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Abstract: The ongoing opening of optical network infrastructures is progressively favoring their automation in terms of maintenance and optimization. A proof-of-concept for the autonomous equalization of independent open reconfigurable optical add-drop multiplexers (ROADM)s via network configuration protocol (NETCONF) is provided in this work. The code has been developed in order to prove the feasibility of a software defined network (SDN) framework, formatting and parsing extensible markup language (XML) requests sent via NETCONF to the ROADMs. In addition, representational state transfer (REST) endpoints are exposed providing power level measurements for each deployed connection. It is shown that the developed interface is capable to set the multiplexer attenuation values in order to equalize all the channels composing the propagating spectrum.

1. Introduction

The application of the openness and disaggregation concepts to optical networks are progressively determining the independent control [1] of the different network elements (NE)s composing the physical layer and their interoperability in multi-vendor infrastructures [2]. This enables a more cost-effective, flexible scaling and independent upgrade of the NEs with respect to legacy static networks [3]. A white-box reconfigurable optical add-drop multiplexer (ROADM) is a device allowing a complete access to the status information, the monitor measurements, and the possibility to configure each part of the system[4]. This enables the use of advanced equalization techniques[5], greater flexibility and modularity in terms of optical network design and implementation [3]. Dually, traditional black-box ROADMs can perform a limited, non-programmable number of operations[6].

The general ROADM architecture considered in this work is represented in Fig. 1. The internal components are a Nx1 port multiplexer (MUX) connected to an optical booster (BST) amplifier and a variable optical attenuator (VOA) on the output line, while an optical pre-amplifier (PRE) is connected to a 1xN port demultiplexer (DMX) on the input line, where N is the number of available ports for each switching component. The MUX combines multiple optical signals creating the wavelength division multiplexing (WDM) comb transmitted over a single optical fiber. On the other hand, the DMX is responsible for splitting a multiplexed optical signal back into its individual component signals. This is typically done using a wavelength selective switch (WSS) or other wavelength-selective element that can be configured to pass or block specific wavelengths of light. ROADM equalization operations are crucial in two main scenarios, which engage the use of the integrated MUX and DMX in aggregating and splitting the propagating spectrum, respectively[7]. In the first case, the MUX equalization defines the launch power profile to be propagated through the corresponding optical line system at the input of the booster (BST) optical amplifier, recovering signal power unbalance of different lightpaths traveling through the optical network or channels added in the considered node. Secondly, the DMX equalization allows to attenuate the dropped channels in order to match the transceiver (TRX) power specifications, avoiding further bit-error-rate (BER) degradation and improving the reliability of the TRX characterization and modeling. This work is focused on the

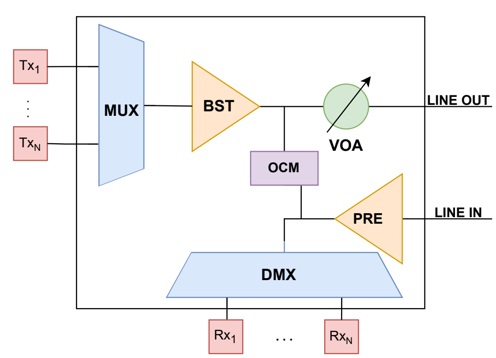


Fig. 1: White-box ROADM architecture.

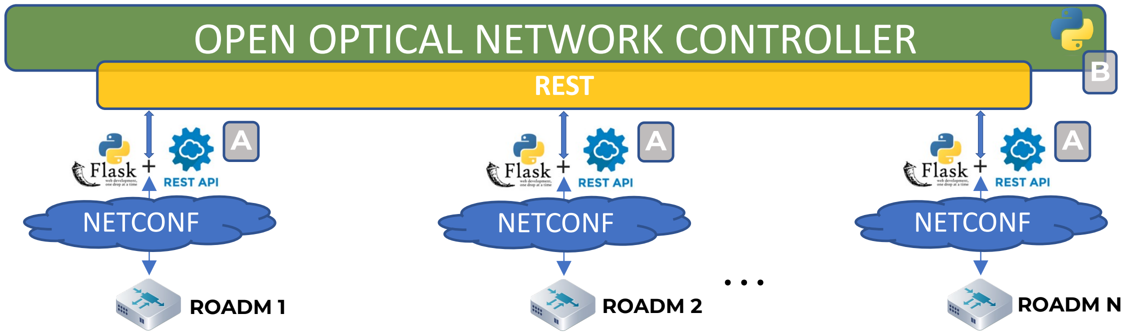


Fig. 2: Conceptual sketch of the software framework: (A) ROADM NETCONF agent; (B) open optical network controller.

equalization of independent white-box ROADMs via network configuration protocol (NETCONF) protocol. In this perspective, a representational state transfer (REST) application programming interfaces (API)s have been developed in order to work as parser for the NETCONF extensible markup language (XML). In particular, a GET interface allows the retrieval of all the power values measured by the ROADM monitors [8] while a POST interface enables to set the attenuation levels of the configured ports. Leveraging on these, it is feasible to implement different equalization strategies. In particular, this work demonstrates the implementation of an automatic flat equalization strategy.

2. Software Framework

As the world of optical networks is going towards an software-defined networking (SDN) approach [9, 10], this software framework has been developed in order to work within such environment. In this scenario, all the NEs are managed by a centralized network operating system (NOS) in charge to keep an active communication session with all the devices [11]. In order to develop a software framework compliant with NOSs approach, the ROADM equalization procedure has been divided into two main parts, as described in Fig. 2. This solution has been chosen in order to be ready for future NOSs support and to reduce the vendor-dependent code.

2.1. ROADM NETCONF Agent

In order to simulate a SDN-NOS environment, each ROADM within the network has to expose data structure related to the monitor power values of each active connection, and subsequently, configure on the corresponding port a provided attenuation value. For this purpose, a Python interface with this dual function has been developed. The code is both in charge of formatting XML NETCONF remote procedure call (RPC) and to extract the data within the RPC-reply from NE. In detail, this has been implemented by exposing two REST endpoints. The first one is a GET operation on the whole power values, sending a NETCONF request to the device, parsing the received XML retrieved by the optical channel monitor (OCM) of the ROADM, shown in Fig. 1, and returning all the power within the reply. The other endpoint works through a POST request that accepts as a body the port attenuation values, which need to be configured on the specified connections. This endpoint generates an *edit-config* NETCONF RPC and sends it to the device in order to set all the attenuation values. Since the developed interface creates and extracts data using XML files, a single instance is defined for each device within the network.

2.2. Open Optical Network Controller

The second software module is responsible to collect all the data coming from ROADM and compute attenuation values, taking advantage of the endpoints exposed by the first module. This choice is dictated by the need to be already compatible with future endpoints developed for NOSs. Firstly, the framework needs to set all the attenuation values on the ROADM to 0 dB in order to obtain the real power values. Thus, the GET operation of the ROADM NETCONF agent is used in order to collect the power values of the connections. At this point, if the difference between the maximum and minimum power levels falls below a certain threshold, equalization is performed. Independently on the chosen equalization strategy, the obtained algorithm output is an attenuation vector with different attenuation values to be applied on each connection in use. Different equalization strategies can be implemented, as long as they produce as output an attenuation vector to be applied to the connections. Once all the attenuation values have been obtained, the tool can exploit the POST endpoint in order to send all the attenuation values to the device. This operation is first applied on the MUX and then on the DMX. This process continues in a loop, with periodic checks and adjustments to ensure that the power levels remain within the acceptable range. By implementing this loop, the optical equalization can effectively compensate for power variations and maintain signal quality over time, enabling reliable long-distance communication in optical fiber systems.

3. Experimental Setup & Results

The involved open and disaggregated optical network is described in Fig. 3. The topology has been built in order to demonstrate the importance and the feasibility of a flat power spectrum equalization for an optical line system (OLS) between two ROADMs. The topology is composed by two Cassini AS7716-24SC, used as source and destination points, and two ROADMs [12] able to route the traffic within the network. The two optical ROADMs rely on the same schema described in Fig. 1 including two flex-grid WSS with a granularity of 12.5 GHz. A 70-channel WDM comb is created at the Node A side. The comb is centered at 193.5 THz and it is composed of channels modulated at 32 GBd with a channel spacing of 50 GHz. The comb is created using 4 modulated channels, centered at 192, 193, 194 and 195 THz and generated by CFP2-ACO/DCO coherent pluggable transceivers provided by Lumentum. Additionally, a commercial wave shaper filter is used to shape the output of an ASE noise source, which generates 66 channels.

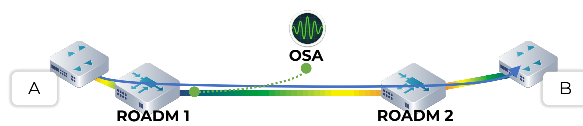
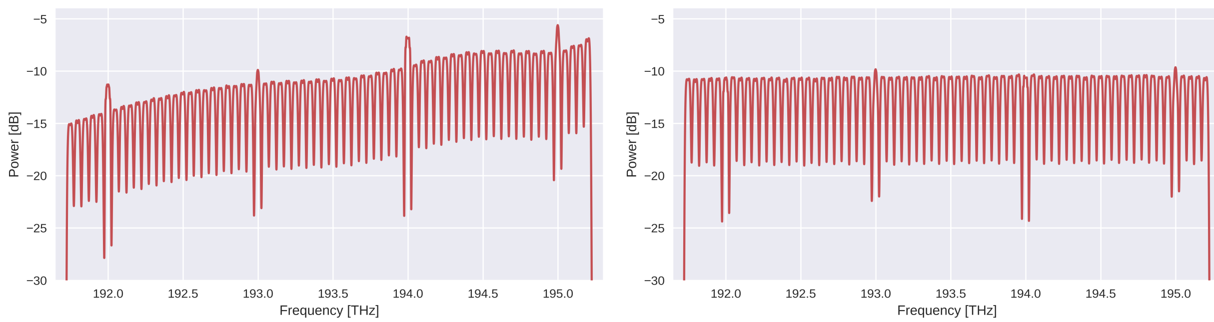


Fig. 3: Experimental setup of the optical network set in laboratory.

These channels are combined with the 4 CUTs to create the 70-channel OLS spectral load. As the aim of this work is to propagate a flat launch power spectrum along an OLS between two ROADMs, the demonstration has been carried out using an optical spectrum analyzer (OSA) placed at the first ROADM output. The results are shown in Figs. 4a and 4b. In this case study the chosen equalization is the flat equalization technique at the exit of the first ROADM. The flat equalization technique has been found to be an effective method for mitigating the impairments in optical networks and it is widely used in practice. By applying the flat equalization technique at the exit of the first ROADM, the optical spectrum can be equalized across all channels, resulting in improved signal quality and extended transmission distances. This technique has the advantage of being relatively simple to implement and can be easily adapted to different network configurations. Overall, the choice of the flat equalization strategy at the exit of the first ROADM is a promising approach for achieving optimal performance in optical networks, and it is expected to provide significant benefits in terms of quality of transmission signal and network efficiency. According to the topology description, Fig. 4a depicts the spectra of the C-band WDM comb after the deployment of all the connections. The measured power difference between the lower and the higher power of the channels is about 8.3 dB, and it can be noticed that the 4 modulated channels clearly stand out in terms of power compared to the others. On the contrary, Fig.4b shows the C-band WDM comb after the completion of the equalization procedure. In this case, the residual ripple of the measured power profile is within 0.2 dB.

4. Conclusions

This work demonstrates the potentialities of open and disaggregated optical infrastructures, highlighting the use of standard protocols as NETCONF and further pushing in the direction of the ongoing standardization process in the optical communication world in terms of NOS functionalities and common interfaces. However, in order to fully realize the benefits of optical spectrum equalization, it is important to have a standard model that can be complied with by all devices. The YANG standard model, such as OpenROADM[13], provides a uniform set of instructions for controlling and managing optical networks, which can improve interoperability between devices and facilitate network management. Therefore, implementing the YANG standard model is essential for achieving optimal performance and ensuring seamless operation of optical spectrum equalization in fiber networks. As a part of the future work, the presence of in-line amplifiers will be incorporated into the investigation of optical spectrum equalization. In-line amplifiers have the potential to introduce additional impairments, such as amplified spontaneous emission (ASE) noise and nonlinear distortion, which can adversely affect the quality of the equalized signal. To address this issue, the impact of in-line amplifiers on the performance of optical spectrum equalization will be explored, and new techniques will be developed to mitigate their effects. By incorporating in-line amplifiers into the equalization process, it will be ensured that the equalized signal maintains its quality over longer distances and across more complex network



(a) Spectrum of the C-band WDM comb before equalization. (b) Spectrum of the C-band WDM comb after equalization.

Fig. 4: Optical spectrum analyzer slots at the exit for ROADM 1.

topologies.

Acknowledgment

This project has received funding from the EU Horizon Europe research and innovation program, ALLEGRO Project, GA No. 101092766, and it has been partially supported by the European Union under the Italian National Recovery and Resilience Plan (NRRP) of NextGenerationEU, partnership on “Telecommunications of the Future” (PE00000001 - program “RESTART”). This research activity has been made possible also thanks to valuable contributions by Links Foundation and Lumentum.

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