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PCEP Extension for WSON Routing and Wavelength Assignment

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Abstract

This draft provides the Path Computation Element communication Protocol (PCEP) extensions for the support of Routing and Wavelength Assignment (RWA) in Wavelength Switched Optical Networks (WSON). Lightpath provisioning in WSONs requires a routing and wavelength assignment (RWA) process. From a path computation perspective, wavelength assignment is the process of determining which wavelength can be used on each hop of a path and forms an additional routing constraint to optical light path computation.

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1. Terminology

This document uses the terminology defined in [RFC4655], and [RFC5440].

2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

3. Introduction

[RFC4655] defines the PCE based Architecture and explains how a Path Computation Element (PCE) may compute Label Switched Paths (LSP) in Multiprotocol Label Switching Traffic Engineering (MPLS-TE) and Generalized MPLS (GMPLS) networks at the request of Path Computation Clients (PCCs). A PCC is shown to be any network component that makes such a request and may be for instance an Optical Switching Element within a Wavelength Division Multiplexing (WDM) network. The PCE, itself, can be located anywhere within the network, and may be within an optical switching element, a Network Management System (NMS) or Operational Support System (OSS), or may be an independent network server.

The PCE communications Protocol (PCEP) is the communication protocol used between PCC and PCE, and may also be used between cooperating PCEs. [RFC4657] sets out the common protocol requirements for PCEP. Additional application-specific requirements for PCEP are deferred to separate documents.

This document provides the PCEP extension for the support of Routing and Wavelength Assignment (RWA) in Wavelength Switched Optical Networks (WSON) based on the requirements specified in [PCE-RWA].

WSON refers to WDM based optical networks in which switching is performed selectively based on the wavelength of an optical signal. In this document, it is assumed that wavelength converters require electrical signal regeneration. Consequently, WSONs can be transparent (A transparent optical network is made up of optical devices that can switch but not convert from one wavelength to another, all within the optical domain) or translucent (3R regenerators are sparsely placed in the network).

A LSC Label Switched Path (LSP) may span one or several transparent segments, which are delimited by 3R regenerators (typically with electronic regenerator and optional wavelength conversion). Each transparent segment or path in WSON is referred to as an optical path. An optical path may span multiple fiber links and the path should be assigned the same wavelength for each link. In such case, the optical path is said to satisfy the wavelength-continuity constraint. Figure 1 illustrates the relationship between a LSC LSP and transparent segments (optical paths).

```
+---+       +-----+       +-----+      +-----+         +-----+
|   |I1     |     |       |     |      |     |       I2|     |
|   |o------|     |-------[(3R) ]------|     |--------o|     |
|   |       |     |       |     |      |     |         |     |
+---+       +-----+       +-----+      +-----+         +-----+
    [X  LSC]     [LSC  LSC]    [LSC  LSC]     [LSC  X]       SwCap
     <------->   <------->       <----->     <------->
     <-----------------------><---------------------->
      Transparent Segment         Transparent Segment
    <------------------------------------------------->
                           LSC LSP
```

Figure 1 Illustration of a LSC LSP and transparent segments

Note that two optical paths within a WSON LSP need not operate on the same wavelength (due to the wavelength conversion capabilities). Two optical paths that share a common fiber link cannot be assigned the same wavelength. To do otherwise would result in both signals interfering with each other. Note that advanced additional multiplexing techniques such as polarization based multiplexing are not addressed in this document since the physical layer aspects are

not currently standardized. Therefore, assigning the proper wavelength on a lightpath is an essential requirement in the optical path computation process.

When a switching node has the ability to perform wavelength conversion, the wavelength-continuity constraint can be relaxed, and a LSC Label Switched Path (LSP) may use different wavelengths on different links along its route from origin to destination. It is, however, to be noted that wavelength converters may be limited due to their relatively high cost, while the number of WDM channels that can be supported in a fiber is also limited. As a WSON can be composed of network nodes that cannot perform wavelength conversion, nodes with limited wavelength conversion, and nodes with full wavelength conversion abilities, wavelength assignment is an additional routing constraint to be considered in all lightpath computation.

For example, within a translucent WSON, a LSC LSP may be established between interfaces I1 and I2, spanning 2 transparent segments (optical paths) where the wavelength continuity constraint applies (i.e. the same unique wavelength MUST be assigned to the LSP at each TE link of the segment). If the LSC LSP induced a Forwarding Adjacency / TE link, the switching capabilities of the TE link would be [X X] where X < LSC (PSC, TDM, ...).

[Ed note: in general, WSON LSC may not be the only switching layer with switching constraints. From a GMPLS/PCEP perspective, wavelength assignment corresponds to label allocation. This document should align with GMPLS extensions for PCEP. Wavelength restrictions and constraints should be formulated in terms of labels (i.e. LABEL_SET, SUGGESTED_LABEL, UPSTREAM_LABEL, etc.)In addition to those label switching constraints, each optical path is constrained by the optical signal quality. The optical signal quality depends first on the optical sender and receiver capabilities. Second contributors to optical signal constraints are the optical elements used on the path (optical fibers, amplifiers, boosters, optical components). All those elements have an impact on the optical signal quality that limits the ability of the optical path to carry traffic. In order to improve the signal quality and limit some optical effects several advanced modulation processing are used. Those modulation properties contribute not only to optical signal quality checks but also constrain the selection of sender and receiver, as they should have matching signal processing capabilities.

The optical modulation properties, also referred to as signal compatibility, are already considered in signaling in [RWA-Encode] and [WSON-OSPF].

This document includes signal compatibility constraint as part of RWA path computation. That is, the signal processing capabilities (e.g., modulation and FEC) must be compatible between the sender and the receiver of the optical path across all optical elements.

This document, however, does not address optical impairments as part of RWA path computation. See [WSON-Imp] and [PSVP-Imp] for more information on optical impairments and GMPLS.

4. Encoding of a RWA Path Request

Figure 2 shows one typical PCE based implementation, which is referred to as Combined Process (R&WA). With this architecture, the two processes of routing and wavelength assignment are accessed via a single PCE. This architecture is the base architecture from which the requirements have been specified in [PCE-RWA] and the PCEP extensions that are going to be specified in this document based on this architecture.

```
                       +-----------------------------+
            +-----+    |      +--------+     +--+      |
            |     |    |      |Routing|     |WA|      |
            | PCC |<----->|      +--------+     +--+      |
            |     |    |                               |
            +-----+    |             PCE               |
                       +-----------------------------+
```

Figure 2 Combined Process (R&WA) architecture

4.1. Wavelength Assignment (WA) Object

The current RP object is used to indicate routing related information in a new path request per [RFC5440]. Since a new RWA path request involves both routing and wavelength assignment, the wavelength assignment related information in the request SHOULD be coupled in the path request.

Wavelength allocation can be performed by the PCE by different means:

(a) By means of Explicit Label Control, in the sense that one (or two) allocated labels MAY appear after an interface route subobject.

(b) By means of a Label Set, containing one or more allocated Labels, provided by the PCE.

Option (b) allows distributed label allocation (performed during signaling) to complete wavelength assignment.

Additionally, given a range of potential labels to allocate, the request SHOULD convey the heuristic / mechanism to the allocation, including vendor-specific approaches.

The format of a PCReq message after incorporating the WA object is as follows:

```
<PCReq Message> ::= <Common Header>

                       [<svec-list>]

                       <request-list>

   Where:

      <request-list>::=<request>[<request-list>]

      <request>::= <RP>

                   <ENDPOINTS>

                   <WA>

                   [other optional objects...]
```

If WA object is present in the request, the WA object MUST be encoded after the ENDPOINTS object.

The format of the Wavelength Assignment (WA) object body is as follows:

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                           Flags                        |  O  |M|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
   //                      Optional TLVs                          //
   |                                                               |
```

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3 WA Object

o Flags (32 bits)

The following new flags SHOULD be set

. M (Mode - 1 bit): M bit is used to indicate the mode of wavelength assignment. When M bit is set to 1, this indicates that the label assigned by the PCE must be explicit. That is, the selected way to convey the allocated wavelength is by means of Explicit Label Control (ELC) [RFC4003] for each hop of a computed LSP. Otherwise, the label assigned by the PCE needs not be explicit (i.e., it can be suggested in the form of label set objects in the corresponding response, to allow distributed WA. In such case, the PCE MUST return a Label_Set object in the response if the path is found.

(Ed note: When the distributed WA is applied, some specific wavelength range and/or the maximum number of wavelengths to be returned in the Label Set might be additionally indicated. The optional TLV field will be used for conveying this additional request. The details of this encoding will be provided in a later revision.)

. O (Order - 3 bits): O bit is used to indicate the wavelength assignment constraint in regard to the order of wavelength assignment to be returned by the PCE. This case is only applied when M bit is set to "explicit." The following indicators should be defined:

000 - Reserved

001 - Random Assignment

010 - First Fit (FF) in descending Order

011 - First Fit (FF) in ascending Order

100 - Last Fit (LF) in ascending Order

101 - Last Fit (LF) in descending Order

110 - Vendor Specific/Private

111 - Reserved

When the Order bit is set for "Vendor Specific/Private", the optional TLV field will be used to indicate specifics of the order algorithm applied by the PCE.

4.2. Wavelength Restriction Constraint TLV

For any request that contains a wavelength assignment, the requester (PCC) MUST be able to specify a restriction on the wavelengths to be used. This restriction is to be interpreted by the PCE as a constraint on the tuning ability of the origination laser transmitter or on any other maintenance related constraints. Note that if the LSP LSC spans different segments, the PCE MUST have mechanisms to know the tunability restrictions of the involved wavelength converters / regenerators, e.g. by means of the TED either via IGP or NMS. Even if the PCE knows the tunability of the transmitter, the PCC MUST be able to apply additional constraints to the request.

[Ed note: Which PCEP Object will home this TLV is yet to be determined. Since this involves the end-point, The END-POINTS Object might be a good candidate to encode this TLV, which will be provided in a later revision.]

[Ed note: The current encoding assumes that tunability restriction applied to link-level.]

The TLV type is TBD, recommended value is TBD. This TLV MAY appear more than once to be able to specify multiple restrictions.

The TLV data is defined as follows:

```
<Wavelength Restriction Constraint> ::=

               <Action> <Format> <Reserved>

               (<Link Identifiers> <Wavelength Restriction>)...
```

Where

```
<Link Identifiers> ::=

            <Unnumbered IF ID> | <IPV4 Address> | <IPV6 Address>
```

```
   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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   | Action          |    Format      |          Reserved           |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                     Link Identifiers                          |
   |                          . . .                                |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                Wavelength Restriction Field                   |
   //                        . . . .                              //
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 4 Wavelength Restriction

o Action: 8 bits

- 0 - Inclusive List indicates that one or more link identifiers are included in the Link Set. Each identifies a separate link that is part of the set.

- 1 - Inclusive Range indicates that the Link Set defines a range of links. It contains two link identifiers. The first identifier indicates the start of the range (inclusive). The second identifier indicates the end of the range (inclusive). All links with numeric values between the bounds are considered to be part of the set. A value of zero in either position indicates that there is no bound on the corresponding portion of the range. Note that the Action field can be set to 0 when unnumbered link identifier is used.

Note that "interfaces" such as those discussed in the Interfaces MIB [RFC2863] are assumed to be bidirectional.

o Format: The format of the link identifier (8 bits)

. 0 -- Unnumbered Link Identifier
. 1 -- Local Interface IPv4 Address
. 2 -- Local Interface IPv6 Address
. Others TBD.

Note that all link identifiers in the same list must be of the same type.

o Reserved: Reserved for future use (16 bits)

o Link Identifiers: Identifies each link ID for which restriction is applied. The length is dependent on the link format. See the following section for Link Identifier encoding.

4.2.1. Link Identifier sub-TLV

The link identifier field can be an IPv4, IPv6 or unnumbered interface ID.

<Link Identifier> ::=

<IPV4 Address> | <IPV6 Address> | <Unnumbered IF ID>

The encoding of each case is as follows:

IPv4 prefix Sub-TLV

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Type = 1       | IPv4 address (4 bytes)                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| IPv4 address (continued)      | Prefix Length |   Attribute   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

IPv6 prefix Sub-TLV

```
 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
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |  Type = 2       | IPv6 address (16 bytes)                     |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 | IPv6 address (continued)                                      |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 | IPv6 address (continued)                                      |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 | IPv6 address (continued)                                      |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 | IPv6 address (continued)      | Prefix Length |   Attribute   |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Unnumbered Interface ID Sub-TLV

```
  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
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |  Type = 4       |    Reserved    |  Attribute                 |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                        TE Node ID                             |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                        Interface ID                           |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-
```

4.2.2. Wavelength Restriction Field sub-TLV

The Wavelength Restriction Field of the wavelength restriction TLV is encoded as a Label Set field as specified in [GEN-Encode] section 2.2, as shown below, with base label encoded as a 32 bit LSC label, defined in [RFC6205]. See [RFC6205] for a description of Grid, C.S, Identifier and n, as well as [GEN-Encode] for the details of each action.

```
   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
```

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Action|    Num Labels         |          Length               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Grid | C.S   |    Identifier   |              n                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Additional fields as necessary per action                 |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

4.3. Signal processing capability restrictions

Path computation for WSON include the check of signal processing capabilities, those capability MAY be provided by the IGP, however this is not a MUST. Moreover, a PCC should be able to indicate additional restrictions for those signal compatibility, either on the endpoint or any given link.

The supported signal processing capabilities are the one described in [RWA-Info]:

. Modulation Type List

. FEC Type List

. Bit rate

. Client signal

The Bit-rate restriction is already expressed in [PCEP-GMPLS] in the GENERALIZED-BANDWIDTH object.

The client signal information can be expressed using the REQ-ADAP-CAP object from the [PCEP-Layer].

In order to support the Modulation and FEC information two new TLV are introduced as endpoint-restriction in the END-POINTS type Generalized endpoint:

. Modulation restriction TLV

. FEC restriction TLV.

The END-POINTS type generalized endpoint is extended as follow:

```
<endpoint-restrictions> ::= <LABEL-REQUEST>

                            <label-restriction-list>

                            [<signal-compatibility-restriction>...]
```

Where

```
signal-compatibility-restriction ::=

         <MODULATION-FORMAT-LIST>|<FEC-LIST>
```

The MODULATION-FORMAT-LIST and FEC-LIST TLV are described in the following sections.

4.3.1. MODULATION-FORMAT-LIST Restriction TLV

This optional TLV represents a modulation format restriction. The TLV type is TBD, recommended value 17.

The TLV data is defined as follow:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|S|I| Modulation ID                |     Reserved             |X|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Modulation ID/S bit dependent body                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5 Modulation-Format Field

The format follows the definition from [WSON-Encode] section 5.2. The X bit is set to 1 to exclude the Modulation format, the X bit is set to 0 to include the modulation format.

4.3.2. FEC-LIST Restriction TLV

This optional TLV represents a FEC restriction. The TLV type is TBD, recommended value 18.

The TLV data is defined as follow:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|S|I|          FEC ID             |     Reserved              |X|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|        FEC ID/S bit dependent body                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 6 FEC Field

The format follows the definition from [WSON-Encode] section 5.3. The X bit is set to 1 to exclude the FEC; the X bit is set to 0 to include the FEC.

4.3.3. Signal Processing Exclusion XRO Sub-Object

The PCC/PCE should be able to exclude particular types of signal processing along the path in order to handle client restriction or multi-domain path computation.

In order to support the exclusion a new XRO sub-object is defined: the signal processing exclusion:

```
    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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|X|  Type = X    |     Length    |   Reserved    | Attribute     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 sub-sub objects                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 7 Signaling Processing XRO Sub-Object

The Attribute field indicates how the exclusion sub-object is to be interpreted. The Attribute can only be 0 (Interface) or 1 (Node).

The sub-sub objects are encoded as in RSVP signaling definition [WSON-Sign].

4.3.4. IRO sub-object: signal processing inclusion

Similar to the XRO sub-object the PCC/PCE should be able to include particular types of signal processing along the path in order to handle client restriction or multi-domain path computation.

This is supported by adding the sub-object "processing" defined for ERO in [WSON-Sign] to the PCEP IRO object.

4.3.5. Objective Functions

TBD. [Ed Note: consider a separate draft]

In WSON and DWDM networks the signal is not descrete but has a given spectrum. The spectrum depends in current standard on the channel spacing. In the context of RWA it is important to take into accountthis aspects, as optical effect can cause some cross-talk between the different signals, so it can be desired to reduce it by having sufficient space between the signals. In networks where the channel spacing is constant this can be expressed by the distance between two frequency but also by considering the free spectrum between signals, which is more general and is more important in networks where different system work on different channel spacing.

In order to have a generic expression of this aspect new objective functions are introduced in order to indicate on which criteria the path should be chosen. The following quantities are defined:

- smallest free spectrum on link L is denoted s(L).
- biggest free spectrum on link L is denoted S(L).
- total spectrum width remaining on link L is denoted ST(L)

The Following new objective functions are defined (Objective Function Codes: TBA)

- Maximum residual spectrum

Description: Find a Path such that (Max { (s(Li))), i=1...N}) is minimized.

- Minimize the free spectrum

  Description: Find a Path such that (Max { (S(Li)), i=1...N}) is maximized.

- Maximize the remaining total spectrum.

  Description: Find a Path such that (Max { (ST(Li)), i=1...N}) is maximized.

5. Encoding of a RWA Path Reply

The ERO is used to encode the path of a TE LSP through the network. The ERO is carried within a given path of a PCEP response, which is in turn carried in a PCRep message to provide the computed TE LSP if the path computation was successful. The preferred way to convey the allocated wavelength is by means of Explicit Label Control (ELC) [RFC4003].

In order to encode wavelength assignment, the Wavelength Assignment (WA) Object needs to be employed to be able to specify wavelength assignment. Since each segment of the computed optical path is associated with wavelength assignment, the WA Object should be aligned with the ERO object.

Encoding details will be provided further revisions and will be aligned as much as possible with [WSON-Sign].

5.1. Error Indicator

To indicate errors associated with the RWA request, a new Error Type (TDB) and subsequent error-values are defined as follows for inclusion in the PCEP-ERROR Object:

A new Error-Type (TDB) and subsequent error-values are defined as follows:

- Error-Type=TBD; Error-value=1: if a PCE receives a RWA request and the PCE is not capable of processing the request due to insufficient memory, the PCE MUST send a PCErr message with a PCEP-ERROR Object (Error-Type=TDB) and an Error-value(Error-value=1). The PCE stops processing the request. The corresponding RWA request MUST be cancelled at the PCC.

. Error-Type=TBD; Error-value=2: if a PCE receives a RWA request and the PCE is not capable of RWA computation, the PCE MUST send a PCErr message with a PCEP-ERROR Object (Error-Type=15) and an Error-value (Error-value=2). The PCE stops processing the request. The corresponding RWA computation MUST be cancelled at the PCC.

5.2. NO-PATH Indicator

To communicate the reason(s) for not being able to find RWA for the path request, the NO-PATH object can be used in the PCRep message. The format of the NO-PATH object body is defined in [RFC5440]. The object may contain a NO-PATH-VECTOR TLV to provide additional information about why a path computation has failed.

Two new bit flags are defined to be carried in the Flags field in the NO-PATH-VECTOR TLV carried in the NO-PATH Object.

. Bit TDB: When set, the PCE indicates no feasible route was found that meets all the constraints associated with RWA.

. Bit TDB: When set, the PCE indicates that no wavelength was assigned to at least one hop of the route in the response.

. Bit TDB: When set, the PCE indicate that no path was found satisfying the signal compatibility constraints.

6. Manageability Considerations

Manageability of WSON Routing and Wavelength Assignment (RWA) with PCE must address the following considerations:

6.1. Control of Function and Policy

In addition to the parameters already listed in Section 8.1 of [PCEP], a PCEP implementation SHOULD allow configuring the following PCEP session parameters on a PCC:

. The ability to send a WSON RWA request.

In addition to the parameters already listed in Section 8.1 of [PCEP], a PCEP implementation SHOULD allow configuring the following PCEP session parameters on a PCE:

- The support for WSON RWA.

- A set of WSON RWA specific policies (authorized sender, request rate limiter, etc).

These parameters may be configured as default parameters for any PCEP session the PCEP speaker participates in, or may apply to a specific session with a given PCEP peer or a specific group of sessions with a specific group of PCEP peers.

6.2. Information and Data Models, e.g. MIB module

Extensions to the PCEP MIB module defined in [PCEP-MIB] should be defined, so as to cover the WSON RWA information introduced in this document. A future revision of this document will list the information that should be added to the MIB module.

6.3. Liveness Detection and Monitoring

Mechanisms defined in this document do not imply any new liveness detection and monitoring requirements in addition to those already listed in section 8.3 of [RFC5440].

6.4. Verifying Correct Operation

Mechanisms defined in this document do not imply any new verification requirements in addition to those already listed in section 8.4 of [RFC5440]

6.5. Requirements on Other Protocols and Functional Components

The PCE Discovery mechanisms ([RFC5089] and [RFC5088]) may be used to advertise WSON RWA path computation capabilities to PCCs.

6.6. Impact on Network Operation

Mechanisms defined in this document do not imply any new network operation requirements in addition to those already listed in section 8.6 of [RFC5440].

7. Security Considerations

This document has no requirement for a change to the security models within PCEP [PCEP]. However the additional information distributed in order to address the RWA problem represents a disclosure of network capabilities that an operator may wish to keep private. Consideration should be given to securing this information.

8. IANA Considerations

A future revision of this document will present requests to IANA for codepoint allocation.

9. Acknowledgments

The authors would like to thank Adrian Farrel for many helpful comments that greatly improved the contents of this draft.

This document was prepared using 2-Word-v2.0.template.dot.

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