Better Network Economics with IPoOTN

Using the Intelligent Transport Network™ to Maximize Scale and Increase Efficiency for the Terabit Era
FOREWORD

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Building large scale service provider networks is a complex task. There is no “one size fits all” network design; however, there is one key design principle that operators must consider when constructing the most economical network: “switch when you can, route when you must.” Routing versus switching is an old debate; however, given the cost of equipment and the power it consumes, service providers pay a lot of attention to this very issue—particularly since the growth of bandwidth is so strong.

Large-scale service provider network architectures are hierarchical, with equipment providing one of four key specialized functions: WDM transport, OTN switching, MPLS switching and IP routing. Network costs, measured by processing complexity and the power consumption for each unit of bandwidth delivered increases as you move up the stack. The cost for power, heat dissipation, and photonic switching on a cost per bit basis is much lower for WDM transport than for higher layers. For IP routing, for example, every single packet header is looked at and processed, which means more gates in the ASICs, more power, more heat, etc. There is a huge cost difference between routing a packet flow through a router and switching a wavelength at the optical level. OTN switching is also less complex and costly than IP routing. There is no policy processing required and bandwidth in time slots is simply mapped to optical channels. MPLS switching is more processing-intensive than OTN switching, but not as complicated as IP routing.

It was against this backdrop that Ovum evaluated Infinera’s network design model comparing IP over WDM (IPoWDM) and IP over OTN (IPoOTN) network designs. While the cost of every network is different depending on size, cost and operation of equipment, traffic type and mix and other variables, we found the two models representing a large North American long haul collector network and mid-sized European national backbone to be fair representations of real-world network designs. We also found Infinera’s three-tier service demand model provides a fair representation of traffic flows between nodes and that the company did not bias the outcome by using unrealistic network cost metrics.

Large scale, multi-layer network modeling is notoriously complex. Outcomes are dependent on carrier specifics and a multitude of variables. Infinera’s premise of using the deterministic nature of OTN and the technology’s low cost per processed bit economics to bypass IP transit over a routed network is an appealing alternative for scaling multi-service networks to meet growing demand.
Introduction

It’s a given that IP traffic is growing exponentially. All industry analysts and bodies agree on the tremendous surge of traffic – IEEE estimates a rate of more than 30% compounded annually. This is impacting the infrastructure that serves to transport it in different ways – the IEEE 802.3 Industry Connections report from 2012 outlined how the core network and server input/output links are reacting to this deluge.

From the figure, it is evident that core network scaling is forcing service providers to have a wide-ranging discussion about how to best optimize, evolve and converge packet-optical networks in order to reduce the total network cost.

![Figure 1: Core Network Traffic Growth](image)

Core networks aggregate traffic from the edges and are defined by their key function of switching and transmitting traffic between the source and destination using large bandwidth pipes. To do so, they utilize multiple layers of functionality, each having a distinct use:

- IP layer: **Interfaces** with applications which are all IP today, **converts** traffic into IP packets
- MPLS layer: Provides simplified **switching** of packet flows using labels
- OTN layer: **Maps** packets into OTN circuits, **switches** and **multiplexes** to maximize efficiency
- WDM layer: **Transmits** traffic across the media (wavelengths on the fiber)

As traffic increases on the network, each layer must grow to accommodate it. The techniques of multiplexing and switching serve to boost efficiencies without scaling unreasonably. At the same time, service providers seek to eliminate the cost and operational complexities of multiple platforms, each serving a specific function in a given layer. This is driving the industry toward converged platforms that combine multiple sets of functions into a single system, thereby providing cost savings and reducing space, power use and operational complexity. Finally, the design must also consider protecting against fiber cuts or node failures. A key trend in this regard is towards packet-optical convergence, and discussions abound on how to intelligently implement a Packet-Optical Transport Network (P-OTN).

Building an Intelligent Transport Network for the core with the right technology mix is vitally important, so that providers can scale and converge functional layers, ultimately taming costs and operations.
Core Network Architectures

Typically, today’s core networks utilize full-functionality routers supporting a wide range of IP services, peering, packet forwarding and MPLS switching including P/PE functions, connected in a “sparse” mesh across transponder/ROADM-based WDM networks. This is called “full core” because these routers require significant amounts of memory and functionality for high-touch packet services and thus they are high cost with little optimization for simpler network functions such as MPLS-only switching. Additionally, when IP “full” core networks are deployed this way in a sparse mesh, there is minimal router offload, meaning many packets may transit through several unnecessary intermediate router hops. Since each router hop means a packet consumes a portion of the optical interface to get into and out of the router, as well a portion of the packet forwarding capability going in and out, all for no value-added purpose, all such router transits incur unnecessary cost, while also increasing packet latency, and thus burden the IP layer with a “router tax.”

One option proposed to reduce the cost of the IP layer is to deploy lower-priced routers or packet-forwarding cards that support only MPLS switching, through which transit packets can be routed at a lower cost as compared to full-functionality IP services routers. This is termed as “thin” or “lean” core. Cheaper MPLS-only routers somewhat reduce network cost simply by reducing the price/functionality of routers, but this does not substantially change the router link connectivity and the associated “router tax” incurred for transit router hops. The above are complemented by an architecture approach termed IP over WDM (IPoWDM), which proposes to simply move the colored WDM interface from the WDM layer into the router platform. IPoWDM can be used with either IP routers or MPLS switches, and here we use IPoWDM to mean both. This architecture uses the same “sparse mesh” link connectivity described above, providing minimal router offload and incurring a “router tax” for every transit router hop. By itself, IPoWDM does not save costs as it simply shifts the cost of WDM optics from the transponder to the router, and in many cases may make managing router links more difficult as routers must now manage optical link impairments such as Optical Signal-to-Noise Ratio (OSNR), wavelength blocking, fault sectionalization, and more. Worse still, using IPoWDM at 100 Gb/s per wavelength means that all but the absolute highest packet flows are multiplexed along with others to maximally fill the 100 Gb/s IPoWDM router links, thereby further increasing the probability that a given packet must undergo transits at intermediate router nodes. Furthermore, because of the heat generated and space consumed by the discrete analog optics used in these scenarios, router slot capacity may be dramatically underutilized, e.g. a 1 x 100GbE WDM optic in a slot that is capable of 140G or even 400G.

A more radical approach called the “hollow” core proposes entirely eliminating the IP core network and directly meshing aggregation routers through a switched OTN core, enabling significant router offload and network cost savings. However, this could lead to complexity due to meshing hundreds or thousands of routers, as well as the limitations of typical routers to support the required adjacencies and routing tables. There have been some studies indicating that Software Defined Networking (SDN), which offloads the router control plane from low powered on-board processors to a much more powerful data center compute platform, may enable this and could be economically attractive, but it has yet to be proven.

Instead of the above, an alternative is to leverage the inherent capabilities of an Intelligent Transport Network to enable a much more efficient approach to packet-optical networking, termed IP over OTN (IPoOTN) to provide an economically compelling, efficient and operationally
scalable alternative. IPoOTN reduces network cost by right-sizing router links using a range of interface speeds (rather than all 100 Gb/s), which enables router offload (and thus reduces router transit and the associated “router tax”), lets routers use their full slot capacity to maximize router density, and improves operational flexibility through the use of a proven reconfigurable, resilient and converged OTN/WDM layer.

Modeling Core Networks

In this whitepaper we compare two architectures for packet-optical convergence. The first approach, IPoWDM, uses IP/MPLS routers with integrated 100 Gb/s colored WDM interfaces, connected to each other via switched wavelength connections in the WDM layer using Reconfigurable Optical Add/Drop Multiplexers (ROADMs). The second approach, IPoOTN, uses routers equipped with short-reach Ethernet interfaces at either 10 Gb/s, 40 Gb/s or 100 Gb/s, selected based on the required router link connectivity defined by end-to-end packet flows. These interfaces are connected to a converged OTN/WDM transport layer, which provides multiplexing, bandwidth management and transport using WDM interfaces converged with an OTN switching platform.

Topology Consideration

The two architectures of IPoWDM and IPoOTN were modeled on core IP networks representative of a typical large service provider in North America as well as a mid-sized European country.

For the **North American topology**, the IP core network had a total traffic volume of 12.6 Tb/s and was comprised of 82 “outer-core” PE/P routers, used “thin core” functionality, meshed over a smaller number of “super-core” P routers using simpler MPLS-only “lean-core” functionality and was connected by fiber links over a 32,130 kilometer fiber network, using either IPoWDM connected over ROADMs, or IPoOTN using converged WDM/OTN systems.
For the **European national topology**, the IP core network had a total traffic volume of 6.3 Tb/s and was comprised of 12 “outer-core” router nodes, meshed over a smaller number of “super-core” router nodes and connected by WDM links over a 4,818 kilometer fiber network. The European network model utilized the same router types in the outer and full cores, and compared the same IPoWDM and IPoOTN architectures as modeled in the American network example.

For both topologies, packet traffic flows were modeled for IP service demands that included city-to-city IP traffic, data center traffic, and international traffic, and assumed over-provisioning of router links consistent with typical industry practices. A hierarchical architecture was used for the IP/MPLS network topology, with outer-cores consisting of PE routers to peer to other IP networks and aggregate IP traffic from hundreds or thousands of aggregation routers (these provide services to enterprises, service providers, etc., as well as peering to other IP networks). Each outer-core router connects to two super-core routers via disjoint paths carrying 50% of the IP traffic, providing redundancy in case of router or link failure. This hierarchy thus limits router adjacencies between outer-core routers. The super-core nodes function as MPLS (Provider) P-routers that simply provide mid-point switching of MPLS packet flows and are connected to each other over two disjoint paths, each carrying 50% of total traffic. Both architectures were continually optimized for the number of super-core nodes to achieve the lowest cost possible for each. Both IPoWDM and IPoOTN architectures utilized 100G coherent WDM optics that have the same ultra-long-haul (ULH) reach.

### Design Parameters

The following design parameters for each network model are summarized below.

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<th>IPoWDM</th>
<th>IPoOTN</th>
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<td><strong>Super-core</strong></td>
<td>100G (OTU4) colored WDM interfaces connected to wavelength-switched ROADM. The 100G interface was allowed to fill up to 75% before additional router-router connections were added. The 100G WDM connections bypassed intermediate routers.</td>
<td>Connected to the converged WDM/OTN switch using short-reach Ethernet interface at 10/40/100G. The Ethernet links were mapped to ODUk payloads (ODU2e/3/4) in the OTN switch and multiplexed and connected via 100G WDM interfaces between the switches to maximize fiber capacity. This choice increased the number of possible direct connections compared with the IPoWDM architecture resulting in a more meshed super-core with increased bypass of routing hops. The maximum number of router adjacencies was limited to 32.</td>
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<td><strong>Outer-core</strong></td>
<td>Connected to the super-core using 10/40/100G based on traffic. The 10/40G used short-reach Ethernet optics multiplexed onto 100G WDM muxponders to maximize fiber capacity, while the 100G used integrated WDM interfaces on the router.</td>
<td>Connected to the converged WDM/OTN switch using short-reach Ethernet interface at 10/40/100G. The Ethernet links were mapped to ODUk payloads (ODU2e/3/4) in the OTN switch and multiplexed and connected via 100G WDM interfaces between the switches to maximize fiber capacity.</td>
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Modeling Results

The results of the modeling are illustrated in the below figures. Both networks exhibited total network cost savings of around 30% when using IPoOTN as compared to IPoWDM architecture.

![Graph showing network economics for North American Topology](image)

**Figure 5**: Large-sized Core Network

![Graph showing network economics for European National Topology](image)

**Figure 6**: Medium-sized Core Network

The model calculated total network costs, which included both the IP and optical layers and then normalized them for comparison. The OTN/WDM costs in the IPoWDM option included regenerators required to extend WDM links, and the costs in the IPoOTN architecture included the converged OTN/WDM switch nodes. The IPoOTN architecture significantly reduced the cost of both the outer and super-core IP networks by enabling more router bypass using cost-optimal 10/40G direct router-router links, thereby increasing the number of direct router-to-router links (i.e. meshing), and enabled off-loading of unnecessary optical interfaces and packet-forwarding cards at intermediate router nodes. This significantly reduced the “router tax” for packets going through intermediate router hops. These savings were compounded by the use of much lower cost Ethernet interfaces on the routers in the IPoOTN architecture, instead of the WDM interfaces in the IPoWDM architecture. The greater density of Ethernet interfaces per router line-card over IPoWDM interfaces also enabled more router links to be supported for a given number of slots and packet forwarding cards, thus further optimizing the costs of the router layer using the IPoOTN architecture.

Finally, router slot capacity has always historically lagged transport slot capacity. IPoWDM cards support fewer ports per slot than if they were equipped with grey-optic Ethernet ports. This introduces significant penalties when analyzed from the perspective of an overall network cost, and not just a platform level view. In contrast, IPoOTN maximizes the use of router slot as well as transport slot capacities.
Conclusion: The Practical Benefits of IPoOTN for an Intelligent Transport Network

The economic analysis of core transport network architectures shows savings of approximately 30% when using IPoOTN as compared to IPoWDM. These results were similar for two diverse topologies (large-sized North American network and medium-sized European national network). The IPoOTN architecture enables service providers to get the best efficiencies out of ALL layers in the core network today and in the future as:

- The routers are interconnected with the “right-size” interface at 10/40/100G, which makes the IP layer most cost-effective;

- Converged packet-optical network uses Ethernet and WDM interfaces having lower cost/bit compared to IP/router interfaces.

- IP links are multiplexed by the OTN layer into 100G per wavelength, or into 500G super-channels, maximizing the network’s WDM capacity;

- IP transit traffic is kept at the OTN layer to reduce router capacity needs, and by reducing traffic makes right sized 10/40/100G links even more powerful; and

- It allows both the DWDM/OTN platform and the router platform to maximize slot capacity utilization, extracting all of the value per bit possible from each layer vs. underutilization of both layers with IPoWDM.

Building an Intelligent Transport Network for the core with the IPoOTN architecture allows providers to scale and converge functional layers with the utmost efficiency. It helps them tame network costs and operations while they can focus on serving their customers in the best possible manner.