PCEP extensions for GMPLS
draft-ietf-pce-gmpls-pcep-extensions-05

Abstract

This memo provides extensions for the Path Computation Element communication Protocol (PCEP) for the support of GMPLS control plane.

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1. Introduction

PCEP RFCs [RFC5440], [RFC5521], [RFC5541], [RFC5520] are focused on path computation requests in MPLS networks. [RFC4655] defines the PCE framework also for GMPLS networks. This document complements these RFCs by providing some consideration of GMPLS applications and routing requests, for example for OTN and WSON networks.

The requirements on PCE extensions to support those characteristics are described in [I-D.ietf-pce-gmpls-aps-req] and [I-D.ietf-pce-wson-routing-wavelength].

1.1. Contributing Authors

Elie Sfeir, Franz Rambach (Nokia Siemens Networks) Francisco Javier Jimenez Chico (Telefonica Investigacion y Desarrollo) Suárez-BR, Young Lee, SenthilKumar S, Jun Sun (Huawei Technologies), Ramon Casellas (CTTC)

1.2. PCEP requirements for GMPLS

The document [I-D.ietf-pce-gmpls-aps-req] describe what are the set of PCEP requirements to support GMPLS TE-LSPs. When requesting a path computation (PCReq) to PCE, the PCC should be able to indicate the following additional information:

- Which data flow is switched by the LSP: a combination of Switching capability (for instance L2SC or TDM), Switching Encoding (e.g., Ethernet, SONET/SDH) and sometime Signal Type (in case of TDM/LSC switching capability)

- Data flow specific traffic parameter, which can vary a lot, for instance In SDH/SONET and G.709 OTN networks the Concatenation Type, Concatenation Number have influence on the switched data and on which link it can be supported

- Support for asymmetric bandwidth requests.

- Support for unnumbered interfaces: as defined in [RFC3477]

- Label information and technology specific label(s) such as wavelength label as defined in [RFC6205]. PCC should also be able to specify Label restriction similar to the one supported by RSVP.

- Ability to indicate the requested granularity for the path ERO: node, link, label. This is to allow the use of the explicit label control of RSVP.
We describe in this document a proposal to fulfill those requirements.

1.3. PCEP existing objects related to GMPLS

PCEP as of [RFC5440], [RFC5521] and [I-D.ietf-pce-inter-layer-ext], supports the following information (in the PCReq and PCRep) related to the described requirements.

From [RFC5440]:

- numbered endpoints
- bandwidth (encoded as IEEE float)
- ERO
- LSP attributes (setup and holding priorities)
- Request attribute (include some LSP attributes)

From [RFC5521], Extensions to PCEP for Route Exclusions, definition of a XRO object and a new semantic (F bit):

- This object also allows to exclude (strict or not) resources; XRO includes the diversity level (node, link, SRLG). The requested diversity is expressed in the XRO
- This Object with the F bit set indicates that the existing route is failed and resources present in the RRO can be reused.

From [I-D.ietf-pce-inter-layer-ext]:

- INTER-LAYER : indicates if inter-layer computation is allowed
- SWITCH-LAYER : indicates which layer(s) should be considered, can be used to represent the RSVP-TE generalized label request
- REQ-ADAP-CAP : indicates the adaptation capabilities requested, can also be used for the endpoints in case of mono-layer computation

The shortcomings of the existing PCEP information are:

The BANDWIDTH and LOAD-BALANCING objects do not describe the details of the traffic request (for example NVC, multiplier) in the context of GMPLS networks, for instance TDM or OTN networks.
The END-POINTS object does not allow specifying an unnumbered interface, nor the labels on the interface. Those parameters are of interest in case of switching constraints.

The IRO/XRO objects do not allow to include/exclude labels

Current attributes do not allow to express the requested link level protection and end-to-end protection attributes.

The covered PCEP extensions are:

New objects are introduced (GENERALIZED-BANDWIDTH and GENERALIZED-LOAD-BALANCING) for flexible bandwidth encoding,

A new object type is introduced for the END-POINTS object (generalized-endpoint),

A new TLV is added to the LSPA object.

A new TLV type is allowed in IRO

In order to indicate the mandatory routing granularity in the response, a new flag in the RP object is added.

1.4. 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 RFC 2119.
2. PCEP objects and extensions

This section describes the required PCEP objects and extensions. The PCReq and PCRep messages are defined in [RFC5440]. The format of the request and response messages with the proposed extensions (GENERALIZED-BANDWIDTH, GENERALIZED-LOAD-BALANCING, SUGGESTED-LABEL-SET and LABEL-SET) is as follows:

```
<request>::= <RP>
    <segment-computation>|<path-key-expansion>

<segment-computation> ::= 
    <END-POINTS>
    [<LSPA>]
    [<BANDWIDTH>]
    [<GENERALIZED-BANDWIDTH>...]
    [<metric-list>]
    [<OF>]
    [<RRO> [BANDWIDTH] [<GENERALIZED-BANDWIDTH>...]]
    [<IRO>]
    [<LOAD-BALANCING>]
    [<GENERALIZED-LOAD-BALANCING>...]
    [<XRO>]

<path-key-expansion> ::= <PATH-KEY>

<response>::=<RP>
    [<NO-PATH>]
    [<attribute-list>]
    [<path-list>]

<path-list>::=<path>[<path-list>]
<path>::= <ERO><attribute-list>
<metric-list>::=<METRIC>[<metric-list>]
```

Where:

```
<attribute-list>::=[<LSPA>]
    [<BANDWIDTH>]
    [<GENERALIZED-BANDWIDTH>...]
    [<GENERALIZED-LOAD-BALANCING>...]
    [<metric-list>]
    [<IRO>]
```

For point-to-multipoint (P2MP) computations, the proposed grammar is:
<segment-computation> ::=<br>

Explicit label control (ELC) is a procedure supported by RSVP-TE, where the outgoing label(s) is(are) encoded in the ERO. In consequence, the PCE may be able to provide such label(s) directly in the path ERO. The PCC, depending on policies or switching layer, may be required to use explicit label control or expect explicit link, thus it need to indicate in the PCReq which granularity it is expecting in the ERO. This correspond to requirement 11 of [I-D.ietf-pce-gmpls-aps-req] The possible granularities can be node, link, label. The granularities are inter-dependent, in the sense that link granularity imply the presence of node information in the ERO, similarly a label granularity imply that the ERO contain node, link and label information.

A new 2-bit routing granularity (RG) flag is defined in the RP object. The values are defined as follows
When the RP object appears in a request within a PCReq message the flag indicates the requested route granularity. The PCE MAY try to follow this granularity and MAY return a NO-PATH if the requested granularity cannot be provided. The PCE MAY return more details on the route based on its policy. The PCC can decide if the ERO is acceptable based on its content.

If a PCE did use the requested routing granularity in a PCReq it MUST indicate the routing granularity in the PCRep. The RG flag is backward-compatible with previous RFCs: the value sent by an implementation not supporting it will indicate a node granularity. This flag is optional for responses. A new capability flag in the PCE-CAP-FLAGS from [RFC5088] and [RFC5089] may be added.

2.2. Traffic parameters encoding, GENERALIZED-BANDWIDTH

The PCEP BANDWIDTH does not describe the details of the signal (for example NVC, multiplier), hence the bandwidth information should be extended to use the RSVP Tspec object encoding. The PCEP BANDWIDTH object defines two types: 1 and 2. C-Type 2 is representing the existing bandwidth in case of re-optimization.

The following possibilities cannot be represented in the BANDWIDTH object:

- Asymmetric bandwidth (different bandwidth in forward and reverse direction), as described in [RFC6387]
- GMPLS (SDH/SONET, G.709, ATM, MEF etc) parameters are not supported.

This correspond to requirement 3,4,5 and 10 of [I-D.ietf-pce-gmpls-aps-req].

According to [RFC5440] the BANDWIDTH object has no TLV and has a fixed size of 4 bytes. This definition does not allow extending it with the required information. To express this information, a new object named GENERALIZED-BANDWIDTH having the following format is defined:
The GENERALIZED-BANDWIDTH has a variable length. The Traffic spec length field indicates the length of the Traffic spec field. The bits R and O have the following meaning:

- **O bit**: when set the value refers to the previous bandwidth in case of re-optimization.
- **R bit**: when set the value refers to the bandwidth of the reverse direction.

The Object type determines which type of bandwidth is represented by the object. The following object types are defined:

1. Intserv
2. SONET/SDH
3. G.709
4. Ethernet

The encoding of the field Traffic Spec is the same as in RSVP-TE, it can be found in the following references.
The GENERALIZED-BANDWIDTH MAY appear more than once in a PCReq message. If more than one GENERALIZED-BANDWIDTH have the same Object Type, Reserved, R and O values, only the first one is processed, the others are ignored.

A PCE MAY ignore GENERALIZED-BANDWIDTH objects, a PCC that requires a GENERALIZED-BANDWIDTH to be used can set the P (Processing) bit in the object header.

When a PCC needs to get a bi-directional path with asymmetric bandwidth, it SHOULD specify the different bandwidth in forward and reverse directions through two separate GENERALIZED-BANDWIDTH objects. If the PCC set the P bit on both object the PCE MUST compute a path that satisfies the asymmetric bandwidth constraint and return the path to PCC if the path computation is successful. If the P bit on the reverse GENERALIZED-BANDWIDTH object the PCE MAY ignore this constraint.

A PCE MAY include the GENERALIZED-BANDWIDTH objects in the response to indicate the GENERALIZED-BANDWIDTH of the path.

Optional TLVs may be included within the object body to specify more specific bandwidth requirements. The specification of such TLVs is outside the scope of this document.

2.3. Traffic parameters encoding, GENERALIZED-LOAD-BALANCING

The LOAD-BALANCING object is used to request a set of maximum Max-LSP TE-LSP having in total the bandwidth specified in BANDWIDTH, each TE-LSP having a minimum of min-bandwidth bandwidth. The LOAD-BALANCING
follows the bandwidth encoding of the BANDWIDTH object, it does not
describe enough details for the traffic specification expected by
GMPLS. A PCC should be allowed to request a set of TE-LSP also in
case of GMPLS traffic specification.

According to [RFC5440] the LOAD-BALANCING object has no TLV and has a
fixed size of 8 bytes. This definition does not allows extending it
with the required information. To express this information, a new
Object named GENERALIZED-LOAD-BALANCING is defined.

The GENERALIZED-LOAD-BALANCING object, as the LOAD-BALANCING object,
allows the PCC to request a set of TE-LSP having in total the
GENERALIZED-BANDWIDTH traffic specification with potentially Max-Lsp,
each TE-LSP having a minimum of Min Traffic spec. The GENERALIZED-
LOAD-BALANCING is optional.

GENERALIZED-LOAD-BALANCING Object-Class is to be assigned by IANA.
The GENERALIZED-LOAD-BALANCING Object type determines which type of
minimum bandwidth is represented by the object. The following object
types are defined:

1.  Intserv
2.  SONET/SDH
3.  G.709
4.  Ethernet

The GENERALIZED-LOAD-BALANCING has a variable length.

The format of the GENERALIZED-LOAD-BALANCING 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Traffic spec length        |     Flags   |R|     Max-LSP   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|        Min  Traffic Spec                                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
~                Optional   TLVs                                ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Traffic spec length (16 bits): the total length of the min traffic
specification. It should be noted that the RSVP traffic
specification may also include TLV different than the PCEP TLVs.

Flags (8 bits): The undefined Flags field MUST be set to zero on transmission and MUST be ignored on receipt. The following flag is defined:

R Flag : (1 bit) set when the value refer to the bandwidth of the reverse direction

Max-LSP (8 bits): maximum number of TE LSPs in the set.

Min-Traffic spec (variable): Specifies the minimum traffic spec of each element of the set of TE LSPs.

The encoding of the field Traffic Spec is the same as in RSVP-TE, it can be found in the following references.

<table>
<thead>
<tr>
<th>Object Type</th>
<th>Name</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Intserv</td>
<td>[RFC2210]</td>
</tr>
<tr>
<td>4</td>
<td>SONET/SDH</td>
<td>[RFC4606]</td>
</tr>
<tr>
<td>5</td>
<td>G.709</td>
<td>[RFC4328]</td>
</tr>
<tr>
<td>6</td>
<td>Ethernet</td>
<td>[RFC6003]</td>
</tr>
</tbody>
</table>

Traffic Spec field encoding

The GENERALIZED-LOAD-BALANCING MAY appear more than once in a PCReq message. If more than one GENERALIZED-LOAD-BALANCING have the same Object Type, and R Flag, only the first one is processed, the others are ignored.

a PCE MAY ignore GENERALIZED-LOAD-BALANCING objects. A PCC that requires a GENERALIZED-LOAD-BALANCING to be used can set the P (Processing) bit in the object header.

When a PCC needs to get a bi-directional path with asymmetric bandwidth, it SHOULD specify the different bandwidth in forward and reverse directions through two separate GENERALIZED-LOAD-BALANCING objects with different R Flag. If the PCC set the P bit on both object the PCE MUST compute a path that satisfies the asymmetric bandwidth constraint and return the path to PCC if the path computation is successful. If the P bit on the reverse GENERALIZED-LOAD-BALANCING object the PCE MAY ignore this constraint.

Optional TLVs may be included within the object body to specify more
specific bandwidth requirements. The specification of such TLVs is outside the scope of this document.

The GENERALIZED-LOAD-BALANCING object has the same semantic as the LOAD-BALANCING object; If a PCC requests the computation of a set of TE LSPs so that the total of their generalized bandwidth is X, the maximum number of TE LSPs is N, and each TE LSP must at least have a bandwidth of B, it inserts a GENERALIZED-BANDWIDTH object specifying X as the required bandwidth and a GENERALIZED-LOAD-BALANCING object with the Max-LSP and Min-traffic spec fields set to N and B, respectively.

For example a request for one co-signaled n x VC-4 TE-LSP will not use the GENERALIZED-LOAD-BALANCING. In case the V4 components can use different paths, the GENERALIZED-BANDWIDTH will contain a traffic specification indicating the complete n x VC4 traffic specification and the GENERALIZED-LOAD-BALANCING the minimum co-signaled VC4. For a SDH network, a request to have a TE-LSP group with 10 VC4 container, each path using at minimum 2VC4 container, can be represented with a GENERALIZED-BANDWIDTH object with OT=4, the content of the Traffic specification is ST=6,RCC=0,NCC=0,NVC=10,MT=1. The GENERALIZED-LOAD-BALANCING, OT=4,R=0,Max-LSP=5, min Traffic spec is (ST=6,RCC=0,NCC=0,NVC=2,MT=1). The PCE can respond with a response with maximum 5 path, each of then having a GENERALIZED-BANDWIDTH OT=4,R=0, and traffic spec matching the minimum traffic spec from the GENERALIZED-LOAD-BALANCING object of the corresponding request.

2.4. END-POINTS Object extensions

The END-POINTS object is used in a PCReq message to specify the source and destination of the path for which a path computation is requested. From [RFC3471] the source IP address and the destination IP address are used to identify those. A new Object Type is defined to address the following possibilities:

- Different endpoint types.
- Label restrictions on the endpoint.
- Specification of unnumbered endpoints type as seen in GMPLS networks.

The Object encoding is described in the following sections.
2.4.1. Generalized Endpoint Object Type

In GMPLS context the endpoints can:

- Be unnumbered
- Have label(s) associated to them
- May have different switching capabilities

The IPv4 and IPv6 endpoints are used to represent the source and destination IP addresses. The scope of the IP address (Node or Link) is not explicitly stated. It should also be possible to request a Path between a numbered link and an unnumbered link, or a P2MP path between different type of endpoints.

Since the PCEP END-POINTS object only support endpoints of the same type a new C-Type is proposed that support different endpoint types, including unnumbered. This new C-Type also supports the specification of constraints on the endpoint label to be use. The PCE might know the interface restrictions but this is not a requirement. On the path calculation request only the Tspec and switch layer need to be coherent, the endpoint labels could be different (supporting a different Tspec). Hence the label restrictions include a Generalized label request in order to interpret the labels. This correspond to requirement 6 and 9 of [I-D.ietf-pce-gmpls-aps-req].

The proposed object format consists of a body and a list of TLVs, which give the details of the endpoints and are described in Section 2.4.2. For each endpoint type, a different grammar is defined. The TLVs defined to describe an endpoint are:

1. IPv4 address.
2. IPv6 address.
3. Unnumbered endpoint.
4. Label request.
5. Label.
6. Upstream label.
7. Old Label.
8. Old Upstream label.


10. Suggested label set.

The labels TLV are used to restrict the label allocation in the PCE. They follow the set of restrictions provided by signaling with explicit value (label and upstream label), mandatory range restrictions (Label set) and optional range restriction (suggested label set). Single suggested value is using the suggested label set. The Old Label and Old Upstream Labels are used to represent existing label(s) when requesting a re-optimization. The Old Label and Old upstream Label MAY be present only when the Reoptimization flag (R) of the RP object is set. The label range restrictions are valid in GMPLS networks, either by PCC policy or depending on the switching technology used, for instance on given Ethernet or ODU equipment having limited hardware capabilities restricting the label range. Label set restriction also applies to WSON networks where the optical sender and receivers are limited in their frequency tunability ranges, restricting then in GMPLS the possible label ranges on the interface. The END-POINTS Object with Generalized Endpoint object type is encoded as follow:

```
+-----------+-----------+-----------+-----------+-----------+-----------+-----------+-----------+-----------+-----------+-----------+-----------+-----------+-----------+-----------+
| Reserved  | endpoint type | Reserved  | endpoint type | TLVs | Reserved  | endpoint type |
|-----------+-----------+-----------+-----------+-----------+-----------+-----------+-----------+-----------+-----------+-----------+-----------+-----------+-----------+
```

Reserved bits should be set to 0 when a message is sent and ignored when the message is received.

the endpoint type is defined as follow:
<table>
<thead>
<tr>
<th>Value</th>
<th>Type</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Point-to-Point</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Point-to-Multipoint</td>
<td>New leaves to add</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Old leaves to remove</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Old leaves whose path can be modified/reoptimized</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Old leaves whose path must be left unchanged</td>
</tr>
<tr>
<td>5-244</td>
<td>Reserved</td>
<td></td>
</tr>
<tr>
<td>245-255</td>
<td>Experimental range</td>
<td></td>
</tr>
</tbody>
</table>

The endpoint type is used to cover both point-to-point and different point-to-multipoint endpoint semantic. Endpoint type 0 MAY be accepted by the PCE, other endpoint type MAY be supported if the PCE implementation supports P2MP path calculation. A PCE not supporting a given endpoint type MUST respond with a PCErr with error code "Path computation failure", error type "Unsupported endpoint type in ENDPOINTS Generalized Endpoint object type". The TLVs present in the object body MUST follow the following grammar:

```
<generalized-endpoint-tlvs>::=
  <p2p-endpoints> | <p2mp-endpoints>

<p2p-endpoints> ::= <source-endpoint> <destination-endpoint>

<source-endpoint> ::= <endpoint> [<endpoint-restriction-list>]

<destination-endpoint> ::= <endpoint> [<endpoint-restriction-list>]

<p2mp-endpoints> ::= <endpoint> [<endpoint-restriction-list>]
                   [<endpoint> [<endpoint-restriction-list>]]...
```

For endpoint type Point-to-Multipoint several endpoint objects may be
present in the message and represent a leave, exact meaning depend on the endpoint type defined of the object.

An endpoint is defined as follows:

\[ \text{<endpoint>::=}<\text{IPV4-ADDRESS}|<\text{IPV6-ADDRESS}|<\text{UNNUMBERED-ENDPOINT}> \]

\[ \text{<endpoint-restriction-list> ::= } \text{<endpoint-restriction>} [\text{<endpoint-restriction-list>}] \]

\[ \text{<endpoint-restriction>::=} \text{<LABEL-REQUEST><label-restriction-list>} \]

\[ \text{<label-restriction-list> ::= } \text{<label-restriction>} [\text{<label-restriction-list>}] \]

\[ \text{<label-restriction>::=} \text{<LABEL>|<UPSTREAM-LABEL>|<OLD-LABEL>|<OLD-UPSTREAM-LABEL>|<LABEL-SET>|<SUGGESTED-LABEL-SET>} \]

The different TLVs are described in the following sections. A PCE MAY support IPV4-ADDRESS, IPV6-ADDRESS or UNNUMBERED-ENDPOINT TLV. A PCE not supporting one of those TLV in a PCReq MUST respond with a PCRep with NO-PATH with the bit "Unknown destination" or "Unknown source" in the NO-PATH-VECTOR TLV, the PCRep MUST include the ENDPOINT object in the response with only the TLV it did not understood.

A PCE MAY support LABEL-REQUEST, LABEL, UPSTREAM-LABEL, OLD-LABEL, OLD-UPSTREAM-LABEL, LABEL-SET or SUGGESTED-LABEL-SET TLV. If the TLV OLD-LABEL or OLD-UPSTREAM-LABEL are present the R bit of the RP object MUST be set or a PCErr message with error type="Reception of an invalid object" error value="OLD-LABEL or OLD-UPSTREAM-LABEL TLV present without R bit set in RP" For non supported TLV in the ENDPOINTS a PCE MUST respond with a PCErr message with error type="Path computation failure" error value="Unsupported TLV present in ENDPOINTS Generalized Endpoint object type" and the message MUST include the ENDPOINT object in the response with only the endpoint and endpoint restriction TLV it did not understood. A PCE not supporting being able to fulfill the label restriction MUST respond with a PCRep with NO-PATH with the bit "No endpoint label resource" or "No endpoint label resource in range" in the NO-PATH-VECTOR TLV, the PCRep MUST include the ENDPOINT object in the response with only the TLV where it could not met the constraint.

2.4.2. END-POINTS TLVs extensions

All endpoint TLVs have the standard PCEP TLV header as defined in [RFC5440] section 7.1
2.4.2.1. IPV4-ADDRESS

This TLV represent a numbered endpoint using IPv4 numbering, the format of the IPv4-ADDRESS TLV value (TLV-Type=TBA) 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          IPv4 address                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

This TLV MAY be ignored, in which case a PCRep with NO-PATH should be responded, as described in Section 2.4.1.

2.4.2.2. IPV6-ADDRESS TLV

This TLV represent a numbered endpoint using IPv6 numbering, the format of the IPv6-ADDRESS TLV value (TLV-Type=TBA) 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              IPv6 address (16 bytes)                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

This TLV MAY be ignored, in which case a PCRep with NO-PATH should be responded, as described in Section 2.4.1.

2.4.2.3. UNNUMBERED-ENDPOINT TLV

This TLV represent an unnumbered interface. This TLV has the same semantic as in [RFC3477] The TLV value is encoded as follow (TLV-Type=TBA)

```
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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          LSR’s Router ID                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Interface ID (32 bits)                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

This TLV MAY be ignored, in which case a PCRep with NO-PATH should be responded, as described in Section 2.4.1.
2.4.2.4. LABEL-REQUEST TLV

The LABEL-REQUEST TLV indicates the switching capability and encoding type of the label restriction list. Its format is the same as described in [RFC3471] Section 3.1 Generalized label request. The LABEL-REQUEST TLV use TLV-Type=TBA. The fields are encoded as in the RSVP-TE. The Encoding Type indicates the encoding type, e.g., SONET/SDH/GigE etc., that will be used with the data associated with the LSP. The Switching type indicates the type of switching that is being requested on the link. G-PID identifies the payload of the TE-LSP. This TLV and the following one are introduced to satisfy requirement 13 for the endpoint.

This TLV MAY be ignored, in which case a PCRep with NO-PATH should be responded, as described in Section 2.4.1.

2.4.2.5. Labels TLV

Label or label range restrictions may be specified for the TE-LSP endpoints. Those are encoded in the TLVs. The label value need to be interpreted with a description on the Encoding and switching type. The REQ-ADAP-CAP object from [I-D.ietf-pce-inter-layer-ext] can be used in case of mono-layer request, however in case of multilayer it is possible to have in the future more than one object, so it is better to have a dedicated TLV for the label and label request (the scope is then more clear). Those TLV MAY be ignored, in which case a PCRep with NO-PATH should be responded, as described in Section 2.4.1. TLVs are encoded as follow (following RFC5440):

- LABEL TLV, Type=TBA. The TLV Length is variable, the value is the same as [RFC3471] Section 3.2 Generalized label. This represent the downstream label.

- UPSTREAM-LABEL TLV, Type=TBA, The TLV Length is variable, the value is the same as [RFC3471] Section 3.2 Generalized label. This represent the upstream label.

- OLD-LABEL TLV, Type=TBA. The TLV Length is variable, the value is the same as [RFC3471] Section 3.2 Generalized label. This represent the old downstream label in case of re-optimization. This Label MAY be reused. The R bit of the RP object MUST be set.

- OLD-UPSTREAM-LABEL TLV, Type=TBA, The TLV Length is variable, the value is the same as [RFC3471] Section 3.2 Generalized label. This represent the old upstream label in case of re-optimization. This Label MAY be reused. The R bit of the RP object MUST be set.
o LABEL-SET TLV, Type=TBA. The TLV Length is variable, Encoding follow [RFC3471] Section 3.5 "Label set" with the addition of a U bit: the U bit is set for upstream direction in case of bidirectional LSP.

```
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Action     |    Reserved     |U|        Label Type         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Subchannel 1                         |
|                              ...                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Subchannel N                         |
|                              ...                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

o SUGGESTED-LABEL-SET TLV Set, Type=TBA. The TLV length is variable, Encoding is as LABEL-SET TLV.

A LABEL TLV represent the label used on the unnumbered interface, bit U is used to indicate which exact direction is considered. The label type indicates which type of label is carried. A LABEL-SET TLV represents a set of possible labels that can be used on the unnumbered interface. the label allocated on the first link SHOULD be within the label set range. The action parameter in the Label set indicates the type of list provided. Those parameters are described by [RFC3471] section 3.5.1. A SUGGESTED-LABEL-SET TLV has the same encoding as the LABEL-SET TLV, it indicates to the PCE a set of preferred (ordered) set of labels to be used. the PCE MAY use those labels for label allocation.

The U bit has the following meaning:

U: Upstream direction: set when the label or label set is in the reverse direction

2.5. IRO TLV extension

The IRO as defined in [RFC5440] is used to include specific objects in the path. RSVP allows to include label definition, in order to fulfill requirement 13 the IRO should support the new TLV Type as defined in [RFC3473]:

Type Sub-object

3    LABEL

The L bit of such sub-object has no meaning within an IRO.

The Label subobject MUST follow a subobject identifying a link, currently an IP address subobject (Type 1 or 2) or an interface id (type 4) subobject. The procedure associated with this subobject is as follow

If the PCE allocate labels the PCE MUST allocate one label of within the set of label values for the given link. If the PCE does not assign labels an error

2.6. XRO TLV extension

The XRO as defined in [RFC5521] is used to exclude specific objects in the path. RSVP allows to exclude labels ([RFC6001], in order to fulfill requirement 13 the XRO should support a new TLV for the label exclusion.

The encoding of the XRO Label subobject is identical follow the encoding of the Label ERO subobject defined in [RFC3473] and XRO TLVs defined in [RFC5521]. The XRO Label subobject is defined as follows:

XRO Subobject Type 3: Label Subobject.

\[
\begin{array}{cccc}
0 & 1 & 2 & 3 \\
\hline
0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 0 & 1 \\
\hline
X | Type=3 | Length | U | Reserved | C-Type \\
| Label | ... |
\end{array}
\]

X (1 bit)

See [RFC5521].

Type (7 bits)
The Type of the XRO Label subobject is 3.

Length (8 bits)

See [RFC5521], the total length of the subobject in bytes (including the Type and Length fields). The Length is always divisible by 4.

U (1 bit)

See [RFC3471].

C-Type (8 bits)

The C-Type of the included Label Object. Copied from the Label Object (see [RFC3471]).

Label

See [RFC3471].

XRO Label subobjects MUST follow the numbered or unnumbered interface subobjects to which they refer. Several XRO Labels subobject MAY be present.

Type Sub-object

3    LABEL

The L bit of such sub-object has no meaning within an XRO.

2.7.  LSPA extensions

The LSPA carries the LSP attributes. In the end-to-end protection context this also includes the protection state information. This object is introduced to fulfill requirement 7 and is used as a policy input for route and label selection. The LSPA object can be extended by a protection TLV type: Type TBA: PROTECTION-ATTRIBUTE
LSP Flags can be considered for routing policy based on the protection type. The other attributes are only meaningful for a s_ateful PCE.

This TLV is optional and MAY be ignored by the PCE, in which case MUST NOT include the TLV in the LSPA, if present, of the PCRep. When the TLV is used by the PCE, a LSPA object and the PROTECTION-ATTRIBUTE TLV MUST be included in the PCRep. Fields that were not considered MUST be set to 0.

2.8. NO-PATH Object Extension

The NO-PATH object is used in PCRep messages in response to an unsuccessful path computation request (the PCE could not find a path satisfying the set of constraints). In this scenario, PCE MUST include a NO-PATH object in the PCRep message. The NO-PATH object may carries the NO-PATH-VECTOR TLV that specifies more information on the reasons that led to a negative reply. In case of GMPLS networks there could be some more additional constraints that led to the failure like protection mismatch, lack of resources, and so on. Few new flags have been introduced in the 32-bit flag field of the NO-PATH-VECTOR TLV and no modifications have been made in the NO-PATH object.

2.8.1. Extensions to NO-PATH-VECTOR TLV

The modified NO-PATH-VECTOR TLV carrying the additional information is as follows:

Bit number TBA – Protection Mismatch (1-bit). Specifies the mismatch of the protection type in the PROTECTION-ATTRIBUTE TLV in the request.

Bit number TBA – No Resource (1-bit). Specifies that the resources are not currently sufficient to provide the path.
Bit number TBA - Granularity not supported (1-bit). Specifies that the PCE is not able to provide a route with the requested granularity.

Bit number TBA - No endpoint label resource (1-bit). Specifies that the PCE is not able to provide a route because of the endpoint label restriction.

Bit number TBA - No endpoint label resource in range (1-bit). Specifies that the PCE is not able to provide a route because of the endpoint label set restriction.
3. Additional Error Type and Error Values Defined

A PCEP-ERROR object is used to report a PCEP error and is characterized by an Error-Type that specifies the type of error while Error-value that provides additional information about the error type. An additional error type and few error values are defined to represent some of the errors related to the newly identified objects related to SDH networks. For each PCEP error, an Error-Type and an Error-value are defined. Error-Type 1 to 10 are already defined in [RFC5440]. Additional Error- values are defined for Error-Type 10 and a new Error-Type is introduced (value TBA).

<table>
<thead>
<tr>
<th>Error-Type</th>
<th>Error-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Reception of an invalid object</td>
</tr>
<tr>
<td></td>
<td>Error-value=TBA: Bad Generalized Bandwidth Object value.</td>
</tr>
<tr>
<td></td>
<td>Error-value=TBA: Unsupported LSP Protection Type in PROTECTION-ATTRIBUTE TLV.</td>
</tr>
<tr>
<td></td>
<td>Error-value=TBA: Unsupported LSP Protection Flags in PROTECTION-ATTRIBUTE TLV.</td>
</tr>
<tr>
<td></td>
<td>Error-value=TBA: Unsupported Secondary LSP Protection Flags in PROTECTION-ATTRIBUTE TLV.</td>
</tr>
<tr>
<td></td>
<td>Error-value=TBA: Unsupported Link Protection Type in PROTECTION-ATTRIBUTE TLV.</td>
</tr>
<tr>
<td></td>
<td>Error-value=TBA: Unsupported Link Protection Type in PROTECTION-ATTRIBUTE TLV.</td>
</tr>
<tr>
<td></td>
<td>Error-value=TBA: OLD-LABEL or OLD-UPSTREAM-LABEL TLV present without R bit set in RP.</td>
</tr>
<tr>
<td>TBA</td>
<td>Path computation failure</td>
</tr>
<tr>
<td></td>
<td>Error-value=TBA: Unacceptable request message.</td>
</tr>
<tr>
<td></td>
<td>Error-value=TBA: Generalized bandwidth object not supported.</td>
</tr>
<tr>
<td></td>
<td>Error-value=TBA: Label Set constraint could not be met.</td>
</tr>
<tr>
<td></td>
<td>Error-value=TBA: Label constraint could not be met.</td>
</tr>
</tbody>
</table>
Error-value=TBA: Unsupported endpoint type in END-POINTS Generalized Endpoint object type
Error-value=TBA: Unsupported TLV present in END-POINTS Generalized Endpoint object type
Error-value=TBA: Unsupported granularity in the RP object flags
4. Manageability Considerations

Liveness Detection and Monitoring This document makes no change to the basic operation of PCEP and so there are no changes to the requirements for liveness detection and monitoring set out in [RFC4657] and [RFC5440].
5. IANA Considerations

IANA assigns values to the PCEP protocol objects and TLVs. IANA is requested to make some allocations for the newly defined objects and TLVs introduced in this document. Also, IANA is requested to manage the space of flags that are newly added in the TLVs.

### 5.1. PCEP Objects

As described in Section 2.2 and Section 2.3 new Objects are defined. IANA is requested to make the following Object-Type allocations from the "PCEP Objects" sub-registry.

<table>
<thead>
<tr>
<th>Object Class to be assigned</th>
<th>Name</th>
<th>GENERALIZED-BANDWIDTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object-Type</td>
<td>0 to 6</td>
<td></td>
</tr>
<tr>
<td>Reference</td>
<td>This document (section Section 2.2)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Object Class to be assigned</th>
<th>Name</th>
<th>GENERALIZED-LOAD-BALANCING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object-Type</td>
<td>0 to 6</td>
<td></td>
</tr>
<tr>
<td>Reference</td>
<td>This document (section Section 2.3)</td>
<td></td>
</tr>
</tbody>
</table>

As described in Section 2.4.1 a new Object type is defined. IANA is requested to make the following Object-Type allocations from the "PCEP Objects" sub-registry. The values here are suggested for use by IANA.

<table>
<thead>
<tr>
<th>Object Class</th>
<th>Name</th>
<th>END-POINTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object-Type 5</td>
<td>5 : Generalized Endpoint</td>
<td>6-15 : unassigned</td>
</tr>
<tr>
<td>Reference</td>
<td>This document (section Section 2.2)</td>
<td></td>
</tr>
</tbody>
</table>
5.2.  END-POINTS object, Object Type Generalized Endpoint

IANA is requested to create a registry to manage the endpoint type field of the END-POINTS object, Object Type Generalized Endpoint and manage the code space.

New endpoint type in the Reserved range may be allocated by an IETF consensus action. Each endpoint type should be tracked with the following qualities:

- endpoint type
- Description
- Defining RFC

New endpoint type in the Experimental range are for experimental use; these will not be registered with IANA and MUST NOT be mentioned by RFCs.

The following values have been defined by this document, (Section 2.4.1, Table 4):

<table>
<thead>
<tr>
<th>Value</th>
<th>Type</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Point-to-Point</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Point-to-Multipoint</td>
<td>New leaves to add</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Old leaves to remove</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Old leaves whose path can be modified/reoptimized</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Old leaves whose path must be left unchanged</td>
</tr>
<tr>
<td>5-244</td>
<td>Reserved</td>
<td></td>
</tr>
<tr>
<td>245-255</td>
<td>Experimental range</td>
<td></td>
</tr>
</tbody>
</table>

5.3.  New PCEP TLVs

IANA manages the PCEP TLV code point registry (see [RFC5440]). This is maintained as the "PCEP TLV Type Indicators" sub-registry of the "Path Computation Element Protocol (PCEP) Numbers" registry. This document defines new PCEP TLVs, to be carried in the END-POINTS object with Generalized Endpoint object Type. IANA is requested to
do the following allocation. The values here are suggested for use by IANA.

<table>
<thead>
<tr>
<th>Value</th>
<th>Meaning</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>IPv4 endpoint</td>
<td>This document (section 2.4.2.1)</td>
</tr>
<tr>
<td>8</td>
<td>IPv6 endpoint</td>
<td>This document (section 2.4.2.2)</td>
</tr>
<tr>
<td>9</td>
<td>Unnumbered endpoint</td>
<td>This document (section 2.4.2.3)</td>
</tr>
<tr>
<td>10</td>
<td>Label request</td>
<td>This document (section 2.4.2.4)</td>
</tr>
<tr>
<td>11</td>
<td>Requested GMPLS Label</td>
<td>This document (section 2.4.2.5)</td>
</tr>
<tr>
<td>12</td>
<td>Requested GMPLS Upstream Label</td>
<td>This document (section 2.4.2.5)</td>
</tr>
<tr>
<td>13</td>
<td>Requested GMPLS Label Set</td>
<td>This document (section 2.4.2.5)</td>
</tr>
<tr>
<td>14</td>
<td>Suggested GMPLS Label Set</td>
<td>This document (section 2.4.2.5)</td>
</tr>
<tr>
<td>15</td>
<td>Old Requested GMPLS Label</td>
<td>This document (section 2.4.2.5)</td>
</tr>
<tr>
<td>16</td>
<td>Old Requested GMPLS Upstream Label</td>
<td>This document (section 2.4.2.5)</td>
</tr>
<tr>
<td>15</td>
<td>LSP Protection Information</td>
<td>This document (section 2.7)</td>
</tr>
</tbody>
</table>

5.4.  RP Object Flag Field

As described in Section 2.1 new flag are defined in the RP Object Flag IANA is requested to make the following Object-Type allocations from the "RP Object Flag Field" sub-registry. The values here are suggested for use by IANA.
5.5. New PCEP Error Codes

As described in Section Section 3, new PCEP Error-Type and Error Values are defined. IANA is requested to make the following allocation in the "PCEP-ERROR Object Error Types and Values" registry. The values here are suggested for use by IANA.

<table>
<thead>
<tr>
<th>Error Type</th>
<th>Error name</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type=10</td>
<td>Reception of an invalid object</td>
<td>[RFC5440]</td>
</tr>
<tr>
<td>Value=2</td>
<td>Bad Generalized Bandwidth Object value.</td>
<td>This Document</td>
</tr>
<tr>
<td>Value=3</td>
<td>Unsupported LSP Protection Type in PROTECTION-ATTRIBUTE TLV.</td>
<td>This Document</td>
</tr>
<tr>
<td>Value=4</td>
<td>Unsupported LSP Protection Flags in PROTECTION-ATTRIBUTE TLV.</td>
<td>This Document</td>
</tr>
<tr>
<td>Value=5</td>
<td>Unsupported Secondary LSP Protection Flags in PROTECTION-ATTRIBUTE TLV.</td>
<td>This Document</td>
</tr>
<tr>
<td>Value=6</td>
<td>Unsupported Link Protection Type in PROTECTION-ATTRIBUTE TLV.</td>
<td>This Document</td>
</tr>
<tr>
<td>Value=7</td>
<td>Unsupported Link Protection Type in PROTECTION-ATTRIBUTE TLV.</td>
<td>This Document</td>
</tr>
<tr>
<td>Value=8</td>
<td>OLD-LABEL or OLD-UPSTREAM-LABEL TLV present without R bit set in RP.</td>
<td>This Document</td>
</tr>
<tr>
<td>Type=14</td>
<td>Path computation failure</td>
<td>This Document</td>
</tr>
<tr>
<td>Value=1</td>
<td>Unacceptable request message.</td>
<td>This Document</td>
</tr>
<tr>
<td>Value=2</td>
<td>Generalized bandwidth object not supported.</td>
<td>This Document</td>
</tr>
<tr>
<td>Value=3</td>
<td>Label Set constraint could not be met.</td>
<td>This Document</td>
</tr>
</tbody>
</table>
5.6. New NO-PATH-VECTOR TLV Fields

As described in Section Section 2.8.1, new NO-PATH-VECTOR TLV Flag Fields have been defined. IANA is requested to do the following allocations in the "NO-PATH-VECTOR TLV Flag Field" sub-registry. The values here are suggested for use by IANA.

Bit number 23 - Protection Mismatch (1-bit). Specifies the mismatch of the protection type of the PROTECTION-ATTRIBUTE TLV in the request.

Bit number 22 - No Resource (1-bit). Specifies that the resources are not currently sufficient to provide the path.

Bit number 21 - Granularity not supported (1-bit). Specifies that the PCE is not able to provide a route with the requested granularity.

Bit number 20 - No endpoint label resource (1-bit). Specifies that the PCE is not able to provide a route because of the endpoint label restriction.

Bit number 19 - No endpoint label resource in range (1-bit). Specifies that the PCE is not able to provide a route because of the endpoint label set restriction.

5.7. New Subobject for the Include Route Object

The "PCEP Parameters" registry contains a subregistry "PCEP Objects" with an entry for the Include Route Object (IRO).

IANA is requested to add a further subobject that can be carried in the IRO as follows:
5.8. New Subobject for the Exclude Route Object

The "PCEP Parameters" registry contains a subregistry "PCEP Objects" with an entry for the XRO object (Exclude Route Object).

IANA is requested to add a further subobject that can be carried in the XRO as follows:

<table>
<thead>
<tr>
<th>Subobject type</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Label suboject</td>
</tr>
<tr>
<td></td>
<td>[RFC3473]</td>
</tr>
</tbody>
</table>
6. Security Considerations

None.
7. Contributing Authors

Nokia Siemens Networks:

Elie Sfeir
St Martin Strasse 76
Munich, 81541
Germany

Phone: +49 89 5159 16159
Email: elie.sfeir@nsn.com

Franz Rambach
St Martin Strasse 76
Munich, 81541
Germany

Phone: +49 89 5159 31188
Email: franz.rambach@nsn.com

Francisco Javier Jimenez Chico
Telefonica Investigacion y Desarrollo
C/ Emilio Vargas 6
Madrid, 28043
Spain

Phone: +34 91 3379037
Email: fjjc@tid.es

Huawei Technologies

Suresh BR
Shenzhen
China
Email: sureshbr@huawei.com

Young Lee
1700 Alma Drive, Suite 100
Plano, TX 75075
USA

Phone: (972) 509-5599 (x2240)
Email: ylee@huawei.com

SenthilKumar S
Shenzhen
China
Email: senthilkumars@huawei.com
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9. References

9.1. Normative References


[RFC5088] Le Roux, JL., Vasseur, JP., Ikejiri, Y., and R. Zhang,


9.2. Informative References

[I-D.ietf-pce-gmpls-aps-req]
Caviglia, D., Zhang, F., Ogaki, K., and T. Otani,

[I-D.ietf-pce-inter-layer-ext]

[I-D.ietf-pce-wson-routing-wavelength]

[I-D.zhang-ccamp-gmpls-evolving-g709]


Authors’ Addresses

Cyril Margaria (editor)
Nokia Siemens Networks
St Martin Strasse 76
Munich, 81541
Germany

Phone: +49 89 5159 16934
Email: cyril.margaria@nsn.com

Oscar Gonzalez de Dios (editor)
Telefonica Investigacion y Desarrollo
C/ Emilio Vargas 6
Madrid, 28043
Spain

Phone: +34 91 3374013
Email: ogondio@tid.es

Fatai Zhang (editor)
Huawei Technologies
F3-5-B R&D Center, Huawei Base
Bantian, Longgang District
Shenzhen, 518129
P.R.China

Email: zhangfatai@huawei.com