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PCEP extensions for GMPLS
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Abstract

A Path Computation Element (PCE) provides path computation functions for Multiprotocol Label Switching (MPLS) and Generalized MPLS (GMPLS) networks. Additional requirements for GMPLS are identified in RFC7025.

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

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1. Introduction

Although [RFC4655] defines the PCE architecture and framework for both MPLS and GMPLS networks, most preexisting PCEP RFCs [RFC5440], [RFC5521], [RFC5541], [RFC5520] are focused on MPLS networks, and do not cover the wide range of GMPLS networks. This document complements these RFCs by addressing the extensions required for GMPLS applications and routing requests, for example for Optical Transport Network (OTN) and Wavelength Switched Optical Network (WSON) networks.

The functional requirements to be addressed by the PCEP extensions to support these applications are fully described in [RFC7025] and [RFC7449].

1.1. Terminology

This document uses terminologies from the PCE architecture document [RFC4655], the PCEP documents including [RFC5440], [RFC5521], [RFC5541], [RFC5520], [RFC7025] and [RFC7449], and the GMPLS documents such as [RFC3471], [RFC3473] and so on. Note that it is expected the reader is familiar with these documents. The following abbreviations are used in this document

ODU ODU Optical Channel Data Unit [G.709-v3]

OTN Optical Transport Network [G.709-v3]

L2SC Layer-2 Switch Capable [RFC3471]

TDM Time-Division Multiplex Capable [RFC3471]

LSC Lambda Switch Capable [RFC3471]

SONET Synchronous Optical Networking

SDH Synchronous Digital Hierarchy

PCC Path Computation Client

RSVP-TE Resource Reservation Protocol - Traffic Engineering

LSP Label Switched Path

TE-LSP Traffic Engineering LSP

IRO Include Route Object

ERO Explicit Route Object

XRO eXclude Route Object

RRO Record Route Object

LSPA LSP Attribute

SRLG Shared Risk Link Group

NVC Number of Virtual Components [RFC4328][RFC4606]

NCC Number of Contiguous Components [RFC4328][RFC4606]

MT Multiplier [RFC4328][RFC4606]

RCC Requested Contiguous Concatenation [RFC4606]

PCReq Path Computation Request [RFC5440]

PCRep Path Computation Reply [RFC5440]

MEF Metro Ethernet Forum

SSON Spectrum-Switched Optical Network

P2MP Point to Multi-Point

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.

1.2. PCEP Requirements for GMPLS

The document [RFC7025] describes the set of PCEP requirements to support GMPLS TE-LSPs. This document assumes a significant familiarity with [RFC7025] and existing PCEP extensions. As a short overview, those requirements can be broken down into the following categories.

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

- o Data flow specific traffic parameters, which are technology specific. For instance, in SDH/SONET and [G.709-v3] OTN networks the Concatenation Type and the Concatenation Number have an influence on the switched data and on which link it can be supported

- o Support for asymmetric bandwidth requests.

- o Support for unnumbered interface identifiers, as defined in [RFC3477]

- o Label information and technology specific label(s) such as wavelength labels as defined in [RFC6205]. A PCC should also be able to specify a label restriction similar to the one supported by RSVP-TE in [RFC3473].

- o Ability to indicate the requested granularity for the path ERO: node, link or label. This is to allow the use of the explicit label control feature of RSVP-TE.

The requirements of [RFC7025] apply to several objects conveyed by PCEP, this is described in Section 1.3. Some of the requirements of [RFC7025] are already supported in existing documents, as described in Section 1.4.

This document describes a set of PCEP extensions, including new object types, TLVs, encodings, error codes and procedures, in order to fulfill the aforementioned requirements not covered in existing RFCs.

1.3. Requirements Applicability

This section follows the organization of [RFC7025] Section 3 and indicates, for each requirement, the affected piece of information carried by PCEP and its scope.

1.3.1. Requirements on Path Computation Request

(1) Switching capability/type: as described in [RFC3471] this piece of information is used with the Encoding Type and Signal Type to fully describe the switching technology and data carried by the TE-LSP. This is applicable to the TE-LSP itself and also to the TE-LSP endpoint (Carried in the END-POINTS object for MPLS networks in [RFC5440]) when considering multiple network layers. Inter-layer path computation requirements are addressed in in [RFC8282] which addressing the TE-LSP itself, but the TE-LSP endpoints are not addressed.

(2) Encoding type: see (1).

(3) Signal type: see (1).

(4) Concatenation type: this parameter and the Concatenation Number (5) are specific to some TDM (SDH and ODU) switching technology. They MUST be described together and are used to derive the requested resource allocation for the TE-LSP. It is scoped to the TE-LSP and is related to the [RFC5440] BANDWIDTH object in MPLS networks. See [RFC4606] and [RFC4328] about concatenation information.

(5) Concatenation number: see (4).

(6) Technology-specific label(s): as described in [RFC3471] the GMPLS Labels are specific to each switching technology. They can be specified on each link and also on the TE-LSP endpoints , in WSON networks for instance, as described in [RFC6163]. The label restriction can apply to endpoints and on each hop, the related PCEP objects are END-POINTS, IRO, XRO and RRO.

(7) End-to-End (E2E) path protection type: as defined in [RFC4872], this is applicable to the TE-LSP. In MPLS networks the related PCEP object is LSPA (carrying local protection information).

(8) Administrative group: as defined in [RFC3630], this information is already carried in the LSPA object.

(9) Link protection type: as defined in [RFC4872], this is applicable to the TE-LSP and is carried in association with the E2E path protection type.

(10) Support for unnumbered interfaces: as defined in [RFC3477]. Its scope and related objects are the same as labels

(11) Support for asymmetric bandwidth requests: as defined [RFC6387], the scope is similar to (4)

(12) Support for explicit label control during the path computation. This affects the TE-LSP and amount of information returned in the ERO.

(13) Support of label restrictions in the requests/responses: This is described in (6).

1.3.2. Requirements on Path Computation Response

(1) Path computation with concatenation: This is related to Path Computation request requirement (4). In addition there is a specific type of concatenation called virtual concatenation that allows different routes to be used between the endpoints. It is similar to the semantic and scope of the LOAD-BALANCING in MPLS networks.

(2) Label constraint: The PCE should be able to include Labels in the path returned to the PCC, the related object is the ERO object.

(3) Roles of the routes: as defined in [RFC4872], this is applicable to the TE-LSP and is carried in association with the E2E path protection type.

1.4. Existing Support for GMPLS in Base PCEP Objects and its Limitations

The support provided by specifications in [RFC8282] and [RFC5440] for the requirements listed in [RFC7025] is summarized in Table 1 and Table 2. In some cases the support may not be complete, as noted, and additional support need to be provided in this specification.

Req.	Name	Support
1	Switching capability/type	SWITCH-LAYER (RFC8282)
2	Encoding type	SWITCH-LAYER (RFC8282)
3	Signal type	SWITCH-LAYER (RFC8282)
4	Concatenation type	No
5	Concatenation number	No
6	Technology-specific label	(Partial) ERO (RFC5440)
7	End-to-End (E2E) path protection type	No
8	Administrative group	LSPA (RFC5440)
9	Link protection type	No
10	Support for unnumbered interfaces	(Partial) ERO (RFC5440)
11	Support for asymmetric bandwidth requests	No
12	Support for explicit label control during the path computation	No
13	Support of label restrictions in the requests/responses	No

Table 1: RFC7025 Section 3.1 requirements support

Req.	Name	Support
1	Path computation with concatenation	No
2	Label constraint	No
3	Roles of the routes	No

Table 2: RFC7025 Section 3.2 requirements support

As described in Section 1.3 PCEP as of [RFC5440], [RFC5521] and [RFC8282], supports the following objects, included in requests and responses, related to the described requirements.

From [RFC5440]:

o END-POINTS: related to requirements (1, 2, 3, 6, 10 and 13). The object only supports numbered endpoints. The context specifies whether they are node identifiers or numbered interfaces.

o BANDWIDTH: related to requirements (4, 5 and 11). The data rate is encoded in the bandwidth object (as IEEE 32 bit float). [RFC5440] does not include the ability to convey an encoding proper to all GMPLS-controlled networks.

o ERO: related to requirements (6, 10, 12 and 13). The ERO content is defined in RSVP in [RFC3209][RFC3473][RFC3477][RFC7570] and supports all the requirements already.

o LSPA: related to requirements (7, 8 and 9). The requirement 8 (setup and holding priorities) is already supported.

From [RFC5521]:

o XRO:

  * This object allows excluding (strict or not) resources and is related to requirements (6, 10 and 13). It also includes the requested diversity (node, link or SRLG).

  * When the F bit is set, the request indicates that the existing path has failed and the resources present in the RRO can be reused.

From [RFC8282]:

o SWITCH-LAYER: addresses requirements (1, 2 and 3) for the TE-LSP and indicates which layer(s) should be considered. The object can be used to represent the RSVP-TE generalized label request. It does not address the endpoints case of requirements (1, 2 and 3).

o REQ-ADAP-CAP: indicates the adaptation capabilities requested, can also be used for the endpoints in case of mono-layer computation

The gaps in functional coverage of the base PCEP objects are:

The BANDWIDTH and LOAD-BALANCING objects do not describe the details of the traffic request (requirements 4 and 5, 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 potential label restrictions on the interface (requirements 6, 10 and 13). Those parameters are of interest in case of switching constraints.

The Include/eXclude Route Objects (IRO/XRO) do not allow the inclusion/exclusion of labels (requirements 6, 10 and 13).

Base attributes do not allow expressing the requested link protection level and/or the end-to-end protection attributes.

The PCEP extensions defined later in this document to cover the gaps are:

Two new object types are defined for the BANDWIDTH object (Generalized bandwidth, Generalized bandwidth of existing TE-LSP for which a reoptimization is requested).

A new object type is defined for the LOAD-BALANCING object (Generalized Load Balancing).

A new object type is defined for the END-POINTS object (Generalized Endpoint).

A new TLV is added to the Open message for capability negotiation.

A new TLV is added to the LSPA object.

The Label TLV is now allowed in the IRO and XRO objects.

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

2. PCEP Objects and Extensions

This section describes the necessary PCEP objects and extensions. The PCReq and PCRep messages are defined in [RFC5440]. This document does not change the existing grammars.

2.1. GMPLS Capability Advertisement

2.1.1. GMPLS Computation TLV in the Existing PCE Discovery Protocol

IGP-based PCE Discovery (PCED) is defined in [RFC5088] and [RFC5089] for the OSPF and IS-IS protocols. Those documents have defined bit 0 in PCE-CAP-FLAGS Sub-TLV of the PCED TLV as "Path computation with GMPLS link constraints". This capability is optional and can be used to detect GMPLS-capable PCEs. PCEs that set the bit to indicate support of GMPLS path computation MUST follow the procedures in Section 2.1.2 to further qualify the level of support during PCEP session establishment.

2.1.2. OPEN Object Extension GMPLS-CAPABILITY TLV

In addition to the IGP advertisement, a PCEP speaker MUST be able to discover the other peer GMPLS capabilities during the Open message exchange. This capability is also useful to avoid misconfigurations. This document defines a GMPLS-CAPABILITY TLV for use in the OPEN object to negotiate the GMPLS capability. The inclusion of this TLV

in the Open message indicates that the PCEP speaker support the PCEP extensions defined in the document. A PCEP speaker that is able to support the GMPLS extensions defined in this document MUST include the GMPLS-CAPABILITY TLV on the Open message. If one of the PCEP peers does not include the GMPLS-CAPABILITY TLV in the Open message, the peers MUST NOT make use of the objects and TLVs defined in this document.

If the PCEP speaker supports the extensions of this specification but did not advertise the GMPLS-CAPABILITY capability, upon receipt of a message from the PCE including an extension defined in this document, it MUST generate a PCEP Error (PCErr) with Error-Type=10 (Reception of an invalid object) and Error-value=TBA-42 (Missing GMPLS-CAPABILITY TLV), and it SHOULD terminate the PCEP session.

IANA has allocated value TBA-1 from the "PCEP TLV Type Indicators" sub-registry, as documented in Section 5.3 ("New PCEP TLVs"). The description is "GMPLS-CAPABILITY". Its format is shown in the following figure.

```
 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=TBA-1      |           Length              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             Flags                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

No Flags are defined in this document, they are reserved for future use.

2.2. RP Object Extension

Explicit label control (ELC) is a procedure supported by RSVP-TE, where the outgoing labels are encoded in the ERO. As a consequence, the PCE can provide such labels directly in the path ERO. Depending on policies or switching layer, it can be necessary for the PCC to use explicit label control or explicit link ids, thus it needs to indicate in the PCReq which granularity it is expecting in the ERO. This corresponds to requirement 12 of [RFC7025]. The possible granularities can be node, link or label. The granularities are inter-dependent, in the sense that link granularity implies the presence of node information in the ERO; similarly, a label granularity implies that the ERO contains node, link and label information.

A new 2-bit routing granularity (RG) flag (Bits TBA-13) is defined in the RP object. The values are defined as follows

0: reserved
1: node
2: link
3: label

Table 3: RG flag

The flag in the RP object indicates the requested route granularity. The PCE SHOULD follow this granularity and MAY return a NO-PATH if the requested granularity cannot be provided. The PCE MAY return any granularity on the route based on its policy. The PCC can decide if the ERO is acceptable based on its content.

If a PCE honored the requested routing granularity for a request, it MUST indicate the selected routing granularity in the RP object included in the response. Otherwise, the PCE MUST use the reserved RG to leave the check of the ERO to the PCC. The RG flag is backward-compatible with [RFC5440]: the value sent by an implementation (PCC or PCE) not supporting it will indicate a reserved value.

2.3. BANDWIDTH Object Extensions

From [RFC5440] the object carrying the requested size for the TE-LSP is the BANDWIDTH object. The object types 1 and 2 defined in [RFC5440] do not describe enough information to describe the TE-LSP bandwidth in GMPLS networks. The BANDWIDTH object encoding has to be extended to allow the object to express the bandwidth as described in [RFC7025]. RSVP-TE extensions for GMPLS provide a set of encodings allowing such representation in an unambiguous way, this is encoded in the RSVP-TE TSpec and FlowSpec objects. This document extends the BANDWIDTH object with new object types reusing the RSVP-TE encoding.

The following possibilities are supported by the extended encoding:

- o Asymmetric bandwidth (different bandwidth in forward and reverse direction), as described in [RFC6387]

- o GMPLS (SDH/SONET, G.709, ATM, MEF, etc.) parameters.

This corresponds to requirements 3, 4, 5 and 11 of [RFC7025] Section 3.1.

This document defines two Object Types for the BANDWIDTH object:

TBA-2 Generalized bandwidth

TBA-3 Generalized bandwidth of an existing TE-LSP for which a reoptimization is requested

The definitions below apply for Object Type TBA-2 and TBA-3. The 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Bandwidth Spec Length      | Rev. Bandwidth Spec Length    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Bw Spec Type  |   Reserved                                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
~                     Generalized Bandwidth                     ~
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
~          Optional:  Reverse Generalized Bandwidth             ~
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
~                       Optional TLVs                           ~
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The BANDWIDTH object type TBA-2 and TBA-3 have a variable length. The 16-bit Bandwidth Spec Length field indicates the length of the Generalized Bandwidth field. The Bandwidth Spec Length MUST be strictly greater than 0. The 16-bit Reverse Bandwidth Spec Length field indicates the length of the Reverse Generalized Bandwidth field. The Reverse Bandwidth Spec Length MAY be equal to 0.

The Bw Spec Type field determines which type of bandwidth is represented by the object.

The Bw Spec Type corresponds to the RSVP-TE SENDER_TSPEC (Object Class 12) C-Types

The encoding of the fields Generalized Bandwidth and Reverse Generalized Bandwidth is the same as the Traffic Parameters carried in RSVP-TE, it can be found in the following references. It is to be noted that the RSVP-TE traffic specification MAY also include TLVs (e.g., [RFC6003] different from the PCEP TLVs).

Bw Spec Type	Name	Reference
2	Intserv	[RFC2210]
4	SONET/SDH	[RFC4606]
5	G.709	[RFC4328]
6	Ethernet	[RFC6003]
7	OTN-TDM	[RFC7139]
8	SSON	[RFC7792]

Table 4: Generalized Bandwidth and Reverse Generalized Bandwidth field encoding

When a PCC requests a bi-directional path with symmetric bandwidth, it SHOULD only specify the Generalized Bandwidth field, and set the Reverse Bandwidth Spec Length to 0. When a PCC needs to request a bi-directional path with asymmetric bandwidth, it SHOULD specify the different bandwidth in the forward and reverse directions with a Generalized Bandwidth and Reverse Generalized Bandwidth fields.

The procedure described in [RFC5440] for the PCRep is unchanged: a PCE MAY include the BANDWIDTH objects in the response to indicate the BANDWIDTH of the path.

As specified in [RFC5440] in the case of the reoptimization of a TE-LSP, the bandwidth of the existing TE-LSP MUST also be included in addition to the requested bandwidth if and only if the two values differ. The Object Type TBA-3 MAY be used instead of the previously specified object type 2 to indicate the existing TE-LSP bandwidth originally specified with object type TBA-2. A PCC that requested a path with a BANDWIDTH object of object type 1 MUST use object type 2 to represent the existing TE-LSP BANDWIDTH.

OPTIONAL TLVs MAY be included within the object body to specify more specific bandwidth requirements. No TLVs for the Object Type TBA-2 and TBA-3 are defined by this document.

2.4. LOAD-BALANCING Object Extensions

The LOAD-BALANCING object [RFC5440] is used to request a set of at most Max-LSP TE-LSP having in total the bandwidth specified in BANDWIDTH, with each TE-LSP having at least a specified minimum bandwidth. The LOAD-BALANCING follows the bandwidth encoding of the BANDWIDTH object, and thus the existing definition from [RFC5440] does not describe enough details for the bandwidth specification expected by GMPLS.

Similarly to the BANDWIDTH object, a new object type is defined to allow a PCC to represent the bandwidth types supported by GMPLS networks.

This document defines the Generalized Load Balancing object type TBA-4 for the LOAD-BALANCING object. The Generalized Load Balancing object type has a variable length.

The format of the Generalized Load Balancing object type 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Bandwidth Spec Length      | Reverse Bandwidth Spec Length |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Bw Spec Type  |  Max-LSP      | Reserved                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|        Min Bandwidth Spec                                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|        Min Reverse Bandwidth Spec (optional)                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
~                Optional   TLVs                                ~
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Bandwidth Spec Length (16 bits): the total length of the Min Bandwidth Spec field. The length MUST be strictly greater than 0.

Reverse Bandwidth Spec Length (16 bits): the total length of the Min Reverse Bandwidth Spec field. It MAY be equal to 0.

Bw Spec Type (8 bits): the bandwidth specification type, it corresponds to the RSVP-TE SENDER_TSPEC (Object Class 12) C-Types.

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

Min Bandwidth Spec (variable): specifies the minimum bandwidth specification of each element of the TE-LSP set.

Min Reverse Bandwidth Spec (variable): specifies the minimum reverse bandwidth specification of each element of the TE-LSP set.

The encoding of the fields Min Bandwidth Spec and Min Reverse Bandwidth Spec is the same as in RSVP-TE SENDER_TSPEC object, it can be found in Table 4 from Section 2.3 from this document.

When a PCC requests a bi-directional path with symmetric bandwidth while specifying load balancing constraints it SHOULD specify the Min Bandwidth Spec field, and set the Reverse Bandwidth Spec Length to 0. When a PCC needs to request a bi-directional path with asymmetric bandwidth while specifying load balancing constraints, it MUST specify the different bandwidth in forward and reverse directions through a Min Bandwidth Spec and Min Reverse Bandwidth Spec fields.

OPTIONAL TLVs MAY be included within the object body to specify more specific bandwidth requirements. No TLVs for the Generalized Load Balancing object type are defined by this document.

The semantic of the LOAD-BALANCING object is not changed. If a PCC requests the computation of a set of TE-LSPs with at most N TE-LSPs so that it can carry generalized bandwidth X , each TE-LSP must at least transport bandwidth B, it inserts a BANDWIDTH object specifying X as the required bandwidth and a LOAD-BALANCING object with the Max-LSP and Min Bandwidth Spec fields set to N and B, respectively. When the BANDWIDTH and Min Bandwidth Spec can be summarized as scalars, the sum of all TE-LSPs bandwith in the set is greater than X. The mapping of X over N path with (at least) bandwidth B is technology and possibly node specific. Each standard definition of the transport technology is defining those mappings and are not repeated in this document. A simplified example for SDH is described in Appendix A

In all other cases, including for technologies based on statistical multiplexing (e.g., InterServ, Ethernet), the exact bandwidth management (e.g., Ethernet's Excessive Rate) is left to the PCE's policies, according to the operator's configuration. If required, further documents may introduce a new mechanism to finely express complex load balancing policies within PCEP.

The BANDWITH and LOAD-BALANCING Bw Spec Type can be different depending on the endpoint nodes architecture. When the PCE is not able to handle those two Bw Spec Type, it MUST return a NO-PATH with the bit "LOAD-BALANCING could not be performed with the bandwidth constraits " set in the NO-PATH-VECTOR TLV.

2.5. END-POINTS Object Extensions

The END-POINTS object is used in a PCEP request message to specify the source and the destination of the path for which a path computation is requested. From [RFC5440], 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:

o Different source and destination 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.

In path computation within a GMPLS context the endpoints can:

- Be unnumbered as described in [RFC3477].

- Have labels associated to them, specifying a set of constraints on the allocation of labels.

- 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 numbered Link) is not explicitly stated. It is also possible to request a Path between a numbered link and an unnumbered link, or a P2MP path between different type of endpoints.

This document defines the Generalized Endpoint object type TBA-5 for the END-POINTS object. This new type also supports the specification of constraints on the endpoint label to be used. The PCE might know the interface restrictions but this is not a requirement. This corresponds to requirements 6 and 10 of [RFC7025].

2.5.1. Generalized Endpoint Object Type

The Generalized Endpoint object type format consists of a body and a list of TLVs scoped to this object. The TLVs give the details of the endpoints and are described in Section 2.5.2. For each Endpoint Type, a different grammar is defined. The TLVs defined to describe an endpoint are:

1. IPv4 address endpoint.

2. IPv6 address endpoint.

3. Unnumbered endpoint.

4. Label request.

5. Label set.

The Label set TLV is used to restrict or suggest the label allocation in the PCE. This TLV expresses the set of restrictions which may

apply to signaling. Label restriction support can be an explicit or a suggested value (Label set describing one label, with the L bit respectively cleared or set), mandatory range restrictions (Label set with L bit cleared) and optional range restriction (Label set with L bit set). Endpoints label restriction may not be part of the RRO or IRO. They can be included when following [RFC4003] in signaling for egress endpoint, but ingress endpoint properties can be local to the PCC and not signaled. To support this case the label set allows indication which label are used in case of reoptimization. The label range restrictions are valid in GMPLS-controlled 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 senders and receivers are limited in their frequency tunability ranges, consequently restricting the possible label ranges on the interface in GMPLS. The END-POINTS Object with Generalized Endpoint object type is encoded 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Reserved                                 | Endpoint Type |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
~                           TLVs                                ~
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

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:

Value	Type	Meaning
0	Point-to-Point	
1	Point-to-Multipoint	New leaves to add
2		Old leaves to remove
3		Old leaves whose path can be modified/reoptimized
4		Old leaves whose path has to be left unchanged
5-244	Reserved	
245-255	Experimental range	

Table 5: Generalized Endpoint endpoint types

The Endpoint Type is used to cover both point-to-point and different point-to-multipoint endpoints. A PCE may accept only Endpoint Type 0: Endpoint Types 1-4 apply if the PCE implementation supports P2MP path calculation. A PCE not supporting a given Endpoint Type SHOULD respond with a PCErr with Error-Type=4 (Not supported object), Error-value=TBA-15 (Unsupported endpoint type in END-POINTS Generalized Endpoint object type). As per [RFC5440], a PCE unable to process Generalized Endpoints may respond with Error-Type=3 (Unknown Object), Error-value=2 (Unrecognized object Type) or Error-Type=4 (Not supported object), Error-value=2 (Not supported object Type). The TLVs present in the request object body MUST follow the following [RFC5511] grammar:

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

<p2p-endpoints> ::=
  <endpoint> [<endpoint-restriction-list>]
  <endpoint> [<endpoint-restriction-list>]

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

For endpoint type Point-to-Point, 2 endpoint TLVs MUST be present in the message. The first endpoint is the source and the second is the destination.

For endpoint type Point-to-Multipoint, several END-POINT objects MAY be present in the message and the exact meaning depending on the endpoint type defined for the object. The first endpoint TLV is the root and other endpoints TLVs are the leaves. The root endpoint MUST be the same for all END-POINTS objects. If the root endpoint is not the same for all END-POINTS, a PCErr with Error-Type=17 (P2MP END-POINTS Error), Error-value=4 (The PCE cannot satisfy the request due to inconsistent END-POINTS) MUST be returned. The procedure defined in [RFC8306] Section 3.10 also apply to the Generalized Endpoint with Point-to-Multipoint endpoint types.

An endpoint is defined as follows:

```
<endpoint>::=<IPV4-ADDRESS>|<IPV6-ADDRESS>|<UNNUMBERED-ENDPOINT>
<endpoint-restriction-list> ::=               <endpoint-restriction>
             [<endpoint-restriction-list>]

<endpoint-restriction> ::=
                 [<LABEL-REQUEST>][<label-restriction-list>]

<label-restriction-list> ::= <label-restriction>
                             [<label-restriction-list>]
<label-restriction> ::= <LABEL-SET>
```

The different TLVs are described in the following sections. A PCE MAY support any or all of IPV4-ADDRESS, IPV6-ADDRESS, and UNNUMBERED-ENDPOINT TLVs. When receiving a PCReq, a PCE unable to resolve the identifier in one of those TLVs MUST respond using a PCRep with NO-PATH and set the bit "Unknown destination" or "Unknown source" in the NO-PATH-VECTOR TLV. The response SHOULD include the END-POINTS object with only the unsupported TLV(s).

A PCE MAY support either or both of the LABEL-REQUEST and LABEL-SET TLVs. If a PCE finds a non-supported TLV in the END-POINTS the PCE MUST respond with a PCErr message with Error-Type=4 (Not supported object) and Error-value=TBA-15 (Unsupported TLV present in END-POINTS Generalized Endpoint object type) and the message SHOULD include the END-POINTS object in the response with only the endpoint and endpoint restriction TLV it did not understand. A PCE supporting those TLVs but not being able to fulfil the label restriction MUST send a response with a NO-PATH object which has the bit "No endpoint label resource" or "No endpoint label resource in range" set in the NO-PATH-VECTOR TLV. The response SHOULD include an END-POINTS object containing only the TLV(s) related to the constraints the PCE could not meet.

2.5.2. END-POINTS TLV Extensions

All endpoint TLVs have the standard PCEP TLV header as defined in [RFC5440] Section 7.1. For the Generalized Endpoint Object Type the TLVs MUST follow the ordering defined in Section 2.5.1.

2.5.2.1. IPV4-ADDRESS TLV

This TLV represents a numbered endpoint using IPv4 numbering, the format of the IPv4-ADDRESS TLV value (TLV-Type=TBA-6) 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 returned, as described in Section 2.5.1.

2.5.2.2. IPV6-ADDRESS TLV

This TLV represents a numbered endpoint using IPV6 numbering, the format of the IPv6-ADDRESS TLV value (TLV-Type=TBA-7) 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 returned, as described in Section 2.5.1.

2.5.2.3. UNNUMBERED-ENDPOINT TLV

This TLV represents an unnumbered interface. This TLV has the same semantic as in [RFC3477]. The TLV value is encoded as follows (TLV-Type=TBA-8)

```
     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 returned, as described in Section 2.5.1.

2.5.2.4. LABEL-REQUEST TLV

The LABEL-REQUEST TLV indicates the switching capability and encoding type of the following label restriction list for the endpoint. The value format and encoding is the same as described in [RFC3471]

Section 3.1 Generalized label request. The LABEL-REQUEST TLV uses TLV-Type=TBA-9. The Encoding Type indicates the encoding type, e.g., SONET/SDH/GigE etc., of the LSP with which the data is associated. The Switching type indicates the type of switching that is being requested on the endpoint. G-PID identifies the payload. This TLV and the following one are defined to satisfy requirement 13 of [RFC7025] for the endpoint. It is not directly related to the TE-LSP label request, which is expressed by the SWITCH-LAYER object.

On the path calculation request only the GENERALIZED-BANDWIDTH and SWITCH-LAYER need to be coherent, the endpoint labels could be different (supporting a different LABEL-REQUEST). Hence the label restrictions include a Generalized label request in order to interpret the labels. This TLV MAY be ignored, in which case a PCRep with NO-PATH SHOULD be returned, as described in Section 2.5.1.

2.5.2.5. LABEL-SET TLV

Label or label range restrictions can be specified for the TE-LSP endpoints. Those are encoded using the LABEL-SET TLV. The label value need to be interpreted with a description on the Encoding and switching type. The REQ-ADAP-CAP object from [RFC8282] can be used in case of mono-layer request, however in case of multilayer it is possible to have more than one object, so it is better to have a dedicated TLV for the label and label request. These TLVs MAY be ignored, in which case a response with NO-PATH SHOULD be returned, as described in Section 2.5.1. TLVs are encoded as follows (following [RFC5440]):

o LABEL-SET TLV, Type=TBA-10. The TLV Length is variable, Encoding follows [RFC3471] Section 3.5 "Label set" with the addition of a U bit, O bit and L bit. The L bit is used to represent a suggested set of labels, following the semantic of SUGGESTED_LABEL defined by [RFC3471].

```
 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     |    Reserved |L|O|U|        Label Type         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Subchannel 1                         |
|                              ...                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:                               :                               :
:                               :                               :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Subchannel N                         |
|                              ...                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

A LABEL-SET TLV represents a set of possible labels that can be used on an interface. If the L bit is cleared, the label allocated on the first endpoint MUST be within the label set range. The action parameter in the Label set indicates the type of list provided. These parameters are described by [RFC3471] Section 3.5.1.

The U, O and L bits have the following meaning:

U: Upstream direction: The U bit is set for upstream (revers) direction in case of bidirectional LSP.
O: Old Label: set when the TLV represent the old (previously allocated) label in case of re-optimization. The R bit of the RP object MUST be set to 1. If the L bit is set, this bit SHOULD be set to 0 and ignored on receipt. When this bit is set, the Action field MUST be set to 0 (Inclusive List) and the Label Set MUST contain one subchannel.
L: Loose Label: set when the TLV indicates to the PCE a set of preferred (ordered) labels to be used. The PCE MAY use those labels for label allocation.

Labels TLV bits

Several LABEL_SET TLVs MAY be present with the O bit cleared, LABEL_SET TLVs with L bit set can be combined with a LABEL_SET TLV with L bit cleared. At most 2 LABEL_SET TLVs MAY be present with the O bit set, with at most one of these having the U bit set and at most one of these having the U bit cleared. For a given U bit value, if more than one LABEL_SET TLV with the O bit set is present, the first TLV MUST be processed and the following TLVs with the same U and O bit MUST be ignored.

A LABEL-SET TLV with the O and L bit set MUST trigger a PCErr message with Error-Type=10 (Reception of an invalid object) Error-value=TBA-25 (Wrong LABEL-SET TLV present with O and L bit set).

A LABEL-SET TLV with the O bit set and an Action Field not set to 0 (Inclusive list) or containing more than one subchannel MUST trigger a PCErr message with Error-Type=10 (Reception of an invalid object) Error-value=TBA-26 (Wrong LABEL-SET TLV present with O bit and wrong format).

If a LABEL-SET TLV is present with O bit set, the R bit of the RP object MUST be set, otherwise a PCErr message MUST be sent with Error-Type=10 (Reception of an invalid object) Error-value=TBA-24 (LABEL-SET TLV present with O bit set but without R bit set in RP).

2.6. IRO Extension

The IRO as defined in [RFC5440] is used to include specific objects in the path. RSVP-TE allows the inclusion of a label definition. In order to fulfill requirement 13 of [RFC7025] the IRO needs to support the new subobject type as defined in [RFC3473]:

Type	Sub-object
TBA-38	LABEL

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. If an IP address subobject is used, then the given IP address MUST be associated with a link. More than one label subobject MAY follow each link subobject. The procedure associated with this subobject is as follows.

If the PCE is able to allocate labels (e.g., via explicit label control) the PCE MUST allocate one label from within the set of label values for the given link. If the PCE does not assign labels, then it sends a response with a NO-PATH object, containing a NO-PATH-VECTOR TLV with the bit 'No label resource in range' set.

2.7. XRO Extension

The XRO as defined in [RFC5521] is used to exclude specific objects in the path. RSVP-TE allows the exclusion of certain labels ([RFC6001]). In order to fulfill requirement 13 of [RFC7025] Section 3.1, the PCEP's XRO needs to support a new subobject to enable label exclusion.

The encoding of the XRO Label subobject follows the encoding of the Label ERO subobject defined in [RFC3473] and XRO subobject defined in

[RFC5521]. The XRO Label subobject represent one Label and is defined as follows:

XRO Subobject Type TBA-39: Label Subobject.

```
 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=TBA-39 |    Length     |U|   Reserved  |   C-Type      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             Label                             |
|                              ...                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

X (1 bit): as per [RFC5521]. The X-bit indicates whether the exclusion is mandatory or desired. 0 indicates that the resource specified MUST be excluded from the path computed by the PCE. 1 indicates that the resource specified SHOULD be excluded from the path computed by the PCE, but MAY be included subject to PCE policy and the absence of a viable path that meets the other constraints and excludes the resource.

Type (7 bits): The Type of the XRO Label subobject is TBA-39.

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] Section 6.1.

C-Type (8 bits): the C-Type of the included Label Object as defined in [RFC3473].

Label: see [RFC3471].

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. If an IP address subobject is used, then the given IP address MUST be associated with a link. More than one label subobject MAY follow each link subobject.

Type	Sub-object
3	LABEL

2.8. LSPA Extensions

The LSPA carries the LSP attributes. In the end-to-end recovery context, this also includes the protection state information. A new TLV is defined to fulfil requirement 7 of [RFC7025] Section 3.1 and requirement 3 of [RFC7025] Section 3.2. This TLV contains the information of the PROTECTION object defined by [RFC4872] and can be used as a policy input. The LSPA object MAY carry a PROTECTION-ATTRIBUTE TLV defined as: Type TBA-12: PROTECTION-ATTRIBUTE

```
 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                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|S|P|N|O|  Reserved | LSP Flags |     Reserved      | Link Flags|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|I|R|   Reserved    | Seg.Flags |           Reserved            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The content is as defined in [RFC4872] Section 14, [RFC4873] Section 6.1.

LSP (protection) Flags or Link flags field can be used by a PCE implementation for routing policy input. The other attributes are only meaningful for a stateful PCE.

This TLV is OPTIONAL and MAY be ignored by the PCE. If ignored by the PCE, it MUST NOT include the TLV in the LSPA of the response. When the TLV is used by the PCE, a LSPA object and the PROTECTION-ATTRIBUTE TLV MUST be included in the response. Fields that were not considered MUST be set to 0.

2.9. 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 carry 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 additional constraints that led to the failure such as protection mismatch, lack of resources, and so on. Several new flags have been defined in the 32-bit flag field of the NO-PATH-VECTOR TLV but no modifications have been made in the NO-PATH object.

2.9.1. Extensions to NO-PATH-VECTOR TLV

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

Bit number TBA-32 - Protection Mismatch (1-bit). Specifies the mismatch of the protection type in the PROTECTION-ATTRIBUTE TLV in the request.

Bit number TBA-33 - No Resource (1-bit). Specifies that the resources are not currently sufficient to provide the path.

Bit number TBA-34 - Granularity not supported (1-bit). Specifies that the PCE is not able to provide a path with the requested granularity.

Bit number TBA-35 - No endpoint label resource (1-bit). Specifies that the PCE is not able to provide a path because of the endpoint label restriction.

Bit number TBA-36 - No endpoint label resource in range (1-bit). Specifies that the PCE is not able to provide a path because of the endpoint label set restriction.

Bit number TBA-37 - No label resource in range (1-bit). Specifies that the PCE is not able to provide a path because of the label set restriction.

3. Additional Error-Types 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. An additional error type and several error values are defined to represent some of the errors related to the newly identified objects related to GMPLS 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-Types 4 and 10. A new Error-Type is defined (value TBA-27).

The Error-Type TBA-27 (path computation failure) is used to reflect constraints not understood by the PCE, for instance when the PCE is not able to understand the generalized bandwidth. If the constraints are understood, but the PCE is unable to find with those constraints, the NO-PATH is to be used.

```
   Error-Type Error-value

       4      Not supported
              object
              value=TBA-14: Bandwidth Object type TBA-2 or TBA-3 not
                            supported
              value=TBA-15: Unsupported endpoint type in
                            END-POINTS Generalized Endpoint
                            object type
              value=TBA-16: Unsupported TLV present in END-POINTS
                            Generalized Endpoint object type
              value=TBA-17: Unsupported granularity in the RP object
                            flags
       10     Reception of
              an invalid
              object
              value=TBA-18: Bad Bandwidth Object type TBA-2(Generalized
                            bandwidth) or TBA-3( Generalized bandwidth
                            of existing TE-LSP for which a
                            reoptimization is requested)
              value=TBA-20: Unsupported LSP Protection Flags in
                            PROTECTION-ATTRIBUTE TLV
              value=TBA-21: Unsupported Secondary LSP Protection Flags
                            in PROTECTION-ATTRIBUTE TLV
              value=TBA-22: Unsupported Link Protection Type in
                            PROTECTION-ATTRIBUTE TLV
              value=TBA-24: LABEL-SET TLV present with 0 bit set but
                            without R bit set in RP
              value=TBA-25: Wrong LABEL-SET
                            TLV present with
                            0 and L bit set
              value=TBA-26: Wrong LABEL-SET with O bit set and wrong
                            format
              value=TBA-42: Missing GMPLS-CAPABILITY TLV
     TBA-27   Path
              computation
              failure
              value=0:      Unassigned
              value=TBA-28: Unacceptable request message
              value=TBA-29: Generalized bandwidth value not supported
              value=TBA-30: Label Set constraint could not be
                            met
              value=TBA-31: Label constraint could not be
                            met
```

4. Manageability Considerations

This section follows the guidance of [RFC6123].

4.1. Control of Function through Configuration and Policy

This document makes no change to the basic operation of PCEP and so the requirements described in [RFC5440] Section 8.1. also apply to this document. In addition to those requirements a PCEP implementation may allow the configuration of the following parameters:

Accepted RG in the RP object.

Default RG to use (overriding the one present in the PCReq)

Accepted BANDWIDTH object type TBA-2 and TBA-3 parameters in request, default mapping to use when not specified in the request

Accepted LOAD-BALANCING object type TBA-4 parameters in request.

Accepted endpoint type and allowed TLVs in object END-POINTS with object type Generalized Endpoint.

Accepted range for label restrictions in label restriction in END-POINTS, or IRO or XRO objects

PROTECTION-ATTRIBUTE TLV acceptance and suppression.

The configuration of the above parameters is applicable to the different sessions as described in [RFC5440] Section 8.1 (by default, per PCEP peer, etc.).

4.2. Information and Data Models

This document makes no change to the basic operation of PCEP and so the requirements described in [RFC5440] Section 8.2. also apply to this document. This document does not introduce any new ERO sub objects, so that the, ERO information model is already covered in [RFC4802].

4.3. 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] Section 8.3.

4.4. Verifying Correct Operation

This document makes no change to the basic operations of PCEP and considerations described in [RFC5440] Section 8.4. New errors defined by this document should satisfy the requirement to log error events.

4.5. Requirements on Other Protocols and Functional Components

No new Requirements on Other Protocols and Functional Components are made by this document. This document does not require ERO object extensions. Any new ERO subobject defined in the TEAS or CCAMP working group can be adopted without modifying the operations defined in this document.

4.6. Impact on Network Operation

This document makes no change to the basic operations of PCEP and considerations described in [RFC5440] Section 8.6. In addition to the limit on the rate of messages sent by a PCEP speaker, a limit MAY be placed on the size of the PCEP messages.

5. IANA Considerations

IANA assigns values to the PCEP objects and TLVs. IANA is requested to make some allocations for the newly defined objects and TLVs defined 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 2.3, Section 2.4 and Section 2.5.1 new Objects types are defined. IANA is requested to make the following Object-Type allocations from the "PCEP Objects" sub-registry.

Object Class	5
Name	BANDWIDTH
Object-Type	TBA-2: Generalized bandwidth
	TBA-3: Generalized bandwidth of an existing TE-LSP for which a reoptimization is requested
Reference	This document (Section 2.3)

Object Class	14
Name	LOAD-BALANCING
Object-Type	TBA-4: Generalized Load Balancing
Reference	This document (Section 2.4)
Object Class	4
Name	END-POINTS
Object-Type	TBA-5: Generalized Endpoint
Reference	This document (Section 2.5)

5.2. Endpoint type field in Generalized END-POINTS Object

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 are assigned by Standards Action [RFC8126]. Each endpoint type should be tracked with the following attributes:

- o Endpoint type
- o Description
- o 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 2.5.1, Table 5):

Value	Type	Meaning
0	Point-to-Point	
1	Point-to-Multipoint	New leaves to add
2		Old leaves to remove
3		Old leaves whose path can be modified/reoptimized
4		Old leaves whose path has to be left unchanged
5-244	Unassigned	
245-255	Experimental range	

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. IANA is requested to do the following allocation. Note: TBA-11 is not used

Value	Meaning	Reference
TBA-6	IPV4-ADDRESS	This document (Section 2.5.2.1)
TBA-7	IPV6-ADDRESS	This document (Section 2.5.2.2)
TBA-8	UNNUMBERED-ENDPOINT	This document (Section 2.5.2.3)
TBA-9	LABEL-REQUEST	This document (Section 2.5.2.4)
TBA-10	LABEL-SET	This document (Section 2.5.2.5)
TBA-12	PROTECTION-ATTRIBUTE	This document (Section 2.8)
TBA-1	GMPLS-CAPABILITY	This document (Section 2.1.2)

5.4. RP Object Flag Field

As described in Section 2.2 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.

Bit	Description	Reference
TBA-13	routing granularity (2 bits) (RG)	This document, Section 2.2

5.5. New PCEP Error Codes

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

Error	name	Reference
Type=4	Not supported object	[RFC5440]
Value=TBA-14:	Bandwidth Object type TBA-2 or TBA-3 not supported	This Document
Value=TBA-15:	Unsupported endpoint type in END-POINTS Generalized Endpoint object type	This Document
Value=TBA-16:	Unsupported TLV present in END-POINTS Generalized Endpoint object type	This Document
Value=TBA-17:	Unsupported granularity in the RP object flags	This Document
Type=10	Reception of an invalid object	[RFC5440]
Value=TBA-18:	Bad Bandwidth Object type TBA-2(Generalized bandwidth) or TBA-3(Generalized bandwidth of existing TE-LSP for which a reoptimization is requested)	This Document
Value=TBA-20:	Unsupported LSP Protection Flags in PROTECTION-ATTRIBUTE TLV	This Document
Value=TBA-21:	Unsupported Secondary LSP Protection Flags in PROTECTION-ATTRIBUTE TLV	This Document
Value=TBA-22:	Unsupported Link Protection Type in PROTECTION-ATTRIBUTE TLV	This Document
Value=TBA-24:	LABEL-SET TLV present with 0 bit set but without R bit set in RP	This Document
Value=TBA-25:	Wrong LABEL-SET TLV present with 0 and L bit set	This Document
Value=TBA-26:	Wrong LABEL-SET with O bit set and wrong format	This Document
Value=TBA-42:	Missing GMPLS-CAPABILITY TLV	This Document
Type=TBA-27	Path computation failure	This Document
Value=0	Unassigned	This Document
Value=TBA-28:	Unacceptable request message	This Document
Value=TBA-29:	Generalized bandwidth value not supported	This Document
Value=TBA-30:	Label Set constraint could not be met	This Document
Value=TBA-31:	Label constraint could not be met	This Document

5.6. New NO-PATH-VECTOR TLV Fields

As described in Section 2.9.1, 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.

Bit number TBA-32 - Protection Mismatch (1-bit). Specifies the mismatch of the protection type of the PROTECTION-ATTRIBUTE TLV in the request.

Bit number TBA-33 - No Resource (1-bit). Specifies that the resources are not currently sufficient to provide the path.

Bit number TBA-34 - Granularity not supported (1-bit). Specifies that the PCE is not able to provide a path with the requested granularity.

Bit number TBA-35 - No endpoint label resource (1-bit). Specifies that the PCE is not able to provide a path because of the endpoint label restriction.

Bit number TBA-36 - No endpoint label resource in range (1-bit). Specifies that the PCE is not able to provide a path because of the endpoint label set restriction.

Bit number TBA-37 - No label resource in range (1-bit). Specifies that the PCE is not able to provide a path because of the label set restriction.

Bit number TBA-40 - LOAD-BALANCING could not be performed with the bandwidth constraits (1 bit). Specifies that the PCE is not able to provide a path because it could not map the BANDWIDTH into the parameters specified by the LOAD-BALANCING.

5.7. New Subobject for the Include Route Object

The "PCEP Parameters" registry contains a subregistry "IRO Subobjects" 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:

Subobject type		Reference
TBA-38	Label subobject	This Document

5.8. New Subobject for the Exclude Route Object

The "PCEP Parameters" registry contains a subregistry "XRO Subobjects" 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:

Subobject type		Reference
TBA-39	Label subobject	This Document

5.9. New GMPLS-CAPABILITY TLV Flag Field

IANA is requested to create a sub-registry to manage the Flag field of the GMPLS-CAPABILITY TLV within the "Path Computation Element Protocol (PCEP) Numbers" registry.

New bit numbers are to be assigned by Standards Action [RFC8126]. Each bit should be tracked with the following qualities:

- o Bit number (counting from bit 0 as the most significant bit)
- o Capability description
- o Defining RFC

The initial contents of the sub-registry are empty, with all bits marked unassigned

6. Security Considerations

GMPLS controls multiple technologies and types of network elements. The LSPs that are established using GMPLS, whose paths can be computed using the PCEP extensions to support GMPLS described in this document, can carry a high volume of traffic and can be a critical part of a network infrastructure. The PCE can then play a key role in the use of the resources and in determining the physical paths of the LSPs and thus it is important to ensure the identity of PCE and PCC, as well as the communication channel. In many deployments there will be a completely isolated network where an external attack is of very low probability. However, there are other deployment cases in which the PCC-PCE communication can be more exposed and there could be more security considerations. Three main situations in case of an attack in the GMPLS PCE context could happen:

- o PCE Identity theft: A legitimate PCC could request a path for a GMPLS LSP to a malicious PCE, which poses as a legitimate PCE. The answer can make that the LSP traverses some geographical place known to the attacker where confidentiality (sniffing), integrity (traffic modification) or availability (traffic drop) attacks could be performed by use of an attacker-controlled middlebox device. Also, the resulting LSP can omit constraints given in the requests (e.g., excluding certain fibers, avoiding some SRLGs) which could make that the LSP which will be later set-up can look perfectly fine, but will be in a risky situation. Also, the result can lead to the creation of an LSP that does not provide the desired quality and gives less resources than necessary.

- o PCC Identity theft: A malicious PCC, acting as a legitimate PCC, requesting LSP paths to a legitimate PCE can obtain a good knowledge of the physical topology of a critical infrastructure. It could get to know enough details to plan a later physical attack.

- o Message inspection: As in the previous case, knowledge of an infrastructure can be obtained by sniffing PCEP messages.

The security mechanisms can provide authentication and confidentiality for those scenarios where the PCC-PCE communication cannot be completely trusted. [RFC8253] provides origin verification, message integrity and replay protection, and ensures that a third party cannot decipher the contents of a message.

In order to protect against the malicious PCE case the PCC SHOULD have policies in place to accept or not the path provided by the PCE. Those policies can verify if the path follows the provided constraints. In addition, technology specific data plane mechanism can be used (following [RFC5920] Section 5.8) to verify the data plane connectivity and deviation from constraints.

The document [RFC8253] describes the usage of Transport Layer Security (TLS) to enhance PCEP security. The document describes the initiation of the TLS procedures, the TLS handshake mechanisms, the TLS methods for peer authentication, the applicable TLS ciphersuites for data exchange, and the handling of errors in the security checks. PCE and PCC SHOULD use [RFC8253] mechanism to protect against malicious PCC and PCE.

Finally, as mentioned by [RFC7025] the PCEP extensions to support GMPLS should be considered under the same security as current PCE work and this extension will not change the underlying security issues. However, given the critical nature of the network infrastructures under control by GMPLS, the security issues described above should be seriously considered when deploying a GMPLS-PCE based control plane for such networks. For more information on the security considerations on a GMPLS control plane, not only related to PCE/PCEP, [RFC5920] provides an overview of security vulnerabilities of a GMPLS control plane.

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Appendix A. LOAD-BALANCING Usage for SDH Virtual Concatenation

For example a request for one co-signaled n x VC-4 TE-LSP will not use the LOAD-BALANCING. In case the VC-4 components can use different paths, the BANDWIDTH with object type TBA-2 will contain a traffic specification indicating the complete n x VC-4 traffic specification and the LOAD-BALANCING the minimum co-signaled VC-4. For an SDH network, a request to have a TE-LSP group with 10 VC-4 containers, each path using at minimum 2 x VC-4 containers, can be represented with a BANDWIDTH object with OT=TBA-2, Bw Spec Type set to 4, the content of the Generalized Bandwidth is ST=6, RCC=0, NCC=0, NVC=10, MT=1. The LOAD-BALANCING, OT=TBA-4 with Bw Spec Type set to 4, Max-LSP=5, Min Bandwidth Spec is (ST=6, RCC=0, NCC=0, NVC=2, MT=1). The PCE can respond with a response with maximum 5 paths, each of them having a BANDWIDTH OT=TBA-2 and Generalized Bandwidth matching the Min Bandwidth Spec from the LOAD-BALANCING object of the corresponding request.

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