TeraFlowSDN controlling SDM and wideband optical networks

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Abstract:
A SDN controller based on TeraFlow is designed and implemented to control optical networks including parallel fibers and optical-band switching. An experimental validation is carried out with OpenConfig transponders and OpenConfig augmented multi-granular nodes.

1. Introduction

The TeraFlowSDN controller has emerged in the last years as the outcome of the 5GPPP TeraFlow project and later was established as a new ETSI Open Source Group named as TeraFlowSDN [1]. TeraFlowSDN is an open source cloud-native SDN controller able to scale the management of a large number of flows. Its architecture is modular and based on microservices making use of containers to isolate the functionalities of the components. Each microservice is deployed independently and the communication between them occurs through a custom open interface based on Google Remote Procedure Call (gRPC). This approach provides benefits in terms of resiliency, scalability, and flexibility, much needed in cloud-scale applications. TeraFlowSDN is considered for several use cases: e.g., for secure traffic management [2], and layer-3 networks [3]. However, the optical capacities of TeraFlowSDN are still limited to requesting abstract optical connections to an intermediate SDN controller. Further design, development and testing are needed to make TeraFlowSDN an Optical-ready SDN controller.

An Optical SDN controller should now be designed to account for the evolution of next generation optical networks: e.g., the support of space dimension (space division multiplexing – SDM –, e.g., through parallel fibers) [4] and wideband transmission (e.g., S- and E-bands) [5]. Hereafter, we will refer to *widows* as the S-, C-, and L-bands, while we will refer to *optical-band* as a wide portion of spectrum being an entire window or a portion of it.

In this paper, we design and demonstrate an Optical SDN Controller based on TeraFlowSDN. The Optical SDN controller, other than traditional wavelength Routing and Spectrum Assignment (RSA), supports *dynamic optical-band switching* (FLEX-RSA), where an optical-band circuit can be dynamically configured to accommodate an increasing (or decreasing) number of wavelength channels (over the same path) depending on the traffic needs. The output of FLEX-RSA is then translated into devices' configuration. The device configuration is performed through NETCONF [6, 7] and augmented OpenConfig YANG data models [8]. The provisioning of optical connectivity services based on optical-band configuration is demonstrated.

2. TeraFlowSDN-based Optical SDN controller

The proposed Optical SDN controller is based on the TeraFlowSDN controller, which consists of a modular architecture where several components cooperate with each other through a bus structure – as shown in Fig. 1a – triggering specific functions accomplishing the control and management of the network. To enable the control of an optical network, the TeraFlowSDN architecture is impacted as follows. First, a new component (Optical) and novel South Bound Interface (SBI) drivers for optical devices have been designed and introduced, while the Service component has been extended for optical connectivity services. In addition, a new North Bound Interface

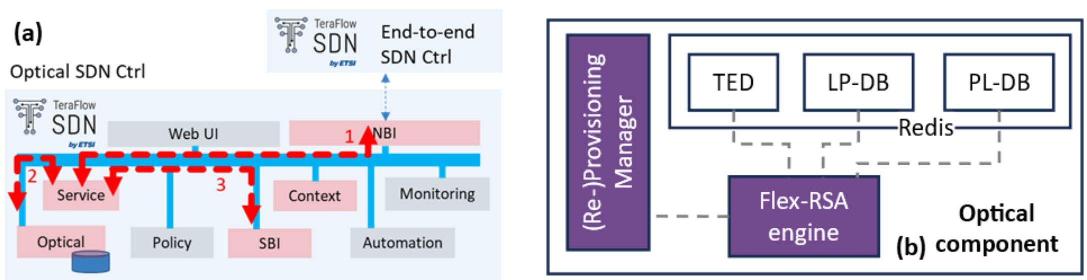

Fig. 1. (a) TeraFlowSDN-based Optical SDN controller and workflow; (b) Optical component.

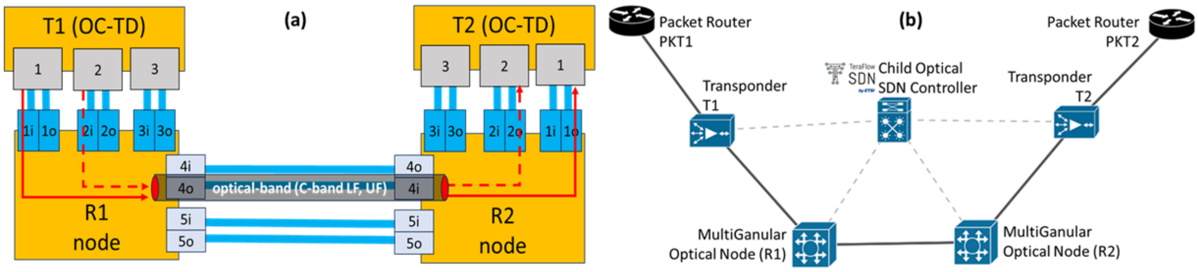

Fig. 2. (a) Scenario of an optical-band; (b) Topology view at End-to-end SDN controller.

(NBI) plugin has been added specifically for supporting optical connection requests issued by an upper layer End-to-End SDN controller (e.g., an orchestrator of IP and optical layers).

The architecture of the new TeraFlowSDN Optical component is shown in Fig. 1b. The *(Re-)Provisioning Manager* is in charge of managing the optical service request defined by parameters including the source, the destination, and the specifications (e.g., requested information rate of the optical service). Once the (Re-) Provisioning Manager receives a request for an optical service provisioning, the routing, space (e.g., fiber Id considering parallel fibers), band, Operational (OP) mode (i.e., a specific combination of modulation format, symbol rate, and FEC driving a line rate), and spectrum assignment (FLEX-RSA) engine is triggered. Thus, the *FLEX-RSA engine* performs resource allocation for the given request. The FLEX-RSA engine also supports optical-band switching, given the wide spectrum offered by S+C+L or E+S+C+L systems. Fig. 2a shows an example of optical-band scenario, with two OpenConfig terminal-device nodes (T1 and T2) and two multi-granular nodes (R1 and R2). A possible multi-granular node architecture, supporting optical-band switching, has been presented in [9]. In the example, the optical-band over the C-band portion in the range LF-UF (e.g., upper-frequency, lower-frequency) is activated between multi-granular node R1 and multi-granular node R2. Two lightpaths, represented in red lines, exploit the existing optical-band. The lightpaths are independent and can be activated at different times. The FLEX-RSA engine exploits a set of databases: the Traffic Engineering Database (TED), the Physical Layer Database (PL-DB) including physical layer information required to perform quality of transmission (QoT) estimation and consequently required to identify the supported modulation format (thus, the OP mode), and a Label Switched Path Database (LSP-DB) storing information on active optical services.

The overall workflow of the Optical SDN controller (Fig. 1a) runs as follows. A request for an optical service arrives from NBI (1), e.g., from End-To-End SDN controller. The endpoints and the connection specifications (i.e., the bitrate) are taken in charge by the Service component, which triggers the Optical component (2) to run the FLEX-RSA. The Optical component reply includes the FLEX-RSA details (e.g., the portion of the spectrum and operational mode) and the rough configuration parameters for each traversed device (flow entries to be configured). Then, the task scheduler of the TeraFlowSDN's Service component is triggered to invoke the SBI drivers (3), preparing the XML messages to configure the data plane devices via NETCONF protocol, according to the YANG model and the flow entry parameters. The Optical component is also able to perform the RSA and the deployment of traditional wavelength-based optical connections, configuring in the proper way all the traversed optical devices.

3. Experimental demonstration

The experimental setup reflects the overall architecture shown in Fig. 1a and the procedure described in the previous section. The topology presented in Fig.2a is composed of four devices, two transponders and two multi-granular nodes. SBI drivers are connected to the NETCONF SDN agents of the devices. Data plane is emulated through its configuration parameters stored in the NETCONF agents. The OpenConfig YANG data models have been adopted. The standard `openconfig-terminal-device` model has been used for the transponders. The `openconfig-wavelength-router` model has been augmented with a section dedicated to the optical-band parameters for the multi-granular nodes, including the optical bandwidth defined by `lower-frequency` and `upper-frequency` tags, and its association to a fiber (because of the presence of parallel fibers).

During the experiment, an optical connectivity service request from T1 to T2 with a bitrate of 400Gb/s arrives from an upper layer End-to-End SDN Controller connected to the NBI of the Optical SDN controller, and the latter runs the FLEX-RSA algorithm. Since no optical-band among the add/drop multi-granular nodes (e.g., R1 and R2) is available, a new optical-band is instantiated assigning a wide portion of the spectrum among the add/drop multi-granular nodes. Currently, the FLEX-RSA has a priority order: C band, L band and finally S band. Then, the edge optical configuration is performed, including the transponder selection at ingress and egress nodes and a cross-connection (e.g., `openconfig-wavelength-router` media-channel) in the add/drop multi-granular nodes, to exploit the optical-band. Fig. 3a shows the captured NETCONF traffic from TeraFlowSDN to the SDN agents in the data-plane. TeraFlowSDN implements NETCONF over SSH, not allowing to dissect the captured packets in

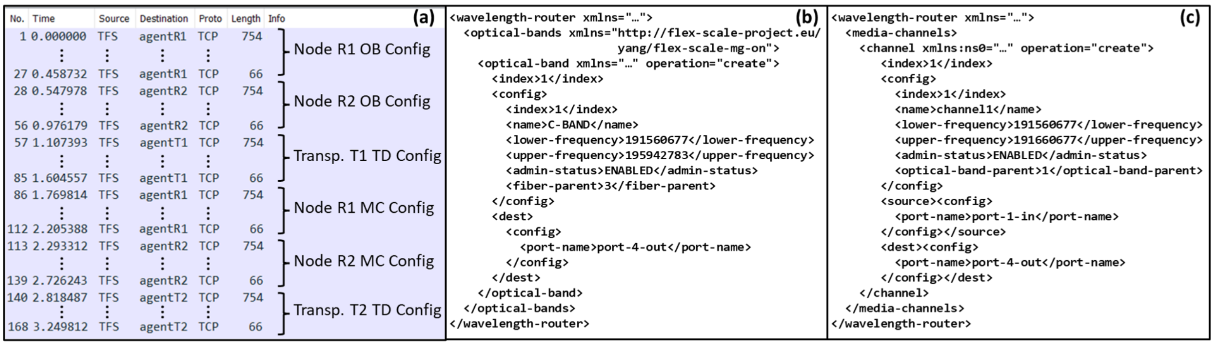

Fig. 3. NETCONF messages (a); edit-config message for optical-band (b) and media-channel (c).

Wireshark, so we extracted the messages from the SBI component's log. The capture starts with the messages sent to configure the optical-band. Messages 1-27 refer to the configuration of multi-granular node *R1*, while messages 28-56 to the configuration of multi-granular node *R2*. In Fig. 3b the details of the XML message sent by the SBI for the optical-band activation are shown. In this case, the portion of the C band comprised between 191.56 THz and 195.94 THz over the fiber with identifier 3 is selected, by configuring the optical-band upper/lower frequency. After the optical-band activation, the lightpath configuration is performed. Then, the messages from TeraFlowSDN towards transponder *T1* (messages $57-85$), multi-granular node *R1* (messages $86-112$), multi-granular node *R2* (messages $113-139$) and transponder *T2* (messages $140-168$), are reported in the exact order. Fig.3c shows the resulting XML sent by the SBI of TeraFlowSDN to multi-granular node *R1* for the media-channel configuration from the add port to optical-band interface. The configuration of transponders *T1* and *T2*, not shown due to the lack of space, is performed in the same way, setting the configuration parameters (i.e., frequency, tx-power and operational-mode) resulting from the FLEX-RSA procedure.

The overall control plane delay measured from the request at NBI to the time the agents process the NETCONF messages is around 3.2 s. The contribution related to the FLEX-RSA accounts for $1-5ms$, with most of the time taken by the NETCONF communication with the devices (around $450-500ms$ for each configuration).

4. Conclusion

This work demonstrates for the first time the TeraFlowSDN Optical component, able to manage optical networks with parallel fibers, space division multiplexing, and optical-band switching. The FLEX-RSA computation contributed $1-5ms$ in the overall optical connection preparation, while the NETCONF communication with the dataplane devices contributed $450-500ms$ for each configuration.

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