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        Extensions to the Path Computation Element Communication Protocol
                       (PCEP) for Route Exclusions

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Abstract

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

   When a Path Computation Client (PCC) requests a PCE for a route, it
   may be useful for the PCC to specify, as constraints to the path
   computation, abstract nodes, resources, and Shared Risk Link Groups
   (SRLGs) that are to be explicitly excluded from the computed route.
   Such constraints are termed "route exclusions".

   The PCE Communication Protocol (PCEP) is designed as a communication
   protocol between PCCs and PCEs. This document presents PCEP
   extensions for route exclusions.

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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.

   When a PCC requests a PCE for a route, it may be useful for the PCC
   to specify abstract nodes, resources, and Shared Risk Link Groups
   (SRLGs) that are to be explicitly excluded from the route.

   For example, disjoint paths for inter-domain Label Switched Paths
   (LSPs) may be computed by cooperation between PCEs, each of which
   computes segments of the paths across one domain. In order to
   achieve path computation for a secondary (backup) path, a PCE may act
   as a PCC to request another PCE for a route that must be
   node/link/SRLG disjoint from the primary (working) path. Another
   example is where a network operator wants a path to avoid specified
   nodes for administrative reasons, perhaps because the specified nodes
   will be out-of-service in the near future.

   [RFC4657] specifies generic requirements for a communication protocol
   between PCCs and PCEs. Generic constraints described in [RFC4657]
   include route exclusions for links, nodes, and SRLGs. That is, the
   requirement for support of route exclusions within the PCC-PCE
   communication protocol is already established.

   The PCE communication protocol (PCEP) is designed as a communication
   protocol between PCCs and PCEs and is defined in [RFC5440]. This
   document presents PCEP extensions to satisfy the requirements for
   route exclusions as described in Sections 5.1.4 and 5.1.16 of
   [RFC4657].

   Note that MPLS-TE and GMPLS signaling extensions for communicating
   route exclusions between network nodes for specific Label Switched
   Paths (LSPs) are described in [RFC4874]. Route exclusions may be
   specified during provisioning requests for specific LSPs by setting
   the mplsTunnelHopInclude object of MPLS-TE-STD-MIB defined in
   [RFC3812] to false (2).

1.1. Conventions Used in This Document

   The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",
   "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this
   document are to be interpreted as described in RFC 2119 [RFC2119].

2. Protocol Procedures and Extensions

   This section describes the procedures adopted by a PCE handling a
   request for path computation with route exclusions received from a
   PCC, and defines how those exclusions are encoded.

   There are two types of route exclusion described in [RFC4874].

   1. Exclusion of certain abstract nodes or resources from the whole
      path. This set of abstract nodes is referred to as the Exclude
      Route List.

   2. Exclusion of certain abstract nodes or resources between a
      specific pair of abstract nodes present in an explicit path. Such
      specific exclusions are referred to as an Explicit Route
      Exclusion.

   This document defines protocol extensions to allow a PCC to specify
   both types of route exclusions to a PCE on a path computation
   request.

   A new PCEP object, the Exclude Route Object (XRO), is defined to
   convey the Exclude Route List. The existing Include Route Object
   (IRO) in PCEP [RFC5440] is modified by introducing a new IRO
   subobject, the Explicit Exclusion Route subobject (EXRS), to convey
   Explicit Route Exclusions.

2.1. Exclude Route Object (XRO)

2.1.1. Definition

   The XRO is OPTIONAL and MAY be carried within Path Computation
   Request (PCReq) and Path Computation Reply (PCRep) messages.

   When present in a PCReq message, the XRO provides a list of network
   resources that the PCE is requested to exclude from the path that it
   computes. Flags associated with each list member instruct the PCE as
   to whether the network resources must be excluded from the computed
   path, or whether the PCE should make best efforts to exclude the
   resources from the computed path.

   The XRO MAY be used on a PCRep message that carries the NO-PATH
   object (i.e., one that reports a path computation failure) to
   indicate the set of elements of the original XRO that prevented the
   PCE from finding a path.

   The XRO MAY also be used on a PCRep message for a successful path
   computation when the PCE wishes to provide a set of exclusions to be

signaled during LSP setup using the extensions to Resource
Reservation Protocol (RSVP)-TE [RFC4874].

The XRO Object-Class is 17.

The XRO Object-Type is 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            |            Flags            |F|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
//                         (Subobjects)                        //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
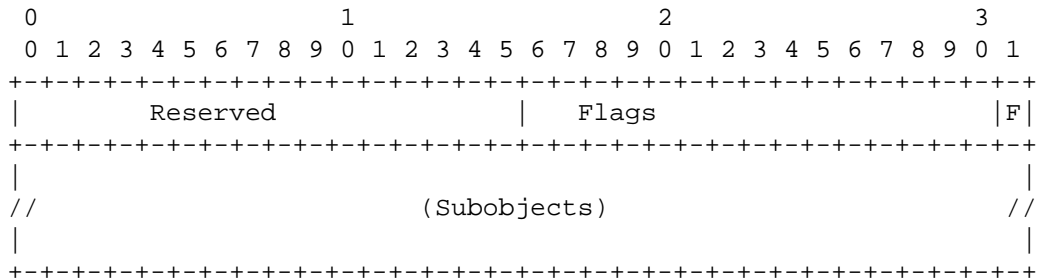
Figure 1: XRO Body Format

Reserved: 16 bits - MUST be set to zero on transmission and SHOULD be
ignored on receipt.

Flags: 16 bits - The following flags are currently defined:

   F (Fail - 1 bit): when set, the requesting PCC requires the
   computation of a new path for an existing TE LSP that has failed.
   If the F bit is set, the path of the existing TE LSP MUST be
   provided in the PCReq message by means of a Record Route Object
   (RRO) defined in [RFC5440]. This allows the path computation to
   take into account the previous path and reserved resources to
   avoid double bandwidth booking should the Traffic Engineering
   Database (TED) have not yet been updated or the corresponding
   resources not be yet been released. This will usually be used in
   conjunction with the exclusion from the path computation of the
   failed resource that caused the LSP to fail.

Subobjects: The XRO is made up of one or more subobject(s). An XRO
with no subobjects MUST NOT be sent and SHOULD be ignored on receipt.

In the following subobject definitions, a set of fields have
consistent meaning as follows:

X
   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
   The type of the subobject. The following subobject types are
   defined.

      Type   Subobject
      -------------+-----------------------------
      1   IPv4 prefix
      2   IPv6 prefix
      4   Unnumbered Interface ID
      32   Autonomous system number
      34   SRLG

Length
   The length of the subobject including the Type and Length fields.

Prefix Length
   Where present, this field can be used to indicate a set of
   addresses matching a prefix. If the subobject indicates a single
   address, the prefix length MUST be set to the full length of the
   address.

Attribute
   The Attribute field indicates how the exclusion subobject is to be
   interpreted.

0 Interface
   The subobject is to be interpreted as an interface or set of
   interfaces. All interfaces identified by the subobject are to be
   excluded from the computed path according to the setting of the
   X-bit. This value is valid only for subobject types 1, 2, and 3.

1 Node
   The subobject is to be interpreted as a node or set of nodes. All
   nodes identified by the subobject are to be excluded from the
   computed path according to the setting of the X-bit. This value
   is valid only for subobject types 1, 2, 3, and 4.

2 SRLG
   The subobject identifies an SRLG explicitly or indicates all of
   the SRLGs associated with the resource or resources identified by
   the subobject. Resources that share any SRLG with those
   identified are to be excluded from the computed path according to
   the setting of the X-bit. This value is valid for all subobjects.

Reserved
    Reserved fields within subobjects MUST be transmitted as zero and
    SHOULD be ignored on receipt.

The subobjects are encoded as follows:

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

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

Unnumbered Interface ID 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 = 3    |     Length    |    Reserved   |   Attribute   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         TE Router ID                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Interface ID                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The TE Router ID and Interface ID fields are as defined in [RFC3477].

Autonomous System Number 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 = 4   |     Length    |      2-Octet AS Number        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Note that as in other PCEP objects [RFC5440] and RSVP-TE objects
[RFC3209], no support for 4-octet Autonomous System (AS) Numbers is
provided. It is anticipated that, as 4-octet AS Numbers become more
common, both PCEP and RSVP-TE will be updated in a consistent way to
add this support.

SRLG 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 = 5   |     Length    |        SRLG Id (4 bytes)      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|       SRLG Id (continued)      |    Reserved   |   Attribute   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The Attribute SHOULD be set to two (2) and SHOULD be ignored on
receipt.

2.1.2. Processing Rules

A PCC builds an XRO to encode all of the resources that it wishes the
PCE to exclude from the path that it is requested to compute. For
each exclusion, the PCC clears the X-bit to indicate that the PCE is
required to exclude the resources, or sets the X-bit to indicate that
the PCC simply desires that the resources are excluded. For each
exclusion, the PCC also sets the Attribute field to indicate how the
PCE should interpret the contents of the exclusion subobject.

When a PCE receives a PCReq message it looks for an XRO to see if
exclusions are required. If the PCE finds more than one XRO, it MUST
use the first one in the message and MUST ignore subsequent
instances.

If the PCE does not recognize the XRO, it MUST return a PCErr message
with Error-Type "Unknown Object" as described in [RFC5440].

If the PCE is unwilling or unable to process the XRO, it MUST return
a PCErr message with the Error-Type "Not supported object" and follow
the relevant procedures described in [RFC5440].

   If the PCE processes the XRO and attempts to compute a path, it MUST
   adhere to the requested exclusions as expressed in the XRO. That is,
   the returned path MUST NOT include any resources encoded with the
   X-bit clear, and SHOULD NOT include any with the X-bit set unless
   alternate paths that match the other constraints expressed in the
   PCReq are unavailable.

   When a PCE returns a path in a PCRep, it MAY also supply an XRO. An
   XRO in a PCRep message with the NO-PATH object indicates that the set
   of elements of the original XRO prevented the PCE from finding a
   path. On the other hand, if an XRO is present in a PCRep message
   without a NO-PATH object, the PCC SHOULD apply the contents using the
   same rules as in [RFC4874] and the PCC or a corresponding LSR SHOULD
   signal an RSVP-TE XRO to indicate the exclusions that downstream LSRs
   should apply. This may be particularly useful in per-domain path
   computation scenarios [RFC5152].

2.2. Explicit Route Exclusion

2.2.1. Definition

   Explicit Route Exclusion defines network elements that must not or
   should not be used on the path between two abstract nodes or
   resources explicitly indicated in the Include Route Object (IRO)
   [RFC5440]. This information is encoded by defining a new subobject
   for the IRO.

   The new IRO subobject, the Explicit Exclusion Route subobject (EXRS),
   has type 33 (see Section 4). The EXRS contains one or more
   subobjects in its own right. An EXRS MUST NOT be sent with no
   subobjects, and if received with no subobjects, MUST be ignored.

   The format of the EXRS 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|L|   Type    |    Length     |            Reserved             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
//                One or more EXRS subobjects                  //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   L

      MUST be set to zero on transmission and MUST be ignored on
      receipt.

Reserved
     MUST be set to zero on transmission and SHOULD be ignored on
     receipt.

The EXRS subobject may carry any of the subobjects defined for
inclusion in the XRO by this document or by future documents. The
meanings of the fields of the XRO subobjects are unchanged when the
subobjects are included in an EXRS, except that scope of the
exclusion is limited to the single hop between the previous and
subsequent elements in the IRO.

2.2.2. Processing Rules

A PCC that supplies a partial explicit route to a PCE in an IRO MAY
also specify explicit exclusions by including one or more EXRSs in
the IRO.

If a PCE that does not support the use of EXRS receives an IRO in a
PCReq message that contains an EXRS, it will respond according to the
rules for a malformed object as described in [RFC5440]. The PCE MAY
also include the IRO in the PCErr to indicate in which case the IRO
SHOULD be terminated immediately after the unrecognized EXRS.

If a PCE that supports the EXRS in an IRO parses an IRO and
encounters an EXRS that contains a subobject that it does not support
or recognize, it MUST act according to the setting of the X-bit in
the subobject. If the X-bit is clear, the PCE MUST respond with a
PCErr with Error-Type "Unrecognized EXRS subobject" and set the
Error-Value to the EXRS subobject type code (see Section 4). If the
X-bit is set, the PCE MAY respond with a PCErr as already stated or
MAY ignore the EXRS subobject: this choice is a local policy
decision.

If a PCE parses an IRO and encounters an EXRS subobject that it
recognizes, it MUST act according to the requirements expressed in
the subobject. That is, if the X-bit is clear, the PCE MUST NOT
produce a path that includes any resource identified by the EXRS
subobject in the path between the previous abstract node in the IRO
and the next abstract node in the IRO. If the X-bit is set, the PCE
SHOULD NOT produce a path that includes any resource identified by
the EXRS subobject in the path between the previous abstract node in
the IRO and the next abstract node in the IRO unless it is not
possible to construct a path that avoids that resource while still
complying with the other constraints expressed in the PCReq message.

A successful path computation reported in a PCRep message MUST
include an ERO to specify the path that has been computed as
specified in [RFC5440]. That ERO MAY contain specific route
exclusions using the EXRS as specified in [RFC4874].

If the path computation fails and a PCErr is returned with a NO-PATH
object, the PCE MAY include an IRO to report the hops that could not
be complied with as described in [RFC5440], and that IRO MAY include
EXRSs.

3. Exclude Route with Confidentiality

3.1. Exclude Route Object (XRO) Carrying Path-Key

3.1.1. Definition

In PCE-based inter-domain diverse path computation, an XRO may be
used to find a backup (secondary) path. A sequential path
computation approach may be applied for this purpose, where a working
(primary) path route is computed first and a backup path route that
must be a node/link/SRLG disjoint route from the working path is then
computed [RFC5298]. Backward Recursive Path Computation (BRPC) may
be used for inter-domain path computation [RFC5441].

In some cases of inter-domain computation (e.g., where domains are
administered by different service providers), confidentiality must be
kept. For primary path computation, to preserve confidentiality,
instead of explicitly expressing the computed route, Path-Key
Subobjects (PKSs) [RFC5520] are carried in the Explicit Route Object
(ERO) in the PCRep Message.

Therefore, during inter-domain diverse path computation, it may be
necessary to request diversity from a path that is not fully known
and where a segment of the path is represented by a PKS. This means
that a PKS may be present as a subobject of the XRO on a PCReq
message.

The format and definition of PKS when it appears as an XRO subobject
are as defined in [RFC5520], except for the definition of the L bit.
The L bit of the PKS subobject in the XRO MUST be ignored.

3.1.2. Processing Rules

   Consider that BRPC is applied for both working and backup path
   computation in a sequential manner. First, PCC requests PCE for the
   computation of a working path. After BRPC processing has completed,
   the PCC receives the results of the working-path computation
   expressed in an ERO in a PCRep message. The ERO may include PKSs if
   certain segments of the path are to be kept confidential.

   For backup path computation, when the PCC constructs a PCReq Message,
   it includes the entire working-path in the XRO so that the computed
   path is node/link disjoint from the working path. The XRO may also
   include SRLGs to ensure SRLG diversity from the working path. If the
   working path ERO includes PKS subobjects, these are also included in
   the XRO to allow the PCE to ensure diversity.

   A set of PCEs for backup path computation may be the same as ones for
   working path computation, or they may be different.

   - Identical PCEs

      In the case where the same PCEs are used for both path
      computations, the processing is as follows. During the process of
      BRPC for backup path computation, a PCE may encounter a PKS as it
      processes the XRO when it creates a virtual path tree (VPT) in its
      own domain. The PCE retrieves the PCE-ID from the PKS, recognizes
      itself, and converts the PKS into a set of XRO subobjects that it
      uses for the local calculation to create the VPT. The XRO
      subobjects created in this way MUST NOT be shared with other PCEs.
      Other operations are the same as BRPC.

   - Different PCEs

      In the case where a set of PCEs for backup path computation is
      different from the ones used for working path computation, the
      processing is as follows. If a PCE encounters a PKS in an XRO
      when it is creating a virtual path tree in its own domain, the PCE
      retrieves the PCE-ID from the PKS and sends a PCReq message to the
      identified PCE to expand the PKS. The PCE computing the VPT
      treats the path segment in the response as a set of XRO subobjects
      in performing its path computation. The XRO subobjects determined
      in this way MUST NOT be shared with other PCEs.

4. IANA Considerations

4.1. PCEP Objects

   The "PCEP Parameters" registry contains a subregistry "PCEP Objects".
   IANA has made the following allocations from this registry.

       Object   Name   Reference
       Class
       17   XRO   [RFC5521]
                    Object-Type
                       1: Route exclusion

   This object should be registered as being allowed to carry the
   following subobjects:

       Subobject Type   Reference
          1 IPv4 prefix   [RFC3209]
          2 IPv6 prefix   [RFC3209]
          4 Unnumbered Interface ID   [RFC3477]
         32 Autonomous system number   [RFC3209]
         34 SRLG   [RFC4874]
         64 Path-Key with 32-bit PCE ID   [RFC5520]
         65 Path-Key with 128-bit PCE ID   [RFC5520]

4.2. New Subobject for the Include Route Object

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

   IANA added a further subobject that can be carried in the IRO as
   follows:

   Subobject Type   Reference

   33 Explicit Exclusion Route subobject (EXRS)   [RFC4874]

4.3. Error Object Field Values

   The "PCEP Parameters" registry contains a subregistry "Error Types
   and Values". IANA made the following allocations from this
   subregistry.

   Error
   Type   Meaning   Reference

   11   Unrecognized EXRS subobject   [RFC5521]

4.4. Exclude Route Flags

   IANA created a subregistry of the "PCEP Parameters" for the bits
   carried in the Flags field of the Exclude Route Object (XRO). The
   subregistry is called "XRO Flag Field".

   New bits may be allocated only by an IETF Consensus action.

   The field contains 16 bits numbered from bit 0 as the most
   significant bit.

       Bit   Name   Description   Reference

       15   F-bit   Fail   [RFC5221]

5. Manageability Considerations

   A MIB module for management of the PCEP is being specified in a
   separate document [PCEP-MIB]. That MIB module allows examination of
   individual PCEP messages, in particular requests, responses and
   errors.

   The MIB module MUST be extended to include the ability to view the
   route exclusion extensions defined in this document.

   Several local policy decisions should be made at the PCE. Firstly,
   the exact behavior with regard to desired exclusions must be
   available for examination by an operator and may be configurable.
   Second, the behavior on receipt of an unrecognized XRO or EXRS
   subobject with the X-bit set should be configurable and must be
   available for inspection. The inspection and control of these local
   policy choices may be part of the PCEP MIB module.

6. Security Considerations

   The new exclude route mechanisms defined in this document allow finer
   and more specific control of the path computed by a PCE. Such
   control increases the risk if a PCEP message is intercepted,
   modified, or spoofed because it allows the attacker to exert control
   over the path that the PCE will compute or to make the path
   computation impossible. Therefore, the security techniques described
   in [RFC5440] are considered more important.

   Note, however, that the route exclusion mechanisms also provide the
   operator with the ability to route around vulnerable parts of the
   network and may be used to increase overall network security.

7. References

7.1. Normative References

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

   [RFC3209]   Awduche, D., Berger, L., Gan, D., Li, T., Srinivasan, V.,
               and G. Swallow, "RSVP-TE: Extensions to RSVP for LSP
               Tunnels", RFC 3209, December 2001.

   [RFC5152]   Vasseur, JP., Ed., Ayyangar, A., Ed., and R. Zhang, "A
               Per-Domain Path Computation Method for Establishing
               Inter-Domain Traffic Engineering (TE) Label Switched Paths
               (LSPs)", RFC 5152, February 2008.

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

   [RFC5441]   Vasseur, JP., Ed., Zhang, R., Bitar, N., and JL. Le Roux,
               "A Backward-Recursive PCE-Based Computation (BRPC)
               Procedure to Compute Shortest Constrained Inter-Domain
               Traffic Engineering Label Switched Paths", RFC 5441, April
               2009.

   [RFC5520]   Bradford, R., Ed., Vasseur, JP., and A. Farrel,
               "Preserving Topology Confidentiality in Inter-Domain Path
               Computation Using a Path-Key-Based Mechanism", RFC 5520,
               April 2009.

7.2. Informative References

   [PCEP-MIB] Koushik, A. S. K., and E. Stephan, "PCE Communication
               Protocol(PCEP) Management Information Base", Work in
               Progress, November 2008.

   [RFC3477]   Kompella, K. and Y. Rekhter, "Signalling Unnumbered Links
               in Resource ReSerVation Protocol - Traffic Engineering
               (RSVP-TE)", RFC 3477, January 2003.

   [RFC3812]   Srinivasan, C., Viswanathan, A., and T. Nadeau,
               "Multiprotocol Label Switching (MPLS) Traffic Engineering
               (TE) Management Information Base (MIB)", RFC 3812, June
               2004.

   [RFC4655] Farrel, A., Vasseur, J.-P., and J. Ash, "A Path
              Computation Element (PCE)-Based Architecture", RFC 4655,
              August 2006.

   [RFC4657] Ash, J., Ed., and J. Le Roux, Ed., "Path Computation
              Element (PCE) Communication Protocol Generic
              Requirements", RFC 4657, September 2006.

   [RFC4874] Lee, CY., Farrel, A., and S. De Cnodder, "Exclude Routes -
              Extension to Resource ReserVation Protocol-Traffic
              Engineering (RSVP-TE)", RFC 4874, April 2007.

   [RFC5298] Takeda, T., Ed., Farrel, A., Ed., Ikejiri, Y., and JP.
              Vasseur, "Analysis of Inter-Domain Label Switched Path
              (LSP) Recovery", RFC 5298, August 2008.

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