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***Abstract*—A line controller architecture for partially disaggregated optical networks is presented, providing automation and interoperability in the use of multi-vendor equipment. Downstream of the architectural definition, the results obtained in an implementation operated on experimental equipment are shown regarding the functioning of the designed interfaces.**

I. INTRODUCTION

The ever-increasing demand for high-speed and reliable data transfer has resulted in a surge in network traffic on optical networks. Cloud computing, video streaming, and IoT devices created exponential increases in bandwidth usage demands that traditional network infrastructure was not ready to handle [15]. In this context, disaggregated optical networks and software-defined networking (SDN) [2, 14] have been identified as promising solutions to address these challenges and optimize the efficiency and scalability of optical networks. Disaggregated optical networks involve the separation of optical components into modular and interchangeable schemes, allowing network operators to combine multi-vendor equipment to meet specific requirements and minimize costs [6]. On the other hand, SDN involves separating the optical control plane from the data plane, allowing for more centralized control and management of network data traffic. The combination of these two approaches provides a powerful solution for addressing the challenges posed by the increasing network traffic demand, necessarily requiring the introduction of some degrees of openness. Consequently, many consortia have been created to allow operators to achieve this goal through the achievement of widely shared agreements [13]. For instance, OpenConfig [8] and Open ROADM MSA [7] proposed several Yet Another Next Generation (YANG) models to enable the control of different network elements (NEs).

However, actual implementations leverage partially disaggregated network models [9], especially in the case of optical line systems (OLSs). Following this approach, portions of a given network can be managed by a single controller in charge of managing a set of NEs through south bound interfaces (SBI). The mentioned controller also interfaces with the central SD network controller via north bound interface (NBI). The authors demonstrated the operation of an open and partially disaggregated optical network architecture, emphasizing on the orchestration of the system relying on the use of the physical layer (PHY) digital twin (DT) for the implementation of the optical control plane and lightpath computation engine [4]. Starting from the latter, this work focuses on the optical line controller (OLC) module, showing the potential of an open architecture in terms of telemetry management and capability of configuring optical amplifiers in a modular and interoperable approach, leaving the possibility of promptly updating or integrating the functioning of the system both in terms of software and hardware. All these are shown in the light of the proposed implementation on a laboratory setup demonstrating the effectiveness of the designed architecture. Furthermore, a possible implementation for an open-OLC is shown and proved via an experimental demonstration.

II. OPTICAL LINE CONTROLLER ARCHITECTURE

This work follows the network architecture proposed in [3]. In particular, the optical nodes are supposed to be controlled in a centralized manner via the SD network controller, whereas OLCs handle all the OLS components, i.e. booster (BST), pre-amplifier (PRE) and optical in-line amplifiers (ILAs). As described in Fig. 1, the arrangement of SDN and partial disaggregation enables the operation of the optical infrastructure in multi-vendor scenarios [1]. Thanks to this combination, each line can be composed by closed single vendor solution having proprietary-code implementation for the SBIs (solution A in Fig. 1). However, following the partially disaggregated network model, all the OLCs should be able to retrieve telemetry information [11] and configure the controlled NEs via common interfaces, suggesting the possibility of an open OLS management architecture. In this perspective, closed solutions do not allow a prompt scalability (e.g. update to the use of multi-band systems) and integration (e.g. introduction of new telemetry devices or sensors) of the infrastructure.

On the other hand, an open OLC can be developed following two different approaches. The first one is the most ecstatic solution exploiting standard data models for the amplifiers and leading to achieve a whole compatibility and compliance between the OLC and NEs. This solution requires vendors sharing common models, resulting in a current non-availability of any product considering the case of optical amplifiers.

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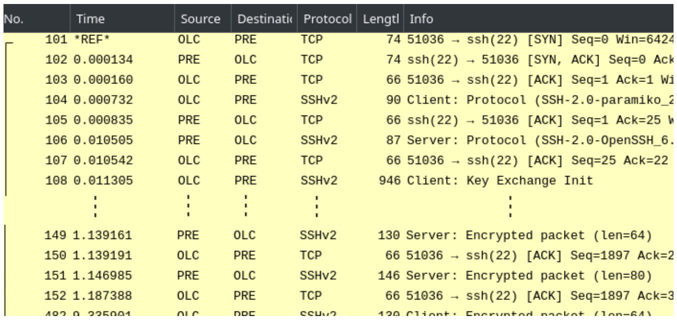
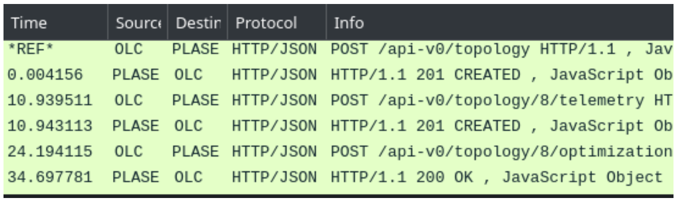


```
No.  Time     Source Destinati Protocol Lengtl Info
 101 *REF*    OLC    PRE       TCP          74 51036 → ssh(22) [SYN] Seq=0 Win=6424
 102 0.000134 PRE    OLC       TCP          74 ssh(22) → 51036 [SYN, ACK] Seq=0 Ack
 103 0.000160 OLC    PRE       TCP          66 51036 → ssh(22) [ACK] Seq=1 Ack=1 Wi
 104 0.000732 OLC    PRE       SSHv2        90 Client: Protocol (SSH-2.0-paramiko_2
 105 0.000835 PRE    OLC       TCP          66 ssh(22) → 51036 [ACK] Seq=1 Ack=25 W
 106 0.010505 PRE    OLC       SSHv2        87 Server: Protocol (SSH-2.0-OpenSSH_6.
 107 0.010542 OLC    PRE       TCP          66 51036 → ssh(22) [ACK] Seq=25 Ack=22
 108 0.011305 OLC    PRE       SSHv2       946 Client: Key Exchange Init
        ⋮       ⋮      ⋮         ⋮                          ⋮
 149 1.139161 PRE    OLC       SSHv2       130 Server: Encrypted packet (len=64)
 150 1.139191 OLC    PRE       TCP          66 51036 → ssh(22) [ACK] Seq=1897 Ack=2
 151 1.146985 PRE    OLC       SSHv2       146 Server: Encrypted packet (len=80)
 152 1.187388 OLC    PRE       TCP          66 51036 → ssh(22) [ACK] Seq=1897 Ack=3
```

Fig. 3. Portion of messages exchanged during connection establishment between OLC and an amplifier.



```
Time      Source Destin Protocol  Info
*REF*     OLC    PLASE  HTTP/JSON POST /api-v0/topology HTTP/1.1 , Jav
0.004156  PLASE  OLC    HTTP/JSON HTTP/1.1 201 CREATED , JavaScript Ob
10.939511 OLC    PLASE  HTTP/JSON POST /api-v0/topology/8/telemetry HT
10.943113 PLASE  OLC    HTTP/JSON HTTP/1.1 201 CREATED , JavaScript Ob
24.194115 OLC    PLASE  HTTP/JSON POST /api-v0/topology/8/optimization
34.697781 PLASE  OLC    HTTP/JSON HTTP/1.1 200 OK , JavaScript Object
```

Fig. 4. Set of REST requests exchanged between OLC and PLASE.

ture has been conducted. At the OLC boot phase, a list of ILAs with their credentials and network references are kept within a database. The sequence of messages exchanged by the controller and the PRE are shown in Fig. 3. The total lapse time to establish a connection between the OLC and the PRE is approximately 1.2 seconds. Since this operation can be parallelized and the number of controlled ILAs can hardly exceed the number of threads of a modern processor, this operation can be considered with complexity of $O(1)$. After the boot is completed, the OLC shares the topology description with the PLASE, saving them into the database and returning to the OLC an unique identifier which can be used for future requests (first couple of requests in Fig. 4). Then, the controller starts a probing procedure in order to retrieve telemetry data needed by PLASE (second couple of request in Fig. 4) to properly feed the PHY model [12]. It is worth noting that this operation can also be implemented using a watchdog periodically obtaining the telemetry and sending it to the PLASE. This allows the engine to be able to exploit a telemetry history instead of a snapshot by perfecting the use of different quality of transmission estimator (QoT-E) strategies.

The last step consists in the request by the OLC to the PLASE to obtain the optimal working points for the amplifiers. Within the body of this request it is possible to specify the type of optimization requested; if not specified, the PLASE uses its own default strategy. For this experiment GNPy is used as QoT-E [5]. Once obtained the working point in terms of target gain and tilt parameters, the OLC accordingly configures each ILA.

V. CONCLUSIONS

In this work, a modular architecture for implementing an optical line controller following a partially disaggregated optical network model is proposed. An experiment is also conducted, demonstrating the feasibility in controlling optical amplifiers and paving the way for the creation of an open-source line controller. Its potential has been shown in a scenario where vendor support is absent. The experiment demonstrated how it is possible to send a telemetry to the PLASE in order to optimize the working point of the amplifiers.

VI. ACKNOWLEDGEMENTS

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