS = Platform As A Service
SaaS = Software As A Service
SMP = Shared Mesh Protection
UNI = User to Network Interconnect
VLAN = Virtual Local Area Network
XaaS = Anything As A Service