A Real-time Simulation Framework for Complex and Large-scale Optical Transport Networks based on the SDN Paradigm

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***Abstract*—Thanks to the recent advancements in the Software-Defined Networking (SDN) and Network Function Virtualization research domains, telecom operators are encouraged to upgrade their optical transport networks towards programmable, energy-efficient, service-oriented, and interoperable architectures. The availability of a large set of open-source building blocks, supported by different standardization bodies makes the selection and the integration of such technologies a very complex task. In this context, the INTENTO project has the objective to create an innovative simulation framework by selecting the best technologies and use it to test applications, services, and advanced optimization algorithms in a real environment. In the initial phase, the project designed a large-scale, distributed, and hierarchical Transport SDN architecture, where optical switches and networking functionalities are monitored and dynamically configured through a two-level structure of SDN controllers. On top of that, Virtual Network Functions are optimally deployed and managed by a centralized orchestrator, based on network condition, user requests, and application requirements. Based on this architecture, the project team started to develop a complex simulation environment that harmoniously integrates within the OpenStack cloud: optical node simulators composed by simulation agent and a suitable hardware emulation layer; proprietary SDN network controller designed to enable the innovative optical nodes characteristics; Open Network Operating System as the second level controller, enabling the integration of third-party or standardized models (multivendor environment), based on standardized interfaces and communication protocols. After having described the main components and functionalities already implemented into the simulation framework, the paper concludes by highlighting future research and development activities.**

***Index Terms*—Optical Transport Networks; Software-Defined Networking; Virtual Network Functions; Simulation Framework**

I. Introduction

Software-Defined Networking (SDN) is a cutting edge technology for the deployment of programmable and virtualized service infrastructures. On the other hand, Network Function Virtualization (NFV) emerged as a new network architecture approach to virtually deploy network functions on generic hardware [1]. The state-of-the-art demonstrates that the combination of SDN and NFV enables unprecedented levels of network control, dynamicity, and flexibility [2]–[4]. Telco operators are encouraged to take this opportunity by integrating SDN and NFV into their large scale geographical networks, eventually known as Transport-SDN (T-SDN). However, this integration is not straight forward and poses numerous challenges due to the large scale complexity of the telecommunication networks and the selection of suitable technology from the available open-source projects backed by different standardization bodies.

The INTENTO (INTElligent NeTwork Orchestration Framework) project [5], recently funded by the Apulia Region (Italy), is going to address the aforementioned issues by developing an innovative simulation framework by selecting the appropriate state of the art technologies and integrate them to test applications, services, and advanced optimization algorithms in the real-time and complex T-SDN environment. In the initial stage of the project, a T-SDN architecture has been designed, that incorporates distributed and hierarchical monitoring and deployment of large scale optical switches and network functionalities (i.e., VNFs) by means of a two-level structure of SDN controllers. The level-1 SDN controller manages the optical nodes, whereas the role of the level-2 controller is to allow the integration with third party and multi-vendor environments. The Virtual Network Functions (VNFs) are optimally deployed via a central orchestrator based on the network and user requirements.

Based on the proposed architecture, the project team has built a real-time and complex simulation environment within the OpenStack cloud, consisting of the following functionalities: (1) Optical node simulators consisting simulation agents with the emulated hardware layer, (2) the level-1 proprietary SDN controller developed as the part of this project to manage the advanced optical nodes features, and (3) Open Network

978-1-7281-7343-6/20/$31.00 ©2020 IEEE

Operating System (ONOS) has been adopted as the level-2 SDN controller in order to facilitate integration for third party and multi-vendor environments on standardized communication protocols like Transport API (T-API), NETCONF, and RESTCONF, for both southbound and northbound interfaces. It is worth noting that in this architecture real equipment can be integrated into the simulation environment. Automated deployment procedure has been developed to effectively deploy the complete simulation environment. At the time of this writing, to certify the effectiveness of the overall simulation framework the project identifies innovative applications, which will be addressed in the final part of the INTENTO Project.

The rest of the paper is organized as follows: Section 2 presents the overview, goals, high-level architecture of the INTENTO project. Section 3 describes the introduced simulation framework, implemented technologies, and the future goals of the project. Section 4 draws the conclusions of this work. Finally, the acknowledgments are given in Section 5.

II. The INTENTO project

INTENTO Project has the target to implement a Telco-Cloud orchestration platform using open source software modules and standardized interfaces. The telecommunication infrastructure includes all the relevant hardware and software components of a T-SDN architecture, ranging from optical nodes through a two-level network management system, to the overall infrastructure management based on a centralized orchestrator. On top of that, VNFs are optimally deployed and managed by a centralized orchestrator in order to implement and test innovative services and applications.

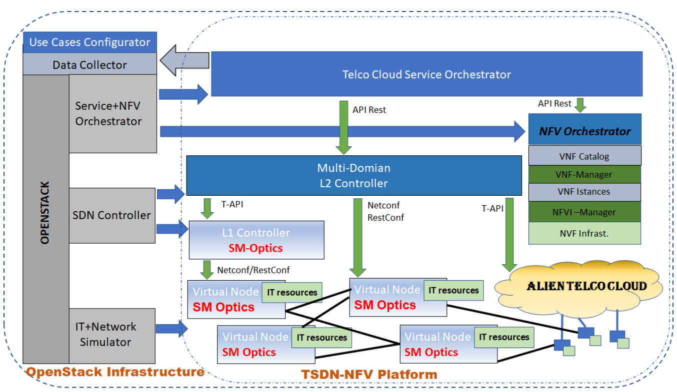

Fig. 1. The conceived high-level framework.

Figure 1 describes the reference architecture of the simulation framework, highlighting the driving factors: 1) development of the node models according the Yet Another Next Generation (YANG) standard, 2) support of T-API interface and NETCONF/RESTCONF communication protocols to ensure the compatibility with existing network standards, 3) support of L1-L3 network layers and related multi-layer management, and 4) implement a NFV infrastructure management enabling the development and testing of VNFs.

The extensive use of a virtualized environment, allow the mix of real nodes and simulators and can be used to reach a very high node count, to test very complex networks.

The Project objectives are supported by an IT infrastructure based on standard servers. More precisely, we aim at demonstrating the overall framework capability of simulating a complex infrastructure management, including optical layer design and planning, multilayer (DWDM / OTN / Packet) management. The simulation framework can be used to carry out complex simulation scenarios, very useful to select the best solutions among alternative option and assess the overall performance. In addition, thanks to the open framework architecture, advanced applications will be selected and tested, i.e., the effectiveness of a set of VNFs, which may be hosted in the optical nodes.

A. *Targeted use cases*

Although embedding multi-level service orchestration architectures in nodes of a telecommunication network is often seen as a way for serving traditional Telco applications as VNFs, this vision leaves out interesting target areas that are non-purely Telco. Indeed, several ICT applications exist that either demand or greatly benefit, from the availability of edge-based processing coupled with synchronous inter-node communication, in terms of low latency, availability, survivability, as well as scalability, especially when all is cleanly modeled as VNFs and orchestrated as such. For example: Content Delivery Network (CDN) for efficient Video distribution, Blockchain processing VNF, Camera processing VNF for social distancing and face mask-wearing rule infringements detection for anti-COVID-19 precaution, IoT data collection and first-level aggregation VNF for sensor arrays, vehicle traffic support systems, and smart grid applications etc.

B. *High-level architecture*

Referring to Figure 1, the items composing the overall architecture are:

1) Telecom Nodes: The simulator of the optical nodes is based on the SM Optics technology and are the base of the Telecom infrastructure, providing the connectivity for each architectural component.

2) Specialized SDN Controller (L1 Controller): The L1 Controller is in charge to manage the Telecom Nodes simulation instances and represent the actual NMS solution for SM Optics nodes.

3) Multi-vendor/Multi-domain SDN Controller (L2 Controller): The L2 controller is supposed to act as a generic SDN controller, based on standard interface, enabling the simulation to deal with multi-domain, multi-vendor environment.

4) VNF Orchestrator: Provide the support for the whole lifecycle of VNF instances, from library management to the actual deployment, to the activation and monitoring functions.

5) Framework Orchestrator: It is based on Openstack and should be intended as the general orchestrator framework needed to exploit all possible services conceived for the proposed infrastructure.

III. The implemented testbed

This section focuses on the technical details related to the implemented simulation framework, while presenting: selected technologies, integrated components, and automated deployment. An example showing the current usage of the simulation framework is discussed as well.

A. Components of the simulation framework

The developed simulation framework consists of:

- *Network Simulation Agent:* The network simulation agents (also known as optical node simulator) are developed to model virtualized optical switches in the network comprising different characteristics i.e., bus speed, number of connecting ports, and type of connectors etc. Each virtual switch can be connected to one or multiple optical switches in the simulation environment.
- *Level-1 SDN controller:* A proprietary SDN controller has been designed and developed as part of the INTENTO project to enable the management and control of simulated optical nodes. The core responsibility of the mentioned controller is the creation and management of the virtualized optical switches on the network simulation agents connected to it. Moreover, it is also responsible for communication with the multi-vendor supportive SDN controller ONOS on level-2. In our proposed simulation environment level-2 SDN controller is connected with a bunch of level-1 SDN controllers associated with an enormous amount of Network Simulation Agents comprising several virtualized optical switches.
- *Level-2 SDN controller:* For the selection of level-2 SDN controller, despite, several open-source controllers available in the industry, the most prominent ones are ONOS and OpenDaylight. The aforementioned controllers allow communication with third-party controllers through the well-known communication protocols available in the industry (i.e., OpenFlow, NETCONF, and RESTCONF). The motivation behind the selection of ONOS in the INTENTO framework is its communication mechanism. ONOS provides support for T-API protocol at the Southbound interface over the REST protocol. In the contrast, OpenDaylight earlier provided support for T-API in their UniMgr project but in the recent releases of ODL, there is no support for T-API, which is the provision in the INTENTO project for communication between the level-1 and level-2 controllers.
- *Modeling language:* YANG is a data modeling language for the definition of data sent over network management protocols such as the NETCONF and RESTCONF. It is used in our project to model both configuration data as well as state data of elements in the network.
- *Application deployment technology:* Containers technology provides an effective way for application deployment. Docker has been selected as the container engine, based on a qualitative cross-comparison of technologies for containerization discussed in [6]. All the executables and the required dependencies for the deployment of the level-1 SDN controller and optical node simulator are packed inside the containers to make the application portable and easily deployable.
- *Operating environment:* The OpenStack cloud has been selected as the Operating environment for the simulation framework. It can virtualize and control large pools of computing, storage, and networking resources. OpenStack has been chosen because of its opensource licensing, wide adaptation in the industry, active community support, and frequent releases of new features as per industry demands [6].

B. Communication protocols and interaction

The network configuration and communication between the components of the simulation framework is carried-out through the following protocols:

- T-API: It is a transport protocol that delivers a flexible North-Bound Interface for integrating SDN controllers in the network by facilitating transport communication through REST API following T-API models, written in YANG.
- RESTCONF/NETCONF: The purpose of these protocols is the communication between multiple controllers and network simulation agents. They provide mechanisms to install, manipulate, and delete the configuration of network devices through remote procedure calls and XML/JSON based data encoding for the configuration data as well as the protocol messages.

C. Achieved implementation and the developed simulation framework

The current simulation framework being developed, integrates deployment of two-level of SDN controllers, within the OpenStack cloud. The proprietary SDN controller developed in this project is deployed on level-1 and an Open-Source multi-vendor supportive ONOS SDN controller has been placed on level-2 in the framework. The optical node simulator, which is also developed as the part of this project is connected to the level-1 and level-2 controllers via the RESTCONF/NETCONF interfaces. As shown in Figure 2, the optical node simulator is dynamically controlled by the level-1 SDN controller. Each optical node simulator represent telecom nodes that can create a large number of virtual interfaces for communication with other telecom nodes. The level-1 SDN controller is connected with the level-2 SDN controller through the T-API interface using the REST API. The level-2 SDN controller can retrieve the information related to simulated nodes either through the level-1 SDN controller or directly from the optical nodes. The topology related information is retrieved through the level-1 SDN controller. The YANG language is used for the communication models between the level-1 and level-2 SDN controllers as well as the optical node simulators. Currently, the level-1 SDN controller can communicate and control the optical node simulators and perform tasks such as creating multiple interfaces on the simulation node, connecting multiple nodes, and defining a network topology. This information is made available at the controller's northbound through the T-API interface. As for the level-2 SDN controller, it is introduced to control and abstract large-scale networks individually handled by each level-1 SDN controller. An customized adapter has been developed as part of this project for the communication between the level-1 and level-2 SDN controllers based on T-API in order to transfer the knowledge of the network topology and other information from the level-1 SDN controllers to the orchestrator.

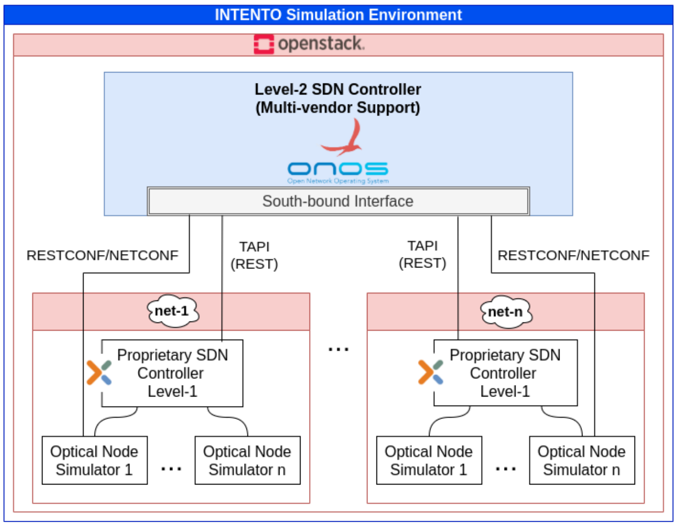

Fig. 2. The developed simulation framework.

D. Automated deployment

An automated procedure has been developed using Ansible, containing YAML files. It creates a 3-layer simulation environment that installs and integrates the level-1 and 2 SDN controllers along with optical node simulators within the OpenStack cloud on the given remote system. The aim of developing an assisted procedure is to minimize the installation time and reduce the complexity required for the creation of the simulation environment for testing. The base requirement for the automated procedure is a local or remote system running Ubuntu operating system.

E. Demo of the simulated optical nodes

As shown in Figure 3, four interfaces are created on the optical node simulator representing a telecom node using the level-1 SDN controller within the conceived simulation environment.

IV. Conclusions and Future Work

This paper presented the vision and goals of the industrial project INTENTO to achieve an innovative simulation framework for the T-SDN paradigm by selecting the best technologies and use it to test services and applications in a real environment. The high-level architecture of the project has been presented and a real-time complex simulation environment

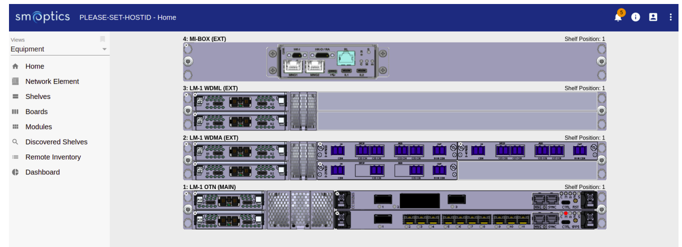

Fig. 3. A virtual telecom node representing multiple interfaces on the optical node simulator.

has been developed within the OpenStack cloud consisting functionalities of optical node simulation agents, two-levels of SDN controllers (one for managing and simulating the advanced optical nodes and other for integrating multi-vendor and third party environments), and communication protocols. A demo of creation of the simulation nodes is also presented in this paper. The future work of the project consists of design and implementation of the routing strategies that ensure energy efficiency and quality of service in the network, Power Management and monitoring applications comprising YANG models for the energy optimization of the framework, implementation at the ONOS southbound for retrieving the actual power consumption data from the optical node simulators and instruct the standby/wakeup statuses, SNMP Management of level-1 SDN controller at the ONOS, and connectivity of the ONOS with the orchestrator. These objectives, when achieved will be discussed in the future versions of the paper.

V. Acknowledgments

This work was mainly supported by the Apulia Region (Italy) Research project INTENTO (36A49H6). It was also partially supported by the PRIN project no. 2017NS9FEY entitled "Realtime Control of 5G Wireless Networks: Taming the Complexity of Future Transmission and Computation Challenges" funded by the Italian MIUR.

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