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Demonstration of Hitless Spectrum Optimization in a Flexgrid Disaggregated System

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Abstract *A spectrum optimization method without service interruption is demonstrated in a flexgrid disaggregated system by extending a transponder laser bright tuning range, adapting OpenConfig data models in devices and implementing algorithms in a network management system. The whole system is composed by commercialized devices. ©2022 The Author(s)*

Overview

Open and disaggregated optical transmission systems are widely deployed in data center interconnect (DCI) networks [1]. Such disaggregation is inherently motivated by the fact that an optical line system (OLS) is evolving at a much slower pace than optical transponders. There are two distinct ways to choose transponder technologies in DCI applications. One is to use the most spectrum efficient embedded optics technology, usually based on vendor specific coherent optics and digital signal processing (DSP) chips, such as 600 Gb/s or 800 Gb/s per wavelength with 90 Gbaud+ symbol rates. Another option is to choose pluggable optics with a standard and interoperable interface, e.g. OIF-400ZR [2] and OpenZR+ [3] with a line rate of 400 Gb/s and symbol rate around 60 Gbaud, which is potentially more cost efficient with a much larger volume. These two choices may co-exist in one OLS.

In such a hybrid deployment scenario, the wavelength multiplexer/demultiplexer with a fixed grid needs to be replaced by a flexible add drop unit, e.g., wavelength selective switches (WSSes) with a high port count, so that a media channel with a proper spectrum width can be assigned to different transponders based on their baud rates and tolerance to pass band narrowing effects [4]. Followed by ITU-T G.694.1 [5], the fine granularity for a spectrum width is 12.5 GHz. As spectra is allocated and deallocated dynamically with time, spectrum fragmentations occur and lead to spectrum utilization ratio reduction. Several defragmentation strategies are proposed for flexgrid optical networks [6]. Push-and-pull method is a promising way since it can optimize the spectrum without service interruption [7]. The mechanism can be summarized in three steps, first extending a media channel of a WSS, second tuning the laser frequency of two transponders to the target frequency in a push-and-pull manner, and third shrinking the media channel to the final state. During this process, the signal quality is guaranteed by keeping the two lasers within their frequency offset tolerance. However, this technique is not widely deployed in field due to the limitation of an integrable tunable laser assembly (ITLA) in a coherent transponder. Suffering from limited driving voltage, full C-band coverage of an ITLA is realized by adjusting two comb filters, which have small difference on the free space range, and is similar to Vernier effect [8]. The drawback of this mechanism is that mode hopping cannot be avoided when tuning the wavelength, so most of the commercial transponders only support *dark* tuning, as it shuts off the laser during the tuning process. Some transponders are capable of *bright* tuning within a very small range, e.g. [-6 GHz, +6 GHz], and it is not enough for defragmentation in a flexgrid system as the channel granularity is 12.5GHz.

1. ITLA bright tuning range extension

We first extend the laser tuning range of an ITLA in a 400G CFP2-DCO module by refining the calibration process of the cavity phase control circuitry. The transponder's *bright* tuning range is as large as +/-40 GHz in C-band at any center frequencies defined by ITU-T G.694.1 [5]. The transponder performance on frequency offset is evaluated at back-to-back (B2B) case, as shown in Fig. 1(a), where two CFP2-DCO modules are connected directly. The modules can tolerate frequency offset as much as +/-5.0 GHz, and within the detuning range of +/-1.0 GHz, the penalty is less than 0.3 dB. It implies that a less than 500-MHz step size is safe enough when we perform the push-and-pull process between two transponders. Fig. 1(b) shows that both Q value and estimated frequency offset queried from the two modules, whose frequencies are changed by 500 MHz every 4 seconds. It confirms that Q value fluctuation is less than 0.3 dB, and frequency offset doesn't exceed 1.0 GHz.

2. Data model adaptation

There are two registers defined in CFP management interface specification [9][8], channel number and fine tune frequency, to

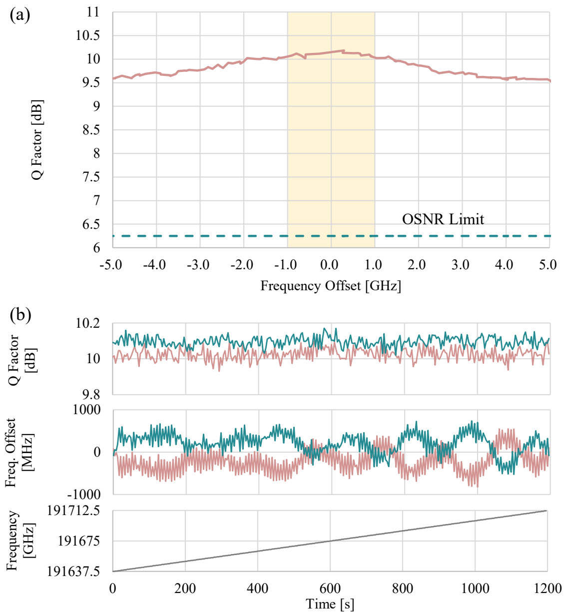

Fig. 1: Performance measurement of 400G CFP2-DCO module with bright frequency tuning capability of +/-37.5 GHz. (a) Frequency offset tolerance is as much as +/-5.0 GHz and Q factor penalty is within 0.3 dB when frequency detuning is within the range of [-1.0 GHz, +1.0 GHz]. (b) Using push and pull method to shift the two modules center frequency from 191.6375 THz to 191.7125 THz without service interruption within the tuning period of 1200 seconds. The upper two curves show the monitored Q factor and frequency offset from two modules.

determine the center frequency together. While for the north bound interface of device, there is only one leaf parameter in the data model of transponder, *frequency*, defined in *openconfig-terminal-device.yang* by OpenConfig [10]. To be compatible with this property, CFP2-DCO's center frequency is equal to *193.1THz + 75GHz*n + fine_tune_value*, where *n* is integer and the range of *fine_tune_value* is set to [-37.5 GHz, 37.5 GHz).

Media-channel in WSS can be managed as wavelength router model from OpenConfig or other augmentation version [11]. Despite the operation of channel addition and deletion, channel width modification including extending and shrinking is realized by Netconf <*edit-config*> operation with merge/replace attribute. Line card logic guarantees that such spectrum migration is continuous without service interruption.

3. *Spectrum optimization algorithm*

According to ITU-T G.872 [12] and G.807 [13], there are three layers related with spectrum optimization, optical tributary signal or optical channel (OCH), network media channel (NMC) and optical multiplex section (OMS). NMC represents the whole path in an OLS for one specific OCH, including OMSes in the route and media channels in WSSes at add/drop or express units. The basic operation in push-and-pull method is equivalent to extend NMC width first, move OCH center frequency *brightly*, and shrink NMC width at the end.

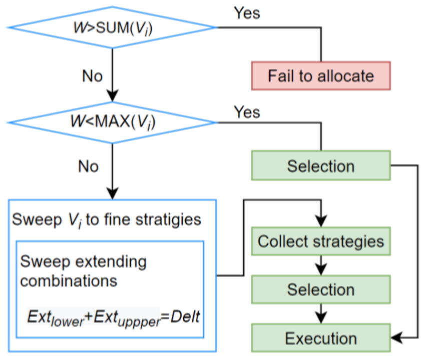

Fig. 2: Flow chart of spectrum optimization upon a new OCH establishment request. W is the requested bandwidth, V_i is the *i-th* vacant spectrum slot. *Delt* is the spectrum width difference between W and Vi, and it can be decomposed into Ext_{lower} and Ext_{upper}, denoting the frequency extension width toward lower and higher frequency directions.

A more intelligent algorithm is developed to realize spectrum optimization during OCH setup process. Considering an OMS with an WSS add/drop unit at each end, and several OCHes with different bandwidths running on it, the NMS has the full information about the spectrum occupation, so it can calculate strategies upon the new OCH setup requests. Fig. 2 shows the strategy generation process, where *W*, and V_i are the widths of newly requested OCH and *i*-th vacant spectrum slot. The requested bandwidth *W* should be smaller than the summation of the total vacant slot widths, otherwise no feasible solution can be achieved. If *W* is larger than the maximum width of vacant slot, spectrum optimization should be considered. In this case, each vacant slot is checked, and all the possible candidate solutions are examined. After this sweep, all the strategies are collected and characterized by two factors, the total movement number of frequency slots and the number of OCHes participating in the optimization. The first one is correlated with time complexity in optimization, and the second one describes the influence scope on existing services. Operators can choose a proper strategy and let NMS execute the commands.

Demo content and implementation

The demo is performed on a point to point disaggregated system with a flexgrid multiplexer/demultiplexer (FMD) on each OMS end, which is connected with 5 pairs of transponders, shown in Fig. 3. Three pairs of 400 Gb/s DCO modules are plugged into two optical terminal devices, and they all support +/-37.5GHz bright tuning range. The other two pairs are from commercial pizza-box equipment with baudrate

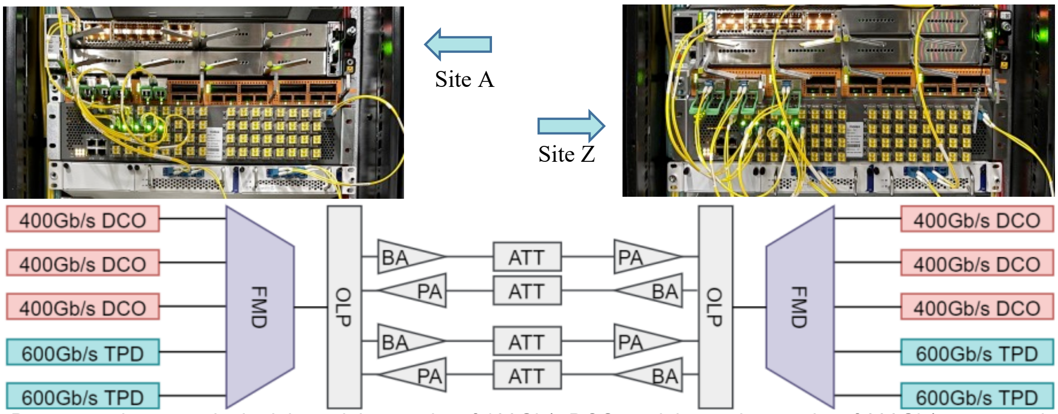

Fig. 3: Demonstration setup in the lab, and three pairs of 400Gb/s DCO modules and two pairs of 600Gb/s transponders are allocated at two sites, which are connected by OLS. FMD: flex multiplexer/demultiplexer, BA: booster amplifier, PA: pre-amplifier, OLP: optical line protection, ATT: attenuator. OLS and two types of transponders belong to different vendors.

of ~91Gbaud, supporting 600 Gb/s per lambda with a channel width of 100 GHz. Both types of transponders have a similar optical signal-to-noise ratio (OSNR) limit around 24 dB, so it is reasonable to put them in the same transmission link.

The demo starts from a brown field assumption that three existed OCHes are delivered by the DCO modules, and the wavelength plan can be defined by the demo session attendees. Next, a new OCH based on the 600 Gb/s embedded modules are requested, and several parameters needs to be input, including the valid frequency range and maximum solution number together with the searching direction on the spectrum. Then all the solutions are calculated and can be evaluated and selected by the attendees, as shown in Fig. 4 (a). Finally, the selected strategy is executed with animation showing in the front-end, including variation of NMC, shift of OCH and also the establishment of new OCH, and Fig. 4 (b) shows a snapshot of this process. During the spectrum optimization, real time OCH performance based on telemetry data stream can be monitored continuously, as shown in Fig. 4 (c).

Conclusions

Spectrum fragmentation may become a serious problem in flexgrid optical system. Push-and-pull is a hitless defragmentation method but its application is limited by small bright tuning range of transponders. This paper proposes a complete solution to implement the push-and-pull method in a practical system. It covers the ITLA laser tuning range extension, adaptation with OpenConfig data model and the spectrum optimization algorithm in NMS. These innovations are verified under a disaggregated optical transmission system.

Fig. 4: (a) Solutions provided by NMS upon a new OCH request. For each solution, affected OCH number and total adjusted frequency are listed. It also provides the target OCH center frequencies and the detailed steps to achieve this final state. Users can evaluate each solution and decide on the proper one. (b) Solution execution page shows the operation log together with the spectrum animation of OCH and NMC layers, which is updated in real time. Dashed rectangular shows the target OCH position. (c) OCH performance is based on telemetry stream data, including BER and frequency offset. The spectrum optimization process is highlighted with the dashed rectangle.

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