AI-based Automation of Multi-layer Multi-domain Transport Networks

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Abstract: With increasing demand for customized connectivity, transport networks must evolve towards an autonomous and customer-driven network management. In this paper we describe a AI-based data-driven control architecture to support end-to-end automated slicing in multi-layer networks.

1. Introduction

The increasing demand for a wide range of applications with advance connectivity requirements has surged beyond the capabilities of the traditional one-size-fits-all network connectivity approach within Beyond 5G transport networks. This surge requires flexible and tailored solutions to meet the evolving needs of these applications.

The concept of transport network slicing has emerge to provide advanced customized connectivity in which Service Level objectives (SLOs), Service Level Expectations (SLEs), network sharing preferences or network availability can be requested by the network customers. The resources of the network infrastructure of the service provider can be partitioned in order to support the concept of slicing.

The modern Service Providers networks that need to support slicing are built with a combination of IP/MPLS based network devices, which in the near term will be also equipped with coherent pluggables becoming de-facto multi-layer IP/Optical devices, disagregated otpical transponders, Open Line Systems (OLS), agregated Optical networks and Microwave devices. Provisioning services and maintaining the SLOs/SLEs of network slices in such evolving complex multi-layer multi-domain environment requires unprecedented levels of automation. The complexity of the network layers and services drive the need of using Artificial intelligenge (AI) with a data-driven network management aproach and real time streaming telemetry.

In this paper we describe a standard-based architecture to automate end-to-end multi-layer IP/MPLS transport Networks able to manage the life cycle of transport network slices. The proposed architecture is being implemented and validated using the cloud-native based Software-Defined Network (SDN) orchestration system Teraflow SDN. An AI-based multi-layer path computation approach is implemented to optimize the slice request process, enhancing its flexibility and efficiency, and thereby supporting the evolving landscape of B5G transport networks.

2. Network Slicing Automation Architecture

The functional architecture, depicted in figure 1.a., builds over the hierarchical SDN architecture proposed by Telecom Infra Project MUST operators in [1] and the Yang based automation framework defined by IETF in [2]. This architecture facilitates the network operation thanks the widespread use of Yang-based data models with different abstraction levels. Such data models provide a programmatic approach to represent network services and topologies at the different layers. They can be used during the different phases of the management life cycle and are the key building block to facilitate the automation. The enabled use cases of automation in the transport network go beyond the service provisioning. The architecture allows the service placement feasibility checks before the service is provisioned, the assurance of the intent of the customer, KPI tracking and monitoring and close loop automations.

2.1. Transport Slice Intent: From customer Requirements to Transport Network Slices

The customer-level connectivity requirements are expressed by high-level intents. The concept of an "Intent", as defined in RFC9315, refers to a declaration of operational goals and desired outcomes for a network service without specifying the implementation details. The "customer intent" declares the service connectivity needs as seen by the customer and provides the requirements in terms of resource sharing level, availability, latency, etc. This customer intent needs to be translated into a Transport Network slice, in terms that are understandable and measurable from an IP/MPLS/Optical network perspective. For example, a Service Profile as defined in TS-28.541 [3] can be mapped in IETF network slices as described in [4].

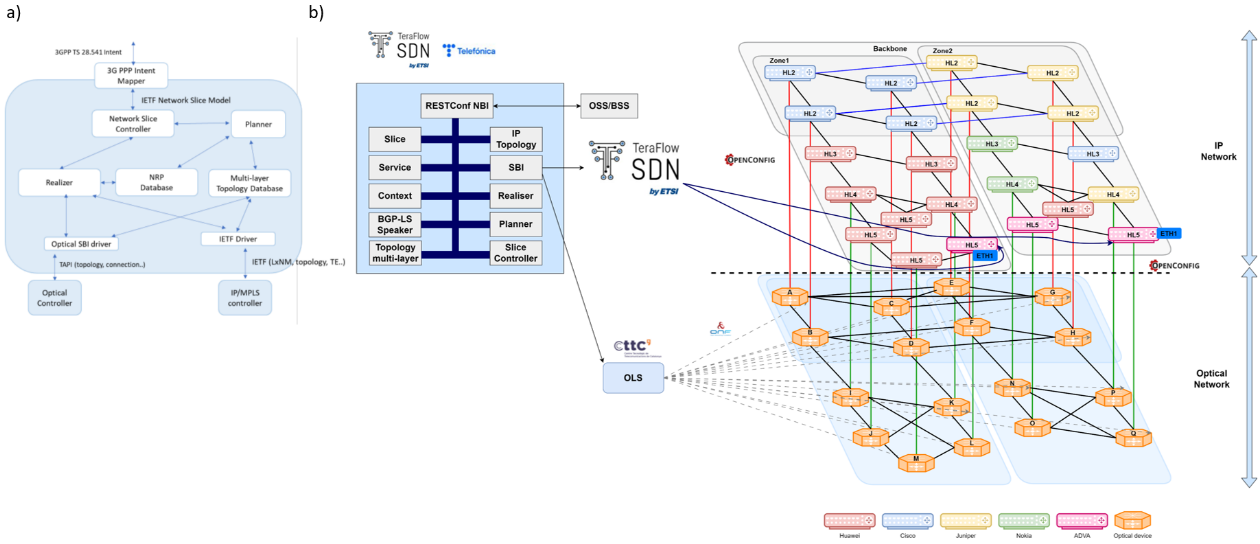

Fig. 1. a) End-to-end slicing architecture, and b) scenario involving TeraFlowSDN orchestrator on top of multiple SDN controllers.

2.2. Network slice controller

The Network Slice Controller (NSC) handles different intents across the network and provides the necessary resources accordingly. It works hand-to-hand with the Network Slice Planning module, which will give a recommendation of the resources to use, and the Network Slice realiser, which will perform the Slice creation, with the aid of the different SDN controllers.

2.3. Network slice planning

The core of the architecture is the multi-layer network planning module. This module encompasses strategic decision-making, resource allocation, and optimisation techniques across multiple network layers. By considering the requirements and constraints of different layers and domains, the network planner aims to maximise the overall performance of the network.

2.4. Multi-layer Topology Database, Network Digital Map and Network Resource partitions

An accurate up-to-date representation of the network topological information is crucial to perform, on the one hand, planning and provisioning tasks, and ,on the other hand, periodic optimizations that require a re-configuration or re-asigning resources in the network. The network digital map defines the main topological entities, their role in the network and relationships both inside each layer and between the layers. The map contains the relationship of the topology with the network services and the assurance information. The Network Resource Partitions are as defined in [5] as ”a subset of buffer/queuing/scheduling resources and associated policies in the underlay network”. How much resources are dedicated to each NRP and if an NRP is dedicated to multiple slices is an operator’s policy, ideally expressed as an operator intent. The policy will drive the decission on grouping slices with similar expectations in the same NRP.

2.5. IP/MPLS Network Controller

The IP/MPLS network controller offers a Yang-based layer in which IP/MPLS services, such as Layer-2 VPNs [6], layer 3 VPNs [7], Peering services, Access Control Lists and routing policies are exposed and can manipulated in a vendor-agnostic fashion. It is also in charge of provisioning the attachment circuits to the customer. In adition, it exposes the topology and summarizes the use of resources. With the help of IETF-based topology models, an accurate view of the network is exported. In order to provide slicing support, Traffic engineering is crucial. In the envisioned architecture, segment Routing policies, either based on MPLS or SRv6, can be requested with a contraints. The controller, by means of a dedicated PCE, is in charge of enforcing the constraints.

3. Experimental Validation of the Transport Network slice architecture

The proposed architecture is validated using the framework of the Teraflow SDN controller [8]. In [9] the authors demonstrated the automation of the VPN service provisioning. Later, in [10] the concept of slicing was introduced for the first time in TFS with hierarchical SDN control. The work is being extended to complete the architecture presented in the paper.

The Teraflow SDN architecture is used to build a full-featured IP SDN controller to interface via Netconf/OpenConfig with the IP/MPLS routers for provisioning, PCEP to support traffic engineering, BGP-LS for real time topology collection and gNMI for telemetry. The communication protocols are built with the netphony network protocols open source suite. Figure 1.b. depicts a hierarchical orchestration/control scenario in which the TeraFlowSDN orchestrator interacts with and manages the underlying specialized domain SDN controllers, which are: TeraFlowSDN IP Controller and Optical Line System (OLS). Depending on the type of slice to be formed, each domain SDN controller configures a distinct network technology.

The Teraflow SDN framework is also used to build the hierarchical controller and the new proposed architectural feature of the Transport Network Slice Controller. The planner is built with Artificial-Intelligence-based algorithm for multi-layer path computation. This technique leverages shared knowledge between the IP and optical layers to provide flexibility and feed more intelligent and efficient planning decisions.

A first prototype of the Mapper between 3GPP TS J28.241 to Network slice according to IETF definitions has been implemented.

In the experiments, each domain SDN controller configures a specific network technology based on the kind of slice to be created. In the IP/MPLS network Segment routing policies are used to steer the traffic following the planning suggestions meeting the SLOs and Layer 2/3 VPNs as the technology to route customer packets. Optical DSR connections are handled on demand using standard TAPI Interface to provide additional resources for the slices.

4. Conclusions

The use of AI and Yang-based data-driven framework facilitates the automation and allows to navigate from top level customer requirements, such as the 3GPP ts 28.541, IETF Network Slice Service with SLOs/SLEs, L2/L3 VPN services, Traffic Engineered Segment routing policies and Optical connectivity services and detailed device models. The architecture is being implemented using Teraflow SDN controller to validate the concepts and asses standard bodies.

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