Extensions to the Path Computation Element Communication Protocol (PCEP) for Inter-Layer MPLS and GMPLS Traffic Engineering

Abstract

   The Path Computation Element (PCE) provides path computation
   functions in support of traffic engineering in Multiprotocol Label
   Switching (MPLS) and Generalized MPLS (GMPLS) networks.

   MPLS and GMPLS networks may be constructed from layered service
   networks. It is advantageous for overall network efficiency to
   provide end-to-end traffic engineering across multiple network layers
   through a process called inter-layer traffic engineering. PCE is a
   candidate solution for such requirements.

   The PCE Communication Protocol (PCEP) is designed as a communication
   protocol between Path Computation Clients (PCCs) and PCEs. This
   document presents PCEP extensions for inter-layer traffic
   engineering.

Status of This Memo

   This is an Internet Standards Track document.

   This document is a product of the Internet Engineering Task Force
   (IETF). It represents the consensus of the IETF community. It has
   received public review and has been approved for publication by the
   Internet Engineering Steering Group (IESG). Further information on
   Internet Standards is available in Section 2 of RFC 7841.

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1. Introduction

   The Path Computation Element (PCE) defined in [RFC4655] is an entity
   that is capable of computing a network path or route based on a
   network graph and applying computational constraints. A Path
   Computation Client (PCC) may make requests to a PCE for paths to be
   computed, and a PCE may initiate or modify services in a network by
   supplying new paths [RFC8231] [RFC8281].

   A network may comprise multiple layers. These layers may represent
   separation of technologies (e.g., packet switch capable (PSC), time
   division multiplex (TDM), and lambda switch capable (LSC)) [RFC3945];
   separation of data-plane switching granularity levels (e.g., Virtual
   Circuit 4 (VC4) and VC12) [RFC5212]; or a distinction between client
   and server networking roles (e.g., commercial or administrative
   separation of client and server networks). In this multi-layer
   network, Label Switched Paths (LSPs) in lower layers are used to
   carry higher-layer LSPs. The network topology formed by lower-layer
   LSPs and advertised as traffic engineering links (TE links) in the
   higher layer is called a Virtual Network Topology (VNT) [RFC5212].
   Discussion of other ways that network layering can be supported such
   that connectivity in a higher-layer network can be provided by LSPs
   in a lower-layer network is provided in [RFC7926].

   It is important to optimize network resource utilization globally,
   i.e., taking into account all layers, rather than optimizing resource
   utilization at each layer independently. This allows better network
   efficiency to be achieved. This is what we call inter-layer traffic
   engineering. This includes mechanisms allowing the computation of
   end-to-end paths across layers (known as inter-layer path
   computation) and mechanisms for control and management of the VNT by
   setting up and releasing LSPs in the lower layers [RFC5212].

   PCE can provide a suitable mechanism for resolving inter-layer path
   computation issues. The framework for applying the PCE-based path
   computation architecture to inter-layer traffic engineering is
   described in [RFC5623].

   The PCE communication protocol (PCEP) is designed as a communication
   protocol between PCCs and PCEs and is defined in [RFC5440]. A set of
   requirements for PCEP extensions to support inter-layer traffic
   engineering is described in [RFC6457].

   This document presents PCEP extensions for inter-layer traffic
   engineering that satisfy the requirements described in [RFC6457].

1.1. Requirements Language

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

2. Overview of PCE-Based Inter-Layer Path Computation

[RFC4206] defines a way to signal a higher-layer LSP, which has an
explicit route that includes hops traversed by LSPs in lower layers.
The computation of end-to-end paths across layers is called inter-
layer path computation.

A Label Switching Router (LSR) in the higher layer might not have
information on the lower-layer topology, particularly in an overlay
or augmented model [RFC3945]; hence, it may not be able to compute an
end-to-end path across layers.

PCE-based inter-layer path computation consists of using one or more
PCEs to compute an end-to-end path across layers. This could be
achieved by relying on a single PCE that has topology information
about multiple layers and can directly compute an end-to-end path
across layers considering the topology of all of the layers.
Alternatively, the inter-layer path computation could be performed
using multiple cooperating PCEs where each PCE has information about
the topology of one or more layers (but not all layers) and where the
PCEs collaborate to compute an end-to-end path.

As described in [RFC5339], a hybrid node may advertise a single TE
link with multiple switching capabilities. Normally, those TE links
exist at the layer/region boarder. In this case, a PCE needs to be
capable of specifying the server-layer path information when the
server-layer path information is required to be returned to the PCC.

[RFC5623] describes models for inter-layer path computation in more
detail. It introduces the Virtual Network Topology Manager (VNTM), a
functional element that controls the VNT, and sets out three distinct
models (and a fourth hybrid model) for inter-layer control involving
a PCE, triggered signaling, and a Network Management System (NMS).

3. Protocol Extensions

This section describes PCEP extensions for inter-layer path
computation. Four new objects are defined: the INTER-LAYER object,
the SWITCH-LAYER object, the REQ-ADAP-CAP object, and the SERVER-
INDICATION object. Also, two new metric types are defined.

3.1. INTER-LAYER Object

The INTER-LAYER object is optional and can be used in Path
Computation Request (PCReq) and Path Computation Reply (PCRep)
messages, and also in Path Computation State Report (PCRpt), Path
Computation Update Request (PCUpd), and Path Computation LSP Initiate
Request (PCInitiate) messages.

In a PCReq message, the INTER-LAYER object indicates whether inter-
layer path computation is allowed, the type of path to be computed,
and whether triggered signaling (hierarchical LSPs per [RFC4206] or
stitched LSPs per [RFC5150] depending on physical network
technologies) is allowed. When the INTER-LAYER object is absent from
a PCReq message, the receiving PCE MUST process as though inter-layer
path computation had been explicitly disallowed (I-bit set to zero --
see below).

In a PCRep message, the INTER-LAYER object indicates whether
inter-layer path computation has been performed, the type of path
that has been computed, and whether triggered signaling is used.

When a PCReq message includes more than one request, an INTER-LAYER
object is used per request. When a PCRep message includes more than
one path per request that is responded to, an INTER-LAYER object is
used per path.

The applicability of this object to PCRpt and PCUpd messages is the
same as for other objects on those messages as described in
[RFC8231]. The applicability of this object to the PCInitiate
message is the same as for other objects on those messages as
described in [RFC8281]. These messages use the <attribute-list> as
defined in [RFC5440] and extended by further PCEP extensions, so the
<attribute-list> as extended in Section 5 can be used to include the
INTER-LAYER object on these messages.

INTER-LAYER Object-Class is 36.

Inter-layer Object-Type is 1.

The format of the INTER-LAYER object body is shown in Figure 1.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Reserved                                             |T|M|I|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
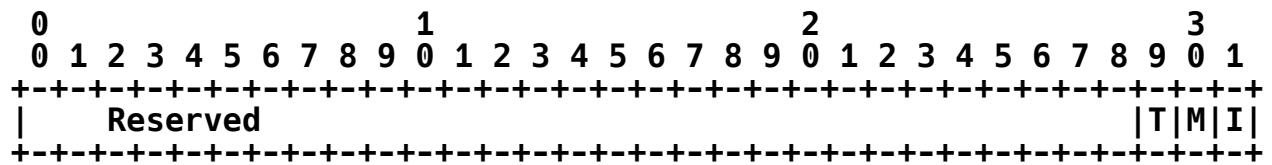
Figure 1: The INTER-LAYER Object

I flag (1 bit): The I flag is used by a PCC in a PCReq message to
indicate to a PCE whether an inter-layer path is allowed. When the I
flag is set (one), the PCE MAY perform inter-layer path computation
and return an inter-layer path. When the flag is clear (zero), the
path that is returned MUST NOT be an inter-layer path.

The I flag is used by a PCE in a PCRep message to indicate to a PCC
whether the path returned is an inter-layer path. When the I flag is
set (one), the path is an inter-layer path. When it is clear (zero),
the path is contained within a single layer because either inter-
layer path computation was not performed or a mono-layer path
(without any virtual TE link and without any loose hop that spans the
lower-layer network) was found notwithstanding the use of inter-layer
path computation.

M flag (1 bit): The M flag is used by a PCC in a PCReq message to
indicate to a PCE whether a mono-layer path or multi-layer path is
requested. When the M flag is set (one), a multi-layer path is
requested. When it is clear (zero), a mono-layer path is requested.

The M flag is used by a PCE in a PCRep message to indicate to a PCC
whether a mono-layer path or multi-layer path is returned. When the
M flag is set (one), a multi-layer path is returned. When the M flag
is clear (zero), a mono-layer path is returned.

If the I flag is clear (zero), the M flag has no meaning and MUST be
ignored.

[RFC6457] describes two sub-options for mono-layer path.

o A mono-layer path that is specified by strict hops. The path may
   include virtual TE links.

o A mono-layer path that includes loose hops that span the lower-
   layer network.

The choice of this sub-option can be specified by the use of the O
flag in the Request Parameter (RP) object specified in [RFC5440].

T flag (1 bit): The T flag is used by a PCC in a PCReq message to
indicate to a PCE whether triggered signaling is allowed. When the T
flag is set (one), triggered signaling is allowed. When it is clear
(zero), triggered signaling is not allowed.

The T flag is used by a PCE in a PCRep message to indicate to a PCC
whether triggered signaling is required to support the returned path.
When the T flag is set (one), triggered signaling is required. When
it is clear (zero), triggered signaling is not required.

Note that triggered signaling is used to support hierarchical
[RFC4206] or stitched [RFC5150] LSPs according to the physical
attributes of the network layers.

If the I flag is clear (zero), the T flag has no meaning and MUST be
ignored.

Note that the I and M flags differ in the following ways. When the I
flag is clear (zero), virtual TE links must not be used in path
computation. In addition, loose hops that span the lower-layer
network must not be specified. Only regular TE links from the same
layer may be used.

o When the I flag is set (one), the M flag is clear (zero), and the
   T flag is set (one), virtual TE links are allowed in path
   computation. In addition, when the O flag of the RP object is
   set, loose hops that span the lower-layer network may be
   specified. This will initiate lower-layer LSP setup; thus, the
   inter-layer path is set up even though the path computation result
   from a PCE to a PCC includes hops from the same layer only.

o However, when the I flag is set (one), the M flag is clear (zero),
   and the T flag is clear (zero), since triggered signaling is not
   allowed, virtual TE links that have not been pre-signaled MUST NOT
   be used in path computation. In addition, loose hops that span
   the lower-layer network MUST NOT be specified. Therefore, this is
   equivalent to the I flag being clear (zero).

Reserved bits of the INTER-LAYER object sent between a PCC and PCE in
the same domain MUST be transmitted as zero and SHOULD be ignored on
receipt. A PCE that forwards a path computation request to other
PCEs MUST preserve the settings of reserved bits in the PCReq
messages it sends and in the PCRep messages it forwards to PCCs.

Note that the flags in the PCRpt message indicate the state of an
LSP, whereas the flags in the PCUpd and the PCInitiate messages
indicate the intended/desired state as determined by the PCE.

3.2. SWITCH-LAYER Object

   The SWITCH-LAYER object is optional on a PCReq message and specifies
   switching layers in which a path MUST, or MUST NOT, be established.
   A switching layer is expressed as a switching type and encoding type.

   When a SWITCH-LAYER object is used on a PCReq, it is interpreted in
   the context of the INTER-LAYER object on the same message. If no
   INTER-LAYER object is present, the PCE MUST process the SWITCH-LAYER
   object as though inter-layer path computation had been explicitly
   disallowed. In such a case, the SWITCH-LAYER object MUST NOT have
   more than one LSP Encoding Type and Switching Type with the I flag
   set.

   The SWITCH-LAYER object is optional on a PCRep message, where it is
   used with the NO-PATH object in the case of unsuccessful path
   computation to indicate the set of constraints that could not be
   satisfied.

   The SWITCH-LAYER object may be used on a PCRpt message consistent
   with how properties of existing LSPs are reported on that message
   [RFC8231]. The PCRpt message uses the <attribute-list> as defined in
   [RFC5440] and extended by further PCEP extensions. This message can
   use the <attribute-list> as extended in Section 5 to carry the
   SWITCH-LAYER object. The SWITCH-LAYER object is not used on a PCUpd
   or PCInitiate messages.

   SWITCH-LAYER Object-Class is 37.

   Switch-layer Object-Type is 1.

   The format of the SWITCH-LAYER object body is shown in Figure 2.

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   | LSP Enc. Type |Switching Type |          Reserved           |I|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                .                              |
  //                                .                             //
   |                                .                              |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   | LSP Enc. Type |Switching Type |          Reserved           |I|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
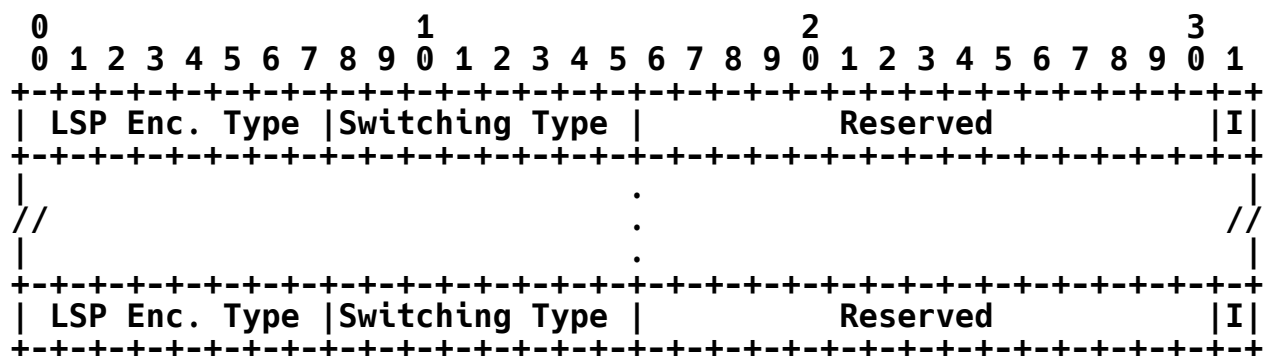
                    Figure 2: The SWITCH-LAYER Object

Each row indicates a switching type and encoding type that must or
must not be used for a specified layer(s) in the computed path.

The format is based on [RFC3471] and has equivalent semantics.

LSP Encoding Type (8 bits): see [RFC3471] for a description of
parameters.

Switching Type (8 bits): see [RFC3471] for a description of
parameters.

I flag (1 bit): the I flag indicates whether a layer with the
specified switching type and encoding type must or must not be used
by the computed path. When the I flag is set (one), the computed
path MUST traverse a layer with the specified switching type and
encoding type. When the I flag is clear (zero), the computed path
MUST NOT enter or traverse any layer with the specified switching
type and encoding type.

When a combination of switching type and encoding type is not
included in the SWITCH-LAYER object, the computed path MAY traverse a
layer with that combination of switching type and encoding type.

A PCC may want to specify only a Switching Type and not an LSP
Encoding Type. In this case, the LSP Encoding Type is set to zero.

3.3. REQ-ADAP-CAP Object

The REQ-ADAP-CAP object is optional and is used to specify a
requested adaptation capability for both ends of the lower-layer LSP.
The REQ-ADAP-CAP object is used in a PCReq message for inter-PCE
communication, where the PCE that is responsible for computing
higher-layer paths acts as a PCC to request a path computation from a
PCE that is responsible for computing lower-layer paths.

The REQ-ADAP-CAP object is used in a PCRep message in case of
unsuccessful path computation (in this case, the PCRep message also
contains a NO-PATH object, and the REQ-ADAP-CAP object is used to
indicate the set of constraints that could not be satisfied).

The REQ-ADAP-CAP object MAY be used in a PCReq message in a mono-
layer network to specify a requested adaptation capability for both
ends of the LSP. In this case, it MAY be carried without an INTER-
LAYER object.

The applicability of this object to PCRpt and PCUpd messages is the
same as for other objects on those messages as described in
[RFC8231]. The applicability of this object to the PCInitiate

message is the same as for other objects on those messages as
described in [RFC8281]. These messages use the <attribute-list> as
defined in [RFC5440] and extended by further PCEP extensions. These
messages can use the <attribute-list> as extended in Section 5 to
carry the REQ-ADAP-CAP object.

REQ-ADAP-CAP Object-Class is 38.

Req-Adap-Cap Object-Type is 1.

The format of the REQ-ADAP-CAP object body is shown in Figure 3.

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Switching Cap |   Encoding    |            Reserved           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                   Figure 3: The REQ-ADAP-CAP Object

The format is based on [RFC6001] and has equivalent semantics as the
Interface Adjustment Capability Descriptor (IACD) Upper Switching
Capability and Lower Switching Capability fields.

Switching Capability (8 bits): see [RFC4203] for a description of
parameters.

Encoding (8 bits): see [RFC3471] for a description of parameters.

A PCC may want to specify a Switching Capability, but not an
Encoding. In this case, the Encoding MUST be set to zero.

3.4. New Metric Types

This document defines two new metric types for use in the PCEP METRIC
object.

IANA has assigned the value 18 to indicate the metric "Number of
adaptations on a path".

IANA has assigned the value 19 to indicate the metric "Number of
layers on a path".

See Sections 4.1, 4.2, and 4.3 for a description of how these metrics
are applied.

3.5. SERVER-INDICATION Object

The SERVER-INDICATION is optional and is used to indicate that path
information included in the Explicit Route Object (ERO) is server-
layer information, and it specifies the characteristics of the server
layer, e.g., the switching capability and encoding of the server-
layer path.

The format of the SERVER-INDICATION object body is shown in Figure 4.

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Switching Cap |    Encoding   |            Reserved           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~                        Optional TLVs                          ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
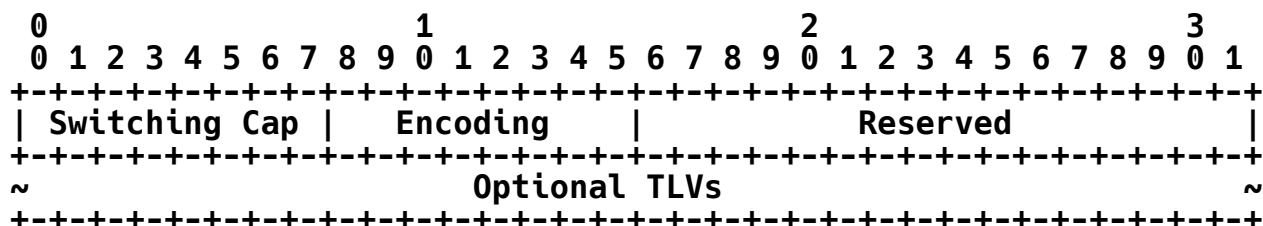
                   Figure 4: The SERVER-INDICATION Object

SERVER-INDICATION Object-Class is 39.

Server-indication Object-Type is 1.

Switching Capability (8 bits): see [RFC4203] for a description of
parameters.

Encoding (8 bits): see [RFC3471] for a description of parameters.

Optional TLVs: Optional TLVs MAY be included within the object to
specify more specific server-layer path information (e.g., traffic
parameters). Such TLVs will be defined by other documents.

4. Procedures

4.1. Path Computation Request

A PCC requests or allows inter-layer path computation in a PCReq
message by including the INTER-LAYER object with the I flag set. The
INTER-LAYER object indicates whether inter-layer path computation is
allowed, which path type is requested, and whether triggered
signaling is allowed.

The SWITCH-LAYER object, which MUST NOT be present unless the INTER-
LAYER object is also present, is optionally used to specify the
switching types and encoding types that define layers that must, or
must not, be used in the computed path. When the SWITCH-LAYER object
is used with the INTER-LAYER object I flag clear (zero), inter-layer

path computation is not allowed, but constraints specified in the
SWITCH-LAYER object apply. Example usage includes path computation
in a single-layer GMPLS network.

The REQ-ADAP-CAP object is optionally used to specify the interface
switching capability of both ends of the lower-layer LSP. The
REQ-ADAP-CAP object is used in inter-PCE communication, where the PCE
that is responsible for computing higher-layer paths makes a request
as a PCC to a PCE that is responsible for computing lower-layer
paths. Alternatively, the REQ-ADAP-CAP object may be used in the
NMS-VNTM model, where the VNTM makes a request as a PCC to a PCE that
is responsible for computing lower-layer paths.

The METRIC object is optionally used to specify metric types to be
optimized or bounded. When metric type 18 is used, it indicates that
path computation MUST minimize or bound the number of adaptations on
a path. When metric type 19 is used, it indicates that path
computation MUST minimize or bound the number of layers to be
involved on a path.

Furthermore, in order to allow different Objective Functions (OFs) to
be applied within different network layers, multiple OF objects
[RFC5541] MAY be present. In such a case, the first OF object
specifies an objective function for the higher-layer network, and
subsequent OF objects specify objection functions of the subsequent
lower-layer networks.

4.2. Path Computation Reply

In the case of successful path computation, the requested PCE replies
to the requesting PCC for the inter-layer path computation result in
a PCRep message that MAY include the INTER-LAYER object. When the
INTER-LAYER object is included in a PCRep message, the I, M, and T
flags indicate semantics of the path as described in Section 3.1.
Furthermore, when the C flag of the METRIC object in a PCReq is set,
the METRIC object MUST be included in the PCRep to provide the
computed metric value, as specified in [RFC5440].

The PCE MAY specify the server-layer path information in the ERO. In
this case, the requested PCE replies with a PCRep message that
includes at least two sets of ERO information in the path-list: one
is for the client-layer path information, and another one is the
server-layer path information. When SERVER-INDICATION is included in
a PCRep message, it indicates that the path in the ERO is the server-
layer path information. The server-layer path specified in the ERO
could be loose or strict. On receiving the replied path, the PCC
(e.g., NMS and ingress node) can trigger the signaling to set up the
LSPs according to the computed paths.

In the case of unsuccessful path computation, the PCRep message also
contains a NO-PATH object, and the SWITCH-TYPE object and/or
REQ-ADAP-CAP MAY be used to indicate the set of constraints that
could not be satisfied.

4.3. Stateful PCE and PCE Initiated LSPs

Processing for stateful PCEs is described in [RFC8231]. That
document defines the PCRpt message to allow a PCC to report to a PCE
that an LSP already exists in the network and to delegate control of
that LSP to the PCE.

When the LSP is a multi-layer LSP (or a mono-layer LSP for which
specific adaptations exist), the message objects defined in this
document are used on the PCRpt to describe an LSP that is delegated
to the PCE so that the PCE may process the LSP.

Furthermore, [RFC8231] defines the PCUpd message to allow a PCE to
modify an LSP that has been delegated to it. When the LSP is a
multi-layer LSP (or a mono-layer LSP for which specific adaptations
exist), the message objects defined in this document are used on the
PCUpd to describe the new attributes of the modified LSP.

Processing for PCE-initiated LSPs is described in [RFC8281]. That
document defines the PCInitiate message that is used by a PCE to
request a PCC to set up a new LSP. When the LSP is a multi-layer LSP
(or a mono-layer LSP for which specific adaptations exist), the
message objects defined in this document are used on the PCInitiate
to describe the attributes of the new LSP.

The new metric types defined in this document can also be used with
the stateful PCE extensions. The format of PCEP messages described
in [RFC8231] and [RFC8281] uses <attribute-list> (which is extended
in Section 5 for the purpose of including the new metrics).

The stateful PCE implementation MAY use the extension of PCReq and
PCRep messages as defined in Section 5 to also enable the use of
inter-layer parameters during passive stateful operations, using the
LSP object.

5. Updated Format of PCEP Messages

   Message formats in this section, as those in [RFC5440], are presented
   using Routing Backus-Naur Format (RBNF) as specified in [RFC5511].

   The format of the PCReq message is updated as shown in Figure 5.

```
    <PCReq Message>::= <Common Header>
                       [<svec-list>]
                       <request-list>

   where:
      <svec-list>::=<SVEC>
                      [<svec-list>]

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

      <request>::= <RP>
                   <END-POINTS>
                   [<LSP>]
                   [<LSPA>]
                   [<BANDWIDTH>]
                   [<metric-list>]
                   [<of-list>]
                   [<RRO>[<BANDWIDTH>]]
                   [<IRO>]
                   [<LOAD-BALANCING>]
                   [<INTER-LAYER> [<SWITCH-LAYER>]]
                   [<REQ-ADAP-CAP>]
   where:

      <of-list>::=<OF>[<of-list>]
      <metric-list>::=<METRIC>[<metric-list>]
```

                  Figure 5: The Updated PCReq Message

   The format of the PCRep message is updated as shown in Figure 6.

```
   <PCRep Message> ::= <Common Header>
                       <response-list>

      where:
         <response-list>::=<response>[<response-list>]

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

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

         <path>::= <ERO><attribute-list>

      where:
         <attribute-list>::=[<of-list>]
                            [<LSPA>]
                            [<BANDWIDTH>]
                            [<metric-list>]
                            [<IRO>]
                            [<INTER-LAYER>]
                            [<SWITCH-LAYER>]
                            [<REQ-ADAP-CAP>]
                            [<SERVER-INDICATION>]

         <of-list>::=<OF>[<of-list>]
         <metric-list>::=<METRIC>[<metric-list>]
```

                 Figure 6: The Updated PCRep Message

6. Manageability Considerations

   Implementations of this specification should provide a mechanism to
   configure any optional features (such as whether a PCE supports
   inter-layer computation and which metrics are supported).

   A Management Information Base (MIB) module for modeling PCEP is
   described in [RFC7420]. Systems that already use a MIB module to
   manage their PCEP implementations might want to augment that module
   to provide controls and indicators for support of inter-layer
   features defined in this document and to add counters of messages
   sent and received containing the objects defined here.

However, the preferred mechanism for configuration is through a YANG
model. Work has started on a YANG model for PCEP [PCEP-YANG], and
this could be enhanced as described for the MIB module, above.

Additional policy configuration might be provided to allow a PCE to
discriminate between the computation services offered to different
PCCs.

A set of monitoring tools for the PCE-based architecture are provided
in [RFC5886]. Systems implementing this specification and PCE
monitoring should consider defining extensions to the mechanisms
defined in [RFC5886] to help monitor inter-layer path computation
requests.

7. IANA Considerations

IANA maintains a registry called "Path Computation Element Protocol
(PCEP) Numbers". Per this document, IANA has carried out actions on
subregistries of that registry.

7.1. New PCEP Objects

IANA has made the following assignments in the "PCEP Objects"
subregistry.

Object-Class Value	Name	Object-Type	Reference
INTER-LAYER	36	0: Reserved 1: Inter-layer 2-15: Unassigned	RFC 8282
SWITCH-LAYER	37	0: Reserved 1: Switch-layer 2-15: Unassigned	RFC 8282
REQ-ADAP-CAP	38	0: Reserved 1: Req-Adap-Cap 2-15: Unassigned	RFC 8282
SERVER-INDICATION	39	0: Reserved 1: Server-indication	RFC 8282

Figure 7: New PCEP Objects

7.2. New Registry for INTER-LAYER Object Flags

   IANA has created a new subregistry to manage the Flag field of the
   INTER-LAYER object called the "Inter-Layer Object Path Property Bits"
   registry.

   New bit numbers may be allocated only by "IETF Review" [RFC8126].
   Each bit should be tracked with the following qualities:

   o Bit number (counting from bit 0 as the most significant bit up to
      a maximum of bit 31)

   o Capability Description

   o Defining RFC

   IANA has populated the registry as follows:

   Bit | Flag | Multi-Layer Path Property | Reference
   ----+------+--------------------------------+------------
   0-28| | Unassigned |
    29 | T | Triggered Signaling Allowed | RFC 8282
    30 | M | Multi-Layer Requested | RFC 8282
    31 | I | Inter-Layer Allowed | RFC 8282

         Figure 8: New Registry for INTER-LAYER Object Flags

7.3. New Metric Types

   Two new metric types are defined in this document for the METRIC
   object (specified in [RFC5440]). IANA has made the following
   allocations from the "Metric Object T Field" registry.

   Value | Description | Reference
   ------+------------------------------------+------------
    18 | Number of adaptations on a path | RFC 8282
    19 | Number of layers on a path | RFC 8282

                  Figure 9: New Metric Types

   IANA has updated the registry to show the registration procedure of
   "IETF Review" as already documented in [RFC5440].

8. Security Considerations

   Inter-layer traffic engineering with PCE may raise new security
   issues when PCE-PCE communication is done between different layer
   networks for inter-layer path computation. Security issues may also
   exist when a single PCE is granted full visibility of TE information
   that applies to multiple layers.

   The Path-Key-based mechanism defined in [RFC5520] MAY be applied to
   address the topology confidentiality between different layers.

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