A Control Hierarchy for Integrated Packet-Optical Networks Utilizing Pluggable Transceivers

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Abstract: A proposed architecture for control of packet-optical networks is analyzed and demonstrated. The specific challenge of managing routers with integrated pluggable WDM transceivers with open optical line systems is addressed while considering standards alignment.

1. Introduction

1.1. *Motivation*

Over the past two decades the telecommunications community has embarked on integration between packet and optical networking systems toward the goal of improvements in efficiency, automation, availability, and capital expenditure. The integration of the WDM interfaces into the router is a compelling design element since this eliminates the costly transponder function of the optical system. Historically, many router vendor implementations required purpose-built WDM line cards which were in many cases relatively expensive compared with standard line cards. Further, these implementations often sacrificed slot bandwidth due to the lower density of the WDM interfaces. Now, with the introduction of pluggable digital coherent optics (DCO) such as ZR+, these limitations have been addressed since the QSFP-DD DCO is compatible with standard router line cards. However, this introduces a new challenge of managing the router pluggable optic and orchestrating the end-to-end path setup across the optical line system (OLS) in an open, multi-vendor environment.

1.2. *Discussion of Controller Architectures*

Different control architectures for packet-optical networks have been proposed [1-4]. However, they do not fit well for a network architecture in which the transponders are embedded in packet devices, either from a technical perspective or from a vendor/ecosystem perspective. Specifically, [1] proposes the addition of another layer in the control hierarchy – an optical controller that configures both the WDM interfaces and the OLS. This is cumbersome and will imply higher solution cost (another software system) as well as control of routers from two sources – the packet controller for IP aspects and the optical controller for the WDM interfaces. Having multiple controllers modifying the same router ("dual write") is problematic and may cause conflicts and loss of database consistency within the controllers. [2] is similar to [1] in that a single optical controller controls the entire optical network, however it assumes a single PCE. This means that transmission feasibility calculation is common across different OLS vendors. While this may work for shorter reach networks in which the lowest common denominator might be sufficient, it is questionable whether different WDM vendors will agree on a common feasibility approach for more demanding links. [2] also forces all vendors to comply to Open ROADM models [5] which is a deviation from how many optical systems are controlled today (e.g. via T-API [6]). [3] advocate that the optical controller of the OLS will also provision the connected optical interfaces. This has the advantage over [2] that the transmission feasibility analysis is done by the OLS vendor software but imposes an unrealistic requirement that multiple optical controllers manage WDM interfaces of the same router. This would be required in cases where the router interfaces with line systems of different vendors (a common scenario). [4] recognizes the problem of workflow coordination between optical and packet controllers and tries to solve it through careful coordination of the workflow. We believe this approach is too sensitive to implementation details and race conditions which will stem from the attempt to control the same router via multiple optical controllers.

2. Hierarchical Controller and API Design

2.1. *Hierarchical Controller Design Considerations*

Our approach is based on an architecture with a single hierarchical controller (HCO) and domain specific controllers for IP (packet) and optical (fig 1). There are variations of this design which have advantages and disadvantages as discussed below:

i. *HCO to interface with dedicated Open Terminal Controller (OTC)* – A dedicated controller that represents all the optical interfaces in the router via T-API. This may be the most elegant option in terms of architectural consistency (the HCO just needs to understand the T-API model for router WDM transceivers). However, this adds yet another control element and has the same draw-back mentioned in the previous section with multiple controllers modifying the same device ("dual write").

ii. *HCO to interface with IP controller via T-API* – The IP controller acts as the OTC for the packet domain. This eliminates the additional OTC and addresses the dual write problem. However, this burdens the IP controller with optical functionality and T-API.

iii. *HCO to interface directly with the routers via Openconfig* – The HCO by-passes the IP controller and directly configures the router. This does not require T-API on the router or the IP controller, but it does have the dual write problem.

iv. *HCO to interface indirectly with the routers through the IP controller via Openconfig* – This is our selected approach and the focus of the text below. It is the most optimized in term of the required logic/code since the IP controller simply passes the requests and responses to the routers. At the same time, unlike approach iii, it does not require the HCO to directly establish sessions with all routers in the network and avoids the dual write problem.

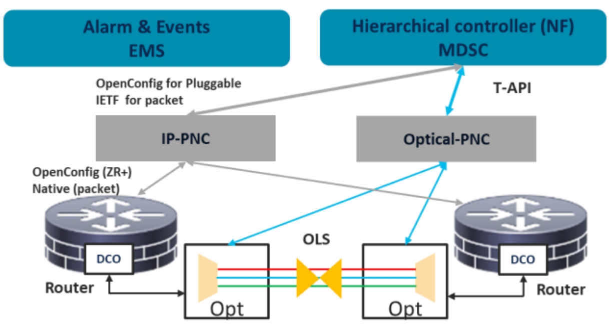

Fig. 1 Architecture

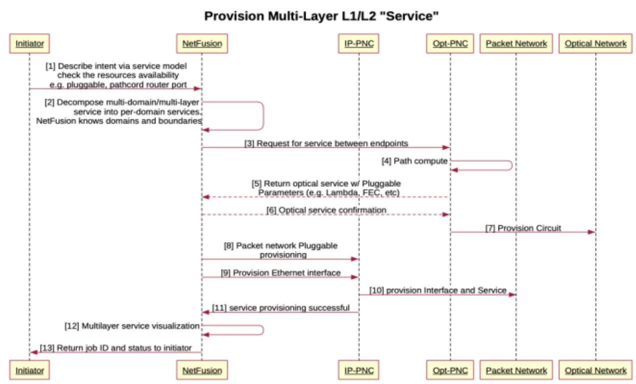

Fig. 2 Provisioning Work-flow

2.2. *Controller Operations*

Each domain controller (IP and Optical) discovers their respective topologies and equipment inventory. The HCO collects the topology of both domains through the API of the domain controllers and constructs a complete multi-layer topology. To discover the inter-layer links (the connections between the router and the OLS), the HCO initiates (via the IP controller) a pattern transmission or power modulation on the TX pluggable. The HCO then requests that the optical controller report the OLS RX port which detects the pattern or the power. If the procedure is successful, the inter-layer link is discovered by the HCO and added to the multi-layer topology.

Additionally, the HCO needs to collect and to share the characteristics of the pluggable transceiver installed in the router. This information can be retrieved via the IP controller and must be shared with the optical controller to provide parameters for the circuit routing and optical impairments verification. The pluggable parameters are summarized in the "operational-mode" parameter associated with the pluggable part number. This method is supported by Openconfig models is also planned for adoption by the Open ROADM MSA. Finally, the operational-mode is mapped to the T-API "application-code" to communicate the pluggable transceiver optical parameters to the optical controller.

The HCO is the only controller having the full network view and plays an important role in service provisioning. The HCO can understand the operator service request and evaluate how the request can be decomposed into multiple requests to the domain controllers as illustrated in Fig 2. Further, the HCO provides other functions like multi-layer network and service visualization, assurance, and troubleshooting.

3. Multilayer Network with Hierarchical Controller Test and Results

Our testbed consisted of 5 physical Cisco ASR 9000 and NCS 5500 routers and one virtual router. There were 2 ZR WDM interfaces creating a 400GE link over dark fiber (Monterey to Phoenix) and 2 ZRP interfaces creating another 400 GE link over a point-to-point optical line system (Los Angeles to Phoenix). The OLS was a pair of Cisco NCS 2000 ROADM nodes with a 30 km fiber span. Additionally, there were 5 IP links over dark fiber to complete the topology as shown in Fig. 3. The OLS was managed by Cisco's optical controller (CONC) and the routers managed by the IP controller (CNC). These controllers were coordinated via the NetFusion HCO (as in Fig. 1).

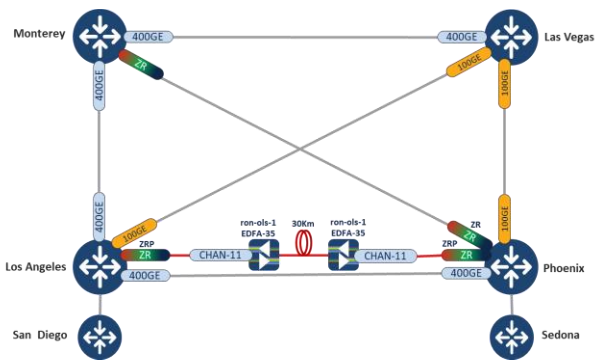

Fig. 3 Test Bed

Fig. 4 Service operational measurements

The use cases we tested were:

1. Multi-layer topology discovery and visualization
2. Provisioning of an IP link between ZRP interfaces over the OLS from HCO
3. Provisioning of Segment Routing policies from HCO via CNC
4. Coordinated maintenance between the IP and optical network

We will focus on the 2nd use case here. The provisioning flow is shown in Fig. 2 and involves interactions between the HCO and both the IP and optical controllers. Based on the service request, the HCO calls the optical controller to calculate the routing, wavelength assignment, and the optical feasibility of the alien wavelength. The HCO uses the returned optical parameters to call the IP controller to configure the router pluggable transceivers. As shown in Fig. 4, the resulting measured optical parameters validate the final configured link performance in both directions. The best indicators of the channel performance are the RX power (within the ZR+ RX power range) and the Pre-FEC BER, which is well within the limit of oFEC error correction capabilities (2.0E-2).

4. Conclusions

Although various control architectures for packet-optical networks have been proposed, these have various drawbacks as discussed in this paper and are not optimal for the case of router pluggable WDM transceivers and open optical line systems. A control hierarchy with a multi-layer HCO and dedicated controllers for IP and Optical does not burden the IP controller with optical requirements and vice versa, does not burden the optical controller with details of the IP devices. Further, it allows devices to only be configured by a single controller such that each domain controller can easily maintain a consistent database. This proposal is well aligned with industry standards for control architectures and data models. The provisioning workflow for the hierarchical control architecture was demonstrated in a live testbed and the resulting service was shown to have acceptable performance as predicted by the optical controller feasibility analysis.

5. References

[1] O. Gonzales, et al., "Experimental Demonstration of service deployment in open packet-optical networks", Optical Fiber Conference, 2020.

[2] B. Mirkhanzadeh1, et al., "Demonstration of Joint Operation across OpenROADM Metro Network, OpenFlow Packet Domain, and OpenStack Compute Domain", Optical Fiber Conference (OFC), 2020.

[3] A. Gonzales, et al., "MUST Optical SDN Controller SBI Technical Requirement for Open Terminals v1.0", TIP/OOPT MUST WG, Telecom Infra Project, https://telecominfraproject.com/, 2021

[4] A. Sgambelluri, et al., "Coordinating Pluggable Transceiver Control in SONiC-based Disaggregated Packet-Optical Networks", Optical Fiber Conference (OFC), 2020.

[5] Open ROADM Multi-Source Agreement (MSA), ONF Open Transport Configuration & Control (OTCC), http://openroadm.org/, 2020.

[6] "TAPI v2.1.3 Reference Implementation Agreement v1.0", ONF Open Transport Configuration & Control (OTCC), https://wiki.opennetworking.org/display/OTCC/TAPI, 2020.