Experimental Demonstration of an Active Stateful PCE Performing Elastic Operations and Hitless Defragmentation

A. Castro(1), F. Paolucci(2), F. Fresi(2), M. Imran(2), B. B. Bhowmik(3), G. Berrettini(2), G. Meloni(4), A. Giorgetti(2), F. Cugini(4), L. Velasco(1), L. Potì(4), and P. Castoldi(2)

(1) Universitat Politècnica de Catalunya (UPC), Barcelona, Spain, acastro@ac.upc.edu
(2) Scuola Superiore Sant'Anna - TeCIP, Pisa, Italy, fr.paolucci@sssup.it
(3) Electrical Engineering Department, Indian Institute of Technology Patna, India
(4) CNIT, Pisa, Italy

Abstract An experimental demonstration of active stateful PCE for flexgrid networks is presented. The PCE enables elastic operations on established connections and, when required, performs hitless defragmentation of spectrum resources. Experimental assessment, including shifting of 400Gbps four sub-carrier superchannel is shown.

Introduction Relevant control and data plane innovations are driving the current evolution of transport networks1-3. From a control plane perspective, the Path Computation Element (PCE) is evolving from a pure state-less condition to an active stateful architecture4. In the latter, Label Switched Path (LSP) state information is stored at the PCE and used to directly trigger networking operations, e.g., defragmentation5. From a data plane perspective, the concept of superchannel is emerging in flexgrid networks1 as a candidate technology to achieve high spectral efficiency and ultra-high data rates by aggregation of multiple optical sub-carriers. Superchannels rely, for each sub-carrier, on advanced transmission techniques based on complex modulation formats (e.g., DP-QPSK) and coherent detection. Several works proposed multi-wavelength sources to generate superchannels6. However, they do not typically meet the control plane requirements for dynamic networking, i.e., they do not guarantee full tunability with stable optical power uniformity among sub-carriers.

The objective of this paper is twofold. First, the active stateful PCE is introduced. In addition to LSP provisioning, the proposed PCE implements algorithms to perform elastic operations, i.e., increase/decrease the bitrate of already established LSPs. An optimization strategy can be triggered, if required, for hitless defragmentation of the optical spectrum targeted to make enough room to perform the elastic operation. Defragmentation is achieved shifting already established LSPs in the spectrum. Second, a comb generation technique is proposed and experimentally assessed. This technique is suitable for superchannel utilization as it provides solid tunability of all sub-carriers guaranteeing stable optical power uniformity.
A specialized module inside the PCE was developed for solving PCCs requests (i.e., the Online Active Solver in Figure 1). This module implements the defragmentation algorithm presented in 7. At this regard, an interface between the PCE and the specialized module was defined (i.e., the Action Handler Figure 1).

Through that interface, the PCE forwards the requests received from a PCC to the Online Active Solver and receives back the solution. Two types of requests were implemented from PCC: a) new_LSP_setup is used to request a new LSP along with routing, spectrum allocation and modulation format; b) update_LSP is used to request an increase/decrease of the bitrate (i.e., elastic operation) of an already established LSP. Note that this does not imply rerouting the LSP but only modifying its spectrum allocation whilst keeping its central frequency constant. The solution returned by the algorithm consists of a list of actions to be performed by the PCE which are queued in the Action queue (see Figure 1). Four action types were defined: a) new_LSP for provisioning of a new LSP, that contains the route, the spectrum allocation and the modulation format; b) update_LSP for elastic operations, that contains the new spectrum allocation; c) move_LSP for spectrum shifting, that contains the new central frequency; d) no_solution returned if a feasible solution is not found for the received request.

For example, if enough resources are available in the network, an update_LSP request could entail a solution list with just one action, i.e., the elastic operation for the given LSP. However, if some defragmentation is needed to make room for the given LSP, a list of actions with the necessary move_LSP actions, in addition to the update_LSP one, should be provided. Note that actions in the queue may need to be serially executed since some dependence among them could exist, i.e. some actions need to wait until some previous ones are actually implemented on the data plane. For instance, an LSP can only be updated once all LSPs have been moved to make the required room. For this reason, each action has a notification_flag indicating if the PCE must wait till it is completed or not. Consequently, if one action has the notification_flag set, the PCE waits the action confirmation message before executing the next action in the queue. This mechanism allows to consider dependence between actions.

Superchannel generation

In order to experimentally validate the proposed solution, a tunable 400 Gbps superchannel has been generated through PM-DQPSK modulation of a four-lines 25 GHz spaced optical comb occupying 100 GHz slot. The optical comb was generated by using two cascaded Mach-Zehnder modulators (MZM), as shown in Figure 2. A continuous wave at 1554.30 nm is provided by a tunable laser source (TLS) with a linewidth of \(~100\) KHz which is passed through a polarization controller and fed to a first stage MZM-1. Both MZMs are biased at null point to operate as double-sideband suppressed-carrier (DSB-SC) modulators. MZM-1 is driven by a 25 GHz RF clock which resultantly provides two new optical carriers 50 GHz apart at the output while suppressing the original carrier frequency. The two newly generated lines are directly fed to the second stage MZM-2 driven by a 12.5 GHz RF clock. Both input lines are further suppressed by MZM-2 providing 25 GHz spaced four lines comb at the output. The cascade configuration provides better carrier suppression and power equalization. Moreover, tuning the TLS frequency all the four sub-carriers shift in a solid way. Figure 3 shows an output power uniformity of 0.39 dB and extinction ratio higher than 30 dB. Note also that the linewidth of comb lines are limited by the OSA resolution bandwidth. The actual value is less than 200 KHz. Power uniformity and stability during laser tuning is of key importance for networking operations, including hitless defragmentation. To assess comb tunability, the feeder laser was tuned to both longer and shorter wavelengths over 15 nm span, without bias adjustment. Figure 4 shows a power peak variations of less than 0.8 dB. As mentioned above, the comb is modulated through an IQ-MZM and polarization multiplexed providing 100 Gbps DP-QPSK for each channel. The overall capacity of the obtained superchannel is 400 Gbps in 100 GHz.
Experimental assessment

To experimentally assess the active stateful PCE controlling a flexgrid data plane (Figure 5), an elastic operation of an established 100 Gbps LSP is considered. Figure 7 illustrates initial spectrum allocation in solid lines. Thus, to increase the LSP bitrate to 200 Gbps increasing the allocated spectrum it is necessary to shift the superchannel. Specifically, upon receiving the PCReq message, event (1) in Figure 7 and Figure 8, the Online Active Solver returns the set of actions required to perform the elastic operation. As a result, the 400 Gbps superchannel is shifted of 100 GHz. Figure 8 captures relevant control messages used to complete the process.

Conclusions

An active stateful PCE is presented and successfully applied in an experimental testbed for elastic operations in flexgrid networks. If necessary, the PCE applies defragmentation to established LSPs, simultaneous shift of the four sub-carriers, generated by DSB-SC technique, composing a 400 Gbps superchannel has been successfully demonstrated.

Acknowledgements.

This research has been partially supported by IDEALIST FP7 project, and “COTONE” project.

References