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Understanding the SDN-Driven IP & Optical Renaissance

*A Heavy Reading white paper produced for
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NOKIA



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INTRODUCTION

IP and optical integration as a concept has a long history, based on the promise to boost network efficiency, reduce network capex and opex, and greatly simplify operating and managing networks. But years of product announcements and industry demonstrations did not materialize in major commercial deployments, until now.

Today, we are seeing a resurgence in IP+optical integration – particularly at the control and management layers – driven by evolving service requirements and enabled by significant advances in optical hardware and in control and management software, including the introduction of software-defined networking (SDN). This white paper provides a detailed look at the new SDN-based IP and optical integration renaissance, including the market drivers, technology enablers, primary applications and use cases, leading operator success stories, and work yet to be done.

STATE OF THE INDUSTRY

It is well known that traffic on operator networks has been growing at high double-digit rates, while operator revenue derived from that traffic is growing at single-digit rates (and often low single-digit rates). Service providers have been grappling with this dilemma for more than a decade, but there is a growing chorus among providers that the current path of just adding more capacity is unsustainable, and that revolutionary changes to the present mode of operation are required in order to grow profitably.

The migration to cloud applications and services delivery has intensified the dilemma, as adapting to the cloud forces network scaling along two dimensions:

- **Capacity scale:** We are seeing a large migration in transport networks from 10 Gbit/s rates to 100 Gbit/s, and now also 200 Gbit/s (using advanced modulation formats and flex grid). The primary driver for this is connecting data centers to other data centers, or data center interconnection (DCI), driven by cloud applications. At the same time, client interfaces for private lines are rapidly growing from 1 Gbit/s to 10/100 Gbit/s.
- **Network and service agility:** The cloud model is based on sharing storage and computing resources across geographies with automation and on demand. In order for these resources to be shared efficiently, however, the underlying communications network has to be both dynamic and flexible – a dramatic change from the static-pipes communications model of the past. Rapid reconfigurability and automation need to be brought into the communications network itself.

The communications industry is turning to software-driven architectures in order to meet the twin challenges of rapid and low-cost scale and network and service agility.

SDN & IP & OPTICAL INTEGRATION

IP and optical integration has a long history, going back to the late 1990s and going by various names over the years, including IP over DWDM, IP+optical, and IP over glass. Although vendors sometimes make distinctions among the terms, they are also often used interchangeably. In essence, there are two main architectures for IP and optical integration:

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- **Physical integration:** Long-reach DWDM (or colored) optics are placed directly into the router in place of short-reach client optics. This architecture eliminates the back-to-back transponders otherwise needed to connect the router to a DWDM system – saving capex. This architecture is mostly applicable to 10 Gbit/s and 100 Gbit/s point-to-point links.
 - **Control/management integration:** Routers and DWDM systems are physically separate network elements, but management and control are integrated via software. Historically, this meant integration under a centralized NMS, with routing and optical transport typically managed in separate, vendor-specific silos. The current trend is software integration via SDN to better exploit IP/optical network benefits, including multi-layer path setup, protection and dynamic restoration capabilities supported by the MPLS and GMPLS control planes.

Both architectures are relevant for different applications, but physical integration strategies are more situational and tactical in their application. Moreover, they are unable to support the multi-layer IP/optical protection schemes that are producing some of the most significant expense reductions when combined with SDN as the common control layer.

Defining SDN in the IP & Optical Context

Heavy Reading defines SDN as having the following attributes:

- Software programmability and automation
- Global (centralized) network view
- Application-centric capabilities
- Network-layer abstraction (control/applications/network)
- Software openness (multi-vendor integration)

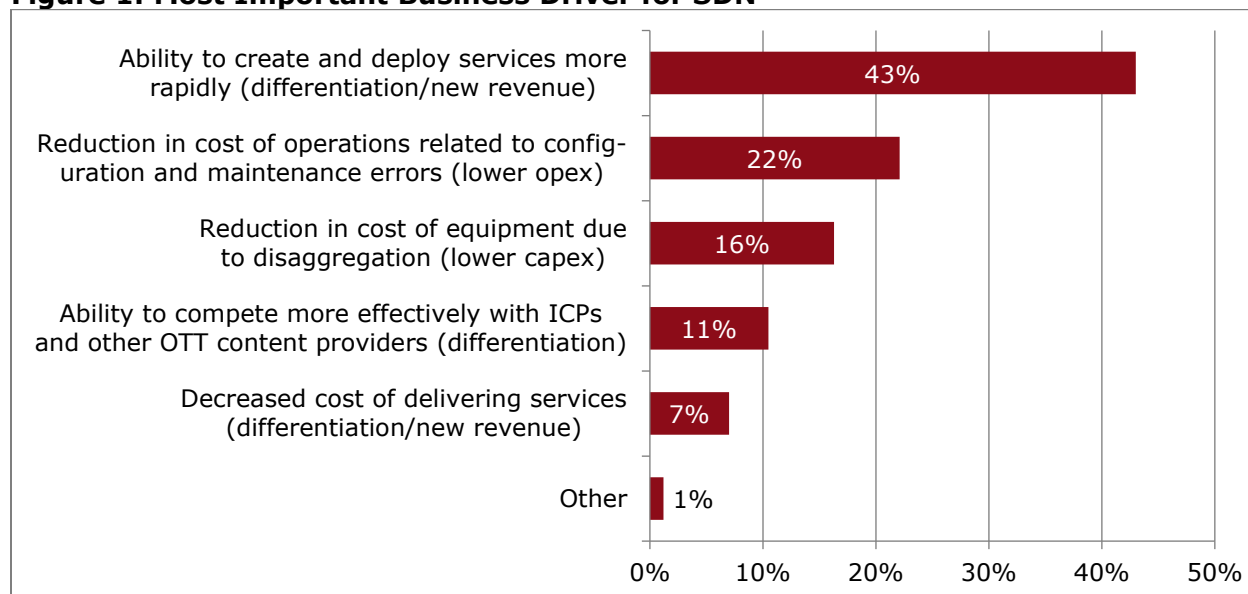
These attributes distinguish SDN from the NMS/EMS layer management of past network architectures and enable particular benefits when used to provision and control IP and optical layers. In contrast to SDN, NMS/EMS layer management was characterized by: 1) Manual services provisioning and off-line updating; 2) Separate IP and optical control planes; 3) Lack of abstraction, leading to closed systems and complexity in making updates; and 4) Proprietary vendor implementations leading to single-vendor networks and high reliance on suppliers for changes and upgrades.

We detail the primary benefits of SDN-based IP and optical integration in the next section.

BENEFITS OF SDN-BASED IP & OPTICAL LAYER INTEGRATION/INTERWORKING

While early operator interest was primarily centered around cost reduction, goals have shifted over the past few years, and the latest Heavy Reading operator surveys identify rapid scaling and network and service agility as the primary drivers. (See **Figure 1.**) This goal is consistent with operators' requirement for network and service ability in the age of cloud applications. Opex reduction due to automation is the second-biggest expected benefit from SDN, followed by capex savings (despite all the early SDN use cases built around white-box hardware).

Figure 1: Most Important Business Driver for SDN



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

Heavy Reading identifies the following primary use cases for IP and optical integration, based on operator surveys and research.

Network Visibility & Analytics

Many service providers are interested in an evolutionary approach to SDN, in which they can gain confidence in the technology before it takes control of the network. For this reason, there is a lot of interest in "early win" applications that understand both layers in the network in read-only fashion and are able to automatically correlate them into a unified view.

Once such a view is built, it is used for feeding existing management systems and improving their accuracy. It is also used for analyzing the network and identifying anomalies in its structure. Such anomalies are prevalent since the vision of the network as dictated by its planning team is often not fully implemented by the operations team. This creates unplanned exposure to failures, inaccurate inventory data and suboptimal service characteristics.

Multi-layer control closes the loop between the actual network as deployed and the planning team, allowing for fully accurate planning processes. A side-effect of this accurate planning is that the planners need not take safety margins in their design of the network, which they take today, to account for uncertainty in their understanding of the network. Removal of safety margins translates directly into capex savings.

Multi-Layer Bandwidth on Demand

Bandwidth on demand (BoD) was one of the first use cases for SDN. Software automation removes the operational complexity and manual processes of provisioning a service and enables operators to respond in near real-time to bandwidth/service requests from customers. Single-layer BoD services have become common in the past two years and include AT&T NetBond, Level 3 Adaptive Network Control and Telstra PEN, among others.

Multi-layer BoD extends the automation and coordination across the IP and optical layers, allowing one-shot provisioning for a service that encompasses both the IP and the optical layers. This is especially needed for very high-speed services, as the ones needed for DCI. While there are many examples today of single-layer BoD services, multi-layer BoD is at an earlier stage, due primarily to the requirement for multi-vendor interoperability, which requires mature standards.

Multi-Layer Network Optimization (Cross-Layer)

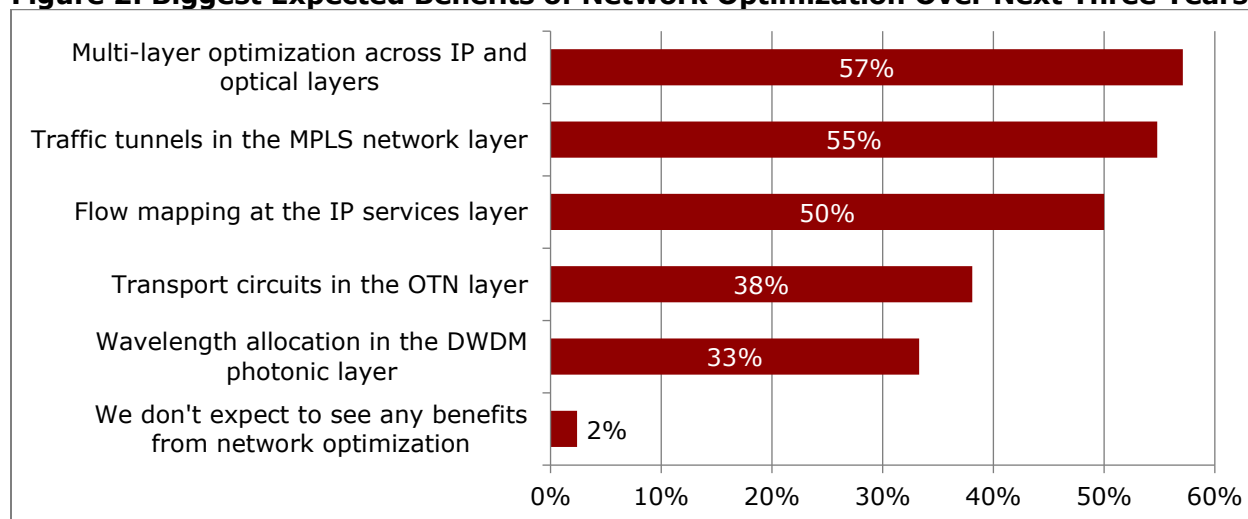
Network optimization is about making networks run more efficiently and with greater utilization, allowing operators to accommodate traffic growth without a commensurate increase in capex. Operators often refer to this as allowing networks to run "hotter." Google sparked the industry's collective imagination when it used SDN to optimize its B4 network for DCI. It was able to achieve near-100 percent utilization by using SDN to continually adjust traffic patterns, something that would be impossible in a traditional, manual network environment.

Google's B4 network applied SDN to a very contained network environment and was used at the IP layer only. Network operators are looking to apply SDN across both the IP and the optical layers to support a diverse set of network services. While Google-like utilization levels are clearly unachievable, the driver is to significantly increase utilization beyond the 20-40 percent levels that have historically been achieved in carrier networks.

One of the primary means of multi-layer network optimization is the router bypass application. Here, the goal is to intelligently coordinate traffic across layers to consolidate and transport, switch or route traffic at the lowest-cost layer that meets the traffic requirements – i.e., performance, service-level agreements (SLAs). Router ports are the most expensive ports on the network, so router bypass only moves traffic up to the IP layer when necessary, thus reducing OEO transitions and saving those ports for their specific job of IP routing.

Heavy Reading operator survey data shows that IP and optical layer optimization is the most critical area of optimization for operators globally. SDN is required for automation and interoperability. (See **Figure 2**.)

Figure 2: Biggest Expected Benefits of Network Optimization Over Next Three Years



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

Multi-Layer Restoration

Historically, restoration in the IP layer and the optical layer have existed in isolation, with no coordination between the two. IP restoration is based on fast reroute (FRR), and optical networks employ 1+1 protection schemes that shift traffic from the working path to the protection path in case of optical failure. In the absence of a failure, however, the protection path sits idle with no traffic – leaving 50 percent of potential capacity unused. (This idle capacity is the largest contributor to the low 20-40 percent network utilization that operators have traditionally achieved.)

Operators understand that significant economic benefits can come from using the photonic layer in conjunction with the IP layer to perform restoration, thereby sharing resources across two layers (IP and photonic) where, in the past, the resilience mechanisms were done separately on the IP and photonic layer. By sharing resources and coordinating across IP and optical layers, operators can achieve carrier-grade levels of availability while dedicating less bandwidth/ports for IP transit traffic and failure redundancy.

TECHNOLOGY ENABLERS

As discussed above, the introduction of SDN with multi-layer control and flexible Layer 0/1 switching are the key enablers for the new multi-layer IP and optical architectures, based on cross-layer management and control. In addition to SDN, there are several other key enablers, including hardware advances. We describe these additional IP and optical enablers below.

Flexible Photonic Layer

SDN requires a programmable data plane on which to act. This has always been in place at the IP layer, but until relatively recently, the photonic layer was largely static. After years of incremental steps forward, full flexibility at the photonic layer came with the commercialization of 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 is a key architectural requirement for operators looking to achieve multi-layer network optimization and provisioning. Some vendors refer to this combination of network control with knowledge of optical interface requirements and channel impairments and per-wavelength OAM as multi-layer wavelength routing (MWR).

Some operators add contentionless hardware functionality (or CDC) for eliminating any color restrictions in traversing ROADM nodes. Using CDC ROADMs in combination with SDN control applications for lambda defragmentation can yield up to 30 percent more photonic layer transport capacity than CD ROADMs. Contentionless functionality also comes with additional complexity and cost, so operators must conduct their own cost/benefit analyses.

Open Programmable Hardware

Historically, all software changes to a system were made by the systems suppliers themselves. Typically, these changes were tied to specific product release dates. Open application programming interfaces (APIs) allow third-party developers (including operators) to program and make changes to systems. Open APIs decouple software development from hardware development, allowing operators to customize systems to their specific requirements as those requirements emerge and to break away from rigid vendor-dictated software development cycles. Open APIs are developed in software, but there is a hardware component as well, since hardware must support open APIs. Not all hardware does.

Multi-Layer, Multi-Vendor Orchestration Software

Multi-layer and multi-vendor orchestration software is the glue that ties different vendors and different domains together and is the key to multi-vendor interoperability. Orchestration can be an ambiguous term, since it is also used to describe management of virtual network functions (VNFs) in network functions virtualization (NFV) architectures. Here we are talking about a higher-layer controller function residing above the domain controllers and below the applications layer. This "super controller" receives requests from the applications above and issues commands to the relevant domain controllers below in order to fulfill applications' requests, such as provisioning an end-to-end service.

The orchestrator/super controller interacts with individual domains through a layer of abstraction that eliminates the need to understand the specific physical attributes of the networks. The abstraction layer is critical, since the complexity of understanding multi-vendor domains would be too great to make the application practical. Standardization is also critical, because operators will require a common interface for the orchestration to communicate with each vendor domain and with the application above. This is called the northbound interface (NBI).

USE CASES & EXAMPLES

Telefónica: Multi-Layer Protection & Restoration

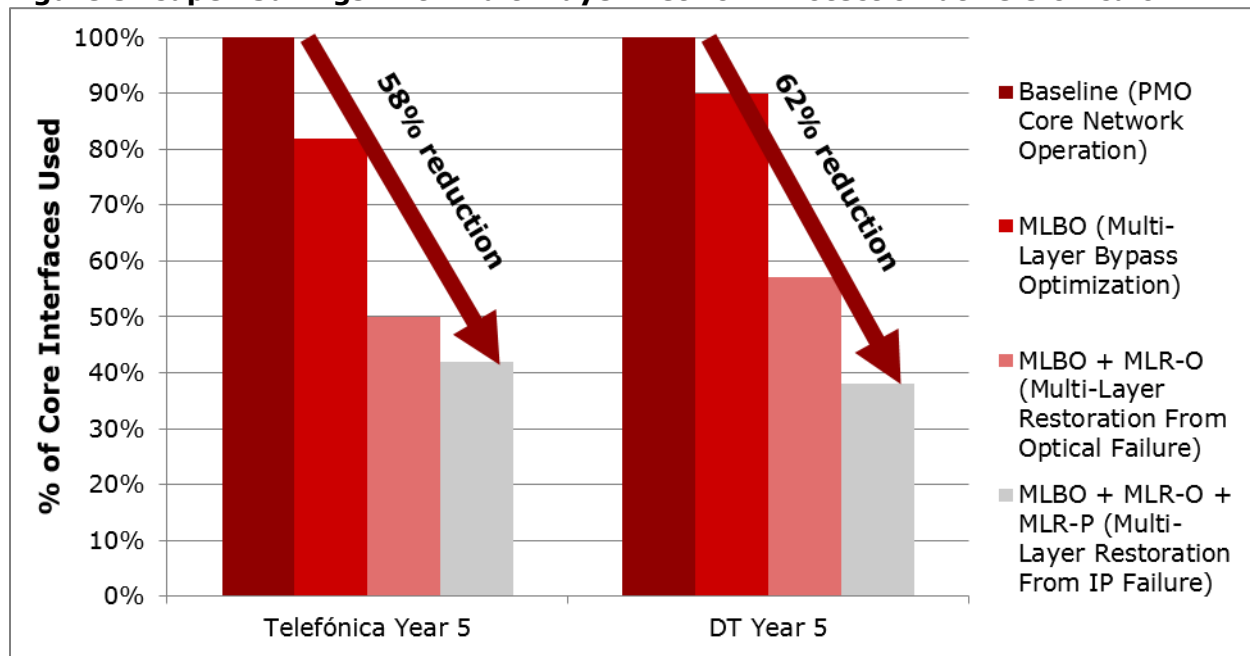
Telefónica has a long history of investigating the benefits of multi-layer network restoration, with work that predates the advent of SDN. The operator was one of the first to recognize and promote the potential for CDC-ROADM-based networks and multi-layer IP and optical layer to deliver both capex and opex savings.

In 2014, Telefónica and DT published a study in IEEE Communications Magazine detailing findings of simulated multi-layer network control in their different core networks, with strong and surprisingly similar results. The simulation work covered both router bypass applications and multi-layer restoration and while each contributed to capex savings, the biggest benefits came from multi-layer restoration – and particularly from multi-layer restoration from an optical layer failure. Results from the joint study are summarized in **Figure 3**.

Since then, Telefónica has been hard at work to standardize interfaces between network controllers and orchestration to make multi-vendor SDN control viable. While the early work proved the potential of multi-layer restoration, Telefónica has made clear that the application is only practical for its core networks if it is multi-vendor and standardized. As such, the operator demonstrated multi-layer, multi-vendor interoperability at SDN and OpenFlow World Congress 2015 and, most recently, was an active operator participant in the OIF's

northbound SDN interface (T-API) demonstration and readouts. In both cases, the orchestration software used was Sedona's NetFusion.

Figure 3: Capex Savings With Multi-Layer Network Protection at Telefónica & DT



Source: IEEE Communications Magazine, Jan. 2014

Globe Telecom: Multi-Layer Bandwidth on Demand

Globe Telecom is a leading telecom operator in the Philippines, operating one of the largest mobile, fixed-line and broadband networks in the country. At the end of 2015, Globe had 54 million mobile subscribers, 4 million broadband customers and 1 million landline subscribers.

Globe is using integrated IP and optical networking combined with carrier SDN across the Philippines to enhance the agility, quality, performance, coverage and capacity of the operator's enterprise data services network. The integrated IP and optical network will allow Globe to deliver coverage to more regions, including the Autonomous Region in Muslim Mindanao (ARMM), such as Lanao del Sur, Maguindanao, Basilan, Sulu and Tawi-Tawi. Using SDN, Globe will be able to provide flexible data services such as BoD nationwide, and expand services to thousands of enterprise customers, global service providers and local government agencies, as well as those serving different vertical markets, such as IT, hospitality, healthcare, etc.

Globe recently invested \$100 million in a new enterprise services network for Layer 2 and Layer 3 services, including on-demand provisioning and flexible SLAs. The first step was deploying carrier SDN across network layers for one-shot, on-demand provisioning. So, for example, when a customer requests an MPLS service, all the supporting layers can be provisioned at once and all new paths can be computed simultaneously to deliver the service to the customer on demand (provided that the underlying network hardware is already in place.)

The second step was to automatically assure new services by running analytics looking at the network and dynamically moving bandwidth to wherever it was requested to meet changing demand and traffic problems. For example, if the operator sees that link utilization is hitting

a certain threshold point for a certain period of time, the network can trigger a policy to add another Ethernet port to a link aggregation group to meet the surge in demand for as long as that demand surge lasts. In this example, both the IP and optical layers are being reprogrammed to ensure that the SLA continues to be met during heavy demand.

China Telecom: Network Optimization

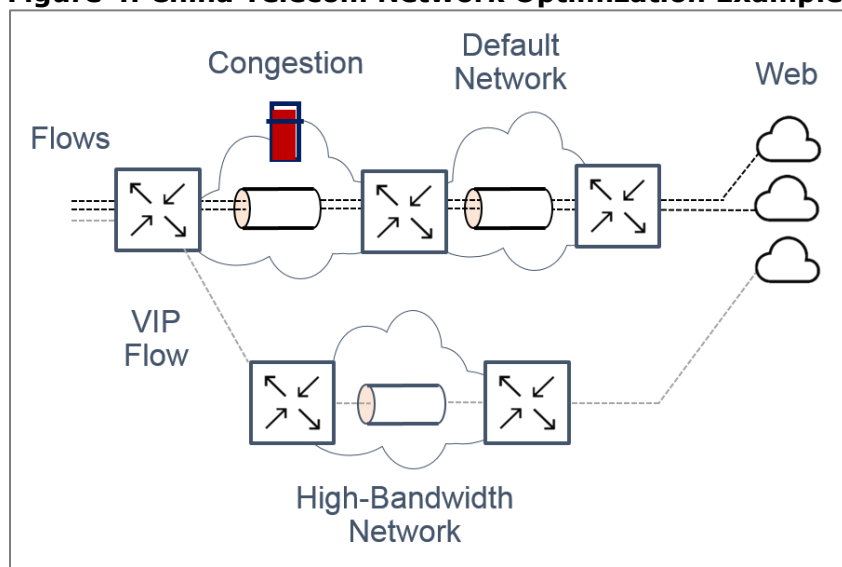
China Telecom is China's largest fixed-line operator and third-largest mobile operator. It is also one of the world's largest telecommunications operators. Jiangsu Telecom, a regional branch of China Telecom, is deploying carrier WAN-SDN at the IP/MPLS layer in data centers in Yangzhou, Changzhou and other cities in Jiangsu, a neighboring province of Shanghai. The deployment, announced in September 2016, is based on Nokia's Network Services Platform (NSP) and Nokia's 7950 XRS core routers.

The operator is applying SDN on a consumer network in order to deal with challenges of massive scale, with video and cloud applications generating massive and unpredictable traffic growth and with tens and even hundreds of millions of users all sharing the same network. A temporary event or activity on the network can quickly saturate areas of the IP and optical networks. Because of the number of subscribers, catastrophe can happen quickly. Because the traffic is unpredictable and dynamic, the operator can't identify specific high-bandwidth links that need to be permanently boosted.

The solution was tight coordination between Internet data centers and the WAN with SDN and the application of network assurance and analytics. China Telecom uses network assurance to check congestion on multiple links/paths to and from its data centers. When congestion occurs, the operator can dynamically remap these flows to secondary links to ensure that link efficiency and customer satisfaction remains high. Significantly, when the congestion event is over, the operator can then redirect flows back to the primary links, if desired.

Figure 4 illustrates VIP flows (identified through analytics) being redirected to higher bandwidth IP/optical paths in order to avoid congestion and service degradation.

Figure 4: China Telecom Network Optimization Example



Source: Nokia, 2017

INDUSTRY NEXT STEPS

NBI Standardization

With the SDN-based IP and optical architecture in place, and with the critical hardware and software innovations commercialized, the industry is indeed moving forward. Still, there is work to be done. The most immediate focus is on standardizing the NBI from the domain controllers to the orchestration layer above, which is essential for multi-vendor interoperability. In one-on-one interviews, operators have repeatedly held Heavy Reading that this is the biggest near-term issue to resolve.

Encouragingly, progress in the past 12 months has been good. Of particular note is the collaboration between the ONF and the OIF in standardizing, validating and testing new Transport API (T-API) NBI specifications designed to fill this domain controller-to-orchestration role. The T-API specifications 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, Europe, and North America. Operator participants in the demonstration were China Telecom, China Unicom, SK Telecom, Telefónica and Verizon. There were 11 vendor participants in the interoperability demonstration representing optical layers, IP layer, SDN controllers, and orchestration.

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 and work on T-API 2.0 is beginning. Also of note is the work in the IETF on a framework for abstraction and control of transport networks (ACTN).

Expansion to New Segments

In addition to NBI standardization, another 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 control automation – nor is it the most important problem to solve. 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 economies of scale are so much larger.

Telemetry/Big Data Analytics

A third development is the inclusion of network telemetry and big data analytics in combination with SDN to assure and optimize network resources, in particular for Internet-enhanced networks. Today operators essentially fly blind, while network traffic patterns have vastly changed due to the dynamics of cloud and IoT. Dynamic traffic load changes can be predictable and solicited, for example scheduled and on-demand bandwidth services, but also unsolicited and unpredictable, due to flash traffic or DoS flooding attacks. As a result, hotspots and network congestion can happen randomly, and the cause is often unclear. To add more capacity at points where congestion happens is likely to be costly and ineffective, while just rerouting traffic may shift the problem to other parts of the network.

Integrating network telemetry and big data analytics into the feedback loop allows the correlation of vast amounts of telemetry data to create a near real-time view of the network. Supplied with actionable intelligence, the SDN layer can respond by implementing policies to remedy the situation, for instance by filtering or blackholing rogue DDoS traffic, resizing link capacity or selectively redirecting congested user traffic. Big data analytics and network telemetry play an essential role in making this feedback loop scalable and enabling it to operate in near real-time.

CONCLUSIONS

Today we are in the midst of a resurgence in IP+optical integration, based on tight coupling of control and management layers. This integration requires full automation of the photonic layer (combining CDC ROADM hardware with software programmability), an open and programmable IP layer, and multi-layer and multi-vendor orchestration software above the individual domains providing intelligence and coordination.

What is really most significant are the applications and benefits for network operators, both near term and longer term, once multi-layer integration is in place. Operators can take a first step toward full integration with applications that understand both layers in the network in read-only fashion and provide a unified cross-layer view to improve network planning speed and accuracy.

Beyond the early steps, top applications for IP and optical integration are:

- **Multi-layer bandwidth on demand:** automating end-to-end bandwidth provisioning;
- **Multi-layer network optimization:** improving network utilization by sharing resources across layers, thus saving capex; and
- **Multi-layer restoration:** coordinating between IP and optical layers to provide network restoration in ways that greatly reduce idle capacity without sacrificing reliability.

Longer term, we expect to see NBI standardization for wide-scale, multi-vendor interoperability, expansion across multiple segments of the network (from core to access), and deep integration of telemetry and big data analytics with SDN. With an eye toward this future, the time to start the IP and optical integration journey is now.