Architecture to Deploy and Operate a Digital Twin Optical Network

R. Vilalta[1], R. Casellas[1], Ll. Gifre[1] R. Muñoz[1], R. Martínez[1], A. Pastor[2] , D. López[2], J.P. Fernández-Palacios[2]

[1] *Centre Tecnològic de Telecomunicacions de Catalunya (CTTC/CERCA), Castelldefels (Barcelona), Spain*
[2] *Telefónica I+D, Madrid, Spain*
e-mail: ricard.vilalta@cttc.es

Abstract: We propose an architecture to deploy Digital Twin Optical Networks (DTON), which provide a virtual representation of the physical optical network. DTON allow the assessment of specific behaviors before actual implementation in the physical network.

1. Introduction

With the advent of technologies such as 5G, Industrial Internet of Things, Edge Computing, and Artificial Intelligence, vertical industries are transformed dramatically through replacing what is used to be manual processes with digital processes. Digital Twins (DT) have been defined as the real-time representation of physical entities in the digital world [1]. They provides the necessary virtual-reality interrelation and real-time interaction that allows iterative operation and process optimization. DT have been successfully applied in intelligent manufacturing, smart city, or complex system operation and maintenance to help with not only object design and testing, but also operation and maintenance.

Optical network operations and maintenance are complex due to optical physical impairments that might affect the provisioned lightpaths. As such, providing novel connectivity services on network will be more and more difficult due to the high risk of interfering with existing services and higher trial cost if no reliable emulation platforms are available. This issue is currently fixed through multiple Quality of Transmission (QoT) estimation techniques [2].

A digital twin network platform can be built by applying Digital Twin technology to networks and creating a virtual image of physical network facilities (emulation). Using virtualization techniques, each network node and SDN controller can be emulated [3]. Digital twin network can help enable closed-loop network management across the entire life-cycle, from deployment and emulation, to visualized assessment, physical deployment, and continuous verification. In doing so, network operators (and end-users to some extent) can get a global, systemic, and consistent view of the network. Also, network operators can safely exercise the enforcement of network planning policies, deployment procedures, without jeopardizing the daily operation of the physical network. The benefits of digital twin network can be classified into: a) low cost of network optimization, b) optimized and safer decision-making, c) safer testing of innovative network capabilities (including ”what if” scenarios), d) privacy and regulatory compliance, and e) customize network operation training.

The authors in [4] presented the concept of Digital Twin Optical Networks (DTON). The usage of digital twin technology in optical networks brings more simplification, automatic, resilient, and full life-cycle operation and maintenance to network operators. A DTON is also fed with real-data that might be used for real-time QoT estimation. Thus, the obtainment of real-time data from physical network is of the essence. Optical physical impairments play an important role to consider the specificities for DTON.

Real-time data can flow from the physical network to its twin network. To support this critical objective, ONF Transport API has been extended to provide network telemetry information based on information streams [5]. The introduction of a data collector based on publish/subscribe event bus (such as Apache Kafka) provides many benefits that have been presented in [6].

This paper presents for the first time an architecture to deploy and operate a DTON, and validates it experimentally. Previous work on data streaming [6] has been the keystone for collecting the necessary data for deploying and updating the DTON. To this end, setup and tear-down delays have been measured for a small-scale DTON, based on the ADRENALINE testbed [7].

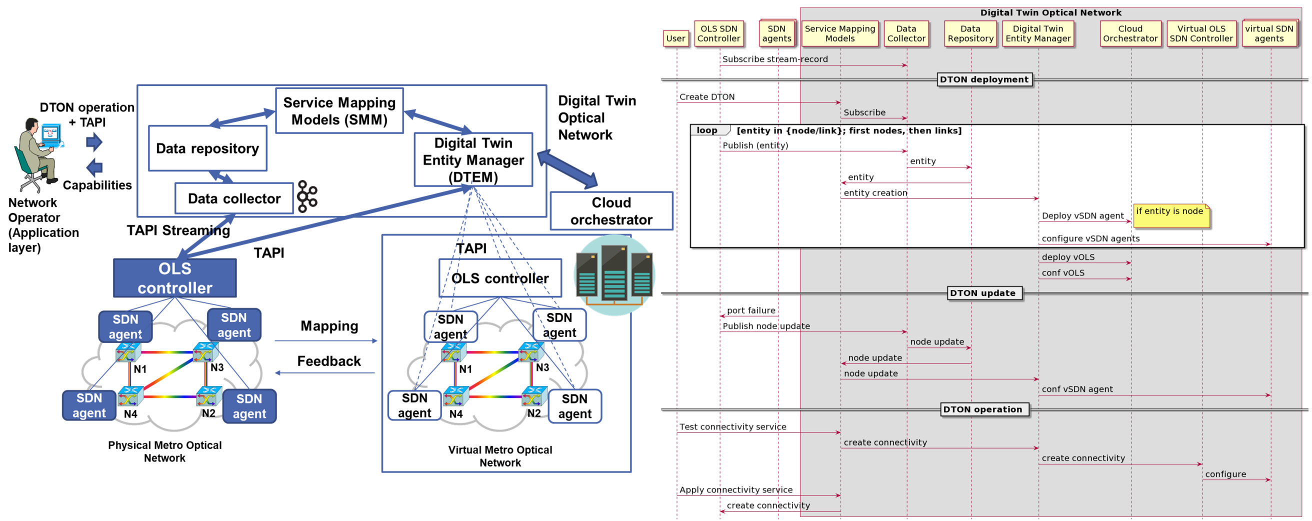

Fig. 1. Proposed architecture (left); Sequence diagram for DTON life-cycle management (right)

2. Proposed architecture

A Digital Twin Optical Network (DTON) is composed of multiple elements that support the life-cycle management of the DT, which might be deployed using a cloud infrastructure (Fig.1 left). Data collector is the data broker based on event publish/subscribe mechanisms. Data repository composes and updates the topological and connectivity views of the physical network. Service Mapping Models (SMM) provides data model instances for various network applications, and maximizes the agility and programmability of network services. Digital Twin Entity Manager (DTEM) provides the management function of DT network, records the life-cycle of the entity, visualizes and controls various elements of the network DT by interfacing towards a virtualization platform (e.g., cloud infrastructure).

The presented DTON life-cycle (Fig.1 right) consists of four phases: a) DTON deployment, where a DTON is requested by the network operator and deployed using virtualization techniques; b) update DTON with real-time adquired data so that DTON reflects current physical network state; c) operate DTON, allowing the network operator to run what-if scenarios and make feasibility studies of novel lightpath deployment; and d) remove DTON.

Previously to DTON deployment, the physical SDN Controller (typically an Open Line System - OLS-controller) shall subscribe to a data collector (e.g., Kafka broker) in order to publish topological and connectivity data streams. In [6], the authors have demonstrated the usage of ONF TR-548 [5] streaming mechanism that handles the providing of information from one system to another in some form of steady and continuous flow based on an event source/server streaming mechanism.

DTON deployment refers to the first stage of DTON life-cycle, where a user requests the deployment of a DTON. This triggers the subscription of SMM to Data Collector, thus all stream-record updates from OLS controller are received (i.e., node and link updates). In case of having a digital twin that reflects exactly the topology (which may not be the case if we want to apply abstract or hierarchical scenarios), for each node, DTEM is responsible to deploy and configure a virtual SDN (vSDN) agent. For each link stream-record, DTEM will re-configure the affected vSDN agent ports. Once all links have been properly re-configured, DTEM triggers the instantiation of a virtual OLS controller (vOLS), which will control the previously deployed and configured vSDN agents. Our DTON will be ready to operate.

Once the DTON is ready to be operated, certain network conditions (e.g., port failure) might affect it and an update of the DTON is necessary. The physical OLS controller publishes updates, which are parsed by SMM. This triggers the necessary re-configuration of the affected vSDN agent.

During DTON operation phase, a connectivity service can be tested through the vOLS, which evaluates connectivity service feasibility (for example using QoT estimator) and the connectivity service is applied to the physical network only if feasible. The creation of a connectivity service in the physical network, will also result in an update of the DTON.

Finally, it is important to remark that the last step of life-cycle is DTON removal. This procedure, requested by the user, will free the virtualization resources by our DTEM. DTEM will remove the deployed vSDN agents and the vOLS controller.

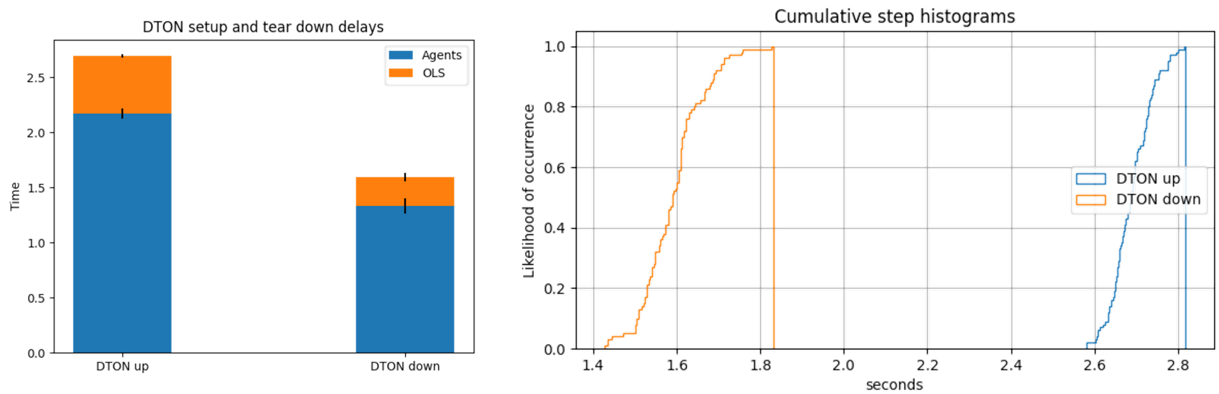

Fig. 2. DTON setup and tear down delays (left); Cumulative histograms (right)

3. Results

In this section, we present the experimental evaluation of the proposed DTON deployment and operation architecture. The proposed physical optical network consist of a hybrid fixed/flexi-grid DWDM core network with 4 whitebox ROADM/OXC nodes, sliceable-bandwidth variable transceivers (S-BVTs) and 5 bidirectional amplified optical links of up to 150 km (610 km of G-652 and G.655 SMF total). Links have 100GHz CS, 50 GHz CS, or flexi-grid using commercially wavelength WSS. OLS controller (Fig. 1 left) provides ONF Transport API 2.1.3 photonic media layer and ONF TAPI streaming [5]. The network element agents implement the front-end towards the OLS with the OpenROADM device model or a REST interface with JSON.

DTON components described in previous section have been developed in Python. SMM subscribes to specific data streams and a Apache Kafka broker has been deployed. SMM are able to receive the log-records and analyse theirs content, storing them in the data repository (MongoDB). DTEM is able to deploy and configure the four vSDN agents and vOLS controller, through the deployment of multiple containers on top of a Kubernetes cluster (i.e., cloud infrastructure).

Fig. 2 left shows the setup and tear down average delays (over 100 times) for deploying and configuring the necessary DTON virtualized elements (i.e., SDN agents and OLS controller). DTON deployment and configuration takes arund 2.7 seconds. As we are not abstracting the topology, most of the time is spent deploying vSDN agents (2.2s), and vOLS is around 0.5s. For DTON tear down, the average is around 1.6s. Fig. 2 right shows the cumulative step histogram for setup and tear down DTON. It can be observed that the variance is very low and we can conclude that these times will be affected depending on the topological view of the physical optical network.

4. Conclusions

We have presented and validated an architecture that allows the deployment and operation of a Digital Twin Optical Network (DTON). Its feasibility has been demonstrated, supporting a use case based on verification of QoT before connectivity service establishment. Measurements of the setup and tear down of the DTON have been presented.

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