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PCEP Extension for WSON Routing and Wavelength Assignment

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Abstract

This document provides the Path Computation Element communication Protocol (PCEP) extensions for the support of Routing and Wavelength Assignment (RWA) in Wavelength Switched Optical Networks (WSON). Path 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 path computation.

Status of this Memo

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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", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

3. Introduction

[RFC5440] specifies the Path Computation Element (PCE) Communication Protocol (PCEP) for communications between a Path Computation Client (PCC) and a PCE, or between two PCEs. Such interactions include path computation requests and path computation replies as well as notifications of specific states related to the use of a PCE in the context of Multiprotocol Label Switching (MPLS) and Generalized MPLS (GMPLS) Traffic Engineering.

A PCC is said 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.

This document provides the PCEP extensions for the support of Routing and Wavelength Assignment (RWA) in Wavelength Switched Optical Networks (WSON) based on the requirements specified in [RFC6163] and [RFC7449].

WSON refers to WDM based optical networks in which switching is performed selectively based on the wavelength of an optical signal. The devices used in WSONs that are able to switch signals based on signal wavelength are known as Lambda Switch Capable (LSC). WSONs can be transparent or translucent. 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. On the other hand, translucent networks include 3R regenerators that are sparsely placed. The main function of the 3R regenerators is to convert one optical wavelength to another.

A Lambda Switch Capable (LSC) Label Switched Path (LSP) may span one or several transparent segments, which are delimited by 3R regenerators (Re-amplification, Re-shaping, Re-timing) 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)
     <------->   <------->       <----->     <------->
     <----------------------><---------------------->
      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 do not need to 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; Otherwise, the two signals would interfere 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 path 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 optical path computation.

For example (see Figure 1), 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 refers to the switching capability of I1 and I2. For example, X can be PSC, TDM, etc.

This document aligns with GMPLS extensions for PCEP [PCEP-GMPLS] for generic properties such as label, label-set and label assignment noting that wavelength is a type of label. Wavelength restrictions and constraints are also formulated in terms of labels per [RFC7579].

The optical modulation properties, which are also referred to as signal compatibility, are already considered in signaling in [RFC7581] and [RFC7688]. In order to improve the signal quality and limit some optical effects several advanced modulation processing capabilities are used. These modulation capabilities 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. This document includes signal

compatibility constraints as part of RWA path computation. That is, the signal processing capabilities (e.g., modulation and FEC) indicated by means of optical interface class (OIC) 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.

4. Encoding of a RWA Path Request

Figure 2 shows one typical PCE based implementation, which is referred to as the 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 specified in [RFC6163] and the PCEP extensions that are specified in this document are based on this architecture.

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

Figure 2 Combined Process (R&WA) architecture

4.1. Wavelength Assignment (WA) Object

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

(a) By means of Explicit Label Control [RFC3471] where the PCE allocates which label to use for each interface/node along the path. The allocated labels MAY appear after an interface route subobject.

(b) By means of a Label Set where the PCE provides a range of potential labels to allocate by each node along the path.

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.

The format of a PCReq message after incorporating the Wavelength Assignment (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 the WA object is present in the request, it MUST be encoded after the ENDPOINTS object as defined in [PCEP-GMPLS]. Orderings with respect to the other following objects are irrelevant.

The format of the 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Reserved             |           Flags             |M|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Wavelength Selection TLV                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             Wavelength Restriction Constraint TLV             |
.                                                               .
.                                                               .
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3 WA Object

o Reserved (16 bits): Reserved for future use and SHOULD be zeroed.

o Flags (16 bits)

One flag bit is allocated as follows:

. 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 for each hop of a computed LSP. Otherwise (M bit is set to 0), the label assigned by the PCE need not be explicit (i.e., it can be suggested in the form of label set objects in the corresponding response, to allow distributed WA. If M is 0, the PCE MUST return a Label Set Field as described in Section 2.6 of [RFC7579] in the response. See Section 5 of this document for the encoding discussion of a Label Set Field in a PCRep message.

All unused flags SHOULD be zeroed.

. Wavelength Selection TLV (32 bits): See Section 4.2 for details.

. Wavelength Restriction Constraint TLV (Variable): See Section 4.3 for details.

4.2. Wavelength Selection TLV

The Wavelength Selection TLV is used to indicate the wavelength selection constraint in regard to the order of wavelength assignment to be returned by the PCE. This TLV is only applied when M bit is set in the WA Object specified in Section 4.1. This TLV MUST NOT be used when the M bit is cleared.

The encoding of this TLV is specified as the Wavelength Selection Sub-TLV in Section 4.2.2 of [RFC7689].

4.3. 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.

The format of the Wavelength Restriction Constraint TLV is as follows:

```
<Wavelength Restriction Constraint> ::=

               <Action> <Count> <Reserved>

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

Where

```
<Link Identifiers> ::= <Link Identifier> [<Link Identifiers>]
```

See Section 4.3.1. for the encoding of the Link Identifiers Field.

The Wavelength Restriction Constraint TLV type is TBD3 (See Section 8.3). This TLV MAY appear more than once to be able to specify multiple restrictions.

The TLV data is defined 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Action        |    Count      |          Reserved             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Link Identifiers                          |
|                          . . .                                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                Wavelength Restriction Field                   |
//                        . . . .                              //
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 4 Wavelength Restriction Constraint TLV Encoding 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 "interfaces" are assumed to be bidirectional.

o Count (8 bits): The number of the link identifiers

Note that a PCC MAY add a Wavelength restriction that applies to all links by setting the Count field to zero and specifying just a set of wavelengths.

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

o Reserved (16 bits): Reserved for future use and SHOULD be zeroed.

o Link Identifiers: Identifies each link ID for which restriction is applied. The length is dependent on the link format and the Count field. See Section 4.3.1. for Link Identifier encoding and Section 4.3.2. for the Wavelength Restriction Field encoding, respectively.

Various encoding errors are possible with this TLV (e.g., not exactly two link identifiers with the range case, unknown identifier types, no matching link for a given identifier, etc.). To indicate errors associated with this type, a new Error-Type (TBD8) and an Error-value (Error-value=3) MUST be defined so that the PCE MUST send a PCErr message with a PCEP-ERROR Object. See Section 5.1 for the details.

4.3.1. Link Identifier Field

The link identifier field can be an IPv4 [RFC3630], IPv6 [RFC5329] or unnumbered interface ID [RFC4203].

```
<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     |    Reserved  (16 bits)                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| IPv4 address (4 bytes)                                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

   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     |    Reserved  (16 bits)                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| IPv6 address (16 bytes)                                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| IPv6 address (continued)                                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| IPv6 address (continued)                                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| IPv6 address (continued)                                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

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 = 3     |    Reserved (16 bits)                         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                        TE Node ID (32 bits)                   |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                        Interface ID (32 bits)                 |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type (8 bits): It indicates the type of the link identifier.

Reserved (16 bits): Reserved for future use and SHOULD be zeroed.

4.3.2. Wavelength Restriction Field

The Wavelength Restriction Field of the wavelength restriction TLV is encoded as a Label Set field as specified in Section 2.6 in [RFC7579] 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 [RFC7579] 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                 |
  |                                                               |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Action (4 bits):

0 - Inclusive List

1 - Exclusive List

2 - Inclusive Range

3 - Exclusive Range

4 - Bitmap Set

Num Labels (12 bits): It is generally the number of labels. It has a specific meaning depending on the action value.

Length (16 bits): It is the length in bytes of the entire label set field.

See Sections 2.6.1 - 2.6.3 of [RFC7579] for details on additional field discussion for each action.

4.4. Signal processing capability restrictions

Path computation for WSON includes checking of signal processing capabilities at each interface against requested capability; this requirement MAY be implemented by the IGP. Moreover, a PCC should be able to indicate additional restrictions to signal processing compatibility, either on the endpoint or any given link.

The supported signal processing capabilities are those described in [RFC7446]:

. Optical Interface Class List

. Bit Rate

. Client Signal

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

In order to support the Optical Interface Class information and the Client Signal information new TLVs are introduced as endpoint-restriction in the END-POINTS type Generalized endpoint:

. Client Signal TLV

. Optical Interface Class List TLV

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

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

```
                            <Wavelength Restriction Constraint>

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

Where

```
   signal-compatibility-restriction ::=

                     <Optical Interface Class List> <Client Signal>
```

The encoding for the Optical Interface Class List is described in Section 4.1 of [RFC7581].

The encoding for the Client Signal Information is described in Section 4.2 of [RFC7581].

4.4.1. 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. [RFC5440] defines how Exclude Route Object (XRO) sub-object is used. In this draft, we add a new XRO sub-object, signal processing sub-object.

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 5 Signaling Processing XRO Sub-Object

Refer to [RFC5521] for the definition of X, Type, Length and Attribute.

Reserved bits (8 bits) are for future use and SHOULD be zeroed.

The Attribute field (8 bits) indicates how the exclusion sub-object is to be interpreted. The Attribute can only be 0 (Interface) or 1 (Node).

The permitted sub-sub objects are the Optical Interface Class List and the Client Signal information whose encodings are described in Section 4.1 and Section 4.2 of [RFC7581], respectively.

4.4.2. 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. [RFC5440] defines how Include Route Object (IRO) sub-object is used. In this draft, we add a new IRO sub-object, signal processing sub-object.

This is supported by adding the sub-object "WSON Processing Hop Attribute TLV" defined for ERO in Section 4.2 [RFC7689] to the PCEP IRO object [RFC5440].

5. Encoding of a RWA Path Reply

This section provides the encoding of a RWA Path Reply for wavelength allocation request as discussed in Section 4. Recall that wavelength allocation can be performed by the PCE by different means:

(a) By means of Explicit Label Control (ELC) where the PCE allocates which label to use for each interface/node along the path.
(b) By means of a Label Set where the PCE provides a range of potential labels to allocate by each node along the path.

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

The Wavelength Allocation TLV type is TBD4 (See Section 8.4). The TLV data is defined 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              Type             |         Length              |M|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Link Identifier                           |
|                          . . .                                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Allocated Wavelength(s)                    |
//                        . . . .                             //
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 6 Wavelength Allocation TLV Encoding

o Type (16 bits): The type of the TLV.

o Length (15 bits): The length of the TLV including the Type and Length fields.

o M (Mode): 1 bit

   - 0 indicates the allocation is under Explicit Label Control.

   - 1 indicates the allocation is expressed in Label Sets.

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

o Link Identifier: Identifies the interface to which assignment wavelength(s) is applied. See Section 4.3.1. for Link Identifier encoding.

o Allocated Wavelength(s): Indicates the allocated wavelength(s) to be associated with the Link Identifier. See Section 4.3.2 for encoding details.

This TLV is encoded as an attributes TLV, per [RFC5420], which is carried in the ERO LSP Attribute Subobjects per [RFC7570].

5.1. Error Indicator

To indicate errors associated with the RWA request, a new Error Type (TBD8) and subsequent error-values are defined as follows for inclusion in the PCEP-ERROR Object:

A new Error-Type (TBD8) and subsequent error-values are defined as follows:

. Error-Type=TBD8; 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=TBD8) 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=TBD8; 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=TBD8) and an Error-value (Error-value=2). The PCE stops processing the request. The corresponding RWA computation MUST be cancelled at the PCC.

. Error-Type=TBD8; Error-value=3: if a PCE receives a RWA request and there are syntactical encoding errors (e.g., not exactly two link identifiers with the range case, unknown identifier types, no matching link for a given identifier, etc.), the PCE MUST send a PCErr message with a PCEP-ERROR Object (Error-Type=TBD8) and an Error-value (Error-value=3).

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 corresponding response. 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.

One new bit flag is defined to be carried in the Flags field in the NO-PATH-VECTOR TLV carried in the NO-PATH Object.

- Bit TBD7: When set, the PCE indicates no feasible route was found that meets all the constraints (e.g., wavelength restriction, signal compatibility, etc.) associated with RWA.

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 [RFC5440], a PCEP implementation SHOULD allow configuration of 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 [RFC5440], a PCEP implementation SHOULD allow configuration of 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. 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].

6.3. 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]

6.4. Requirements on Other Protocols and Functional Components

The PCEP Link-State mechanism [PCEP-LS] may be used to advertise WSON RWA path computation capabilities to PCCs.

6.5. 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

The security considerations discussed in [RFC5440] are relevant for this document, this document does not introduce any new security issues. If an operator wishes to keep private the information distributed by WSON, PCEPS [RFC8253] SHOULD be used.

8. IANA Considerations

IANA maintains a registry of PCEP parameters. IANA has made allocations from the sub-registries as described in the following sections.

8.1. New PCEP Object

As described in Section 4.1, a new PCEP Object is defined to carry wavelength assignment related constraints. IANA is to allocate the following from "PCEP Objects" sub-registry (http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-objects):

Object Class Value	Name	Object Type	Reference
TBD1	WA	1: Wavelength-Assignment	[This.I-D]

8.2. New PCEP TLV: Wavelength Selection TLV

As described in Sections 4.2, a new PCEP TLV is defined to indicate wavelength selection constraints. IANA is to allocate this new TLV from the "PCEP TLV Type Indicators" subregistry (http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-tlv-type-indicators).

Value	Description	Reference
TBD2	Wavelength Selection	[This.I-D]

8.3. New PCEP TLV: Wavelength Restriction Constraint TLV

As described in Sections 4.3, a new PCEP TLV is defined to indicate wavelength restriction constraints. IANA is to allocate this new TLV from the "PCEP TLV Type Indicators" subregistry (http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-tlv-type-indicators).

Value	Description	Reference
TBD3	Wavelength Restriction Constraint	[This.I-D]

8.4. New PCEP TLV: Wavelength Allocation TLV

As described in Section 5, a new PCEP TLV is defined to indicate the allocation of wavelength(s) by the PCE in response to a request by the PCC. IANA is to allocate this new TLV from the "PCEP TLV Type Indicators" subregistry (http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-tlv-type-indicators).

Value	Description	Reference
TBD4	Wavelength Allocation	[This.I-D]

8.5. New PCEP TLV: Optical Interface Class List TLV

As described in Section 4.3, a new PCEP TLV is defined to indicate the optical interface class list. IANA is to allocate this new TLV from the "PCEP TLV Type Indicators" subregistry (http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-tlv-type-indicators).

Value	Description	Reference
TBD5	Optical Interface Class List	[This.I-D]

8.6. New PCEP TLV: Client Signal TLV

As described in Section 4.3, a new PCEP TLV is defined to indicate the client signal information. IANA is to allocate this new TLV from the "PCEP TLV Type Indicators" subregistry (http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-tlv-type-indicators).

Value	Description	Reference
TBD6	Client Signal Information	[This.I-D]

8.7. New No-Path Reasons

As described in Section 5.2., a new bit flag are defined to be carried in the Flags field in the NO-PATH-VECTOR TLV carried in the NO-PATH Object. This flag, when set, indicates that no feasible route was found that meets all the RWA constraints (e.g., wavelength restriction, signal compatibility, etc.) associated with a RWA path computation request.

IANA is to allocate this new bit flag from the "PCEP NO-PATH-VECTOR TLV Flag Field" subregistry (http://www.iana.org/assignments/pcep/pcep.xhtml#no-path-vector-tlv).

Bit	Description	Reference
TBD7	No RWA constraints met	[This.I-D]

8.8. New Error-Types and Error-Values

As described in Section 5.1, new PCEP error codes are defined for WSON RWA errors. IANA is to allocate from the ""PCEP-ERROR Object Error Types and Values" sub-registry (http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-error-object).

Error-Type	Meaning	Error-Value	Reference
TBD8	WSON RWA Error	1: Insufficient Memory	[This.I-D]
		2: RWA computation Not supported	{This.I-D]

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10. References

10.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

[RFC3630] D. Katz, K. Kompella, D. Yeung, "Traffic Engineering (TE) Extensions to OSPF Version 2", RFC 3630, September 2003.

[RFC5329] A. Lindem, Ed., "Traffic Engineering Extensions to OSPF Version 3", RFC 5329, September 2008.

[RFC5440] JP. Vasseur, Ed., JL. Le Roux, Ed., "Path Computation Element (PCE) Communication Protocol (PCEP)", RFC 5440, March 2009.

[RFC6205] Tomohiro, O. and D. Li, "Generalized Labels for Lambda-Switching Capable Label Switching Routers", RFC 6205, January, 2011.

[RFC7570] C. Margaria, et al., "Label Switched Path (LSP) Attribute in the Explicit Route Object (ERO)", RFC 7570, July 2015.

[RFC7579] G. Bernstein and Y. Lee, "General Network Element Constraint Encoding for GMPLS Controlled Networks", RFC 7579, June 2015.

[RFC7581] G. Bernstein and Y. Lee, "Routing and Wavelength Assignment Information Encoding for Wavelength Switched Optical Networks", RFC7581, June 2015.

[RFC7689] Bernstein et al., "Signaling Extensions for Wavelength Switched Optical Networks", RFC 7689, November 2015.

[RFC7688] Y. Lee, and G. Bernstein, "OSPF Enhancement for Signal and Network Element Compatibility for Wavelength Switched Optical Networks", RFC 7688, November 2015.

[RFC8174] B. Leiba, "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", RFC 8174, May 2017.

[PCEP-GMPLS] C. Margaria, et al., "PCEP extensions for GMPLS", draft-ietf-pce-gmpls-pcep-extensions, work in progress.

10.2. Informative References

[RFC3471] Berger, L. (Editor), "Generalized Multi-Protocol Label Switching (GMPLS) Signaling Functional Description", RFC 3471. January 2003.

[RFC4203] K. Kompella, Ed., Y. Rekhter, Ed., "OSPF Extensions in Support of Generalized Multi-Protocol Label Switching (GMPLS)", RFC 4203, October 2005.

[RFC5420] Farrel, A. "Encoding of Attributes for MPLS LSP Establishment Using Resource Reservation Protocol Traffic Engineering (RSVP-TE)", RFC5420, February 2009.

[RFC5440] Vasseur, JP., Ed. and JL. Le Roux, Ed., "Path Computation Element (PCE) communication Protocol", RFC 5440, March 2009.[RFC5521] Oki, E, T. Takeda, and A. Farrel, "Extensions to the Path Computation Element Communication Protocol (PCEP) for Route Exclusions", RFC 5521, April 2009.

[RFC6163] Lee, Y. and Bernstein, G. (Editors), and W. Imajuku, "Framework for GMPLS and PCE Control of Wavelength Switched Optical Networks", RFC 6163, March 2011.

[RFC7446] Y. Lee, G. Bernstein. (Editors),"Routing and Wavelength Assignment Information Model for Wavelength Switched Optical Networks", RFC 7446, February 2015.

[RFC8253] D. Lopez, O. Gonzalez de Dios, Q. Wu, D. Dhody, "PCEPS: Usage of TLS to Provide a Secure Transport for the Path Computation Element Communication Protocol (PCEP)", RFC 8253, October 2017.

[PCEP-LS] Y. Lee, et al., "PCEP Extension for Distribution of Link-State and TE information for Optical Networks", draft-lee-pce-pcep-ls-optical, work in progress.

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