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IP-optical convergence: a complete solution

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IP-optical convergence: a complete solution

The shift to software-defined networking (SDN) architecture for transport networks has given a new lease on life to the IP-over-optical solution that has been around for nearly two decades. Converging the IP and optical network layers to centralize network control is an excellent way to increase service velocity and lower total cost of ownership (TCO) for network operators.

STEFAN DAHLFORT AND DIEGO CAVIGLIA

The current SDN movement in the telecoms industry offers a much-needed solution to attain the high levels of automation that modern networks demand – for both IP and optical systems. In parallel, and to some extent related to this, service providers are moving away from the independent operation of IP and optical transport toward a converged approach, with joint operation.

The problem with separate IP and optical transport networks is the unnecessary resource overhead it creates. Basically, each network has its own control and management mechanisms, which not only increases the number of resources needed to reach a given performance target, but also makes networks more complex than they need to be. Like many other issues that operators face today, this causes costs to rise and lowers the ability to evolve with changing business environments.

The challenge – which is not entirely new – is to bring these two transport networks together. Looking back to the late 1990s, when the volumes of IP traffic started to rise significantly, dense wavelength division multiplexing (DWDM) technology raised the capability of fiber optic communications close to their full potential. At this point, the telecoms industry identified the need for a way to combine IP and optical transport technologies.

Protocol layering was one of the first converged approaches that had the right balance of traffic control, multiservice support, payload efficiency and low operational complexity. As a result of this early work, several equipment changes have occurred. For example, IP router products are now offered with DWDM interfaces for aggregation and metro networks, which reduces the number of fibers needed to deliver a given traffic volume. This kind of approach has generally been referred to as IPoDWDM – meaning DWDM interfaces integrated into the router line cards. As well as reducing network complexity, this approach reduces the need for network components such as shelves, which in turn makes opex reductions possible.

Another approach to converging IP and optical has been used on the multilayer control plane. Developments in this area conducted by standards organizations such as IETF have resulted in the GMPLS protocol suite[1]. The protocols in this suite enable automated provisioning for services that use resources

BOX A Terms and abbreviations

ASIC	application-specific integrated circuit
BGP-LS	Border Gateway Protocol Link State
CPE	customer premises equipment
CFP	100Gbps small form-factor pluggable
CLI	command-line interface
DWDM	dense wavelength division multiplexing
EDFA	erbium-doped fiber amplifiers
EON	elastic optical networks
FCAPS	fault, configuration, accounting, performance, security
FEC	forward error correction
FW	forwarding
GMPLS	generalized multi-protocol label switching
IETF	Internet Engineering Task Force
IPoDWDM	IP over DWDM
LH	long-haul
ML	multilayer
MP-BGP	multi-protocol BGP
MPLS	multi-protocol Label Switching
Mpx	muxponder
NE	network element
NMS	network management system
OF	OpenFlow
O&M	Operation and Maintenance
OLA	optical line amplifier
OTN	optical transport network
PCE	path computation element
PCEP	PCE protocol
PDEF	protocol definition language
ROADM	reconfigurable optical add/drop multiplexer
SDN	software-defined networking
SFP+	small form-factor pluggable for up to 10Gbps
SR	Segment Routing
TCO	total cost of ownership
TDM	time division multiplexing
TNC	transport network controller
Tpx	transponder
VPN	virtual private network
VM	virtual machine
WSON	wavelength-switched optical network
XFP	10Gbps small form-factor pluggable

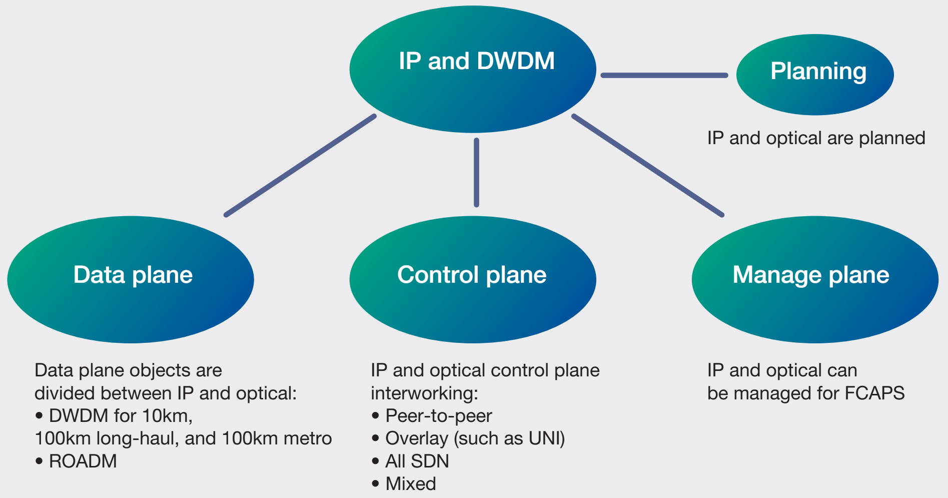
in several network layers, and is the first standard control plane for wavelength-switched optical networks (WSONs).

Since then, network operators have introduced reconfigurable optical add/drop multiplexers (ROADMs). These components simplify the operation of large numbers of DWDM channels and reduce the number of signal regenerators needed in metro and core networks.

To date, however, there have been only a few deployed networks in which control plane integration of IP routers and optical transport systems has been implemented using DWDM and ROADMs. One reason is the typical organizational division of IP and optical operations. Add to this the fact that IP routers have limited support for GMPLS and that data plane (DWDM layer) interworking has presented a significant challenge. The result is low-level adoption of the technology.

Today, the optical industry is trending toward using independent 100Gbps coherent DWDM ASICs. These chips simplify data plane interoperability (at the DWDM layer) among the different network element vendors – a factor of paramount importance when it comes to combined control.

FIGURE 1 **IP-optical taxonomy overall**



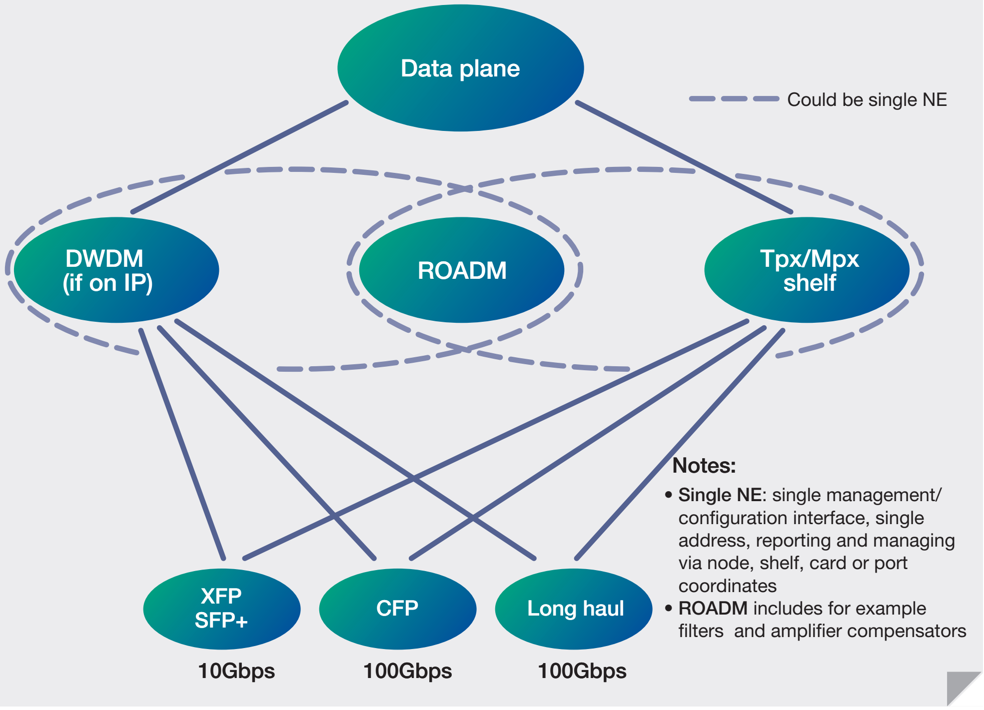
Closing the gap

While some steps have been made to integrate the two transport networks, a fully integrated solution that includes logical integration of all planes – data, control, and management – is still needed. This article outlines such a solution, referred to as IP-optical convergence.

Taxonomy

Both the IP and DWDM layers are multi-domain technologies that include various planes. Each plane can be implemented using one of several architecture variants. This organization is illustrated in Figures 1 and 2, where **Figure 1** shows the overall taxonomy, and **Figure 2** details the data plane.

FIGURE 2 **Data plane taxonomy**



Notes:
- **Single NE**: single management/configuration interface, single address, reporting and managing via node, shelf, card or port coordinates
- **ROADM** includes for example filters and amplifier compensators

Data plane

In the 1980s, coherent receivers and coherent technology were the focus of much study. Unfortunately, the technology never took off due to the complexity of polarization and phase stabilization. Some 30 years later, however, these initial problems have been overcome by advanced digital signal processing, allowing coherent technology to open up new ways of utilizing the bandwidth of optical fibers.

When combined with technologies such as flexible grid allocation[2], multi-rate transmitters/receivers – as part of elastic optical networks (EON)[2] – and super-channels[3], coherent technology allows optical transmission systems to cope with increasing capacity demand without costly upgrades to the physical fiber network.

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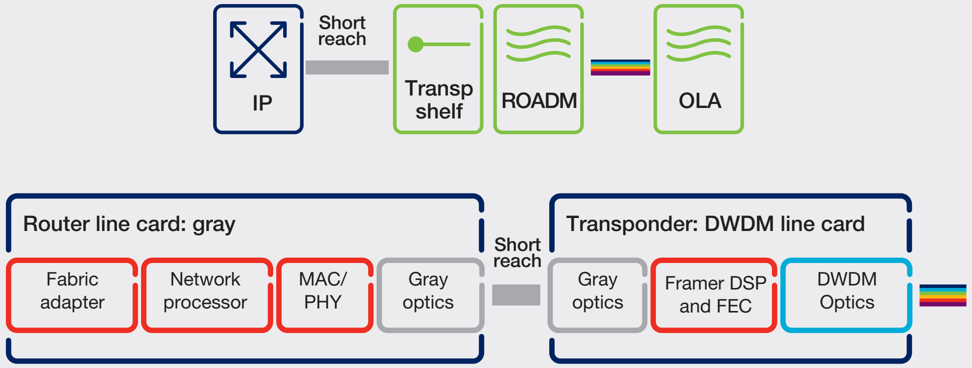
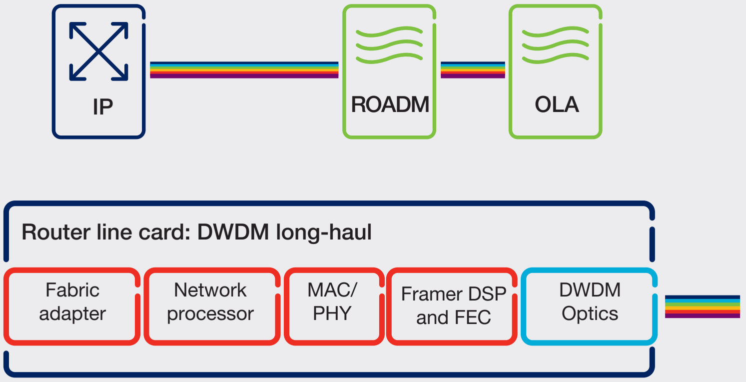
FIGURE 3

Option 1: separated IP router and DWDM optics



Option 2: DWDM and optics integrated on router line cards



On top of the optical transmission layer, time division multiplexing (TDM) offers a networking tool for handling traffic and the OTN framework[4] offers multiplexing and framing capabilities. OTN framing is actively used in transport systems as it offers increased reach – through forward error correction (FEC) and O&M. Depending on their need for additional traffic handling capabilities, operators can use OTN switching in addition to what is offered by IP/MPLS; this approach balances the need for handling capabilities against additional network complexity.

In addition to these operational benefits, IP-optical convergence puts DWDM optics directly onto router line cards. From a technical point of view, this integrated approach is advantageous, as it:

- removes the need for interconnects between IP routers and optical transport equipment – reducing system complexity, but with marginal decrease in TCO;
- reduces the overall equipment footprint and power consumption as gray optical interconnect links are omitted;
- lowers the number of system components, which reduces the effort required at installation, to maintain the inventory, and to provide spare components management;
- simplifies integration in terms of system software, control and management, as the physical pieces all reside on a single line card.

However, this integrated approach has several disadvantages, including the fact that long-haul optics are bulky, power-hungry and temperature-sensitive, which impacts the router line card density and capabilities.

Furthermore, a multitude of different router line cards are needed to cater for many kinds of optics such as 10G, 100G and 400G covering distances from 10km to over 2000km. To overcome the cost of developing a range of different line cards, pluggable optical modules can be used instead. These modules come in several variants to cater for the different data rates and distances. A drawback of this solution, however, is that it typically offers advanced optical capabilities later than is possible with solutions integrated on the line cards.

Another level of complication is added by the pace of evolution: packet-forwarding hardware and fiber-optics hardware may not develop in a synchronized manner, and so a combined card may not be able to take advantage of the most up-to-date technology.

So the questions that need to be answered are: when is it desirable or necessary to keep operations and perhaps ownership of IP and optical transport separate, and when should operation be integrated?

From a pragmatic and a technical point of view, the best solution would be to integrate optics on the router line card if doing so does not negatively impact IP router cost or size capabilities, and then use a separate optical transport shelf/box for all other cases. Such an additional box may be needed anyway to host optical amplifiers, such as erbium-doped fiber amplifiers (EDFA), or Raman amplifiers for improved reach, as well as for DWDM mux/demux and ROADM components.

For joint operation, the existence of two boxes should not be an issue as the separate optical transport box can be seen as an extension of the IP router backplane.

Figure 3 illustrates both approaches, where option 1 is the separated approach and option 2 the integrated one. The illustration shows the optical components without placing any assumption on how they are assembled in an actual network element.

Control plane

There are several ways to implement the control plane in a converged architecture. It can be implemented as a pure GMPLS with all the control plane functions, signaling and routing distributed in the network. Alternatively, the control plane can be implemented as a centralized implementation with centralized PCE[5], with no routing or signaling in the network. There are several alternative architectures between these two extremes, as summarized in **Figure 4**.

An IETF initiative, Segment Routing (SR)[6], offers some advantages, including operational simplification and improved scalability.

For a converged IP-optical control plane in the core network, SR together with SDN is a good solution, while for the aggregation/metro network a single SDN controller with standard OpenFlow for the southbound interface is probably best.

A perfect fit

By leveraging source routing and tunneling, SR improves network scalability and provides a set of tools to implement traffic engineering without requiring any changes to the MPLS data plane.

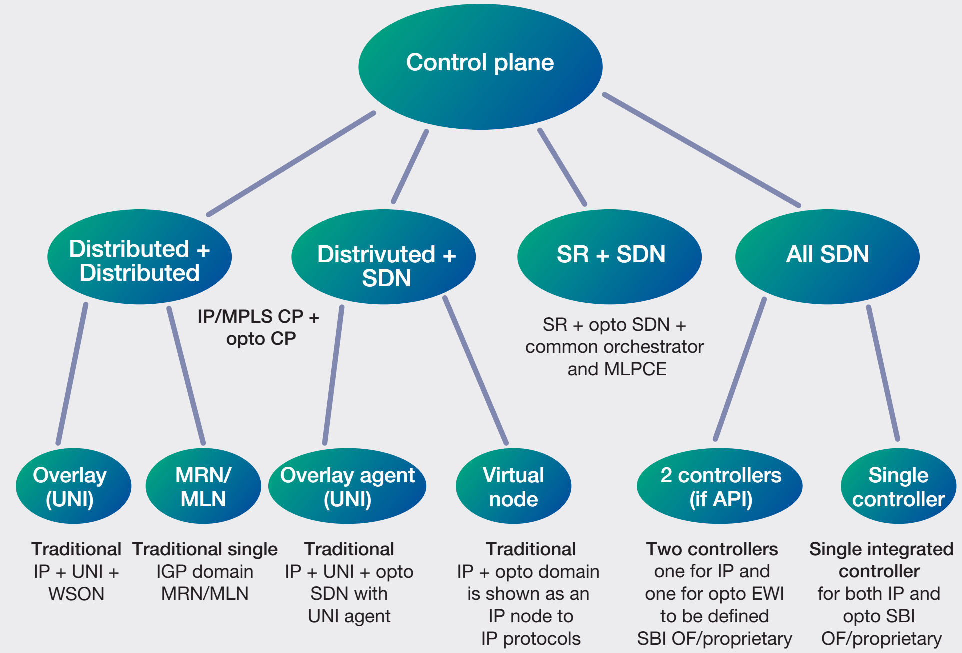
Using SR, the ingress node basically steers a packet through a controlled set of instructions, called segments, by prepending the packet with an SR header.

A segment can be a topological or a service-based instruction. It can use semantics that are local to an SR node or use global semantics that are applicable within an SR domain. Applying SR guarantees that packets follow a predetermined path through any network topology and that a given service chain is applied while at the same time maintaining the per-flow state at the ingress node of the SR domain.

The beauty of the SR architecture lies in the fact that it can be applied to the MPLS data plane directly without making changes to the forwarding plane, and requires only a minor extension to the existing link-state routing protocols.

As shown and summarized in **Figure 5**, the centralized intelligence of SDN with its multilayer ML-PCE capabilities together with SR protocols and architecture are the best fit for converged core networks, together »

FIGURE 4 **Control plane taxonomy**



BOX B **Terms and abbreviations (Figure 4)**

API	application programming interface
CP	control plane
EWI	east-west interface
IGP	Interior Gateway Protocol
MLN	multilayer network
MRN	multi-region network
MLPCE	multilayer path computation engine
OF	OpenFlow
SBI	southbound interface
SDN	software-defined networking
SR	Segment Routing
UNI	User Network Interface
WSON	wavelength switched optical network

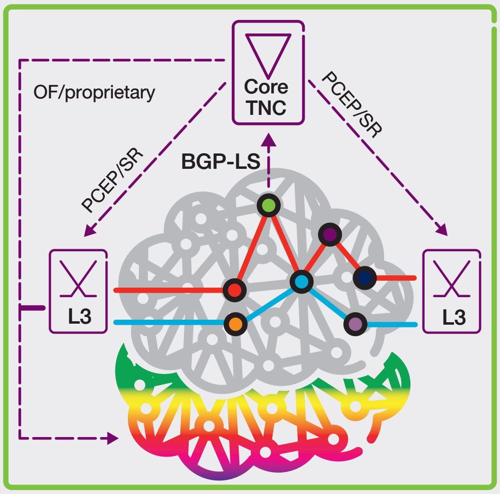
FIGURE 5 **SR and SDN in core networks**

Packet network

- The packet network is an IP/MPLS network running IGP protocols and enabled for segment routing
- Source-routed path is downloaded to ingress node of the packet-network via PCEP
- Edge router is confogured to push a set of tables corresponding to the downloaded path
- Packet recovery can be achieved with both pre-planned protection and IP/ MPLS IGP restoration

Optical network

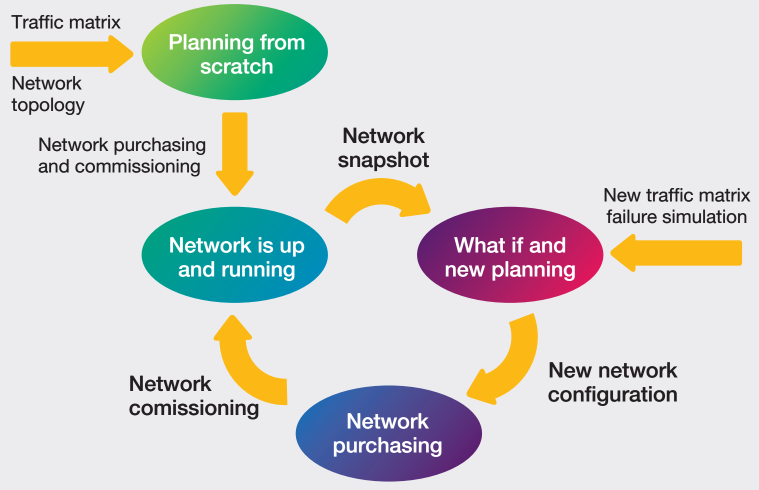
- SDN network with no control plane on nodes
- Dynamic resource provisioning to reflect packet network selected paths and vice versa
- Optical recovery is achieved via on the fly restoration



Single transport SDN controller

- Multilayer path computation element (ML-PCE) and traffic engineering policy

FIGURE 6 **Planning cycle**



with Border Gateway Protocol with link-state extensions (BGP-LS) to upload the network and path status into the transport network controller (TNC).

Management plane

Historically, only a few basic management features have been included in the IP layer, leaving the command-line interface (CLI) to perform the majority of these tasks. On the other hand, the lower layers L0-L2 have a long history of using evolved management systems. Despite the introduction of SDN technology as a primary way to provision and configure paths and services in converged networks, for true converged networking, a comprehensive network management system (NMS) is still needed. Such a management system is a key element of the network and should be capable of dealing with all aspects of it – including the control plane – and be able to run in real time with high levels of automation and dynamicity.

The operation and maintenance functions carried out by an NMS should, for example, include the application of security measures, configuration tasks, software management, performance management, fault management (including the control plane protection and restoration functions performed by the SDN controller), fault correlation and inventory, as well as providing data for business-related functions such as analytics and billing (BSS).

A management system that can provide a consolidated view of a network simplifies the many types of network operations. As such, an NMS needs to be scalable to support high-capacity networks; it needs to be highly capable to handle complex multilayer connectivity; and it needs to be able to support multi-vendor environments.

A unified NMS should provide full network evolution support for both existing O&M features as well as new features such as integration of multi-standard small cells, and support for Wi-Fi, 4GIP networks, SDN and cloud environments. It provides a single interface to network elements and makes relevant network data available through northbound interfaces. A unified NMS can help operators to reach set network-performance targets and improve productivity by enabling increased coverage, more widespread automation, higher network availability and by supporting best-in-class usability. Such high quality and efficient O&M not only reduces TCO of network equipment but also helps improve operator perception with existing and potential subscribers.

Planning

Planning is a fundamental part of efficient networking. It is a cyclical process that starts with network monitoring: traffic matrices and/or events are simulated, the impact is assessed and appropriate actions are taken to assure that the set performance targets are still achievable. Figure 6 illustrates the overall network planning cycle from initial deployment to maintenance.

The best way to plan a converged network is adopt a multilayer approach and retrieve data from the management system, from the controller, or from both.

The result of the planning activity can then be used to purchase any additional equipment needed such as units, nodes or cards, or to initiate a cycle of network optimization.

Use cases and benefits

The main issue with dual operation of IP and optical transport systems is that it creates an unnecessary overhead in both time and resources. To a great extent, optical transport layer resources – wavelength and spectrum – are provisioned when transport bandwidth is lacking. So, with the trigger in the packet layer, operators can save a lot of time by automating provisioning of the optical transport layer. In other words, what is needed is an implementation for single-step, multilayer provisioning.

Use case: time to market

An operator needs to provision a business Layer 2/Layer 3 VPN service on IP Edge on customer premises equipment (CPE). To enable rapid provisioning in this scenario, multilayer operation is a requirement – separate provisioning for each layer of the transport network would simply take too long.

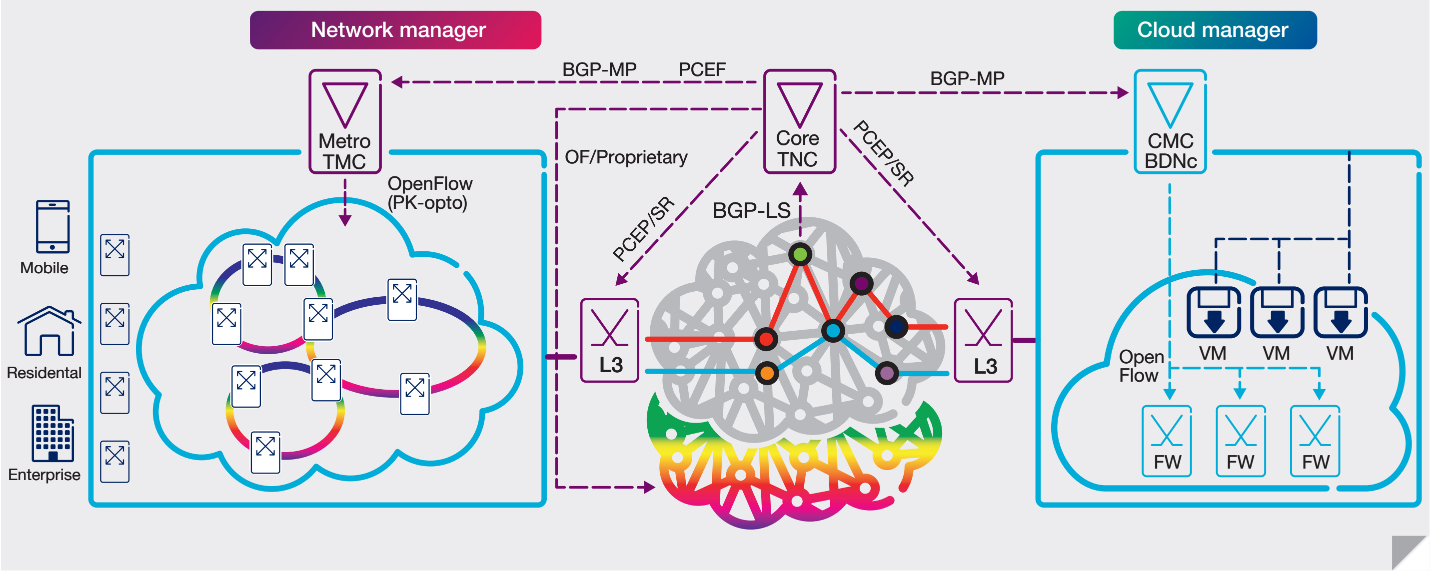
Use case: planning

Multilayer planning can save resources in terms of deployed equipment, time and expertise. To maximize equipment savings, the path computation algorithm of the planning tool should be the same as the one used by the network controller. Planning tends to be carried out offline using updated snapshots of the network, with cycles ranging from a couple of months to several years.

Use case: optimization

Optimization is similar to planning but is carried out online. As the network evolves and becomes more complex, multilayer resource optimization can make intelligent use of resources.

FIGURE 7 **IP-optical convergence reference architecture**



Optimization is performed through a specific application that sits on top of the network controller, allowing the carrier to specify policy and metrics.

Use case: protection/restoration

Applying multilayer protection/restoration removes the need to duplicate protection resources across several layers, and eliminates the conflicts that arise as a result of protection/restoration mechanisms working individually in the different layers.

Overall resource availability can be further improved by combining protection in the IP/MPLS layer – which can be engineered for fast protection – with restoration in the optical layer (which is better suited for this task due to slower ROADM switching times and longer optical amplifier settling times as a result of transients).

Use case: calendar

Dynamic time-sharing of resources may be of interest for, say, data-center interconnects. These links need to support scheduled large-volume data transfers but do not require permanently assigned resources.

Converged architecture

The IP-optical convergence solution offers significant operational gains as it permits the different layers of a network to operate in a single step. This in turn leads to improved service, reduced time to market and optimized utilization of resources.

The technical considerations of each of the planes addressed in this article are summarized below:

Data plane

An integrated approach – optics on router line cards – brings benefits in terms of fewer system components and simplified system management.

Some optical transport components such as ROADMs and optical amplifiers require an additional shelf; placing the optical port on the same shelf improves flexibility and supports the case for separated – yet still automated and centrally managed – optics.

Control plane

Centralized control brings benefits in terms of better utilization of resources and simplified operation. The SDN approach, combined with SR for the IP/PMPLS layer, improves scalability and simplifies operation. Well-defined application interfaces to the controller are a significant factor in the automation of application resource requests – such as the resources to set up a VPN with a data center interconnect.

Management plane

A unified management system capable of handling all the IP and transport layers and equipment end-to-end is key to an efficient converged network. Overall, as such networks are typically multi-vendor, it is important that the unified management system has support for multi-vendor environments, multilayer and multi-domain scenarios.

The complete IP-optical convergence solution with its architecture and key components is illustrated in **Figure 7**.

Overall, a converged architecture makes the most of the current industry shift toward SDN, driven by a need for lower costs, faster services, shorter time to market as well as reduced operational complexity.

Commercially available cutting edge IP-optical convergence offerings encompass emerging protocol suites such as SR and best-of-breed architecture, without forgetting the need for more traditional tools such as planners and management systems. The converged solution described here has the right mix of revolutionary and traditional approaches.

Such an integrated approach offers a viable migration path from the installed base, as well as being an attractive proposal for meeting the IP and transport network requirements for the foreseeable future. ◆

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