An IPoDWDM Implementation Leveraging OpenROADM Standards for Enhanced Service Orchestration

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ABSTRACT
This paper introduces an IP over Dense Wavelength Division Multiplexing (IPoDWDM) framework that integrates commercial state-of-the-art routing devices and Reconfigurable Optical Add-Drop Multiplexers (ROADMs), adhering to the OpenROADM MSA standards. A hierarchical software-defined networking controller (H-SDNC) seamlessly orchestrates network resource reservation across the DWDM aggregation layer and layer 2/3 through RESTCONF and NETCONF protocols. This first proof of concept paves the way for network architectures that closely integrate multi-layer resources to boost efficiency and flexibility in open and multi-vendor networks.
Keywords: IPoDWDM, OpenROADM, SDN, NMC, RESTCONF, and NETCONF Protocols

1. INTRODUCTION

The growth in data traffic from cloud services, video streaming, and the Internet of Things (IoT) has revealed the inadequacies of traditional network architectures. These architectures typically separate optical transport (Layer 0) from switching/IP routing (Layer 2/3), creating inefficiencies in today's dynamic data environment. Puglia and Zadedyurina note a significant shift towards integrating IP directly over DWDM to address these challenges [1]. A key factor in the growing adoption of IPoDWDM has been the development of coherent ZR and OpenZR+ interfaces, now matching the form factor and power budget of router ports and enhancing the efficiency and adoption of DWDM solutions directly integrated into the IP routers.

This paper describes an IPoDWDM framework that leverages Software-Defined Networking (SDN) principles to merge advanced IP routing with ROADMs following the OpenROADM MSA published standards. A hierarchical controller (H-SDNC) orchestrates commercial network equipment across optical and IP layers using RESTCONF and NETCONF protocols. Key contributions include an SDN orchestration controller, which enables the integration of Layer 0 and Layer 2/3 management, and a network metrics collector employing Prometheus and Grafana for enhanced performance monitoring, heralding a future of more agile network architectures.

2. SYSTEM DESCRIPTION

IP over Dense Wavelength Division Multiplexing (IPoDWDM) represents a significant evolution in modern transport network architecture by integrating the optical transport layer directly with IP services, offering a more streamlined and efficient alternative to traditional transponder-based systems. Unlike conventional setups, where transponders serve as intermediaries that convert electrical signals into coherent optical signals and vice versa, IPoDWDM simplifies the transmission process by eliminating these separate units. In addition to reducing the required hardware layers, this direct integration minimizes the rack space, power consumption, and heat generation typically associated with traditional systems.

In traditional systems, transponders add a layer of physical hardware that increases cost, energy consumption, and space utilization. These standalone devices, necessary for the modulation and demodulation of signals across IP and optical networks, create operational inefficiencies. While providing a reliable and robust solution, these systems require dedicated maintenance and management efforts, thereby impacting the overall network operational cost.

The architecture layout at the bottom of Figure 1 highlights the innovative IPoDWDM setup. Routers at the Service A and Z ends, equipped with coherent OpenZR+ 400G tunable pluggable optics, enable direct DWDM signal transmission and reception. As previously mentioned, this integration streamlines data transmission by eliminating additional transponder hardware, enhancing operational efficiency, and merging IP and optical functionalities into a unified network architecture.

3. CHALLENGES AND REQUIRED SOLUTIONS

Implementing the IPoDWDM architecture introduces specific challenges, such as ensuring interoperability across two network layers (L0 or DWDM and L2 or data link/L3 or IP) traditionally separated and managed by distinct network teams, while at the same time maintaining high transmission performance and reliability. From a manufacturing point of view, advanced cooling solutions and heat-dissipative materials are required. From a network management point of view, hierarchical SDN controllers (H-SDNC) must be implemented to configure

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network devices across the two layers. The successful application of 'alien-wavelength' technologies, as Ventorini et al. [2] demonstrated, highlights the potential for robust DWDM transmission and efficient network operations even in complex multi-vendor environments.

4. SOLUTION PROPOSED BY OPENROADM MULTI SOURCE AGREEMENT (MSA)

Recent OpenROADM MSA standards have refined support for external optical pluggables, addressing previous limitations and expanding network capabilities [3]. Notably, the MSA standards introduce enhanced management of OpenROADM-compliant pluggables and alien transceivers, facilitating seamless integration of these devices into ROADM transport networks. This development leverages controllers, such as the ROADM Network Controller (RNC), to achieve efficient device and service management, including the application of 'alien wavelengths.' As a result, alien devices are now more flexibly managed as part of the Open Line System (OLS), with coordination between the RNC and the end-terminal controller (ETC)/IP-SDNC achieved through a hierarchical controller. This streamlined approach represents a strategic advancement in creating adaptable, interoperable optical networks [3].

5. PROOF OF CONCEPT IMPLEMENTATION

Our proof of concept (PoC) for an integrated IPoDWDM framework features a multi-layered control architecture.

5.1 Implementation Overview

Our solution encompasses a Python-implemented H-SDNC, an IP-SDNC, and the open-source TransportPCE as the RNC. Inspired by the architectural principles outlined by Ceccarelli and Lee. [4] and TelecomInfraProject [5], which advocate for the sophisticated integration of optical technologies within packet networks, the setup is designed for two Cisco 8201 routers each equipped with coherent OpenZR+ pluggables connected to a pair of OpenROADM compliant ROADMs. Our PoC demonstrates the framework's capability to effectively orchestrate network elements at different layers. As demonstrated by Ventorini et al. [2], this approach is consistent with similar advances in DWDM networking showcasing that these integrated network solutions are operationally viable and have potential benefits.

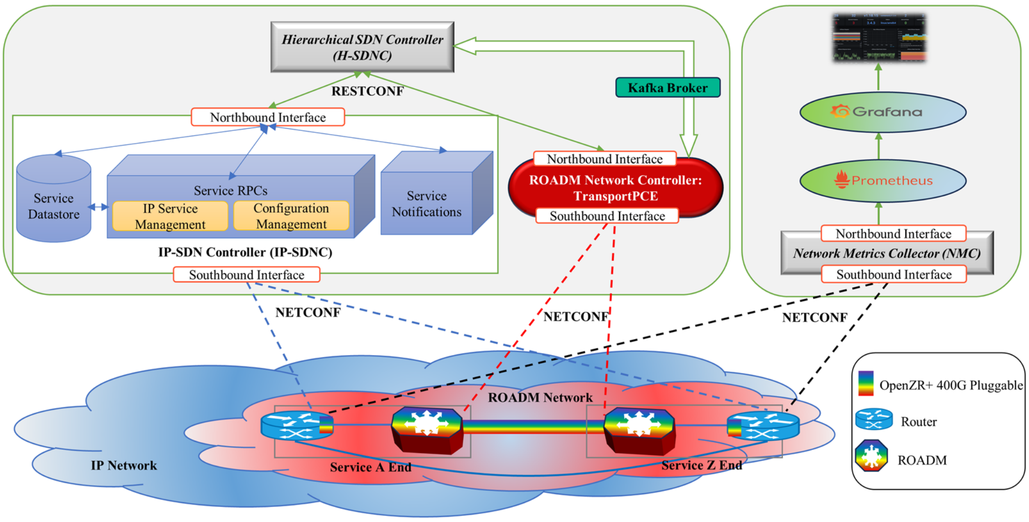

Figure 1: *IPoDWDM High Level Architecture*

Figure 1 delineates the IPoDWDM high-level architecture, detailing the interactions and control mechanisms across a multi-layered network.

5.2 Service Provisioning and Deletion

The operational sequence commences with a service request directed to the H-SDNC for the establishment of a new connection between the routers, as detailed in Figure 2, which outlines the service provisioning process flow. This stage involves the H-SDNC coordinating activities between the IP-SDNC and RNC, progressing through defined steps to enable dynamic service provisioning across the IP and optical domains. Each step is labeled with an incremental number to help trace the order in which the steps are executed.

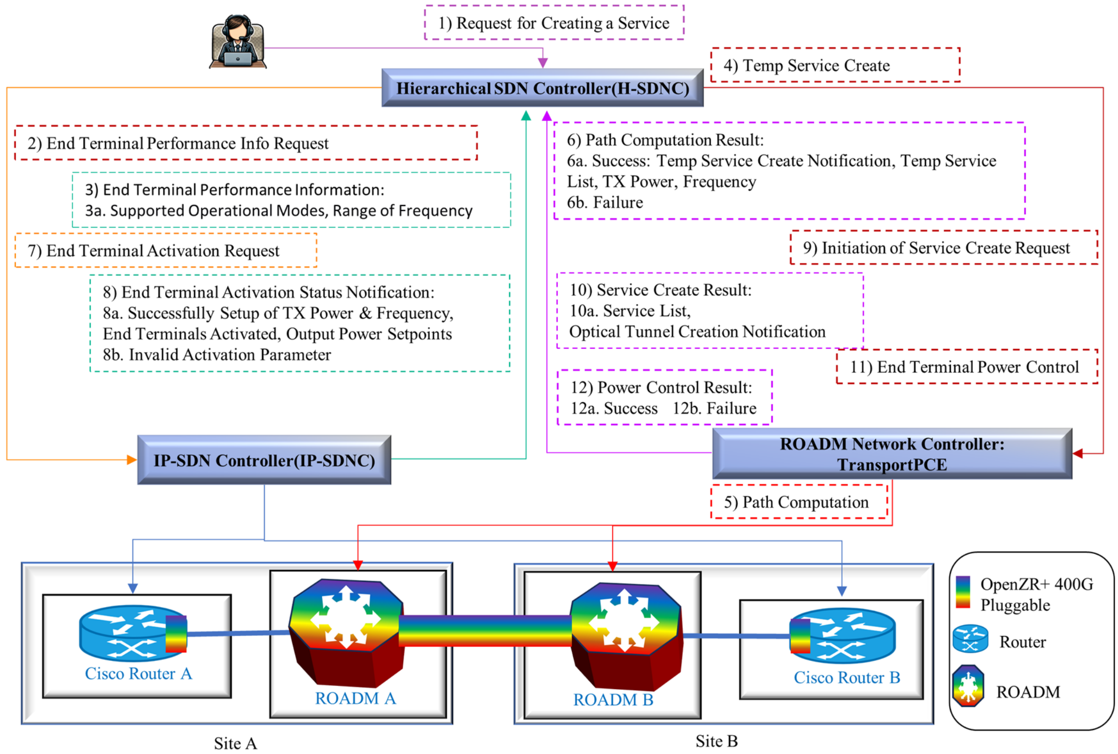

Figure 2: Service Provisioning Process Flow

The steps required to remove a service are shown in Figure 3. Each step is labeled with an incremental number to help trace the order in which the steps are executed. The deletion process ensures the network's operational efficiency and flexibility, relinquishing network resources timely to be redeployed as needed.

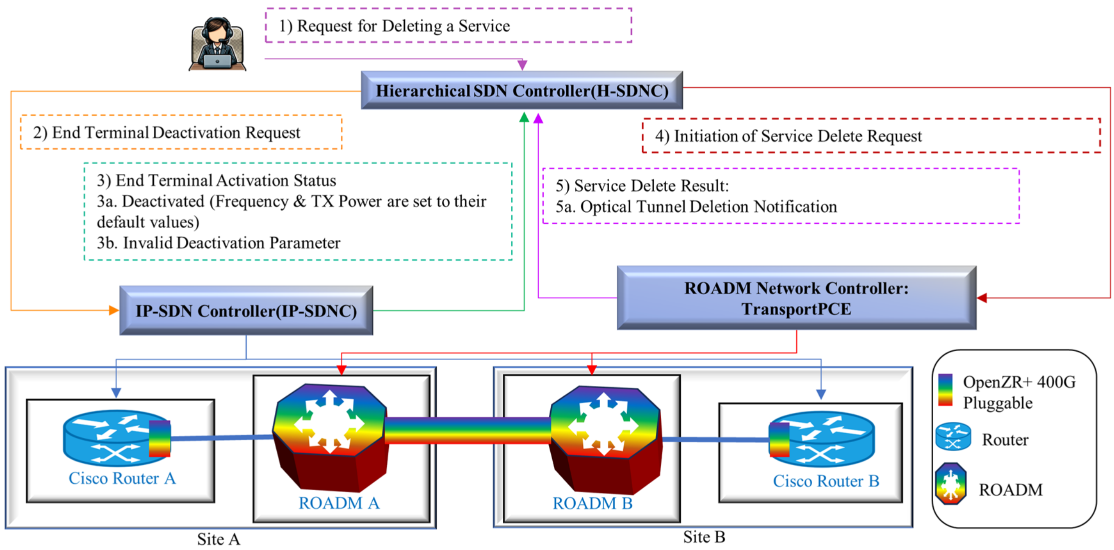

Figure 3: Service Deletion Process Flow

5.3 Performance Monitoring

A Python-based Network Metrics Collector (NMC) uses YANG models and NETCONF to gather key metrics from the coherent ZR+ pluggable, including OSNR, Pre-FEC BER, and transmit power. Prometheus scrapes these metrics from the NMC, while Grafana displays them, ensuring efficient network monitoring and optimization. This setup swiftly identifies and resolves network issues, enhancing service reliability.

6. RESULTS

The results in this section are obtained using our IPoDWDM PoC implementation using commercial equipment. Table I highlights the rapid service management and resource adaptability achieved, with swift processing

TABLE I: Operational Time Metrics for Service Creation and Deletion

Step	Process Type	Time (seconds)	Cumulative Time (minutes)
End Terminal Performance Info Request	*ServiceCreation*	5	0.08
Temporary Service Creation	*ServiceCreation*	209	3.48
End Terminal Activation	*ServiceCreation*	22	3.93
Regular Service Creation	*ServiceCreation*	215	7.52
End Terminal Power Control	*ServiceCreation*	45	8.27
Total Time (Service Creation)		496	8.27
End Terminal Deactivation	*ServiceDeletion*	22	0.37
Service Deletion	*ServiceDeletion*	89	1.85
Total Time (Service Deletion)		111	1.85

observed during both service creation and deletion. These results reflect the network's efficient response to operational demands, showcasing the practical outcomes of the experimental setup.

In terms of performance monitoring, the NMC, along with Prometheus and Grafana, ensures comprehensive oversight by reporting desirable OSNR levels and low Pre and Post-FEC BERs, confirming signal integrity. Grafana dashboards provide insights into operational trends and status. Figures 4 and 5 illustrate satisfactory OSNR at one receiver and error-free data transmission and reliable end-to-end data delivery, respectively.

Figure 4: Optical Signal to Noise Ratio

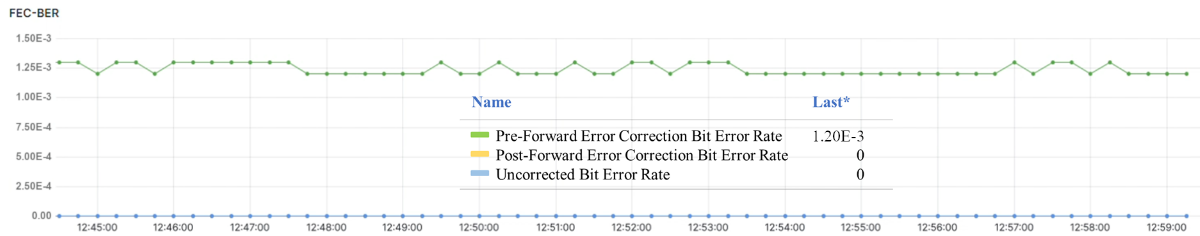

Figure 5: Forward Error Correction Metrics

7. SUMMARY

The IPoDWDM framework improves OpenROADM networks by merging advanced packet routing with ROADMs for scalable and adaptable networks. Central to its design are an H-SDNC, an IP-SDNC, and TransportPCE as the RNC, together enabling efficient service provisioning across multiple layers via RESTCONF and NETCONF protocols. The NMC, combined with Prometheus and Grafana, tracks key metrics like OSNR, BER, and power levels. Our PoC implementation enhances service provisioning time and showcases network cost-effectiveness.

ACKNOWLEDGMENTS

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CITATIONS

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