Survey on Path Computation Element Extensions for Spectrum Switched Optical Networks

Joana Sócrates Dantas*[+], Davide Careglio*, Regina Melo Silveira[+], Wilson Vicente Ruggiero[+] and Josep Solé-Pareta*

[+] *Escola Politécnica da Universidade de São Paulo, São Paulo, Brazil*

* *Universitat Politècnica de Catalunya, Barcelona, Spain, e-mail: joana@ac.upc.edu*

ABSTRACT

Recently, Spectrum Switched Optical Networks (SSON) have been receiving much interest from the research community due to their network performance benefits. Some of these benefits include the possibility of enabling either super channels or sub-wavelength channels, which meet better the granularity of Internet needs. Due to its specific routing and resource assignment characteristics, SSON's primordial procedures, as routing and spectrum assignment (RSA), cannot be suitably assisted by current related protocols from Wavelength Switched Optical Network (WSON). For this very reason, a SSON control plane architecture and protocols should be extended from WSON's control plane in order to be able to support specific information exchange. This paper presents the most recent Path Computation Element (PCE) architecture extension proposals in the literature, which intend to meet SSON specific requirements.

Keywords: PCE, flex-grid optical networks, SSON, RSA, control plane.

1. INTRODUCTION

Recent technology advances have permitted the development of flexible grid optical networks, also referred to as Spectrum Switched Optical Networks (SSON). This novel optical network enables the implement of either large capacity channels or sub-wavelength adaptable capacities channels meeting the diverse traffic granularity needs of future Internet.

A SSON relies on variable sized optical frequency range resulted from a flexible grid architecture [1], therefore lightpaths occupy a variable portion of the spectrum, called frequency slot, which are defined by its nominal central frequency and its frequency width [1]. Consequently, in a SSON the establishment of a connection requires the computation of a physical path (sequence of nodes and links), and a given number of contiguous frequency slots and is known as the Routing and Spectrum Assignment (RSA) problem [2]. The RSA problem can be performed statically in a planning phase or online in a dynamic path computation scenario [3].

Aggregated to the RSA problem, the modulation level may also be computed and the problem is then known as the Routing, Modulation and Spectrum Assignment (RMSA) [3]. The modulation level selected relates to the length of the resulting computed path, aiming on optimizing resources and avoiding physical impairments, therefore the RMSA problem is also known as distance adaptive RSA. In a impairment aware path computation, the probable impairment of the computed path is evaluated before its actual setup with the selected modulation format under the necessary requirements and will be physically established only if it provides a bit error rate under a given threshold [4].

For a centralized dynamic path computation, the Path Computation Element (PCE) may be implemented in a GMPLS controlled flex-grid network to centrally perform either the complete RSA process or solely the routing part of the task, whereas, in this a case, the spectrum assignment may be implemented in a distributed manner by a signaling protocol [3].

In the next section we present the recent researches in PCE protocol extensions to conform to SSON requisites: 1) the requirements for PCE enhancement regarding RSA performance, 2) protocol extension to enable modulation selection, 3) protocol extensions requirements for calculating guard-bands needs, and 4) enhancements on the PCE to collaborate on spectrum use optimization. We conclude the paper summarizing the extensions and enhancements on PCE architecture to consort with the SSON advances.

2. PCEP EXTENSIONS

The PCE was developed aiming on diminishing the computational burden of GMPLS routers and enabling multi-domain end-to-end path computation [5]. Its architecture described in [6] comprises the PCE, the path computation clients (PCC), and the PCE control protocol (PCEP) that defines the messages exchanged between PCE and PCC entities: *i.e.* the format and content for path computation requests (PCReq) from PCC and PCE and the path computation replies (PCRep) from PCE to PCC [7]. The PCE relies on a Traffic Engineering Database (TED) from where it accesses required information regarding network state so to calculate available resources and compute a path. In order to compute a path in a SSON, the messages defined by the PCEP, the information assembled by the TED, and the algorithms performed by the PCE must be enhanced. In the following sub-sections the current extension proposals for the PCE are presented.

978-1-4799-0683-3/13/$31.00

2.1 RSA

When the PCE is implemented in a SSON, it must be designed to perform spectrum assignment instead of wavelength assignment [5]. In order for the PCE to perform path and spectrum assignment some specific information must be accessed, this required information, therefore, must reside in the TED. Work in [2] discriminates what information is required to be advertised by a routing protocol. Some of the information that needs to be accessed by the PCE regards frequency slots details such as minimum and maximum slot width, central frequency granularity, frequency range, and frequency range availability [2].

There are diverse available RSA algorithms, each of them focusing on a specific aspect of the network performance or network condition [9]. For this reason, the PCE can be extended to be able to select which algorithm to use. In [9] authors propose extensions to the PCEP in order to inform the PCE which RSA algorithm to use. The PCReq is therefore upgraded with a RAEO-list object, which includes the algorithms identifier *id* and a priority field *Pri* to determine the priority among the different algorithms. The format of the PCReq is illustrated in Fig. 1.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Object-Class  |   OT  |Res|P|I|   Object Length (bytes)       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             Flags             |    Algorithm Id       | Pri |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
//                      Optional TLVs                          //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 1. RAEO-list object [9].

2.2 Modulation formats

Whilst in conventional WSON optical networks, transmission parameters, as modulation format, are (input) constraints defined by the PCC, in a SSON, the modulation format can be an output of the PCE algorithm [8]. Impairment validation and the modulation format selection are strictly related. For instance, given the bit-rate, the more efficient the modulation format in terms of occupied spectrum, the less robust in terms of Quality of Transmission (QoT). Consequently, because of the QoT, modulation format selection is either affected by or it affects path computation and the subsequent frequency slot assignment [5].

If the PCE has to provide the adequate modulation format, the TED has to contain information regarding bit rate and modulation format of any working LSP in the network. The messages exchanged between PCE and PCC entities must be able to transport these specific data; *i.e.* the PCEP has to be extended to enable the PCReq messages to inform the available modulation format options [8], and the PCRep messages to carry information on assigned frequency slot [5]. Authors in [3] propose an Explicit Route (ERO) sub-object named RMSA as an extension in the PCRep message. The RMSA sub-object contains the optical parameters elected by the PCE. These optical parameters are the modulation, the FEC and spectrum sub-object that are expressed as type-length-value (TLV) tuples. The first parameter conveyed by the RMSA sub-object defines a selection of one or more possible modulation formats, the next parameter identifies the selected FEC, and, finally, the optical spectrum TLV encodes the necessary spectrum width for the selected modulation and FEC.

2.3 Guard bands

The continuous increase of flexibility and bit rate in optical networks promotes increasingly higher impact on inter-channel effects (*e.g.* Cross-phase modulations). To avoid the inter-channel detrimental effects an effective strategy is the introduction of guard bands between adjacent light paths [4]. A guard band is defined as the minimum frequency range separating two contiguous channels with their respective bit rate and modulation format, so that detrimental effects are avoided [4] as illustrated in Fig 2.

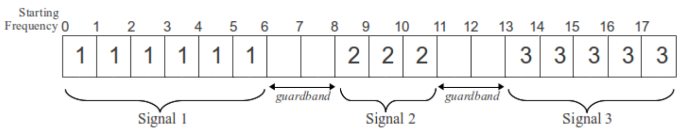

Figure 2. Guard bands between adjacent signals.

The computation of guard bands depends on the bit rate and modulation format of the two interfering channels' signals. These guard bands and their size must be considered during the path computation and resource assignment. For this reason, in [4] requirements for the development of protocol extensions to support PCE management of guard bands are provided.

The RSA or RSMA problem may be integrally performed by the PCE or the spectrum assignment may be performed by a signaling protocol. When performing spectrum assignment, the PCE accesses the extended TED for necessary information and consider the required guard band when computing an LSP. When the RSA problem is divided in two phases, the PCE should inform the ingress node about the guard band requirements for the calculated path so that spectrum resource assignment may comprise with guard band specifications to separate the given LSP from other LSPs. In this case the PCEP must be extended in order to be able to transmit guard band requirements in a PCEP reply message that would be later used by the RSVP-TE protocol when assigning spectrum resources to the connection [4].

2.4 Defragmentation

In a SSON, a dynamic traffic scenario, *i.e.* a constant setup and release of channels, leads to the fragmentation of spectral resources resulting on non-contiguous spectral bands. This non-continuity of the spectral band decreases the probability of future assignment of contiguous frequency slots to a channel, jeopardizing the network's spectral efficiency and increasing blocking probability [9].

In order to amend fragmentation's prejudicial impact, defragmentation techniques have been proposed [9]. In case a defragmentation mechanism is implemented, active connections may be interrupted and moved to a new spectrum or route when the fragmentation level reaches a predetermined threshold. An illustration of spectrum before fragmentation, after fragmentation and after a defragmentation technique can be observed in Fig. 3.

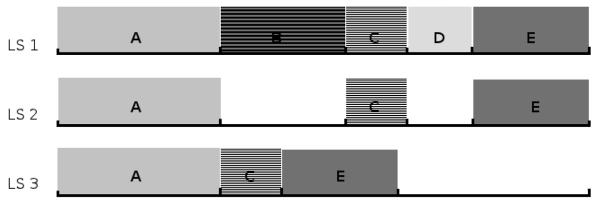

Fig. 3. A,B,C, D and E are client LSPs on a given link, LS 1 is original link state before channels tear down LS 2 is link state after channels tear down LS 3 link state after defragmentation [9] .

However, to be able to implement a defragmentation mechanism, the PCEP must be extended to convey required information to be transferred in order to perform adequate re-routing and/or spectrum re-assignment. For the PCE to trigger the other route or spectrum allocation, the PCEP is extended in [9] with two new types of messages: the Spectrum Defragmentation Request Message and the Spectrum Defragmentation Reply Message. Both messages are enhanced within the Spectrum Defragmentation Target Object (SDTO) that can be observed in Fig. 4.

The SDTO contains the following sub-objects: the “Target Clutter Value" refers to the defragmentation threshold, or the level of fragmentation that should trigger the defragmentation mechanism, the "R" field refers to whether triggering the defragmentation mechanism is obligatory in the network or not, the "Id 1" field refers to the available defragmentation methods, the "Id 2" field represents the number of methods to trigger defragmentation, and, finally, "L" field is for limit of interrupting rate or defragmentation time [9].

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Object-Class  |   OT  |Res|P|I|   Object Length (bytes)       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Flags                | L |Id1|Id2|R|  Pri  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Target Clutter Value                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
//                      Optional TLVs                          //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 4. Spectrum Defragmentation Target Object [Zhao2012pcep].

In a SSON, the PCE may perform three different tasks: path computation, spectrum assignment and de fragmentation. To permit a PCC to inform what task is requested, the Requested Parameter (RP) object in the PCReq message is extended with three extra fields: P, S and D, where P represents path computation, S represents Spectrum Assignment, and D represents Defragmentation [10]. The extended RP object may be observed in Fig. 5.

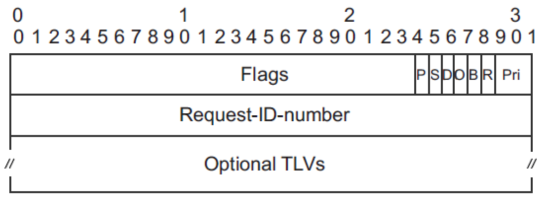

Figure 5. Requested parameter object with extra task fields [10].

3. CONCLUSIONS

A SSON presents a novel and beneficial fashion of switching data in a optical network where the channels are assigned to smaller spectrum ranges or sub-wavelength channels. In this new scenario, control plane protocols are being currently expanded to meet these novel network features.

For the computation of LSPs and resource availability, the PCE has recently been successfully implemented in GMPLS control planes due to its capacity of routing throughout diverse domains while protecting data confidentiality and diminishing path computational burden on routing nodes.

This survey presented the state-of-the-art and research efforts recently accomplished in the context of the PCE architecture extensions for SSON. The following topics were covered by the survey: extensions for information on frequency slot availability, modulation format of active LSPs, guard band requirements and defragmentation mechanism triggering via PCEP messages.

Future research work may lead to a complete novel design of the PCE architecture comprising all the SSON's requirements and guaranteeing its interoperability with other architecture and protocols enhancements such as a GMPLS protocol set focused on SSONs.

ACKNOWLEDGEMENTS

The authors would like to thank Capes Brazilian PhD student scholarship. This work has been partially supported by the Spanish Ministry of Science and Innovation through the DOMINO project (TEC2010-18522).

REFERENCES

[1] ITU-T Recommendation G.694.1, Spectral grids for WDM applications: DWDM frequency grid, draft v1.6-2.0, 2012.
[2] O. Dios *et al*., "Framework for GMPLS based control of flexi-grid DWDM networks", *IETF Internet Draft*, Feb. 2013.
[3] R. Casellas *et al*., "GMPLS/PCE control of flexi-grid DWDM optical networks using CO-OFDM transmission", *Journal of Optical Communications and Networking,* vol. 4, no. 11, pp. B1-B10, 2012.
[4] D. Ceccarelli, G. Bottari, N. Sambo, F. Cugini, F. Zhang, R. Caselles, "Guard bands requirements for GMPLS controlled optical networks", *IETF Internet Draft*, Mar. 2012.
[5] F. Paolucci, F. Cugini, A. Giorgetti, N. Sambo, P. Castoldi, "A survey on the path computation element (PCE) architecture", *IEEE Communications Surveys & Tutorials,* in press, 2013.
[6] A. Farrel, J. P. Vasseur, and J. Ash, "A path computation element (PCE)-based architecture", *IETF, RFC 4655*, Aug 2006.
[7] J. Vasseur and J. Le Roux, "Path computation element (PCE) communication protocol (PCEP)", *IETF, RFC 5440*, Mar. 2009.
[8] G. Cugini *et al*., Demonstration of flexible optical network based on path computation element, *J. Lightwave Technol.*, vol. 30, no. 5, pp. 727-733, Mar. 2012.
[9] Y. Zhao, J. Zhang, T. Peng, X. Yu, X. Cao, D. Wang, "PCEP protocol extension for spectrum utilization optimization in flexi-grid networks", *IETF Internet Draft*, Apr. 2012.
[10] Y. Zhao, X. Yua, Y. Yua, J. Zhanga, L. Wangb, "Novel control plane framework and protocol extensions for spectrum-efficient optical transport networks", *Optical Switching and Networking*, vol. 10, no. 3, pp. 211-222, Jul. 2013.