Demo: Design and Implementation of Hierarchical Cross-Domain Orchestration Using TeraFlowSDN

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***Abstract*—This demonstration showcases the autonomous creation of optical lightpaths across two geographically optical network testbeds, using TeraFlowSDN (TFS) as a high-level intent-based orchestrator for optical service provisioning. Unlike existing approaches that create lightpaths independently within a single domain, our system highlights a hierarchical control model in which a centralized TFS instance coordinates two heterogeneous domain controllers: a vendor-specific controller at Politecnico di Milano (Italy) and a local TFS instance at Sant'Anna School of Advanced Studies (Italy). Southbound adapters enable the translation of high-level service intents into device-specific configurations, making it possible to integrate different controllers and vendors without modifying the underlying infrastructure. The live demo demonstrates automated provisioning of optical lightpaths triggered via a user-friendly graphical interface. The process includes endpoint discovery, transceiver selection, and lightpath establishment, all performed autonomously across multiple domains to support a video streaming service. This work demonstrates the novelty of hierarchical cross-domain orchestration, showing how TFS can unify multi-vendor environments under a single platform with minimal configuration overhead. This lays the groundwork for future developments in automated service provisioning, closed-loop control, and scalable cross-domain networking.**

***Index Terms*—Software-Defined Networking (SDN), Optical Networks, Cross-Domain Orchestration, Network Automation, Multi-Vendor Interoperability, TeraFlowSDN, Transport Network Management, Disaggregated Networks.**

I. Introduction

The current network evolution shows the need for further flexibility, configurability, and management in network architectures to handle the requests of modern applications. For instance, cloud-based services and video streaming platforms require adaptive networks that can scale dynamically and support diverse use cases with low end-to-end service latency. Traditional network architectures, often rigid and difficult to reconfigure, struggle to meet these demands. To address the limitations of current network architectures in terms of management and flexibility, Software-Defined Networking (SDN) is considered a promising solution that separates the control plane and data plane, providing centralized, agile, and programmable control over network resources [1], [2].

SDN controllers function as network operating systems, enabling dynamic hardware management and configuration in network operations. However, managing multiple network domains requires multiple SDN controllers, each potentially handling different aspects of the network. The deployment of multiple controllers introduces the need for seamless coordination and synchronization to avoid policy conflicts and performance bottlenecks. In this context, a hierarchical control model can address these challenges. The architecture consists of a high-level orchestrator that coordinates lower-level controllers, each managing specific optical domains.

In this demonstration, we use TeraFlowSDN (TFS), a cloud-native and open-source SDN controller that supports a microservices architecture [3], [4], to automate optical service provisioning. A centralized TFS acts as the main orchestrator, coordinating two testbeds: one located at Politecnico di Milano (PoliMi) and the other at Sant'Anna School of Advanced Studies in Pisa (Sant'Anna). Both testbeds are equipped with SDN controllers, with SMOptics, a proprietary controller, managing the PoliMi testbed and a separate TFS instance managing the Sant'Anna testbed.

The demonstration focuses on the automation of optical connectivity services, specifically lightpath provisioning, across these two geographically distributed and technologically distinct domains. The system operates by virtualizing the southbound interaction through lightweight adapters, allowing TFS to issue high-level orchestration commands that are translated into vendor-specific configurations via REST APIs. This enables seamless service provisioning without requiring changes to the native controllers.

The key contribution of this work is the demonstration of how TFS, acting as the main orchestrator, can autonomously manage lightpath creation within each domain independently, supporting services such as video streaming with minimal configuration overhead. The integration of multi-vendor SDN solutions and the ability to manage separate optical domains from a single orchestration platform showcases the potential for future automated cross-domain networking solutions.

II. Experimental Testbed Architecture

The demonstration environment comprises two independent optical testbeds, whose integration is shown in Fig. 1:

- **PoliMi testbed**: The optical testbed at PoliMi visible in Fig. 2 consists of three filterless Reconfigurable Optical Add-Drop Multiplexers (ROADMs) [5], a proprietary SMOptics controller, and a Raspberry Pi [1] that acts as a client accessing a remote video streaming service. Each

[1]Weblink (accessed on August 11th, 2025): https://www.raspberrypi.com/

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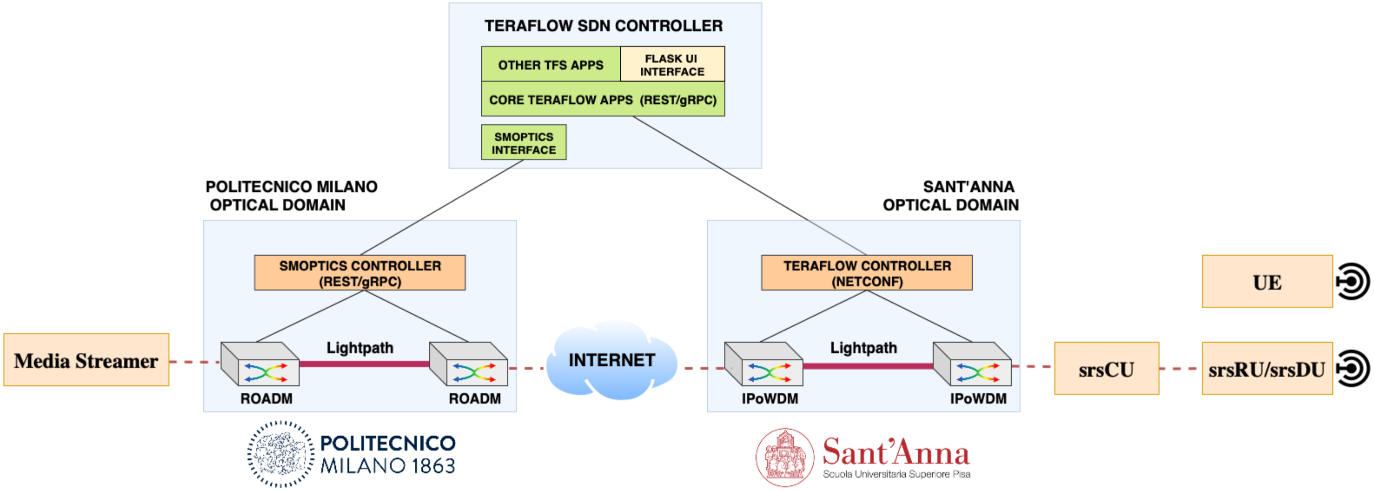

Fig. 1. Cross-domain lightpath provisioning using TeraFlowSDN across heterogeneous optical controllers located at two academic sites.

ROADM is equipped with 10G interfaces to establish 10G non-coherent lightpaths. All ROADMs are managed through the SMOptics SDN controller, which communicates with the ROADMs using REST APIs, enabling orchestration and management of the optical network.

- **Sant'Anna testbed**: The testbed at Sant'Anna also visible in Fig. 3 supports both the radio and the optical technologies, emulating a complete telco operator. The reference scenario consists of a Radio Access Network (RAN). In particular, an x410 Universal Software Radio Peripherals (USRP) is exploited as as Radio Unit (RU) together with srsRAN Distributed Unit (srsDU), srsRAN Central Unit (srsCU). The srsCU and core network are deployed in different physical machines and are interconnected with the optical segment. The optical segment includes two commercial IPoWDM boxes equipped with a pair of ZR+ pluggable transceivers. The boxes are controlled with a local TFS instance, via a NETCONF agent with an OpenConfig model [6], configuring frequency and TX power. The Open5GS CN is exploited to evaluate 5G core network functions. A Quectel UE is connected wirelessly to the RU.
- **TFS**: The centralized instance of TFS communicates with both domains using Flask-based[2] User Interface (UI) apps that leverage REST/gRPC services tailored to each controller's proprietary API. These apps handle endpoint discovery, service instantiation, and translation of orchestration commands.

The Graphical User Interface (GUI) allows the operator to select endpoints from both the PoliMi and Sant'Anna domains and request the creation of a lightpath to establish connectivity between them. In the PoliMi domain, a lightpath is created to enable connectivity through the local optical network, and a corresponding lightpath is established in the Sant'Anna domain to ensure seamless connectivity across the domains. TeraFlowSDN processes the request, validates the compatibility of the selected endpoints, and provisions the lightpaths in both domains through the appropriate adapters. Successful provisioning is confirmed via real-time feedback on the UI, which displays the status of the lightpath creation in both the PoliMi and Sant'Anna domains. The environment is fully virtualized and containerized, simulating optical hardware responses where necessary. This setup allows for remote execution and real-time orchestration of lightpath provisioning, ensuring continuous and efficient connectivity between the two domains.

To provide a quantitative perspective, the system reports a set of key performance indicators (KPIs) collected during operation: (i) provisioning success rate, i.e., the percentage of lightpath requests that are completed successfully; (ii) provisioning latency, defined as the time from the orchestration intent issued at the GUI to the confirmation of lightpath setup; (iii) service setup time, measured as the interval between the provisioning request and the actual availability of the end-to-end service (e.g., video streaming); and (iv) log-based traces of orchestration steps, which expose the sequence of control operations executed during provisioning. These KPIs are exposed during the demo, providing both functional validation and an initial quantitative assessment of the proposed architecture.

III. Demo Implementation

The demonstration is implemented through the development and deployment of a TeraFlowSDN module that acts as an interconnection layer between a vendor-specific SMOptics controller in the PoliMi testbed and centralized TFS's orchestration platform. This module is developed in Python, fully integrated within the TeraFlowSDN microservices framework, and interacts with the SMOptics controller via REST APIs. The module translates orchestration commands into SMOptics-specific REST calls, enabling lightpath provisioning in the PoliMi domain. In the same setup, the Sant'Anna testbed is managed by a separate local TFS instance. Data from the

[2]Weblink (accessed on August 11th, 2025): https://flask.palletsprojects.com/en/stable/

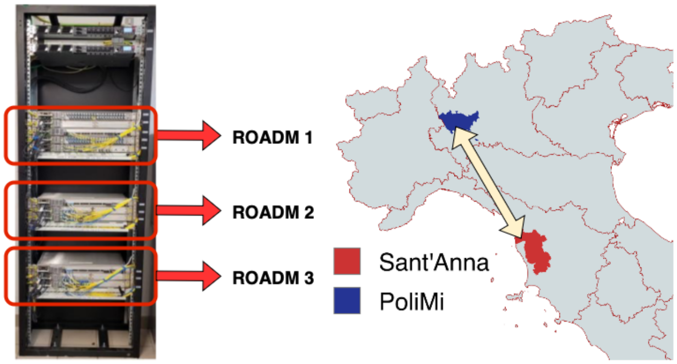

Fig. 2. PoliMi testbed setup featuring three ROADMs and a proprietary SDN controller, along with the geographical locations of Pisa and Mila

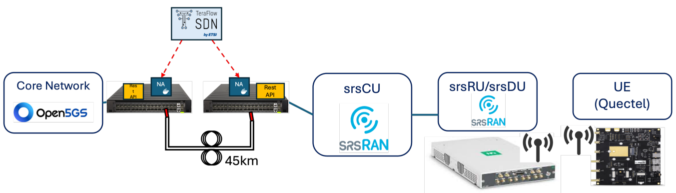

Fig. 3. Sant'Anna testbed setup, showing the integration of radio and optical technologies.

Sant'Anna testbed is made available through TeraFlowSDN's core functionalities, which allows seamless access to orchestration features, as the main TeraFlowSDN controller coordinates both testbeds. This architecture facilitates the unified management of the testbeds from the central TeraFlowSDN instance, acting as parent, which can control the full system.

The module, controlled via a Flask-based web interface, allows operators to: 1) Select source and destination endpoints across the PoliMi and Sant'Anna domains. 2) Trigger lightpath provisioning requests via TeraFlowSDN. 3) Monitor the provisioning status and receive real-time feedback on the provisioning status.

The UI communicates with the TeraFlowSDN core via GRPC [7], issuing orchestration intents that are processed by the interconnection module, which translates these requests into the appropriate actions for the SMOptics controller in the PoliMi testbed. The entire system, including the TeraFlowSDN core, the interconnection module, and the UI, operates within a containerized environment orchestrated by Kubernetes [8], ensuring scalability and portability. This approach, relying on the centralized TeraFlowSDN controller, paves the way for seamless multi-vendor orchestration and the future expansion of the system to support additional vendors with minimal integration effort. The design enables zero-touch optical service provisioning across heterogeneous domains, offering a highly modular and extensible framework.

IV. Conclusion

This demonstration successfully illustrates the autonomous creation of optical lightpaths within two distinct optical testbeds, highlighting the capability of TeraFlowSDN (TFS) to automate optical service provisioning. By leveraging a hierarchical architecture, TFS effectively orchestrates the creation of lightpaths within two geographically distributed domains, PoliMi and Sant'Anna, which are managed by different SDN controllers. The system operates autonomously within each domain, establishing dedicated lightpaths to support a video streaming service, thus ensuring reliable connectivity. The modular approach adopted in this demonstration enables seamless integration of vendor-specific controllers through lightweight adapters, allowing TFS to issue high-level service intents and translate them into vendor-specific configurations via REST APIs. The use of TeraFlowSDN as the main orchestrator ensures that lightpath provisioning occurs without any changes to the underlying infrastructure of the native controllers, demonstrating the scalability and flexibility of the system.

This work confirms the feasibility of automated optical lightpath provisioning in multi-vendor, multi-domain environments and paves the way for future advancements in fully automated, domain-specific networking. With TeraFlowSDN's centralized control and support for dynamic orchestration, the system is ready to facilitate the extension of the framework to support additional domains and vendors with minimal integration effort. Future developments can further refine the system to enable end-to-end service provisioning, advanced telemetry integration, and closed-loop control, leading to more robust and efficient optical transport networks.

Acknowledgment

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