Independent market research and competitive analysis of next-generation business and technology solutions for service providers and vendors

Driving IP & Optical Benefits With Multi-Layer Integration

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INTRODUCTION

The road to IP and optical integration has been a long one. Demonstrations and product announcements over the decades never translated to commercial deployments for several reasons, including a lack of flexibility at the photonic layer, a lack of viable standards for interoperability, capacity tradeoffs in adding transponders to IP routers, and a lack of demonstrable business case.

However, a new era is now emerging, defined not by physical layer integration of the past but by software-driven integration of IP and optical layer control and management planes, enabled by software-defined networking (SDN). This white paper provides an overview of IP and optical integration with a focus on the benefits and trajectory of multi-layer, multi-vendor interoperability enabled by SDN. In this paper, we define the operator benefits of multi-layer, multi-vendor integration, outline the technology enablers and work yet to be done, and identify the likely next steps in the software-driven IP and optical evolution.

IP & OPTICAL INTEGRATION HISTORY

IP and optical integration has a long history going back to the late 90s, and going by various names over the years, including IP over DWDM (IPODWDM), IP+optical and IP over glass.

The IP over glass concept described connecting IP router hardware directly to DWDM hardware with no intermediate layers between – particularly Sonet/SDH or ATM layers. The promised benefit was to save capex by eliminating Sonet/SDH and ATM equipment in the network. But there was little flexibility in data rates (only wavelength level) and no topology flexibility (only point-to-point connections between DWDM systems and IP routers), and so IP over glass remained confined to lab testing and technical demonstrations.

Popularized by leading routing vendors Cisco and Juniper, physical IP and optical integration involved taking long reach optics and inserting them directly onto IP routers, eliminating the need for the short-reach optics connections that connect routers to DWDM systems and, thus, savings transponder capex.

Eliminating back-to-back transponders is a solid operator benefit, but this architecture came with significant tradeoffs as well. A big drawback was vendor lock-in, as operators were required to buy DWDM and routers from the routers supplier – reducing vendor diversity in the network.

In addition, there was a technical tradeoff in placing long reach optics directly on the router. Long reach optics are typically larger than short-reach client optics, particularly at leading-edge data rates – with long reach optics often 2x as large as the equivalent client rate. Thus, outfitting a router with long reach optics would effectively strand 50% of router capacity, cutting the router capacity in half. For many operators, the capex hit on the router capacity eliminated any of the benefits to be gained from transponder reduction.

IP+optical can be an ambiguous term (sometimes denoting physical integration as described above), but it typically refers to interworking between IP and optical layers, without the use of physical integration. Like the other concepts described above, IP+optical interworking has also been around for decades. The OIF took the lead in demonstrating multi-vendor and
multi-layer interoperability, beginning with a 25-vendor interoperability demonstration highlighted at the Supercomm 2001 tradeshow. Other demonstrations occurred over the years, with the IETF's GMPLS used as the unified control plane for interoperability.

However, operators found that GMPLS was extremely complex to implement and left too many holes for proprietary hooks from individual vendors. While brute force could produce a technical demonstration (as with the OIF), operators, in practice, never implemented GMPLS as a multi-layer, multi-vendor control plane due to its complexity. (Note that GMPLS has been widely deployed globally as a single vendor/single domain control plane, but these deployments fall far short of the original intent.)

FUTURE OF IP & OPTICAL PHYSICAL INTEGRATION

As noted above, physical integration of DWDM optics on IP routers has existed for many years in niche applications but never took off into mainstream adoption. Currently, there is a resurgence in physical integration of optics in routers, particularly for metro data center interconnect (DCI) applications where there appears to be some fit.

In March 2016 at the OFC conference in Anaheim, Inphi announced that, in partnership with Microsoft, it had developed a 100 Gbit/s DWDM module that plugs into data center switches and is good for intermediate DCI transmission distances in the range of 10 to 80 km. A strong champion of this physically-integrated approach, Microsoft executives explained that it closely steered the development of the module through an RFP process that started in 2013.

The integration stands out on a couple of fronts:

- By limiting the distance specs to sub-100 km, Inphi was able to eliminate coherent detection (and associated bulk) and fit the required components into the standardized QSFP28 form factor, using direct detect PAM4 modulation. For Microsoft, the reduced distance was more than sufficient for its metro DCI applications because, executives said, 40 km is the sweet spot for transmission distances, based on their topology.
- Unlike past IPoDWDM, the 100G module is developed by a component vendor and not tied to a single switching/routing vendor. In this case, compatibility with Arista Networks and Cisco was announced on Day 1. But other switch/router suppliers that meet spec requirements can integrate Inphi’s ColorZ as well.

Drawbacks of Physical Integration

The Inphi/Microsoft integration gave new life to the IPoDWDM concept that had been relegated to niche status for so long. Using the QSFP28 form factor (at 18x52x8.5mm) eliminated the faceplate tradeoff of past attempts at physically integrating long reach optics on routers.

But the engineering breakthrough comes at a cost in terms of distance. Even with Inphi’s advances, the ColorZ module is limited to 80km metro access, whereas coherent detect modulation formats can transmit many hundreds of km to many thousands of km, depending on which format is used.

In addition to distance limitations, direct detect 100G transmission poses greater planning and complexity challenges for service providers compared to coherent detection. PAM4, like
other direct detect modulation formats, requires dispersion compensating fiber to mitigate broad chromatic dispersion that occurs at high data rates. Dispersion compensating fibers add some capital costs to the network, but also add operational costs and complexity in tuning the compensators.

Further planning complexity results from the distance limitations and point-to-point nature of these physically integrated systems. Planners must know to a very high degree of accuracy the future capacity and topology demands of these networks. They are not switched connections and, in making changes to topologies, planners may find that distance specs are exceeded.

**Benefits of Disaggregation**

Above, we described the main drawbacks of physically integrated IP and optical layers in a single system. Below, we highlight some of the main benefits of keeping layers physically separate.

**Specialization:** Integrated telecommunications systems (regardless of the technologies) have always faced a tradeoff of functionality for convenience, and IP and optical integration is no exception. Routers with the highest density/performance will always be standalone and, as discussed above, the highest performance optics (distance, modulation format, capacity) will be on purpose-built DWDM systems.

**Choice:** Optical innovation and electronic processing innovation run on different timelines and schedules, with different drivers, limitations, processes and ecosystems. Keeping the IP and optical layers physically separate yields maximum choice to take advantage of innovations at each layer when they occur and with the maximum number of vendors from which to choose.

Google is one example of a Webscale that has publicly stated its intent to keep its IP and optical layers physically separate moving forward, despite Microsoft’s lead in this area. But perhaps the best example of disaggregation today is AT&T, which has been very vocal about breaking multiple types of network elements into basic functions and spreading those functions across multiple servers and even geographies. AT&T’s functional disaggregation provides a strong counter trend to the physical integration that defined packet-optical transport over the last decade.

Separate, but related, AT&T’s Open ROADM multi-source agreement (MSA) is an example of taking advantage of optical specialization while advancing greater choice through interoperability. Significantly, Open ROADM confines itself to interoperability across optical layer functions only.

**FUTURE OF IP & OPTICAL MULTI-LAYER INTERWORKING**

Although operator interest in physical integration of IP and optical layers is increasing, as described in the previous section, the greater operator interest – by far, based on Heavy Reading research – is control and management of the IP and optical layers, or IP and optical interworking. In this type of architecture, IP and optical equipment remains physically separate but with interoperability across the control and management planes. Ideally, operators
are free to choose different vendors for IP and optical layers but still achieve multi-layer interworking due to standardized interfaces.

The primary technology enabler for multi-layer and multi-vendor interworking is SDN, which yields the following benefits:

- Software programmability
- Multi-element (or global) network view
- Application-centric capabilities
- Network-layer abstraction (control/applications/network)
- Software openness

In a Heavy Reading global network operator survey published in June 2016, we asked operators to identify the most important potential business benefit they expect to achieve by using SDN. The results from this question were clear: the ability to create and deploy services more rapidly is the biggest business benefit operators expect from SDN, followed by reductions in opex and then by capex reductions (see Figure 1).

**Figure 1: Most Important Potential Business Benefit of SDN**

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to create and deploy services more rapidly (differentiation/new revenue)</td>
<td>43%</td>
</tr>
<tr>
<td>Reduction in cost of operations related to configuration and maintenance errors (lower opex)</td>
<td>22%</td>
</tr>
<tr>
<td>Reduction in cost of equipment due to disaggregation (lower capex)</td>
<td>16%</td>
</tr>
<tr>
<td>Ability to compete more effectively with ICPs and other OTT content providers (differentiation)</td>
<td>11%</td>
</tr>
<tr>
<td>Decreased cost of delivering services (differentiation/new revenue)</td>
<td>7%</td>
</tr>
<tr>
<td>Other</td>
<td>1%</td>
</tr>
</tbody>
</table>

*Source: Carrier SDN: Service Provider Perspectives, Transition Strategies & Use Cases 2016: A Heavy Reading Multi-Client Study, June 2016*

For operators, the goal of SDN is clear. Significantly, the connection between SDN and IP and optical integration is also clear to operators. For example, in past Heavy Reading surveys, operators have placed a low priority on the application of SDN for the optical layers alone (generally at the bottom of the priority list). However, when we asked operators...
about the application of SDN for multi-layer transport (i.e., combining IP and optical layers via SDN), this option rises near the top of their priorities list.

In the 2016 Heavy Reading network operator survey, we asked operators to identify specifically the benefits they expect to achieve in using SDN for IP and optical layer integration. The results from the survey question are shown in Figure 2.

**Figure 2: Main Benefits of SDN-Based IP & Optical Integration**

- Combining IP & optical network views & control to ensure the best paths are computed to maximize network utilization: 59%
- Combining IP & optical network views & control to ensure the best paths are computed when turning up multi-layer service instance: 53%
- One-shot provisioning – remove the operational complexity & manual processes of provisioning a service that encompasses both IP & optical layers: 48%
- Combining IP & optical network views & control to achieve optimized resilience/recovery: 36%
- We have no plans to use SDN for IP & optical integration: 10%

*N=86
Source: Carrier SDN: Service Provider Perspectives, Transition Strategies & Use Cases 2016: A Heavy Reading Multi-Client Study, June 2016*

According to our survey, operators are most interested in three primary benefits:

- Improving network utilization (59%)
- Turning up multi-layer services (53%)
- Automating provisioning across layers (48%)

Significantly, the desired benefits cut across all of operators' macro network transformation goals from capex reduction (improving network utilization) to opex reduction (automating provisioning across layers) to revenue generation (turning up multi-layer services).

Also significantly, the new focus on multi-vendor, multi-layer interworking resolves some of the biggest challenges posed by physical integration approaches, specifically the faceplate tradeoff caused by placing long reach optics directly on routers and vendor lock-in caused by requiring hardware and software from a single supplier.

**Figure 3** provides a snapshot of the primary historical barriers to IP and optical integration and how these barriers are addressed with multi-layer IP and optical integration with SDN.
### Figure 3: Historical Barriers & New Solutions to IP & Optical Integration

<table>
<thead>
<tr>
<th>Historical Barrier</th>
<th>Description of Barrier</th>
<th>New Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk of vendor lock-in</td>
<td>Physical integration of DWDM optics into an IP router required a single vendor. Lack of viable standards meant management and control integration was also proprietary across layers.</td>
<td>New focus is on multi-layer inter-working, not physical integration. New standards are addressing multi-vendor control and management specifically to ensure multi-vendor implementations.</td>
</tr>
<tr>
<td>Faceplate/capacity tradeoffs</td>
<td>Long-reach DWDM optics are larger than short-reach client optics. Physically outfitting an IP router with DWDM optics typically means cutting the IP routing capacity in half. Historically, most operators have been unwilling to make this routing capacity tradeoff in order to save capex by eliminating back-to-back transponders.</td>
<td>New focus is primarily on multi-layer interworking, not on physical integration, thus avoiding the faceplate/capacity tradeoff issue altogether.</td>
</tr>
<tr>
<td>Lack of a flexible photonic layer</td>
<td>GMPLS-based software control allowed automation of the IP layer but not the photonic layer. Early generation ROADM lacked the hardware flexibility needed to truly automate Layer 0. Hardwired constraints greatly diminished the value proposition for integrating these layers.</td>
<td>Commercialization of colorless and directionless (CD) ROADM was the first step toward true photonic layer flexibility and automation (sometimes also including contentionless, or CDC, as well). Development and standardization of software control (via SDN) was the second key enabler.</td>
</tr>
<tr>
<td>Lack of demonstrable business case</td>
<td>All the above combined to yield little business benefits for operators to pursue IP+optical integration. Seeing few benefits, operators did not push their vendors to innovate.</td>
<td>With all of the above in place, a much stronger value proposition emerges. Operators are strongly pushing suppliers to combine IP and optical in open way.</td>
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</table>

*Source: Heavy Reading, 2016*

### Hardware Advances: The Flexible Photonic Layer

We noted the role that software plays in the next generation of IP and optical integration, but there was also some key hardware innovation and commercialization that was required to propel IP and optical integration forward – even with the advances of SDN. Specifically needed was the commercialization of a flexible photonic layer thanks to new colorless and directionless (CD) ROADM hardware. Early-generation ROADMs allowed for switchable and automated intermediate points along an optical route, but still required manual provisioning to configure the endpoints. This need for manual configuration drastically reduced the flexibility of the photonic layer compared to Layer 2 and above.

Today, however, CD ROADMs allow for the automation of not just midpoints, but also the endpoints in ROADM networks, eliminating the need for manual provisioning along the path. This full automation of the photonic layer and is a key architectural requirement for operators looking to achieve multi-layer network optimization and provisioning.

Some operators add contentionless hardware functionality (or CDC) for additional ROADM flexibility but contentionless also comes with additional complexity and cost. Most operators achieve sufficient photonic layer reconfigurability with CD ROADM architectures.
Operator Examples of IP & Optical Integration

It is early days in SDN-enabled IP and optical integration, but leading-edge operators are building their use cases and business cases. Here, we cite two Tier 1 innovators.

Verizon: Verizon is interested in IP+optical integration for DCI by programming the switching/routing layer to work with the optical layer. With IP+optical integration, cost reductions would be achieved by keeping traffic in the optical layer when possible and come up to the routing layer only when needed. The reasons for introducing IP+optical integration in DCI are twofold:

- There are clear benefits in greater network efficiency (cost savings) by adding SDN programmability. While parameters can be set up more manually with existing technology, SDN makes this cheaper and more dynamic.
- Because DCI networks are simpler than customer-facing network in terms of topology and connections, introducing SDN technologies in DCI first is a good starting point to learn about benefits and limitations. Verizon’s plan is to introduce IP+optical into customer facing networks (such as access) over time.

Telefónica: The operator’s first SDN use case is at the IP layer only, but Telefónica wants to support SDN orchestration beyond the IP layer. Specifically, Telefónica is targeting the metro network to use SDN control for metro DWDM wavelengths. This expansion of SDN into metro networks with WDM is the operator’s main target for SDN commercialization for 2017. The main business outcome for this use case is opex and capex savings. Telefónica can do more efficient planning and traffic engineering, so the motivation for multi-domain IP is achieving an efficient network deployment.

INDUSTRY NEXT STEPS

Despite much opportunity in the new era of SDN-based IP and optical integration and some great progress during the past two years, there is still work to be done to make multi-layer, multi-vendor IP and optical integration a wide-scale commercial reality. The biggest challenge lies in standardization, which is required in order to achieve control plane interoperability across vendors. While some operators will choose single vendor implementations for speed of deployment and simplicity, the majority (and particularly Tier 1 and large Tier 2 operators) will require a path to multi-vendor interoperability to avoid the vendor lock-in issue that inhibited past physical integration approaches.

Of particular focus for standardization is the northbound interface (NBI), which connects vendor SDN controllers to the orchestration layer above that coordinates between different layers, vendors and domains. In the absence of a standardized NBI, operators have only two options, neither of which is desirable:

- Operator separate SDN islands that don’t communicate with one another
- Build out their own proprietary interfaces to tie vendors and domains together, with all the associated added operational expenses and time commitments

There is no industry-standardized NBI at this time, but efforts are underway from traditional standards development organizations and newer open-source communities to achieve one. Examples include the ONF NBI WG, IETF NETCONF WG, the OIF, OpenDaylight and ONOS.
One recent advancement is the collaboration between the ONF and the OIF in standardizing, validating and testing the new Transport API (TAPI) NBI specifications, which were approved by the ONF in the second half of 2016. Based on the approved specifications, the ONF and OIF conducted a global interoperability test and demonstration, addressing multi-layer and multi-domain networks in global carrier labs across Asia (China Telecom, China Unicom, SK Telecom), Europe (Telefónica) and North America (Verizon); 11 vendors also participated in the demonstration. Lessons from this test are now being fed back into ONF specification development, as well as shared across the industry, including other standards development groups.

While recent work is promising, industry participants must come to a consensus on the best protocols and framework for moving forward in order to avoid fragmentation. The sooner consensus can be achieved, the sooner wide-scale adoption will occur.

In addition to NBI standardization, the next step forward will be expansion of IP and optical integration into different segments of the network. Early operator focus has been on building the business case for IP and optical integration in core networks. Work has been promising in the core, but the core is not the only segment that can benefit from multi-layer integration and SDN – nor is it the most important. Core network nodes are measured in the tens, but metro nodes at large operators are in the hundreds. Access nodes are measured by the thousands or even tens of thousands. Operators see the greatest value in applying automation in their metro and access networks because the numbers are so much larger.

Additionally, as networks move closer to the customer – from core to metro to access – they become closer to revenue-producing services. Heavy Reading research shows that SDN cases that are tied to revenue are being prioritized (by senior management) over those that are cost-savings based (either opex or capex). This trend provides another incentive to bring IP and optical integration into metro networks. And, although network complexity increases, we will see IP and optical pushing further in this direction.

CONCLUSIONS

The road to IP and optical integration has spanned several decades, but recent developments are ushering in a new software-driven era of IP and optical integration. Rather than focused on the physical integration of the past, the new IP and optical era is largely defined physical separation of IP and optical elements (or disaggregation) with a tight coupling of control and management, enabled by advances in SDN. The new, disaggregated vision for IP and optical integration avoids the primary challenges of previous physically integrated architectures, and, more important, delivers business benefits to operators including:

- Multi-layer network optimization that allows operators to get more efficiency from existing networks and reduce capex
- Automated provisioning across layers to speed capacity delivery, reduce errors and lower overall opex
- Ability to turn up multi-layer services for new revenue and services differentiation

With hardware and software components falling into place, the time for IP+optical integration has come, and the benefits will be big value for operators that invest in multi-layer and multi-vendor integration.