Disaggregated Optical Network Orchestration based on the Physical Layer Digital Twin

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Abstract: The architecture and functionality of an open and disaggregated optical network is presented, focusing on the orchestration of the physical layer digital twin and the optical network controller, implemented on an experimental multi-vendor triangular-topology setup.

1. Introduction

Driven by the increased demand for data traffic in recent years, optical network operators are aiming to avoid vendor lock-in and reduce capital and operation expenditures, in order to maintain efficient and adequate services with reasonable promptness [1]. From observation of the evolution of the current market, and by following the answers provided by the optical communications community in recent conferences, one of the most requested solutions to mitigate these requirements is the introduction of some degree of openness and disaggregation within optical network infrastructures [2]. To enable these innovations, a large effort has been made to encourage operators and vendors to adopt a unified mindset in terms of hardware and software standardization. This has resulted in the birth of multiple projects and consortia over the last decade (e.g. OpenConfig [3], Open ROADM [4], Telecom Infra Project [5]). The central issue for achieving independent and vendor-neutral handling of the control, data and management planes consists of two main themes: the interoperability of multi-vendor equipment forming the physical layer (PHY) – in particular transponders, transceivers (TRXs) and ROADMs – and the choice of shared data structures and protocols. Regarding this last point, combining the YANG data modeling language [6] and the NETCONF standardized protocol appears to represent a valid option to support the outlined scenario [7]. In [8], the authors experimentally validated a partially disaggregated optical network with linear topology (up to 1400 km). In this work the focus is upon optical network control at the PHY level, and highlighting that the network's physical layer digital twin (PHY-DT) has a central role when orchestrating the entire control system to transparently manage traffic requests. First, a more detailed software architecture that is based on the concepts of openness and disaggregation and given in terms of involved actors and functionality is illustrated, followed by experimental results obtained on a network with a triangular topology in a laboratory set-up that consists of multi-vendor open equipment.

2. Physical Layer Control Architecture

The diagram depicted in Fig. 1 provides a general view of the main actors involved in the conceived PHY control framework and how they exchange information. TRXs, ROADMs, optical fiber spools, and optical amplifiers comprise the PHY optical hardware infrastructure. For each switching direction, a booster (BST) and pre-amplifier (PRE) are considered to be combined in a single ROADM. An optical line system (OLS) is considered in this network design as a ROADM-to-ROADM optical line, which includes the control of both the BST and PRE of the

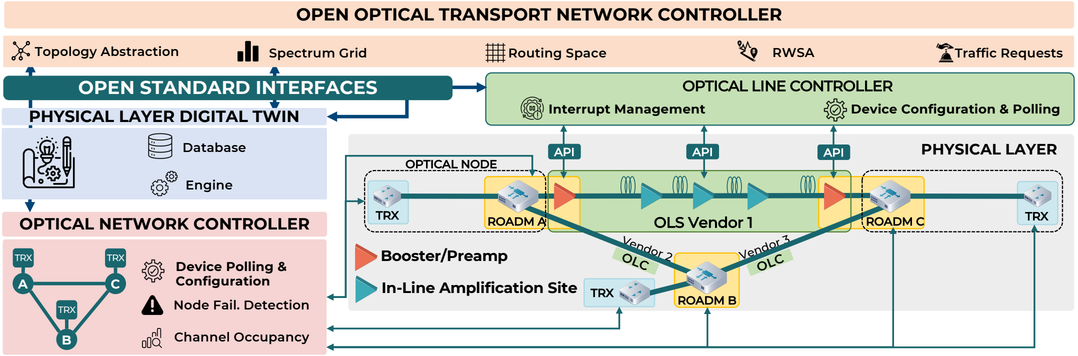


Fig. 1. Representation of the conceived physical layer control architecture acting on a partially disaggregated optical network.

ROADMs at both line endpoints. The optical equipment is governed through the collaboration of three separate software modules: the optical network controller (ONC), an optical line controller (OLC) for each OLS, and the PHY-DT. Communication between modules, TRXs and ROADMs is accomplished through the use of open interfaces and standard protocols. The ONC is aware of the condition of the optical nodes and their connections since it directly controls each TRX and ROADM in the network, allowing it to develop an abstraction of the network architecture and to detect PHY failures. A relevant task of the ONC is to retrieve the channel occupancy/availability for each link within the network. Each OLC manages the corresponding OLS, which is typically offered by a single vendor. The OLC communicates with the amplification sites of the OLS, BST, and PRE via established APIs, gathering telemetry data by means of device polling, configuring the amplifier operating points, and notifying status information derived from interrupt management. The PHY-DT holds PHY-related data, the PHY topology, and executes multiple computational algorithms to complete various tasks. The main PHY-DT's functions are the working point optimization of a given OLS [9] and the LP computation engine (L-PCE) [10]. In order to transparently realize the allocation of traffic requests within the optical network, an additional orchestrator, the Open Optical Transport Network Controller (OOTNC), has been developed, which processes the data coming from the software modules and helps to harmonize the deployment procedure. The OOTNC builds the spectrum grid description, giving a single configuration for the channel frequencies in use via a static external configuration that provides the central frequencies for all optical tributary signals. Then, thanks to the topology abstraction provided by the ONC, the routing space is defined, containing information about all feasible paths within the network and the availability of the channels within them. By exploiting those structures, the OOTNC performs the routing wavelength and spectrum assignment (RWSA), assisted by the PHY-DT transmission performance indicators, according to external incoming traffic requests between pairs of source-destination nodes.

3. Experimental Setup & Results

Fig. 2 represents the laboratory setup reproducing a triangular topology optical network. Three nodes constitute the laboratory-built sample network, each of which is outfitted with commercial TRXs and ROADMs. The nodes are connected by three separate multi-span amplified OLSs, resulting in two optical paths for the channels under test (CUTs). The TRXs are CFP2-ACO/DCO coherent pluggables from Lumentum that are set up to provide 4 separate signals (DP-QPSK or DP-16-QAM modulated) and continually track the associated bit error rate (BER), giving an updated average value every 15 seconds. They are connected to an open network packet-optical box by Edgecore, the Cassini AS7716-24SC, which has line card slots that can accommodate ACO/DCO optical ports based on coherent digital signal processing and optical TRXs. By using NETCONF interfaces, IPInfusion's OcNOS operating system manages the Cassini whitebox and provides setup and monitoring capabilities. The Node A side generates a C-band wavelength division multiplexing (WDM) comb with a 193.5 THz center, 75 channels separated at 50 GHz, and each modulated at 32 GBaud. A commercial wave shaper filter (1000S from Finisar) is programmed to shape the output of an ASE noise source, generating 71 channels that, when combined with the 4 CUTs, assemble the 75 channels OLS spectral load. These 4 CUTs are centered at 192, 193, 194 and 195 THz, respectively. The first straight, LP 1, connects Node A to Node C through 6 spans, each based on a commercial EDFA operating in constant gain mode and followed by a standard single mode fiber (SSMF) of 65 km nominal length; in the middle of the latter, ROADM 2 can drop the CUTs so that their BER can be evaluated, or forward them towards Node C. ROADM 1 can be configured to add the 75 channels and to route them towards Node C either through Line 2A and Line 2B, which together constitute LP 2; these lines are made up of 5 amplified SSMF spans, each measuring roughly 100 km. ROADM 3 eventually drops them whether or not the 4 CUTs are transmit-

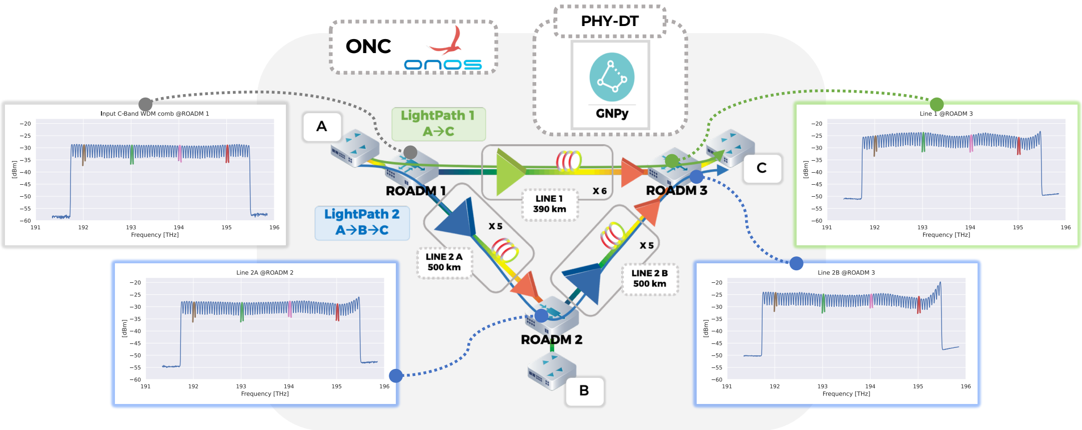
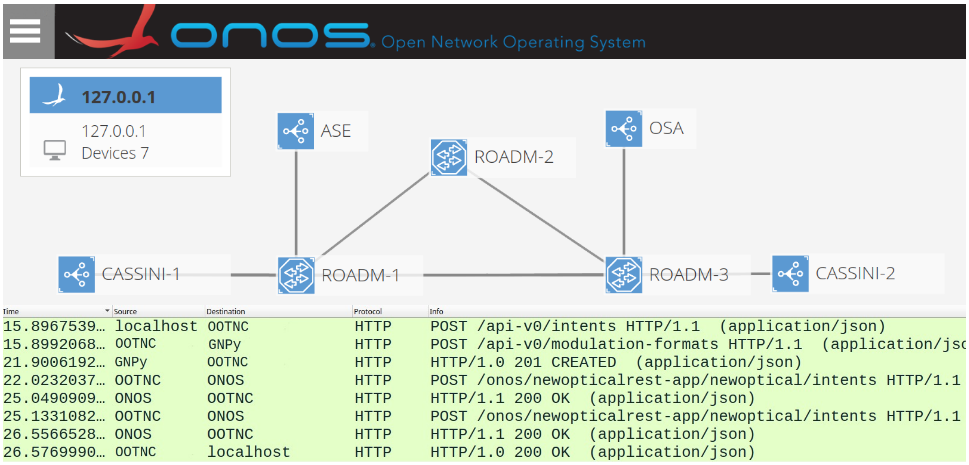


Fig. 2. Laboratory set-up of an optical network with a multi-vendor triangular topology using ONOS as a optical network controller and GNPy as the physical layer model inside the PHY-DT.



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Time              Source     Destination  Protocol  Info
15.8967539… localhost OOTNC        HTTP      POST /api-v0/intents HTTP/1.1  (application/json)
15.8992068… OOTNC      GNPy        HTTP      POST /api-v0/modulation-formats HTTP/1.1  (application/jsc
21.9006192… GNPy      OOTNC        HTTP      HTTP/1.0 201 CREATED  (application/json)
22.0232037… OOTNC     ONOS         HTTP      POST /onos/newopticalrest-app/newoptical/intents HTTP/1.1
25.0490909… ONOS      OOTNC        HTTP      HTTP/1.1 200 OK  (application/json)
25.1331082… OOTNC     ONOS         HTTP      POST /onos/newopticalrest-app/newoptical/intents HTTP/1.1
26.5566528… ONOS      OOTNC        HTTP      HTTP/1.1 200 OK  (application/json)
26.5769990… OOTNC     localhost    HTTP      HTTP/1.0 200 OK  (application/json)
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Fig. 3. Experimental results: ONOS topology abstraction of the laboratory triangular setup; Wireshark data traffic analysis for a connection deployment within the optical network control system.

ted through Line 1 or Line 2. The adopted implementation involves the use of ONOS as a network controller [11], GNPy as a quality of transmission estimator (QoT-E) [12] within the PHY-DT, REST endpoints for the creation of communication interfaces, and OpenConfig YANG data models for abstracting the network topology. ONOS and the PHY-DT are hosted in two different servers in order to emulate the cloud environment. The Secure Shell (SSH) protocol, which enables the opening of a control flow permitting the setting and polling of the EDFA's operating settings and performance monitors, has been used in the implementation of each OLC.

First, the optical network was validated in terms of transmission performance for both LPs, after having optimized the working point of the OLS on the basis of the PHY characterization [8,9]. An intent request of 400 Gbps bit rate between the Nodes A and C is emulated. The pair of nodes is then sent to the PHY-DT, which uses the L-PCE to determine the maximum modulation format possible for all the modulated channels and for all routes with the nodes given as end points [13]. This calculation is based on the PHY topology and the TRX descriptions. The assessed modulation formats are subsequently sent to the ONC through all accessible LPs. Specifically, the LP setup starts examining the availability of every channel for every link connecting the SRC/DST node couple. The RWSA is then applied to the generated table, fully defining the LP in accordance with the required bit rate and according to a predetermined strategy. Based on the transmission performance, the request can be satisfied using two DP-16-QAM (200 G each) through the Line 1. The topology abstraction retrieved by ONOS and the data traffic analysis that shows the management of the request are reported in Fig. 3. The exchange of REST requests shows that OOTNC first receives the modulation formats available on the network by means of GNPy, spending approximately 6 seconds. Then, the OOTNC performs RWSA on the basis of the routing space and the retrieved modulation formats, iteratively defining a connection request for ONOS until the traffic is satisfied. In this case, two connection requests are sent and deployed, satisfying the overall 400 G traffic request within a total time lapse of 4.5 seconds, in agreement with [11].

4. Conclusion

A disaggregated optical network architecture for controlling the physical layer has been presented highlighting the key role of the PHY-DT. The functionality has been tested through an experimental proof-of-concept consisting of a multi-vendor triangular-topology setup, obtaining deployment time intervals compatible with recent analogous works.

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