The Evolution of Open and Disaggregated Optical Networks: From Open Line System to Open Box System

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Abstract: Optical networks have been evolving from proprietary and close systems to open line systems, and further to open box systems. Technologies that enabled the evolution are reviewed and discussed. © 2024 The Author(s)

1. Introduction

Optical transport networks have traditionally operated as closed and proprietary systems due to the inherent analog nature of optical signals. In addition to the tight coupling of hardware components such as optical transponders, wavelength multiplexers/demultiplexers, optical amplifiers, and so on, control and management software has also been closely integrated with hardware equipment. To open up optical transport networks, numerous efforts have been done by academia, standard bodies, network operators and equipment vendors [1,2]. Many projects such as T-API [3], Open ROADM [4], OpenConfig [5] were initialized and their work has been adopted by the industry and successfully deployed in real networks. In the past few years, with the rapid development of inter-data center interconnects (DCIs) driven by hyperscale data center operators, open line systems (OLS) have been proved as a practical way for massive deployment. Modular transport equipment with standardized northbound interfaces and data models is used, and Yang models defined by OpenConfig are widely used. With open and disaggregation, operators have the flexibility to select transponders and line systems from diverse vendors, thereby expediting the deployment of new technologies.

Meanwhile, an open-source network operating system (NOS) known as Software for Open Networking in the Cloud (SONiC) has gained significant popularity in whitebox switches and routers [6]. For operators, SONiC addresses the issues associated with the diversity of vendors' proprietary NOSes. For component vendors, utilizing an open-source NOS greatly reduces development efforts. SONiC has become a standardized NOS for whitebox switches and routers.

In this paper, we review the evolution of open and disaggregated optical transport networks. The initial stage is characterized by the adoption of open line systems, where a transport network is decoupled into terminals, line systems, and management platforms. In the context of mesh networks, the line system can be further disaggregated through optical multiplex sections (OMS) and C + L bands. Network automation plays a crucial role in effectively managing the growing complexity of networks. SONiC has been extended recently to optical transport networks to enable whitebox optical equipment, where an abstraction interface is introduced to handle the diversity at component level in optical equipment. The recent progress on SONiC for optical networks is also discussed in the paper.

2. Open Line Systems

2.1. Point-to-point systems

Open and disaggregated optical networks start with open line systems. The system is divided into three decoupled parts as shown in Fig. 1(a). The first part consists of multiple standalone terminals from various vendors, each operating at different wavelengths. The second part comprises an independent line system that accommodates third-party wavelengths. The third part is a unified cloud-based control and management platform. The protocols employed for communication between the controller and hardware equipment include Netconf [7], Restconf [8], Telemetry [9], simple network management protocol (SNMP) [10], command line interface (CLI), and others.

In a disaggregated system, hardware equipment tends to be implemented as standalone and compact boxes to ensure simplicity and modularity. For instance, in a point-to-point metro DCI architecture, optical multiplex section protection (OMSP) is commonly employed. This configuration typically consists of an optical line protection (OLP) switch, working and protection optical amplifiers (OAs), along with an optical supervisory channel (OSC), optical channel monitor (OCM) and optical time-domain reflectometer (OTDR). These modules are integrated into an OLP card and two OA cards, collectively referred to as an optical line terminal (OLT). The adoption of this standardized configuration facilitates efficient replication and rapid deployment.

Another crucial issue is standardized device northbound interfaces. Operators need a unified interface to manage and control the transport equipment, which is independent of the vendor. Similarly, vendors aim to employ a single data model that satisfies the diverse requirements of all users. We adopt OpenConfig models as our vendor-neutral data models. A lot of work has been dedicated to defining and expanding the models. With the standard models, the effort required for device model adaptation has been significantly reduced.

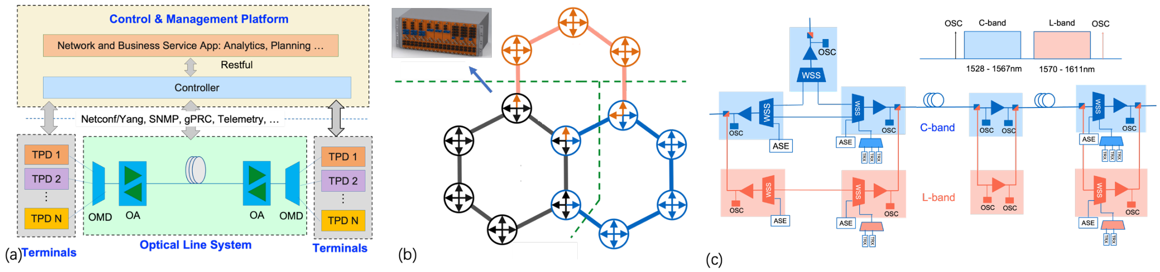

Fig. 1. (a) Architecture of an open and disaggregated optical transport system for point-to-point links. (b) The disaggregated line system by OMS for mesh networks. (c) The disaggregated line system with C + L bands.

2.2. Mesh Networks

Due to stringent latency and bandwidth requirements, point-to-point links are commonly employed to connect data centers in metro areas. However, the fiber count in a point-to-point architecture increases exponentially with the number of data centers. Mesh networks are needed not only in backbone networks, but also in metropolitan regions that comprise numerous small-scale data centers as well. As the line system evolves towards a mesh network, the capital expenditure (CapEx) associated with the line system constitutes a substantial portion of the overall transport system's cost. To overcome the limitations of a single-vendor or a separated multi-vendor line system, it is preferable to further open the line system. A practical approach to achieve this is by disaggregating vendors through OMS. However, within a reconfigurable optical add drop multiplexer (ROADM) node, there are variations in MPO fiber-connectors' standards on the wavelength selective switch (WSS) linecards among vendors, which makes it impossible to directly connect ROADM degrees from different vendors. We design an optical cross-connect (OXC) fiber shuffle [11], as illustrated in Fig. 1(b), to connect each WSS with a vendor-specific fiber interface. This design enables easy scalability of a mesh network as business expands, without being constrained by vendor limitations.

2.3 Disaggregated C + L bands

Another heterogenous case is observed in disaggregated C + L band networks. The increasing demand for high-capacity accelerates DCI towards C + L band networks, particularly in scenarios where fiber resources are limited. To establish a C + L system, one approach is to utilize C + L integrated linecards, which may incur high initial CapEx during network deployment and service interruption as existing C-band systems have to be taken out. Alternatively, a pay-as-you-grow model can be adopted by initially deploying a C band network and later upgrading to a C + L band network as required. However, the vendor providing the L band equipment is usually required to be the same as the one providing the C band equipment. To overcome this limitation, we propose a method to decouple the C and L band systems. The two systems share a single fiber and a common passive C/L filter. Each system incorporates an OSC dedicated to out-of-band communication to decouple their management channel. This design enables a seamless upgrade from a C to a C+L system without vendor restrictions.

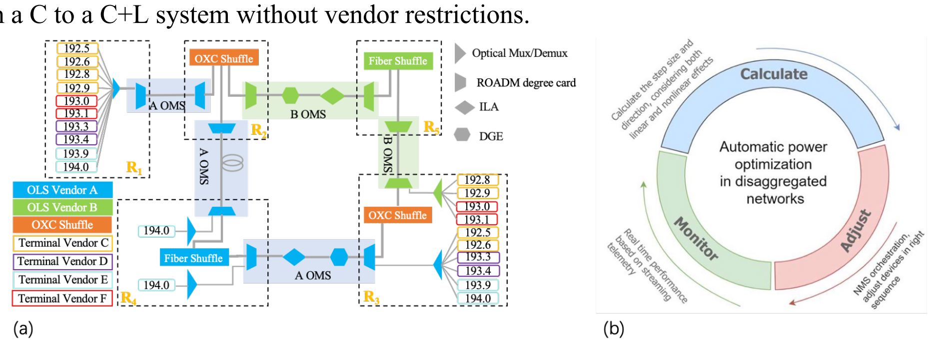

Fig. 2. (a) The setup of a disaggregated ROADM network. (b) The automatic control algorism in three steps.

2.4. Automation

To operate open and disaggregated DCI networks growing at scale, it is crucial to have network-wide programmability and automation with direct access to equipment from the network-layer controller. A network-layer control algorithm is developed to manage power adjustments of each device from different vendors [11]. To demonstrate the effectiveness of the algorithm, we set up a disaggregated ROADM network, with five ROADM nodes, two inline amplifier (ILA) nodes, two dynamic gain equalizer (DGE) node and 22 terminal lineside ports from different vendors, as shown in Fig. 2(a). The automatic control algorism is implemented in network controller with three parts as illustrated in Fig. 2(b). Firstly, the real time performance parameters are collected through streaming telemetry. Secondly, an engineering planning tool is employed to pre-calculate the target power values for every checkpoint along a specified route. In this calculation process, both linear and nonlinear effects are taken into account. Lastly, the network controller iteratively configures the devices in a margin-guaranteed manner using an adaptive step size. The step size is determined by monitoring real-time generalized optical signal-to-noise ratio (GOSNR) margins generated from pre-forward error correction (pre-FEC) bit error rate (BER) of the receivers.

3. Open Box System

3.1. Architecture

In an OLS, standardization is observed in the northbound interface protocol and Yang data models, but the NOSes remain proprietary and vary among different equipment vendors. These proprietary NOSes offer diverse performances, alarm functionalities, CLI capabilities, and have different release schedules. Furthermore, any bug fixes or the implementation of new features must be performed by equipment vendors, thereby impeding the time for fast deployment. Consequently, these variations introduce complexities into open and disaggregated optical networks.

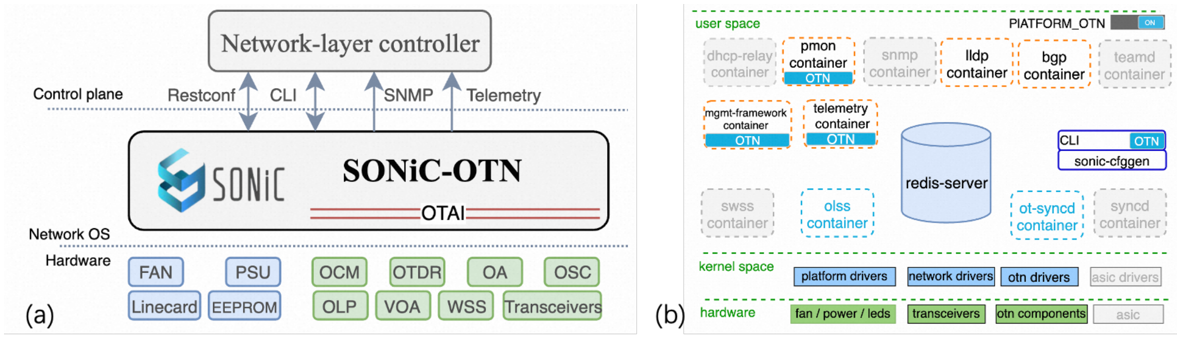

Fig. 3. (a) The software architecture of the SONiC-based NOS. (b) The high-level design of SONiC-OTN.

SONiC offers complete solutions for northbound interfaces, system and peripheral device management. We have developed a SONiC-based NOS specifically designed for whitebox transport equipment. The software architecture of our NOS is depicted in Figure 3(a). Our NOS assumes two key responsibilities, namely, managing the optical hardware components and providing a standardized northbound management interface for the network-layer controller. To achieve a unified and vendor-neutral optical module application layer, we introduce the optical transport abstraction interface (OTAI) [12]. This enables our NOS to effectively manage diverse optical components, including OA, OSC, OLP, and WSS within the same application.

3.2. Progress

We have started the transition from open line system to open box system. This transition is marked by the introduction of the first industry release featuring a SONiC-based NOS for whitebox terminals and line systems [12]. Furthermore, we have made this SONiC-based NOS available as an open-source project within the SONiC-OTN community [13]. The high-level design is shown in Fig. 3(b). The NOS introduces optical linecard state service (OLSS) and optical transport synchronization daemon (ot-syncd) to manage optical components, and enhances the other SONiC services to fulfill OTN requirements. We believe that the adoption of the SONiC-OTN NOS will significantly accelerate the evolution of both optical hardware and software. Cloud operators, hardware vendors, and optical module suppliers will benefit from the advancements made in the SONiC-OTN community.

4. Conclusion

We review the evolution of open and disaggregated optical transport networks. The open line system is characterized by the adoption of decoupled architecture between terminals, line system and management platform, along with multi-layer disaggregation and network wide automation. Meanwhile, the open box system is denoted by the open-source SONiC-based NOS. We build up the OTAI interface to address the vender diversity at component level. A SONiC-OTN community is established to further accelerate the evolution of optical transport networks.

[1] C. Xie, et al., Proc. of the IEEE, DOI:10.1109/JPROC.2022.3178977.
[2] V. Kamalov, et al., OFC, paper M2E.2, 2017.
[3] https://www.oiforum.com/technical-work/hot-topics/sdn-transport-api-2/
[4] http://openroadm.org/
[5] http://www.openconfig.net/
[6] https://github.com/Azure/SONiC/wiki/Architecture
[7] M. Bjorklund, ed., IETF RFC 6020, 2010.
[8] https://tools.ietf.org/html/rfc8040
[9] A. Sadasivarao, et al., OFC, paper Tu3D.3, 2018.
[10] https://tools.ietf.org/html/rfc3411
[11] H. Zhang et al, ECOC, Demo 1, 2021
[12] W. Zheng et al, ECOC, paper Tu5.61, 2022.
[13] https://github.com/sonic-otn