Integration and Control of Heterogeneous Telecom and Data Center Optical Networks Aided by FBD and TAPI for Enhancing Large-scale Optical Path Services and Network Resiliency

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Abstract *A common approach to facilitate the integration/control of disaggregate/legacy optical networks is developed with the aid of a functional block-based disaggregation (FBD) model and TAPI. Integration/control of heterogeneous Telecom and Data Center optical network resources, models, and APIs are demonstrated with a disaster recovery scenario.*

Introduction

Open and disaggregate reconfigurable optical add/drop multiplexers (ROADM) technologies promise to enable Telecom network operators to flexibly select or replace desired functions in optical networks with lower capital expenditures and operating expenditures[1]-[3]. This is also beneficial to operators in case of failure/disaster recovery[4],[5]. OpenROADM was introduced to model the disaggregate ROADM and enhance multivendor interoperability[6]-[8]. In addition, studies towards disaggregate and open data center (DC) optical networks have been conducted[9]-[11]. ONF transport API (TAPI) provides a unified model that facilitates connectivity services across networks[12]-[14]. For disaggregate optical networks, a functional block-based disaggregation (FBD) model has been proposed to describe the entire internal structures and corresponding constraints of disaggregate ROADMs at the component level, e.g., wavelength selective switch (WSS), wavelength blocker, optical amplifier, splitter, coupler, etc[15]. By introducing mapping capability between the FBD and OpenROADM device model, automated node structure update, e.g., inserting a new blade, has been demonstrated[16]. Furthermore, an FBD-based blade abstraction interface (FBD-BAI) has been introduced to unify blade control and ease the use of diverse blades in heterogeneous ROADMs[17]. However, our previous studies[15]-[17] merely focused on disaggregate Telecom optical networks, the diversity in DC optical networks were not tackled.

In this paper, extending our works[15]-[17], we investigate a common approach to and for the first time we demonstrate the integration and control of heterogeneous optical networks in both Telecom and DC scenarios with the aid of FBD and TAPI. We demonstrate large-scale heterogenous resource integration/control to extend the scope of optical path services and ease emergency integration/control of surviving resources in a disaster recovery scenario.

A Common approach for diverse Telecom/DC network integration with aid of FBD and TAPI

Fig. 1 illustrates such an approach with a conceptual reference model, mainly from a modelling perspective from the device to domain levels. With this approach, we can handle the diversities in the underlying vendors' hardware products and upper different network integrators' coexisting device/network models. To ease the integration of different hardware products also the models at different levels and achieve the integrated control, FBD-BAI[17] and model translation middle-ware (e.g., mappers) between different models are introduced, respectively. For hardware vendors such as blades or legacy ROADMs, FBD-BAI enables the wide application of the same hardware products in various scenarios without developing new APIs. For

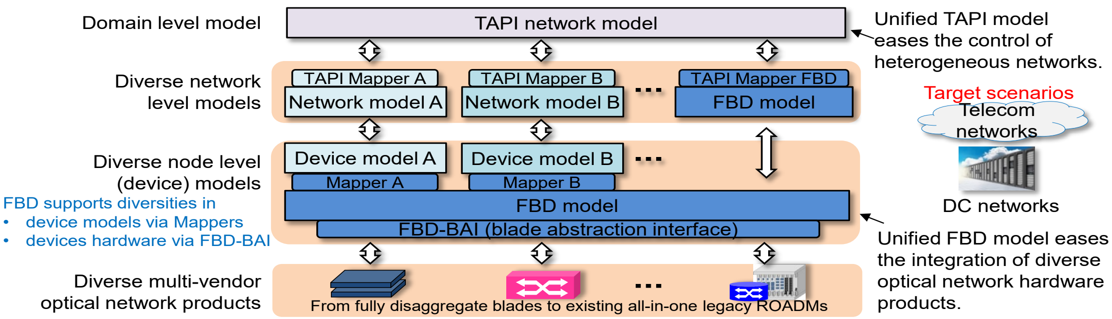

Fig. 1: Reference model for integration/control of heterogeneous Telecom/DC optical networks aided by FBD-BAI & TAPI

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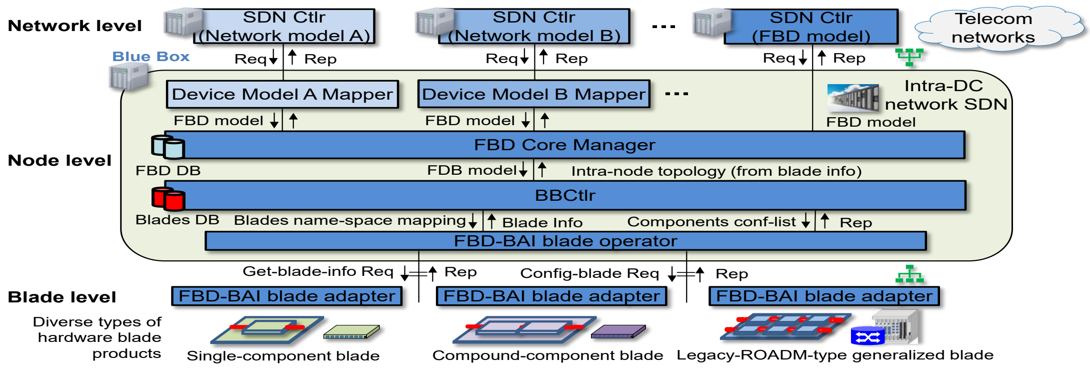


Fig. 2: Unified FBD-based nodal structure in Telecom and DC optical networks

network integrators, with the FBD model and FBD mappers, the underlying hardware can be handled in a unified and abstracted way, which results in simplified systems. For Telecom and DC operators, with TAPI and TAPI-mappers, the integration and control of Telecom/DC optical networks can be achieved, which facilitates the large-scale resource utilization.

Generalized node structure for Telecom & DC

To support diverse hardware products and device/network models in different scenarios (Fig. 1), we improve upon previous works[15]-[17] and develop a generalized FBD-based node structure as shown in Fig. 2. On the bottom of Fig. 2, the FBD-BAI serves as a unified interface that bridges the FBD-based blade models and diverse types of blade products where the FBD-BAI blade adapter wraps different vendor proprietary APIs. On the top of Fig. 2, the device model mappers (e.g., Device Model A and B mappers, etc.) performs automated generation and translation of different device models. With this node structure, different types of Telecom optical nodes and intra-DC optical networks can be operated based on a common approach. As shown in Fig. 2 (right), the FBD model can be employed as both the device and network models. In addition, the FBD model can be employed to directly model and create the SDN system of the intra-DC optical network that is abstracted as a *hyper* node. The integration and control of Telecom/DC networks are demonstrated later.

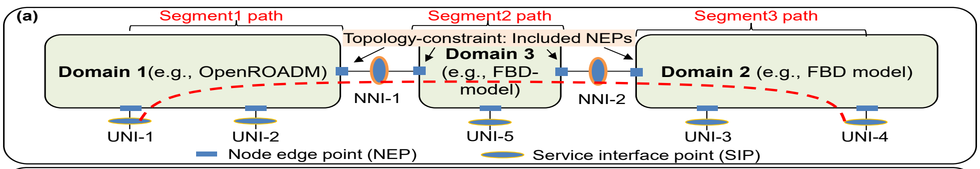
TAPI/TAPI-mappers in Telcom/DC integration

As shown in Fig. 1, in future open and disaggregated network systems, diverse network models will coexist and must be handled in a unified manner. TAPI offers users or upper-level systems such a unified interface to facilitate the application of the underlying networks[12]-[14]. In line with TAPI, we implement TAPI-mappers to first perform a simple modelling translation between the network models and TAPI (Fig. 3). After defining the TAPI inter-domain topology and service interface points (SIP), as shown in Fig. 3a, the mappings between TAPI's SIPs/node-edge-points and the node interfaces in each domain are defined (Fig. 3b). The TAPI-mappers of FBD and OpenROADM are demonstrated later.

Implementation and demonstrations

Fig. 4 shows the demonstration setup which comprises a heterogenous data-plane (D-plane) and a control/management-plane (C/M-plane) with different device/network models. In the D-plane, four ROADMs A/B/C/D were employed. Legacy ROADMs A and D were two WSS-based vendor-x systems, and C was a wavelength-blocker-based vendor-y system. In addition, a disaggregate ROADM B was assembled with two WSS single-component-type blades and two EDFA-array blades to form a directional and colourless ROADM. In the middle of the D-plane, a simple DC optical network was constructed with: (*i*) two optical cross-connects (OXC), one was a core OXC for the ADD/DROP of trans-domain paths, and the other was a top of rack (ToR) OXC for end-host connections, (*ii*) AWG-based Mux/DeMux, and (*iii*) EDFA arrays. It was assumed that after a disaster, to perform swift disaster recovery, *hybrid* node A (highlighted with a damage mark) was damaged and attached with

(a)



(b) **TAPI Mappers**— In our experiment, TAPI mappers define the mapping between TAPI SIPs of the global domain topology and the individual interfaces (IFs) of nodes in each domain which adopts model x.

Domain 1 (e.g.,OpenROADM)

TAPI NNI1	UNI1	UNI2
Domain 1 IF1	IF2	IF3

Domain 2 (e.g., FBD model)

TAPI NNI2	UNI3	UNI4
Domain 2 IF1	IF2	IF3

Domain 3 (e.g., FBD model)

TAPI NNI1	NNI2	UNI5
Domain 3 IF1	IF2	IF3

Fig. 3: TAPI topology/mappers in integration/control of heterogenous optical networks spanning from Telecom to DC. (a) TAPI topology of heterogenous domain with different device/network models, (b) TAPI mappers of individual networks

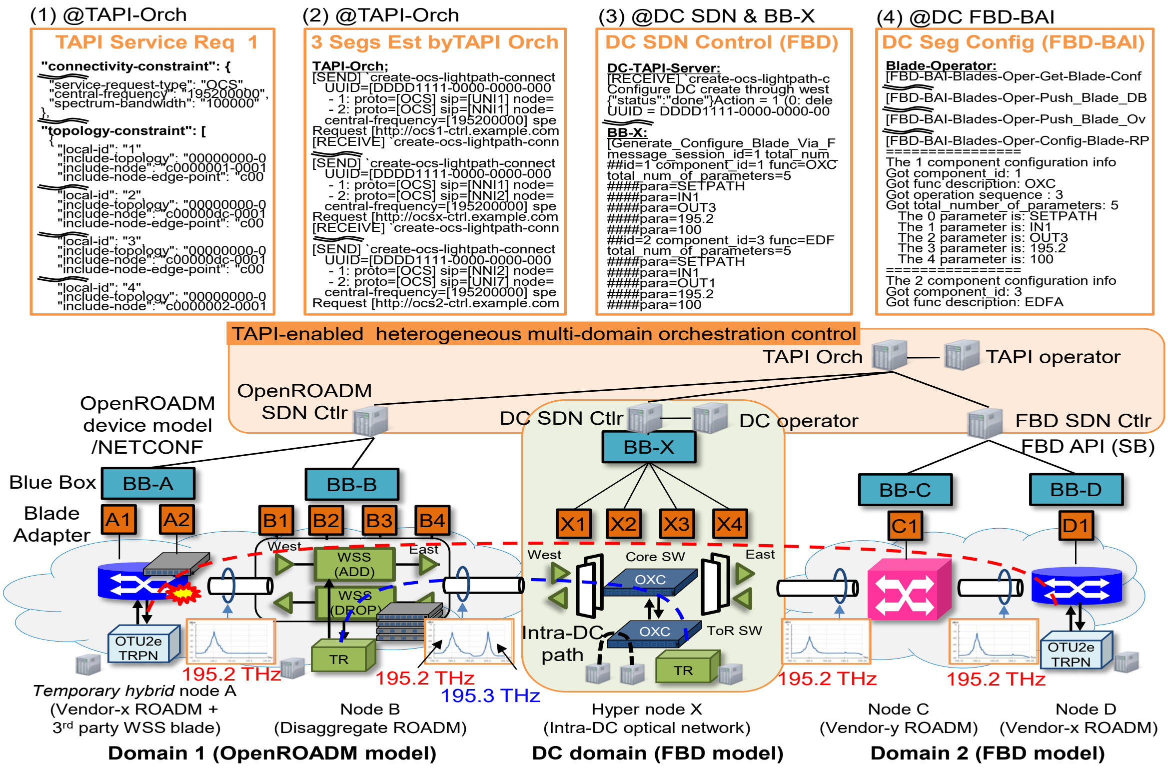


Fig. 4: Experiment of integration/control of heterogenous Telecom and DC optical networks aided by TAPI and FBD

a third-party WSS blade to replace the damaged DROP in the original node[17]. Nodes A and B formed Domain 1. The surviving nodes C and D formed Domain 2. They were interconnected with the DC domain to create an emergency optical network in the disaster area to recover communication. Optical supervisory channel (OSC) handshake units[4] were used to bypass the vendor OSC signals and enable the links between the ROADMs of different vendors.

In the C/M-plane, we implemented the aforementioned generalized FBD framework for each node. The OpenROADM (including mappers) and FBD device/network models were used for Domains 1 and 2, respectively. The FBD device model was used for the DC domain which was treated as a *hyper* node *X*. The TAPI/TAPI-mappers-enabled domain SDN controllers (Ctlr) and an orchestrator (Orch) were implemented to provision trans-domain path traversing heterogeneous Telecom/DC optical networks.

With this C/M-plane, two trans-domain paths, <A, D> and <B, X>, with the center-frequency of 195.20 and 195.30 THz and 100 GHz slot-width, and a locally FBD SDN controlled intra-DC path were successfully established. In the D-plane, Fig. 4 plots the monitored spectrums after the boosters of nodes A and B, and before the pre-AMPs of nodes C and D, which demonstrates the successful path provisioning across the heterogeneous Telecom/DC optical networks. In the C/M-plane, the logs for establishing the trans-domain path <A, D> are shown from (1) to (4) on the top of Fig. 4 for example. (1) highlights the TAPI connectivity-service request, including the experimental extension of TAPI YANG for center-frequency and slot-width specification, as well as the topology-constraint, which specifies the border node edge points along the path's route. (2) shows three segment configurations one for each domain, which was executed at TAPI Orch. (3) shows the responses of the TAPI mapper in the TAPI server and FBD blue-box (BB) X for the configuration of the DC segment at DC-SDN Ctlr as an example. (4) details blade configuration via the FBD-BAI performed by the FBD-BAI operator in BB-X. Note that the messages for path provisioning are omitted due to space limitations. Open issues, e.g., the computation for the trans-domain paths and physical impairment issues, are left as future work.

Conclusions

To bridge research in Telecom and DC fields, we demonstrate a common approach to integrate/ control optical networks with diverse hardware products and device/network models with the aid of FBD and TAPI. This is beneficial in terms of extending the scope of optical path services and enhancing optical network resiliency.

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