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PCEP Extension for Flow Specification
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Abstract

The Path Computation Element (PCE) is a functional component capable of selecting the paths through a traffic engineered network. These paths may be supplied in response to requests for computation, or may be unsolicited directions issued by the PCE to network elements. Both approaches use the PCE Communication Protocol (PCEP) to convey the details of the computed path.

Traffic flows may be categorized and described using "Flow Specifications". RFC 5575 defines the Flow Specification and describes how it may be distributed in BGP to allow specific traffic flows to be associated with routes.

This document specifies a set of extensions to PCEP to support dissemination of Flow Specifications. This allows a PCE to indicate what traffic should be placed on each path that it is aware of.

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.

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1. Introduction

[RFC4655] defines the Path Computation Element (PCE), a functional component capable of computing paths for use in traffic engineering networks. PCE was originally conceived for use in Multiprotocol Label Switching (MPLS) for Traffic Engineering (TE) networks to derive the routes of Label Switched Paths (LSPs). However, the scope of PCE was quickly extended to make it applicable to Generalized MPLS (GMPLS) networks, and more recent work has brought other traffic engineering technologies and planning applications into scope (for example, Segment Routing (SR) [I-D.ietf-pce-segment-routing]).

[RFC5440] describes the Path Computation Element Communication Protocol (PCEP). PCEP defines the communication between a Path Computation Client (PCC) and a PCE, or between PCE and PCE, enabling computation of path for MPLS-TE LSPs.

Stateful PCE [RFC8231] specifies a set of extensions to PCEP to enable control of TE-LSPs by a PCE that retains state about the the LSPs provisioned in the network (a stateful PCE). [RFC8281] describes the setup, maintenance, and teardown of LSPs initiated by a stateful PCE without the need for local configuration on the PCC, thus allowing for a dynamic network that is centrally controlled. [RFC8283] introduces the architecture for PCE as a central controller and describes how PCE can be viewed as a component that performs computation to place 'flows' within the network and decide how these flows are routed.

Dissemination of traffic flow specifications (Flow Specifications) was introduced for BGP in [RFC5575]. A Flow Specification is comprised of traffic filtering rules and actions. The routers that receive a Flow Specification can classify received packets according to the traffic filtering rules and can direct packets based on the actions.

When a PCE is used to initiate tunnels (such as TE-LSPs or SR paths) using PCEP, it is important that the head end of the tunnels understands what traffic to place on each tunnel. The data flows intended for a tunnel can be described using Flow Specifications, and when PCEP is in use for tunnel initiation it makes sense for that same protocol to be used to distribute the Flow Specifications that describe what data is to flow on those tunnels.

This document specifies a set of extensions to PCEP to support dissemination of Flow Specifications. The extensions include the creation, update, and withdrawal of Flow Specifications via PCEP and can be applied to tunnels initiated by the PCE or to tunnels where control is delegated to the PCE by the PCC. Furthermore, a PCC requesting a new path can include Flow Specifications in the request to indicate the purpose of the tunnel allowing the PCE to factor this in during the path computation.

Flow Specifications are carried in TLVs within a new Flow Spec Object defined in this document. The flow filtering rules indicated by the Flow Specifications are mainly defined by BGP Flow Specifications.

2. Terminology

This document uses the following terms defined in [RFC5440]: PCC, PCE, PCEP Peer.

The following term from [RFC5575] is used frequently throughout this document:

Flow Specification (FlowSpec): A Flow Specification is an n-tuple consisting of several matching criteria that can be applied to IP traffic, including filters and actions. Each FlowSpec consists of a set of filters and a set of actions.

This document uses the terms "stateful PCE" and "active PCE" as advocated in [RFC7399].

3. Procedures for PCE Use of Flow Specifications

There are three elements of procedure:

o A PCE and a PCC must be able to indicate whether or not they support the use of Flow Specifications.

o A PCE or PCC must be able to include Flow Specifications in PCEP messages with clear understanding of the applicability of those Flow Specifications in each case including whether the use of such

information is mandatory, constrained, or optional, and how overlapping Flow Specifications will be resolved..

o Flow Specification information/state must be synchronized between PCEP peers so that, on recovery, the peers have the same understanding of which Flow Specifications apply.

The following subsections describe these points.

3.1. Capability Advertisement

3.1.1. PCEP OPEN Message

During PCEP session establishment, a PCC or PCE that supports the procedures described in this document announces this fact by including the "PCE FlowSpec Capability" TLV (described in Section 4) in the OPEN Object carried in the PCEP Open message.

The presence of the PCE FlowSpec Capability TLV in the OPEN Object in a PCE's OPEN message indicates that the PCE can support distribute the FlowSpec to PCCs and can receive FlowSpecs in messages from the PCCs.

The presence of the PCE FlowSpec Capability TLV in the OPEN Object in a PCC's OPEN message indicates that the PCC supports the FlowSpec functionality described in this document.

If either one of a pair of PCEP peers does not indicate support of the functionality described in this document by not including the PCE FlowSpec Capability TLV in the OPEN Object in its OPEN message, then the other peer MUST NOT include a FlowSpec object in any PCEP message sent to the peer that does not support the procedures. If a FlowSpec object is received even though support has not been indicated, the receiver will respond with a PCErr message reporting the objects containing the FlowSpec as described in [RFC5440]: that is, it will use 'Unknown Object' if it does not support this specification, and 'Not supported object' if it supports this specification but has not chosen to support FlowSpec objects on this PCEP session.

3.1.2. IGP PCE Capabilities Advertisement

The ability to advertise support for PCEP and PCE features in IGP advertisements is provided for OSPF in [RFC5088] and for IS-IS in [RFC5089]. The mechanism uses the PCE Discovery TLV which has a PCE-CAP-FLAGS sub-TLV containing bit-flags each of which indicates support for a different feature.

This document defines a new PCE-CAP-FLAGS sub-TLV bit, the FlowSpec Capable flag (bit number TBD1). Setting the bit indicates that an advertising PCE supports the procedures defined in this document.

Note that while PCE FlowSpec Capability may be advertised during discovery, PCEP speakers that wish to use Flow Specification in PCEP MUST negotiate PCE FlowSpec Capability during PCEP session setup, as specified in Section 3.1.1. A PCC MAY initiate PCE FlowSpec Capability negotiation at PCEP session setup even if it did not receive any IGP PCE capability advertisement.

3.2. Dissemination Procedures

This section describes the procedures to support Flow Specifications in PCEP messages.

The primary purpose of distributing Flow Specification information is to allow a PCE to indicate to a PCC what traffic it should place on a path (such as an LSP or an SR path). This means that the Flow Specification may be included in:

- o PCInitiate messages so that an active PCE can indicate the traffic to place on a path at the time that the PCE instantiates the path.

- o PCUpd messages so that an active PCE can indicate or change the traffic to place on a path that has already been set up.

- o PCRpt messages so that a PCC can report the traffic that the PCC plans to place on the path.

- o PCReq messages so that a PCC can indicate what traffic it plans to place on a path at the time it requests the PCE to perform a computation in case that information aids the PCE in its work.

- o PCRep messages so that a PCE that has been asked to compute a path can suggest which traffic could be placed on a path that a PCC may be about to set up.

- o PCErr messages so that issues related to paths and the traffic they carry can be reported to the PCE by the PCC, and so that problems with other PCEP messages that carry Flow Specifications can be reported.

To carry Flow Specifications in PCEP messages, this document defines a new PCEP object called the PCEP Flow Spec Object. The object is OPTIONAL in the messages described above and MAY appear more than once in each message.

The PCEP Flow Spec Object carries zero or one Flow Filter TLV which describes a traffic flow.

The inclusion of multiple PCEP Flow Spec Objects allows multiple traffic flows to be placed on a single path.

Once a PCE and PCC have established that they can both support the use of Flow Specifications in PCEP messages, such information may be exchanged at any time for new or existing paths.

The application and prioritization of Flow Specifications is described in Section 8.7.

3.3. Flow Specification Synchronization

The Flow Specifications are carried along with the LSP State information as per [RFC8231] making the Flow Specifications part of the LSP database (LSP-DB). Thus, the synchronization of the Flow Specification information is done as part of LSP-DB synchronization. This may be achieved using normal state synchronization procedures as described in [RFC8231] or enhanced state synchronization procedures as defined in [RFC8232].

The approach selected will be implementation and deployment specific and will depend on issues such as how the databases are constructed and what level of synchronization support is needed.

4. PCE FlowSpec Capability TLV

The PCE-FLOWSPEC-CAPABILITY TLV is an optional TLV that can be carried in the OPEN Object [RFC5440] to exchange PCE FlowSpec capabilities of PCEP speakers.

The format of the PCE-FLOWSPEC-CAPABILITY TLV follows the format of all PCEP TLVs as defined in [RFC5440] and 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Type=TBD2             |           Length=2            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Value=0             |           Padding             |
+---------------------------------------------------------------+
```

Figure 1: PCE-FLOWSPEC-CAPABILITY TLV format

The type of the PCE-FLOWSPEC-CAPABILITY TLV is TBD2 and it has a fixed length of 2 octets. The Value field is set to default value 0. The two bytes of padding MUST be set to zero and ignored on receipt.

The inclusion of this TLV in an OPEN object indicates that the sender can perform FlowSpec handling as defined in this document.

5. PCEP Flow Spec Object

The PCEP Flow Spec object defined in this document is compliant with the PCEP object format defined in [RFC5440]. It is OPTIONAL in the PCReq, PCRep, PCErr, PCInitiate, PCRpt, and PCUpd messages and MAY be present zero, one, or more times. Each instance of the object specifies a traffic flow.

The PCEP Flow Spec object carries a FlowSpec filter rule encoded in a TLV (as defined in Section 6.

The FLOW SPEC Object-Class is TBD3 (to be assigned by IANA).

The FLOW SPEC Object-Type is 1.

The format of the body of the PCEP Flow Spec object 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            FS-ID                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                Reserved                                     |R|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                   Flow Filter TLV (variable)                  |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2: PCEP Flow Spec Object Body Format

FS-ID (32-bits): A PCEP-specific identifier for the FlowSpec information. A PCE creates an FS-ID for each FlowSpec, the value is unique within the scope of the PCE and is constant for the lifetime of a PCEP session. All subsequent PCEP messages can identify the FlowSpec using the FS-ID. The values 0 and 0xFFFFFFFF are reserved and MUST NOT be used.

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

R bit: The Remove bit is set when a PCEP Flow Spec Object is included in a PCEP message to indicate removal of the Flow Specification from the associated tunnel. If the bit is clear, the Flow Specification is being added or modified.

Flow Filter TLV (variable): One TLV MAY be included.

The Flow Filter TLV is OPTIONAL when the R bit is set. The TLV MUST be present when the R bit is clear. If the TLV is missing when the R bit is clear, the PCEP peer MUST respond with a PCErr message with error-type TBD8 (FlowSpec Error), error-value 2 (Malformed FlowSpec).

6. Flow Filter TLV

A new PCEP TLV is defined to convey Flow Specification filtering rules that specify what traffic is carried on a path. The TLV follows the format of all PCEP TLVs as defined in [RFC5440]. The Type field values come from the codepoint space for PCEP TLVs and has the value TBD4.

The Value field contains one or more sub-TLVs (the Flow Specification TLVs) as defined in Section 7. Only one Flow Filter TLV can be present and represents the complete definition of a Flow Specification for traffic to be placed on the tunnel indicated by the PCEP message in which the PCEP Flow Spec Object is carried. The set of Flow Specification TLVs in a single instance of a Flow Filter TLV are combined to indicate the specific Flow Specification.

Further Flow Specifications can be included in a PCEP message by including additional Flow Spec objects.

7. Flow Specification TLVs

Flow Filter TLV carries one or more Flow Specification sub-TLV. The Flow Specification TLV also follows the format of all PCEP TLVs as defined in [RFC5440], however, the Type values are selected from a separate IANA registry (see Section 10) rather than from the common PCEP TLV registry.

Type values are chosen so that there can be commonality with Flow Specifications defined for use with BGP. This is possible because the BGP Flow Spec encoding uses a single octet to encode the type where PCEP uses two octets. Thus the space of values for the Type field is partitioned as shown in Figure 3.

```
Range          |
---------------+-------------------------------------------------
0              | Reserved - must not be allocated.
               |
1 .. 255       | Per BGP registry defined by [RFC5575].
               | Not to be allocated in this registry.
               |
256 ..   65535 | New PCEP Flow Specs allocated according to the
               | registry defined in this document.
```

Figure 3: Flow Specification TLV Type Ranges

The content of the Value field Flow in each TLV is specific to the type and describes the parameters of the Flow Specification. The definition of the format of many of these Value fields is inherited from BGP specifications as shown in Figure 4. Specifically, the inheritance is from [RFC5575] and [I-D.ietf-idr-flow-spec-v6], but may also be inherited from future BGP specifications.

When multiple Flow Specification TLVs are present in a single Flow Filter TLV they are combined to produce a more detailed description of a flow. For examples and rules about how this is achieved, see [RFC5575].

An implementation that receives a PCEP message carrying a Flow Specification TLV with a type value that it does not recognize or does not support MUST respond with a PCErr message with error-type TBD8 (FlowSpec Error), error-value 1 (Unsupported FlowSpec) and MUST NOT install the Flow Specification.

When used in other protocols (such as BGP) these Flow Specifications are also associated with actions to indicate how traffic matching the Flow Specification should be treated. In PCEP, however, the only action is to associate the traffic with a tunnel and to forward matching traffic on to that path, so no encoding of an action is needed.

Section 8.7 describes how overlapping Flow Specifications are prioritized and handled.

Type	Description	Value defined in
*	Destination IPv4 Prefix	[RFC5575]
*	Source IPv4 Prefix	[RFC5575]
*	IP Protocol	[RFC5575]
*	Port	[RFC5575]
*	Destination port	[RFC5575]
*	Source port	[RFC5575]
*	ICMP type	[RFC5575]
*	ICMP code	[RFC5575]
*	TCP flags	[RFC5575]
*	Packet length	[RFC5575]
*	DSCP	[RFC5575]
*	Fragment	[RFC5575]
*	Flow Label	[I-D.ietf-idr-flow-spec-v6]
*	Destination IPv6 Prefix	[I-D.ietf-idr-flow-spec-v6]
*	Source IPv6 Prefix	[I-D.ietf-idr-flow-spec-v6]
*	Next Header	[I-D.ietf-idr-flow-spec-v6]
TBD5	Route Distinguisher	[I-D.dhodylee-pce-pcep-ls]
TBD6	IPv4 Multicast Flow	[This.I-D]
TBD7	IPv6 Multicast Flow	[This.I-D]

* Indicates that the TLV Type value comes from the value used in BGP.

Figure 4: Table of Flow Specification TLV Types

All Flow Specification TLVs with Types in the range 1 to 255 have Values defined for use in BGP (for example in [RFC5575] and [I-D.ietf-idr-flow-spec-v6]) and are set using the BGP encoding, but without the type or length octets (the relevant information is in the Type and Length fields of the TLV). The Value field is padded with trailing zeros to achieve 4-byte alignment if necessary.

[I-D.dhodylee-pce-pcep-ls] defines a way to convey identification of a VPN in PCEP via a Route Distinguisher (RD) [RFC4364] and encoded in ROUTE-DISTINGUISHER TLV. A Flow Specification TLV with Type TBD5 carries a Value field matching that in the ROUTE-DISTINGUISHER TLV and is used to identify that other flow filter information (for example, an IPv4 destination prefix) is associated with a specific VPN identified by the RD. See Section 8.6 for further discussion of VPN identification.

Although it may be possible to describe a multicast Flow Specification from the combination of other Flow Specification TLVs with specific values, it is more convenient to use a dedicated Flow Specification TLV. Flow Specification TLVs with Type values TBD6 and TBD7 are used to identify a multicast flow for IPv4 and IPv6 respectively. The Value field is encoded as shown in Figure 5.

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Rsvd  |S|W|R|    Rsvd   |B|Z|  Src Mask Len | Grp Mask Len  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~                         Source Address                        ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~                 Group multicast Address                       ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5: Multicast Flow Specification TLV Encoding

The fields of the two Multicast Flow Specification TLVs are as described in Section 4.9.1 of [RFC7761] noting that the two address fields are 32 bits for the IPv4 Multicast Flow and 128 bits for the IPv6 Multicast Flow. Reserved fields MUST be set to zero and ignored on receipt.

8. Detailed Procedures

This section outlines some specific detailed procedures for using the protocol extensions defined in this document.

8.1. Default Behavior and Backward Compatibility

The default behavior is that no Flow Specification is applied to a tunnel. That is, the default is that the Flow Spec object is not used as is the case in all systems before the implementation of this specification.

In this case it is a local matter (such as through configuration) how tunnel head ends are instructed what traffic to place on a tunnel.

[RFC5440]describes how receivers respond when they see unknown PCEP objects.

8.2. Composite Flow Specifications

Flow Specifications may be represented by a single Flow Specification TLV or may require a more complex description using multiple Flow Specification TLVs. For example, a flow indicated by a source-destination pair of IPv6 addresses would be described by the combination of Destination IPv6 Prefix and Source IPv6 Prefix Flow Specification TLVs.

8.3. Modifying Flow Specifications

A PCE may want to modify a Flow Specification associated with a tunnel, or a PCC may want to report a change to the Flow Specification it is using with a tunnel.

It is important that the specific Flow Specification is identified so that it is clear that this is a modification of an existing flow and not the addition of a new flow as described in Section 8.4. The FS-ID field of the PCEP Flow Spec Object is used to identify a specific Flow Specification.

When modifying a Flow Specification, all Flow Specification TLVs for the intended specification of the flow MUST be included in the PCEP Flow Spec Object and the FS-ID MUST be retained from the previous description of the flow.

8.4. Multiple Flow Specifications

It is possible that multiple flows will be place on a single tunnel. In some cases it is possible to to define these within a single PCEP Flow Spec Object: for example, two Destination IPv4 Prefix TLVs could be included to indicate that packets matching either prefix are acceptable. PCEP would consider this as a single Flow Specification identified by a single FS-ID.

In other scenarios the use of multiple Flow Specification TLVs would be confusing. For example, if flows from A to B and from C to D are to be included then using two Source IPv4 Prefix TLVs and two Destination IPv4 Prefix TLVs would be confusing (are flows from A to D included?). In these cases, each Flow Specification is carried in its own PCEP Flow Spec Object with multiple objects present on a single PCEP message. Use of separate objects also allows easier removal and modification of Flow Specifications.

8.5. Adding and Removing Flow Specifications

The Remove bit in the the PCEP Flow Spec Object is left clear when a Flow Specification is being added or modified.

To remove a Flow Specification, a PCEP Flow Spec Object is included with the FS-ID matching the one being removed, and the R bit set to indicate removal. In this case it is not necessary to include any Flow Specification TLVs.

If the R bit is set and Flow Specification TLVs are present an implementation MAY ignore them. If the implementation checks the Flow Specification TLVs against those recorded for the FS-ID of the Flow Specification being removed and finds a mismatch, the Flow Specification MUST still be removed and the implementation SHOULD record a local exception or log.

8.6. VPN Identifiers

VPN instances are identified in BGP using Route Distinguishers (RDs) [RFC4364]. These values are not normally considered to have any meaning outside of the network, and they are not encoded in data packets belonging to the VPNs. However, RDs provide a useful way of identifying VPN instances and are often manually or automatically assigned to VPNs as they are provisioned.

Thus the RD provides a useful way to indicate that traffic for a particular VPN should be placed on a given tunnel. The tunnel head end will need to interpret this Flow Specification not as a filter on the fields of data packets, but using the other mechanisms that it uses to identify VPN traffic. This could be based on the incoming port (for port-based VPNs) or may leverage knowledge of the VRF that is in use for the taffic.

8.7. Priorities and Overlapping Flow Specifications

TBD

An implementation that receives a PCEP message carrying a Flow Specification that it cannot resolve against other Flow Specifications already installed MUST respond with a PCErr message with error-type TBD8 (FlowSpec Error), error-value 3 (Unresolvable conflict) and MUST NOT install the Flow Specification.

9. PCEP Messages

The figures below use the notation defined in [RFC5511].

The FLOW SPEC Object is OPTIONAL and MAY be carried in the PCEP messages.

The PCInitiate message is defined in [RFC8281] and updated as below:

```
<PCInitiate Message> ::= <Common Header>
                         <PCE-initiated-lsp-list>

Where:
   <PCE-initiated-lsp-list> ::= <PCE-initiated-lsp-request>
                                [<PCE-initiated-lsp-list>]

   <PCE-initiated-lsp-request> ::=
                                 ( <PCE-initiated-lsp-instantiation>|
                                   <PCE-initiated-lsp-deletion> )

   <PCE-initiated-lsp-instantiation> ::= <SRP>
                                         <LSP>
                                         [<END-POINTS>]
                                         <ERO>
                                         [<attribute-list>]
                                         [<flowspec-list>]

   Where:
      <flowspec-list> ::= <FLOWSPEC> [<flowspec-list>]
```

The PCUpd message is defined in [RFC8231] and updated as below:

```
<PCUpd Message> ::= <Common Header>
                    <update-request-list>

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

   <update-request> ::= <SRP>
                        <LSP>
                        <path>
                        [<flowspec-list>]

   Where:
      <path>::= <intended-path><intended-attribute-list>

      <flowspec-list> ::= <FLOWSPEC> [<flowspec-list>]
```

The PCRpt message is defined in [RFC8231] and updated as below:

```
<PCRpt Message> ::= <Common Header>
                    <state-report-list>

Where:
   <state-report-list> ::= <state-report>[<state-report-list>]

   <state-report> ::= [<SRP>]
                      <LSP>
                      <path>
                      [<flowspec-list>]

    Where:
      <path>::= <intended-path>
                [<actual-attribute-list><actual-path>]
                <intended-attribute-list>

      <flowspec-list> ::= <FLOWSPEC> [<flowspec-list>]
```

The PCReq message is defined in [RFC5440] and updated in [RFC8231], it is further updated below for flow specification:

```
<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>]
                [<RRO>[<BANDWIDTH>]]
                [<IRO>]
                [<LOAD-BALANCING>]
                [<flowspec-list>]

   Where:
      <flowspec-list> ::= <FLOWSPEC> [<flowspec-list>]
```

The PCRep message is defined in [RFC5440] and updated in [RFC8231], it is further updated below for flow specification:

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

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

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

   Where:
      <flowspec-list> ::= <FLOWSPEC> [<flowspec-list>]
```

10. IANA Considerations

IANA maintains the "Path Computation Element Protocol (PCEP) Numbers" registry. This document requests IANA actions to allocate code points for the protocol elements defined in this document.

10.1. PCEP Objects

Each PCEP object has an Object-Class and an Object-Type. IANA maintains a subregistry called "PCEP Objects". IANA is requested to make an assignment from this subregistry as follows:

Object-Class	Value Name	Object-Type	Reference
TBD3	FLOW SPEC	0 (Reserved)	[This.I-D]
		1	[This.I-D]

10.2. PCEP TLV Type Indicators

IANA maintains a subregistry called "PCEP TLV Type Indicators". IANA is requested to make an assignment from this subregistry as follows:

Value	Meaning	Reference
TBD2	PCE-FLOWSPEC-CAPABILITY TLV	[This.I-D]
TBD4	FLOW FILTER TLV	[This.I-D]

10.3. Flow Specification TLV Type Indicators

IANA is requested to create a new subregistry call the PCEP Flow Specification TLV Type Indicators registry.

Allocations from this registry are to be made according to the following assignment policies [RFC8126]:

Range	Assignment policy
0	Reserved - must not be allocated.
1 .. 255	Reserved - must not be allocated. Usage mirrors the BGP FlowSpec registry [RFC5575].
258 .. 64506	Specification Required
64507 .. 65531	First Come First Served
65532 .. 65535	Experimental

IANA is requested to pre-populate this registry with values defined in this document as follows:

Value	Meaning
TBD5	Route Distinguisher
TBD6	IPv4 Multicast
TBD7	IPv6 Multicast

10.4. PCEP Error Codes

IANA maintains a subregistry called "PCEP-ERROR Object Error Types and Values". Entries in this subregistry are described by Error-Type and Error-value. IANA is requested to make the following assignment from this subregistry:

Error-Type	Meaning	Error-value	Reference
TBD8	FlowSpec error	0: Unassigned	[This.I-D]
		1: Unsupported FlowSpec	[This.I-D]
		2: Malformed FlowSpec	[This.I-D]
		3: Unresolvable conflict	[This.I-D]
		4-255: Unassigned	[This.I-D]

10.5. PCE Capability Flag

IANA maintains a subregistry called "Open Shortest Path First v2 (OSPFv2) Parameters" with a sub-registry called "Path Computation

Element (PCE) Capability Flags". IANA is requested to assign a new capability bit from this registry as follows:

Bit	Capability Description	Reference
TBD1	FlowSpec	[This.I-D]

11. Security Considerations

We may assume that a system that utilizes a remote PCE is subject to a number of vulnerabilities that could allow spurious LSPs or SR paths to be established or that could result in existing paths being modified or torn down. Such systems, therefore, apply security considerations as described in [RFC5440], [RFC6952], and [RFC8253].

The description of Flow Specifications associated with paths set up or controlled by a PCE add an further detail that could be attacked without tearing down LSPs or SR paths but causing traffic to be misrouted within the network. Therefore, the use of the security mechanisms for PCEP referenced above is important.

Visibility into the information carried in PCEP does not have direct privacy concerns for end-users' data, however, knowledge of how data is routed in a network may make that data more vulnerable. Of course, the ability to interfere with the way data s routed also makes the data more vulnerable. Furthermore, knowledge of the connected end-points (such as multicast receivers or VPN sites) is usually considered private customer information. Therefore, implementations or deployments concerned to protect privacy MUST apply the mechanisms described in the documents referenced above.

Experience with Flow Specifications in BGP systems indicates that they can become complex and that the overlap of Flow Specifications installed in different orders can lead to unexpected results. Although this is not directly a security issue per se, the confusion and unexpected forwarding behavior may be engineered or exploited by an attacker. Therefore, implementers and operators SHOULD pay careful attention to the Manageability Considerations described in Section 12.

12. Manageability Considerations

TBD

13. Acknowledgements

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14. References

14.1. Normative References

[I-D.dhodylee-pce-pcep-ls]
Dhody, D., Lee, Y., and D. Ceccarelli, "PCEP Extension for Distribution of Link-State and TE Information.", draft-dhodylee-pce-pcep-ls-08 (work in progress), June 2017.

[I-D.ietf-idr-flow-spec-v6]
McPherson, D., Raszuk, R., Pithawala, B., akarch@cisco.com, a., and S. Hares, "Dissemination of Flow Specification Rules for IPv6", draft-ietf-idr-flow-spec-v6-09 (work in progress), November 2017.

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <https://www.rfc-editor.org/info/rfc2119>.

[RFC5440] Vasseur, JP., Ed. and JL. Le Roux, Ed., "Path Computation Element (PCE) Communication Protocol (PCEP)", RFC 5440, DOI 10.17487/RFC5440, March 2009, <https://www.rfc-editor.org/info/rfc5440>.

[RFC5511] Farrel, A., "Routing Backus-Naur Form (RBNF): A Syntax Used to Form Encoding Rules in Various Routing Protocol Specifications", RFC 5511, DOI 10.17487/RFC5511, April 2009, <https://www.rfc-editor.org/info/rfc5511>.

[RFC5575] Marques, P., Sheth, N., Raszuk, R., Greene, B., Mauch, J., and D. McPherson, "Dissemination of Flow Specification Rules", RFC 5575, DOI 10.17487/RFC5575, August 2009, <https://www.rfc-editor.org/info/rfc5575>.

[RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <https://www.rfc-editor.org/info/rfc8174>.

[RFC8253] Lopez, D., Gonzalez de Dios, O., Wu, Q., and D. Dhody, "PCEPS: Usage of TLS to Provide a Secure Transport for the Path Computation Element Communication Protocol (PCEP)", RFC 8253, DOI 10.17487/RFC8253, October 2017, <https://www.rfc-editor.org/info/rfc8253>.

14.2. Informative References

[I-D.ietf-pce-segment-routing]
Sivabalan, S., Filsfils, C., Tantsura, J., Henderickx, W., and J. Hardwick, "PCEP Extensions for Segment Routing", draft-ietf-pce-segment-routing-11 (work in progress), November 2017.

[RFC4364] Rosen, E. and Y. Rekhter, "BGP/MPLS IP Virtual Private Networks (VPNs)", RFC 4364, DOI 10.17487/RFC4364, February 2006, <https://www.rfc-editor.org/info/rfc4364>.

[RFC4655] Farrel, A., Vasseur, J., and J. Ash, "A Path Computation Element (PCE)-Based Architecture", RFC 4655, DOI 10.17487/RFC4655, August 2006, <https://www.rfc-editor.org/info/rfc4655>.

[RFC5088] Le Roux, JL., Ed., Vasseur, JP., Ed., Ikejiri, Y., and R. Zhang, "OSPF Protocol Extensions for Path Computation Element (PCE) Discovery", RFC 5088, DOI 10.17487/RFC5088, January 2008, <https://www.rfc-editor.org/info/rfc5088>.

[RFC5089] Le Roux, JL., Ed., Vasseur, JP., Ed., Ikejiri, Y., and R. Zhang, "IS-IS Protocol Extensions for Path Computation Element (PCE) Discovery", RFC 5089, DOI 10.17487/RFC5089, January 2008, <https://www.rfc-editor.org/info/rfc5089>.

[RFC6952] Jethanandani, M., Patel, K., and L. Zheng, "Analysis of BGP, LDP, PCEP, and MSDP Issues According to the Keying and Authentication for Routing Protocols (KARP) Design Guide", RFC 6952, DOI 10.17487/RFC6952, May 2013, <https://www.rfc-editor.org/info/rfc6952>.

[RFC7399] Farrel, A. and D. King, "Unanswered Questions in the Path Computation Element Architecture", RFC 7399, DOI 10.17487/RFC7399, October 2014, <https://www.rfc-editor.org/info/rfc7399>.

[RFC7761] Fenner, B., Handley, M., Holbrook, H., Kouvelas, I., Parekh, R., Zhang, Z., and L. Zheng, "Protocol Independent Multicast - Sparse Mode (PIM-SM): Protocol Specification (Revised)", STD 83, RFC 7761, DOI 10.17487/RFC7761, March 2016, <https://www.rfc-editor.org/info/rfc7761>.

[RFC8126] Cotton, M., Leiba, B., and T. Narten, "Guidelines for Writing an IANA Considerations Section in RFCs", BCP 26, RFC 8126, DOI 10.17487/RFC8126, June 2017, <https://www.rfc-editor.org/info/rfc8126>.

[RFC8231] Crabbe, E., Minei, I., Medved, J., and R. Varga, "Path Computation Element Communication Protocol (PCEP) Extensions for Stateful PCE", RFC 8231, DOI 10.17487/RFC8231, September 2017, <https://www.rfc-editor.org/info/rfc8231>.

[RFC8232] Crabbe, E., Minei, I., Medved, J., Varga, R., Zhang, X., and D. Dhody, "Optimizations of Label Switched Path State Synchronization Procedures for a Stateful PCE", RFC 8232, DOI 10.17487/RFC8232, September 2017, <https://www.rfc-editor.org/info/rfc8232>.

[RFC8281] Crabbe, E., Minei, I., Sivabalan, S., and R. Varga, "Path Computation Element Communication Protocol (PCEP) Extensions for PCE-Initiated LSP Setup in a Stateful PCE Model", RFC 8281, DOI 10.17487/RFC8281, December 2017, <https://www.rfc-editor.org/info/rfc8281>.

[RFC8283] Farrel, A., Ed., Zhao, Q., Ed., Li, Z., and C. Zhou, "An Architecture for Use of PCE and the PCE Communication Protocol (PCEP) in a Network with Central Control", RFC 8283, DOI 10.17487/RFC8283, December 2017, <https://www.rfc-editor.org/info/rfc8283>.

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