Model-based Service Provisioning in Optical Networks

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Abstract
To support increased traffic demands and facilitate rapid network expansion, we propose a digital twin software architecture considering its design paradigms using OpenROADM to enable performance analysis in optical networks. A service provisioning use-case is presented, showcasing its potential in optical network management.

Introduction

With the advent of 5G-and-Beyond services, the optical transport network (OTN) is required to have network operations that support dynamic service configuration. The performance analysis of the current network state is of paramount importance for optical service provisioning and reconfiguration[1]. This can be achieved by monitoring the network continuously, which helps network operators to respond promptly to any network-related issues while provisioning the optical channel dynamically. An important aspect is to guarantee that service provisioning and reconfigurations do not affect the service level agreement (SLA) of existing active services.

The digital twin (DT) is a paradigm that has been adopted across various industries to virtually model physical entities and understand their behavior under various scenarios[2]. DT has emerged as a popular research topic in the telecommunications industry, where it is used to digitally replicate network infrastructure for the purpose of management, automation, and assessment[3]. The development of DT for OTN requires the creation of a virtual representation of optical network elements (NEs) that can configure, monitor, and replicate the real equipment behavior. DT provides access to most NE operational data, including NE hardware usage, which is challenging to model in network simulations.

There have been recent efforts to develop digital twin (DT) models for the optical physical layer. One such model is based on GNPy to estimate the quality of transmission (QoT) for lightpaths[4]. Another approach utilizes deep learning and involves a concatenation of machine learning (ML) models to characterize links and nodes in an optical network[5]. Both of these approaches have limitations in terms of replicating live state data and mirroring complete optical NEs as a DT. A more comprehensive DT-based approach is proposed[6] to reflect the live state data and behavior of optical NEs but lacks synchronized communication between DT and NE.

In our work, these difficulties are addressed by proposing a software architecture integrating DT based on OpenROADM[7] with synchronized communication to the real network. Experimental evaluation of DT architecture is presented with a service provisioning use case utilizing a physical NW setup in OpenIreland testbed[8]. We show that the DT enables a quick and precise evaluation of the performance of existing services as well as the service-to-be-added, in contrast to other simulation platforms that lack knowledge of the physical network leading to inappropriate outcomes.

Digital Twin Architecture

A critical aspect of a successful DT design for an OTN is the close integration between the DT and physical NEs, with synchronized communication for continuous exchange of operational data. This integration is essential to enable effective network management while dynamically provisioning and reconfiguring optical services. In addition, by abstracting the optical components, the DT can provide valuable insights into the network's performance, helping operators make informed decisions and optimize network operations. In this work, a DT for OTN is designed with a low-complexity software stack with key characteristics, such as device abstraction, scalability, model-driven, and network state prediction[7],[9],[10].

The DT architecture, depicted in Fig. 1a, showcases how each optical NE supporting OpenROADM MSA YANG models is mapped to its specific DT, deployed as a docker container[11] with all the NE capabilities abstracted using the NETCONF manager service[12]. PM data from the real NW are periodically polled and stored into InfluxDB[13], which is periodically updated to respective DTs by DT-Agent as shown in Fig. 1a. The DT also has provisions to integrate with estimation tools or ML models trained from data of its network as seen in Fig. 1b where the physical layer data *PHY. DATA* in each DT can be updated using any of the aforementioned methods.

We have forked the repository from open source OTN estimation tool *GNPy*[14] and integrated it with the DT. Each DT representing an optical NE is considered a source and will estimate performance monitoring (PM) data to all destinations in the topology. The estimated PM data are posted to the DT and also GNPy continuously listens for service creation/deletion in the network. Accordingly, the respective PM data of the available services are estimated and updated to the YANG datastore in DT. This integration of the offline tool is expected to provide a less accurate estimation than the DT connected to real NE, which will be evaluated in the next section.

While provisioning the service, the controller application retrieves PM data of the existing channels from DTs and estimates the QoT parameters of the channel going to be configured. Then a suitable channel configuration is identified and the optical channel is configured in the respective DTs where its workflow is depicted in the flowchart in Fig. 2a. Using the OpenROADM YANG capabilities, the optical channel configurations are made between Transponder-Splitter-ROADM DTs with decided bandwidth, center frequency, modulation format, and channel-specific definitions along the service path.

In the context of OpenROADM initiative, the optical NEs are modeled as circuit packs with defined input and output ports is used to specify the configuration of the NE. The YANG data module for PMs within the OpenROADM framework is of an abstract nature and is not utilized by the YANG modules associated with optical channels or interfaces for the purpose of updating PM data. As such, a basic YANG model is defined in DT along with OpenROADM modules as shown in Fig. 1b.

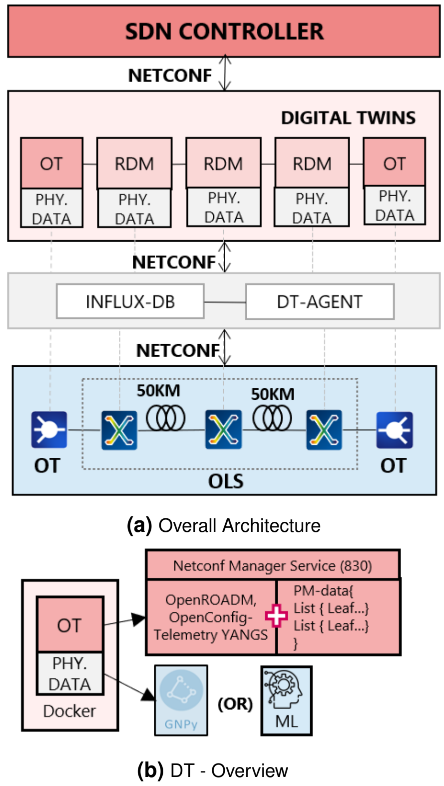


Fig. 1: Digital Twin Architecture - OTN

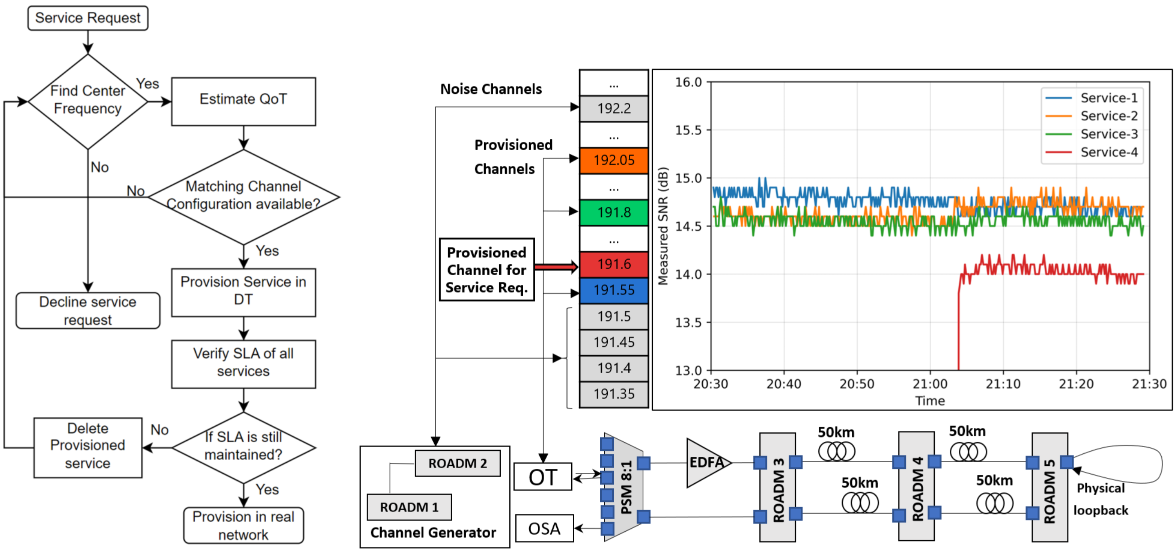
The PM data of the optical channel from the real network or from estimation tools are posted periodically to this user-defined YANG and are used by the controller application to estimate the QoT of the channels. Upon successful service provisioning in DT, the configurations are subsequently replicated to the actual network.

Experimental Setup

The experiment was conducted in OpenIreland Testbed[8], utilizing a topology as shown at the bottom of Fig. 2b. The OTN setup contains two 50-km spans and has a 50-GHz channel spacing. OTs are based on commercially available sliceable bandwidth variable transceivers, configured as 200-Gbit/s 16-QAM. Native channels in the OTN are mimicked by the shaped amplified spontaneous emissions (ASE) noise, generated in the channel loading block. The output of ROADM 1 features a continuous 50-GHz grid of 95 ASE-loaded channels, which are then individually enabled or disabled for transmission in ROADM 2. InfluxDB and DT applications are hosted in a virtual machine connected to the testbed to periodically update PM data.

Results of Service Provisioning Use-Case

For the case study, a sparsely populated spectrum with nine services is provisioned within the OTN. The provisioned channels are located at the



(a) Workflow of Service Creation. **(b)** Service Provisioning and Monitoring SNR in OTN from the testbed.

Fig. 2: Workflow and Provisioning of an Optical Service in Open Ireland testbed.

edge of the C-band with a spectral allocation as shown in Fig. 2b. The monitored OTs integrated into the DT model through the continuous PM data collection and upload to InfluxDB are provisioned at central frequencies of 191.55, 191.80, 192.05 THz, and referred to as Service-1, -2, and -3. The gray noise channels are generated and enabled in the channel loading block.

With the new incoming service request for Service-4, the DT is exploited for the pre-assessment of the service performance before provisioning it in the real production network. The first available free slot in the spectrum at central frequency 191.60 THz is selected for the request. Using the PM data of the existing services from the DT, the QoT estimations can be approached utilizing ML models[15] or parameter-optimized simulations[16]. For simplicity during DT concept verification, we duplicate the PM data of the spectrally closest deployed service and estimate the performance margin present on the neighboring services. Implying this approach with real PM data, the SNR is estimated for the service which is going to be provisioned. With this estimated data, the compatible channel configurations with modulation format, symbol rate, and bandwidth are selected. Then, the service is provisioned in the DT network with all the channel configurations configured using NETCONF. Upon successful creation, the same configuration is mirrored to the real physical network. Fig. 2b shows the resulting SNR plots of the existing services 1, 2, and 3, and the added Service-4 (red).

While service-4 exhibits a lower SNR than its direct neighboring channel, a performance margin of 0.5 dB is sufficient to ensure its performance. For comparison, GNPy integrated with DT is used to evaluate the same network topology. The QoT estimation of Service-4 is performed for similar service requests which results in deviation in the PM data outcomes at a higher margin. This is expected, as the experiment in GNPy has been performed without detailed physical parameters, which are either assumed to be unknown or not applicable to the estimation tool.

This work mainly focuses on service provisioning based on performance analysis from the DT-based network. Each DT is deployed as a docker container with the configuration capabilities of the real NE enabling the scope for assessing closed-loop automation and configuration time analysis.

Conclusions

We have proposed a scalable digital twin architecture to replicate the optical network. The experiment showed that the estimated SNR, with PM data derived from DT network, is reasonably close to the value measured from the real network. The DT-based network management showcases the advantage of mirroring real NW data behavior which helps to make optimal decisions during the network operations. Although work remains to be done, DT-based network management is a promising approach to ensure and maintain the SLA of optical services in a network.

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