Enabling IP/Optical Integration in Core and Metro Networks

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Abstract *This article explores how the introduction of coherent pluggable requires a closer integration between IP and Optical in core and metro optical networks. It highlights the critical role of Software-Defined Networking (SDN) cross-domain control for such integration and assesses the challenges of deploying pluggable optics.*

Introduction

Recently, several technological drivers have paved the way for new IP/optical architectures. The emergence of next-generation 400G QSFP-DD coherent pluggable transceivers has extended the transmission range capabilities. These new coherent pluggable modules can interoperate using 100-400G single wavelength optical port standards. There are several organizations, such as OIF 400ZR [1], OpenROADM [2], and OpenZR+ [3], that have collaborated to define port specifications to enable this interoperability. Implementation agreements like OIF IA-CMIS [4] and Telecom Infra Project (TIP) – Transport Abstraction Interface (TAI) [5] define the interface between the router and the coherent pluggable. These two levels of communication at the data level and at the management level foster a plug-and-play solution for the coherent pluggable market. Additionally, optical disaggregated architectures specify how the transmission of optical channels by third-party Open Terminals (OTs) over Open Line Systems (OLS) for multi-vendor environments. This approach enables flexibility and choice in optical network components.

These technological evolutions have been recognized by network operators, whose contributions in this area within TIP's Open Optical & Packet Transport group (OOPT) are significant. The OOPT group aims to define open technologies, architectures, and interfaces in the domains of optical and internet protocol (IP) networking. OOPT group facilitates the planning and deployment of disaggregated, open systems throughout network operator's infrastructure. Metaverse ready Architectures for Open Transport (MANTRA) group within OOPT is facilitating the advancement of IPoWDM networks by integrating IP routers equipped with 400G and higher-capacity coherent pluggables. Vodafone, Turkcell, Telia, Telefonica, Orange, MTN and Deutsche Telekom present IPoWDM convergent SDN architecture" in [6] to show the direction for commercially viable solutions. This article presents the IP over WDM scenarios, their Software-Defined Network (SDN) architectures, and explores the implementation of these architectures in real scenarios.

Coherent pluggables in IP routers

The main disruption with 400G coherent technologies is the utilization of coherent pluggables within routers. Today, network operators are deploying their infrastructure using what we can call conventional IP-Optical network. This scenario is composed by three entities: IP router, WDM transmission, and optical line system. The IP router processes data packets, the WDM transmission layer maximizes capacity and reach of optical communication systems using advanced modulation formats and digital signal processing, and the optical line system is a collection of network elements that manages the transmission and amplification of optical signals, ensuring efficient and reliable data transfer in optical networks. The communication between the IP router and the WDM transmission is done via so-called "grey" interfaces, and the optical line system receives and transports the WDM signal.

The integration of coherent pluggables in the router allows the coherent signal to go directly to the optical line system without the need for a WDM transport device (Fig. 1).

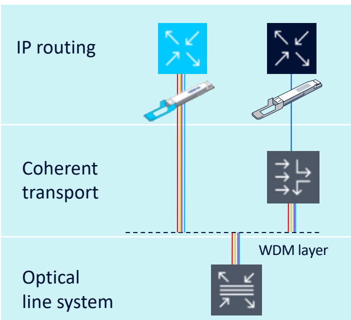

Fig. 1: IP-over-WDM architectures.

This integration reduces the number of elements involved in planning, installation, management, and maintenance, eliminating the need for intermediate transponder/muxponder devices and removes the "grey" client transceivers connecting switches or routers with transponder/muxponder components.

There are several key drivers for adopting the integration of third-party vendor coherent pluggable modules in IP/MPLS routers. First, it offers capital expenditure (CAPEX) savings. At the same time, this integration reduces equipment footprint, points of failure, and power consumption, contributing to more efficient network operations.

Software-Defined Network architectures for IP/optical scenarios

The integration of IP and optical technologies simplifies network requires requires coordination between the IP and Optical controllers. A SDN solution is essential for discovery, service provisioning, and assurance. Without the SDN solution, CAPEX savings could achieve, but without SDN IP/Optical coordination it is practically impossible to deploy coherent pluggables (except in the most basic (p2p) configurations). The coordination of the coherent pluggables with the power management algorithms in the optical network becomes an unmanageable task without an SDN solution.

Three main components constitute the SDN architecture for IP-optical scenarios: the Hierarchical-SDN controller (HSDNc) for multi-layer and multi-domain scenarios, the IP-SDN controller (IPSDNc) for managing the IP elements and the optical SDN controller (OSDNc) for characterizing the performance at the optical domain and managing the optical components. When the coherent pluggables becomes part of the IP router, there are two main alternatives for managing such integration: (1) single or (2) dual SBI management of IPoWDM routers [6]. The router is connected only to the IPSDNc in the single SBI management architecture, while both IPSDNc and OSDNc interface the IP router in the dual managed architecture (Fig 2 and Fig 3).

Traditionally, the OSDNc was the only entity that configured the optical components. However, with pluggable optics in routers, the IPSDNc can configure the coherent pluggable. In the case of single SBI management of IPoWDM routers, the IPSDNc must read and write the optical parameters of the coherent pluggable. The reason why there cannot be two controllers accessing the same network element is the out-of-sync problem. The out-of-sync problem arises when two entities simultaneously configure the router, causing the configuration databases at the controllers to fall out of synchronization. As a result, the recovery time required for reconvergence at the SDN Controller level typically ranges from several seconds to minutes. This situation is not desirable, and TIP operators identified the IPSDNc as the entity to configure the pluggable [6].

The model selected in TIP to configure coherent pluggable is OpenConfig. OpenConfig defines four main parameters target-central-frequency, target-output-power, operational-mode and admin-state. During the device discovery phase, the IPSDNc learns which are the device capabilities either via gNMI or NETCONF. Through gNMI, the IPSDNc can obtain the performance counters of the pluggable interface in the IPoDWDM routers. Thanks to gNMI or NETCONF, the IPSDNc retrieves asynchronous notifications about alarms in the component. Once this information is in the IPSDNc, it has to be exposed to the HSDNc. There is still not an RFC but the work in [7] is a possible solution for device discovery. IPSDNc exposes pluggable performance metrics and alarms through its NBI via notification buses like Kafka.

HSDNc has a ONF TAPI interface with the OSDNc, which is used to perform an end-to-end path computation and impairment validation for a 400G signals. The OSDNc answers with the target-central-frequency, target-output-power and operational-mode after evaluating the physical impairments of the requested path. The

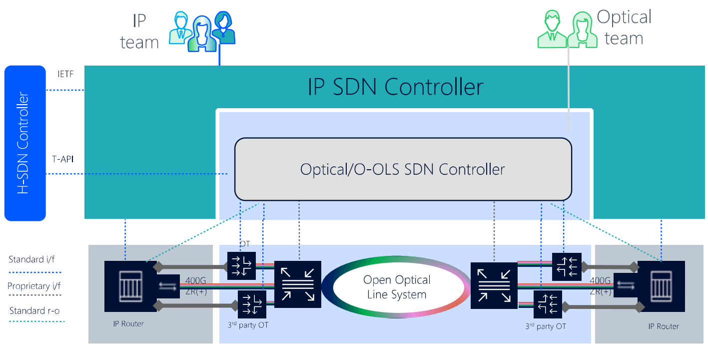

Fig. 2: Dual SBI management of IPoWDM routers

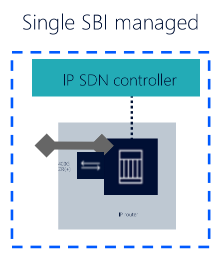

Fig. 3: Single SBI management

provisioning of the media channel is done via TAPI. Besides, the HSDNc requests the configuration of the pluggable using RESTCONF with IETF data models to the IPSDNc, which receives the IETF models and configures the pluggable in the router using OpenConfig.

Dual SBI management architecture comes with the premise that both IPSDNc and OSDNc access to the router. In this architecture, the OSDNc accesses the router in a read-only mode, simplifying the optical information workflow. The optical parameters remain in the OSDNc for discovery, performance and alarms management. During service creation, the OSDNc answers with the parameters to configure the pluggable, but the information is not coming from the IPSDNc to the HSDNc and from the HSDNc to the OSDNc.

Comments about pluggable optics solutions

IPoWDM solutions with pluggable interfaces are based on QSFP-DD DCO. QSFP-DD DCO offers a small form factor, higher port density, and low power consumption compared to technologies like CFP2 DCO. MSAs like 400G ZR or OpenZR+ are suitable for certain environments. They cover access, metro Data-Center-Interconnect or metro aggregation, but there is no interoperable solution for core, long-haul or sub-sea scenarios. CFP2 DCO supports advanced modulation formats and greater reach than 400G ZR or slightly improved reach to OpenZR+, but at the cost of a larger physical size and higher power consumption. The choice between the two technologies depends on application requirements, space and power limitations.

From the SDN perspective, IPoWDM router architectures introduce new requirements to the SDN components, impacting each entity involved as shown in Table 1. The HSDNc has to redirect the optical parameters for configuration in the case of dual SBI management, and for reading and configuration in single SBI management. The IPSDNc has a similar requirement at its NBI. It has to consume the configuration parameters for dual SBI management. Additionally, it has to export the data in the single SBI manage architecture. The IPSDNc controller uses in the SBI OpenConfig to manage the routers configuration. The addition of some optical parameters has a reduced impact.

Finally, the OSDNc has to export the calculated optical parameters in its NBI in both two scenarios. In the case of dual SBI management, the requirement for reading performance and alarms is minor, as this is already being done today for the open terminals.

Tab. 1: New requirements in single and dual SBI management of IPoWDM routers.

Comp\Arch	Single SBI	Dual SBI
HSDNc	Redirection of optical parameters	Redirection of optical parameters
IPSDNc	Management of optical parameters (configuration, performance and alarms) Support for NBI optical models	Configuration of optical parameters Support for NBI optical models
OSDNc	Exposition of optical parameters in the NBI	Exposition of optical parameters in the NBI Read performance and alarms

Conclusions

This article has explored the evolution of pluggable interfaces in IP routers within core and metro optical networks. Integrated pluggable solutions offer cost-efficiency, reduced equipment footprint, fewer points of failure and power savings for network operators. This work shows that SDN control plays a critical role in enabling this integration by providing centralized management, power management, alarm correlation and trouble shooting in IP/optical scenarios. Moreover, the article also discusses the challenges involved in deploying pluggable optics in realistic scenarios.

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