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PCEP Extensions for PCE-initiated LSP Setup in a Stateful PCE Model
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Abstract

The Path Computation Element Communication Protocol (PCEP) provides mechanisms for Path Computation Elements (PCEs) to perform path computations in response to Path Computation Clients (PCCs) requests.

The extensions described in [I-D.ietf-pce-stateful-pce] provide stateful control of Multiprotocol Label Switching (MPLS) Traffic Engineering Label Switched Paths (TE LSP) via PCEP, for a model where the PCC delegates control over one or more locally configured LSPs to the PCE. This document describes the creation and deletion of PCE-initiated LSPs under the stateful PCE model.

Requirements Language

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

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1. Introduction

[RFC5440] describes the Path Computation Element Protocol PCEP. PCEP defines the communication between a Path Computation Client (PCC) and a Path Control Element (PCE), or between PCE and PCE, enabling computation of Multiprotocol Label Switching (MPLS) for Traffic Engineering Label Switched Path (TE LSP) characteristics.

Stateful pce [I-D.ietf-pce-stateful-pce] specifies a set of extensions to PCEP to enable stateful control of TE LSPs between and across PCEP sessions in compliance with [RFC4657]. It includes mechanisms to effect LSP state synchronization between PCCs and PCEs, delegation of control of LSPs to PCEs, and PCE control of timing and sequence of path computations within and across PCEP sessions and focuses on a model where LSPs are configured on the PCC and control over them is delegated to the PCE.

This document describes the setup, maintenance and teardown of PCE-initiated LSPs under the stateful PCE model, without the need for local configuration on the PCC, thus allowing for a dynamic network that is centrally controlled and deployed.

2. Terminology

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

This document uses the following terms defined in [I-D.ietf-pce-stateful-pce]: Stateful PCE, Delegation, Redelegation Timeout, State Timeout Interval LSP State Report, LSP Update Request.

The following terms are defined in this document:

PCE-initiated LSP: LSP that is instantiated as a result of a request from the PCE.

The message formats in this document are specified using Routing Backus-Naur Format (RBNF) encoding as specified in [RFC5511].

3. Architectural Overview

3.1. Motivation

[I-D.ietf-pce-stateful-pce] provides stateful control over LSPs that are locally configured on the PCC. This model relies on the LER taking an active role in delegating locally configured LSPs to the

PCE, and is well suited in environments where the LSP placement is fairly static. However, in environments where the LSP placement needs to change in response to application demands, it is useful to support dynamic creation and tear down of LSPs. The ability for a PCE to trigger the creation of LSPs on demand can make possible agile software-driven network operation, and can be seamlessly integrated into a controller-based network architecture, where intelligence in the controller can determine when and where to set up paths.

A possible use case is one of a software-driven network, where applications request network resources and paths from the network infrastructure. For example, an application can request a path with certain constraints between two LSRs by contacting the PCE. The PCE can compute a path satisfying the constraints, and instruct the head end LSR to instantiate and signal it. When the path is no longer required by the application, the PCE can request its teardown.

Another use case is one of dynamically adjusting aggregate bandwidth between two points in the network using multiple LSPs. This functionality is very similar to auto-bandwidth, but allows for providing the desired capacity through multiple LSPs. This approach overcomes two of the limitations auto-bandwidth can experience: 1) growing the capacity between the endpoints beyond the capacity of individual links in the path and 2) achieving good bin-packing through use of several small LSPs instead of a single large one. The number of LSPs varies based on the demand, and LSPs are created and deleted dynamically to satisfy the bandwidth requirements.

Another use case is that of demand engineering, where a PCE with visibility into both the network state and the demand matrix can anticipate and optimize how traffic is distributed across the infrastructure. Such optimizations may require creating new paths across the infrastructure.

3.2. Operation overview

A PCC or PCE indicates its ability to support PCE provisioned dynamic LSPs during the PCEP Initialization Phase via a new flag in the STATEFUL-PCE-CAPABILITY TLV (see details in Section 4.1).

The decision when to instantiate or delete a PCE-initiated LSP is out of the scope of this document. To instantiate or delete an LSP, the PCE sends a new message, the Path Computation LSP Initiate Request (PCInitiate) message to the PCC. The LSP Initiate Request MUST include the SRP and LSP objects, and the LSP object MUST include the Symbolic Path Name TLV and MUST have a PLSP-ID of 0.

For an instantiation operation, the PCE MUST include the ERO and END-

POINTS object and may include various attributes as per [RFC5440]. The PCC creates the LSP using the attributes communicated by the PCE, and local values for the unspecified parameters. It assigns a unique PLSP-ID for the LSP and automatically delegates the LSP to the PCE. It also generates an LSP State Report (PCRpt) for the LSP, carrying the newly assigned PLSP-ID and indicating the delegation via the Delegate flag in the LSP object. In addition to the Delegate flag, the PCC also sets the Create flag in the LSP object (see Section 5.3.1), to indicate that the LSP was created as a result of a PCinitiate message. This PCRpt message MUST include the SRP object, with the SRP-id-number used in the SRP object of the PCInitate message. The PCE may update the attributes of the LSP via subsequent PCUpd messages. Subsequent LSP State Report and LSP Update Request for the LSP will carry the PCC-assigned PLSP-ID, which uniquely identifies the LSP. See details in Section 5.3.

Once instantiated, the delegation procedures for PCE-initiated LSPs are the same as for PCC initiated LSPs as described in [I-D.ietf-pce-stateful-pce]. This applies to the case of a PCE failure as well. In order to allow for network cleanup without manual intervention, the PCC SHOULD support removal of PCE-initiated LSPs as one of the behaviors applied on expiration of the State Timeout Interval [I-D.ietf-pce-stateful-pce]. The behavior SHOULD be picked based on local policy, and can result either in LSP removal, or into reverting to operator-defined default parameters. See details in Section 6. A PCE may return a delegation to the PCC in order to facilitate re-delegation of its LSPs to an alternate PCE.

To indicate a delete operation, the PCE MUST use the R flag in the SRP object in a PCUpd message. As a result of the deletion request, the PCC MUST remove all state related to the LSP, and send a PCRpt with the R flag set in the LSP object for the removed state. See details in Section 5.4.

4. Support of PCE-initiated LSPs

A PCC indicates its ability to support PCE provisioned dynamic LSPs during the PCEP Initialization phase. The Open Object in the Open message contains the "Stateful PCE Capability" TLV, defined in [I-D.ietf-pce-stateful-pce]. A new flag, the I (LSP-INSTANTIATION-CAPABILITY) flag is introduced to indicate support for instantiation of PCE-initiated LSPs. A PCE can initiate LSPs only for PCCs that advertised this capability and a PCC will follow the procedures described in this document only on sessions where the PCE advertised the I flag.

4.1. Stateful PCE Capability TLV

The format of the STATEFUL-PCE-CAPABILITY TLV is shown in the following figure:

```
  0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |               Type=16         |            Length=4           |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |              Flags                                      |I|S|U|
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-++-+-+-+-+-+-+-+-+-+-+-++-+-+-+-+
```

Figure 1: STATEFUL-PCE-CAPABILITY TLV format

The type of the TLV is defined in [I-D.ietf-pce-stateful-pce] and it has a fixed length of 4 octets.

The value comprises a single field - Flags (32 bits). The U and S bits are defined in [I-D.ietf-pce-stateful-pce].

I (LSP-INSTANTIATION-CAPABILITY - 1 bit): If set to 1 by a PCC, the I Flag indicates that the PCC allows instantiation of an LSP by a PCE. If set to 1 by a PCE, the I flag indicates that the PCE will attempt to instantiate LSPs. The LSP-INSTANTIATION-CAPABILITY flag must be set by both PCC and PCE in order to support PCE-initiated LSP instantiation.

Unassigned bits are considered reserved. They MUST be set to 0 on transmission and MUST be ignored on receipt.

5. PCE-initiated LSP instantiation and deletion

To initiate an LSP, a PCE sends a PCInitiate message to a PCC. The message format, objects and TLVs are discussed separately below for the creation and the deletion cases.

5.1. The LSP Initiate Message

A Path Computation LSP Initiate Message (also referred to as PCInitiate message) is a PCEP message sent by a PCE to a PCC to trigger LSP instantiation or deletion. The Message-Type field of the PCEP common header for the PCInitiate message is set to [TBD]. The PCInitiate message MUST include the SRP and the LSP objects, and may contain other objects, as discussed later in this section. If either the SRP or the LSP object is missing, the PCC MUST send a PCErr as described in [I-D.ietf-pce-stateful-pce]. LSP instantiation is done

by sending an LSP Initiate Message with an LSP object with the reserved PLSP-ID 0. LSP deletion is done by sending an LSP Initiate Message with an LSP object carrying the PLSP-ID of the LSP to be removed and an SRP object with the R flag set (see Section 5.2).

The format of a PCInitiate message for LSP instantiation is as follows:

```
   <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>]

   <PCE-initiated-lsp-deletion> ::= <SRP>
                                    <LSP>

Where:
   <attribute-list> is defined in [RFC5440] and extended by PCEP extensions.
```

The SRP object is used to correlate between initiation requests sent by the PCE and the error reports and state reports sent by the PCC. Every request from the PCE receives a new SRP-ID-number. This number is unique per PCEP session and is incremented each time an operation (initiation, update, etc) is requested from the PCE. The value of the SRP-ID-number MUST be echoed back by the PCC in PCErr and PCRpt messages to allow for correlation between requests made by the PCE and errors or state reports generated by the PCC. Details of the SRP object and its use can be found in [I-D.ietf-pce-stateful-pce].

5.2. The R flag in the SRP Object

The format of the SRP object is shown 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
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                          Flags                            |R|
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                        SRP-ID-number                          |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                                                               |
       //                      Optional TLVs                          //
       |                                                               |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2: The SRP Object format

The type object is defined in [I-D.ietf-pce-stateful-pce].

A new flag is defined to indicate a delete operation initiated by the PCE:

R (LSP-REMOVE - 1 bit): If set to 1, it indicates a removal request initiated by the PCE.

5.3. LSP instantiation

LSP instantiation is done by sending an LSP Initiate Message with an LSP object with the reserved PLSP-ID 0. The LSP is set up using RSVP-TE, extensions for other setup methods are outside the scope of this draft.

Receipt of a PCInitiate Message with a non-zero PLSP-ID and the R flag in the SRP object set to zero results in a PCErr message of type 19 (Invalid Operation) and value 8 (non-zero PLSP-ID in LSP initiation request).

The END-POINTS Object is mandatory for an instantiation request of an RSVP-signaled LSP. It contains the source and destination addresses for provisioning the LSP. If the END-POINTS Object is missing, the PCC MUST send a PCErr message with Error-type=6 (Mandatory Object missing) and Error-value=3 (END-POINTS Object missing).

The ERO Object is mandatory for an instantiation request. It contains the ERO for the LSP. If the ERO Object is missing, the PCC MUST send a PCErr message with Error-type=6 (Mandatory Object missing) and Error-value=9 (ERO Object missing).

The LSP Object MUST include the SYMBOLIC-PATH-NAME TLV, which will be used to correlate between the PCC-assigned PLSP-ID and the LSP. If

the TLV is missing, the PCC MUST send a PCErr message with Error-type=6(Mandatory object missing) and Error-value=14 (SYMBOLIC-PATH-NAME TLV missing). The symbolic name used for provisioning PCE-initiated LSPs must not have conflict with the LSP name of any existing LSP in the PCC. (Existing LSPs may be either statically configured, or initiated by another PCE). If there is conflict with the LSP name, the PCC MUST send a PCErr message with Error-type=23 (Bad Parameter value) and Error-value=1 (SYMBOLIC-PATH-NAME in use). The only exception to this rule is for LSPs for which the State timeout timer is running (see Section 6).

The PCE MAY include various attributes as per [RFC5440]. The PCC MUST use these values in the LSP instantiation, and local values for unspecified parameters. After the LSP setup, the PCC MUST send a PCRpt to the PCE, reflecting these values. The SRP object in the PCRpt message MUST echo the value of the PCInitiate message that triggered the setup. LSPs that were instantiated as a result of a PCInitiate message MUST have the C flag set in the LSP object.

If the PCC determines that the LSP parameters proposed in the PCInitiate message are unacceptable, it MUST trigger a PCErr with error-type=TBD (PCE instantiation error) and error-value=1 (Unacceptable instantiation parameters). If the PCC encounters an internal error during the processing of the PCInitiate message, it MUST trigger a PCErr with error-type=TBD (PCE instantiation error) and error-value=2 (Internal error).

A PCC MUST relay to the PCE errors it encounters in the setup of PCE-initiated LSP by sending a PCErr with error-type=TBD (PCE instantiation error) and error-value=3 (RSVP signaling error). The PCErr MUST echo the SRP-id-number of the PCInitiate message. The PCEP-ERROR object SHOULD include the RSVP Error Spec TLV (if an ERROR SPEC was returned to the PCC by a downstream node). After the LSP is set up, errors in RSVP signaling are reported in PCRpt messages, as described in [I-D.ietf-pce-stateful-pce].

A PCC SHOULD be able to place a limit on either the number of LSPs or the percentage of resources that are allocated to honor PCE-initiated LSP requests. As soon as that limit is reached, the PCC MUST send a PCErr message of type 19 (Invalid Operation) and value TBD "PCE-initiated limit reached" and is free to drop any incoming PCInitiate messages without additional processing.

Similarly, the PCE SHOULD be able to place a limit on either the number of LSP initiation requests pending for a particular PCC, or on the time it waits for a response (positive or negative) to a PCInitiate request from a PCC and MAY take further action (such as closing the session or removing all its LSPs) if this limit is

reached.

On succesful completion of the LSP instantiation, the PCC assigns a PLSP-ID, and immediately delegates the LSP to the PCE by sending a PCRpt with the Delegate flag set. The PCRpt MUST include the SRP-ID-number of the PCInitiate request that triggered its creation. PCE-initiated LSPs are identified with the Create flag in the LSP Object.

5.3.1. The Create flag

The LSP object is defined in [I-D.ietf-pce-stateful-pce] and included here for easy reference.

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                PLSP-ID                |   Flags |C|  O|A|R|S|D|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
//                        TLVs                                 //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3: The LSP Object format

A new flag, the Create (C) flag is introduced. On a PCRpt message, the C Flag set to 1 indicates that this LSP was created via a PCInitiate message. The C Flag MUST be set to 1 on each PCRpt message for the duration of existence of the LSP. The Create flag allows PCEs to be aware of which LSPs were PCE-initiated (a state that would otherwise only be known by the PCC and the PCE that initiated them).

5.4. LSP deletion

PCE-initiated removal of a PCE-initiated LSP is done by setting the R (remove) flag in the SRP Object in the PCInitiate message from the PCE. The LSP is identified by the PLSP-ID in the LSP object. If the PLSP-ID is unknown, the PCC MUST generate a PCErr with error type 19, error value 3, "Unknown PLSP-ID". A PLSP-ID of zero removes all LSPs that were initiated by the PCE. If the PLSP-ID specified in the PCInitiate message is not delegated to the PCE, the PCC MUST send a PCErr message indicating "LSP is not delegated" (Error code 19, error value 1 ([I-D.ietf-pce-stateful-pce]). If the PLSP-ID specified in the PCInitiate message was not created by the PCE, the PCC MUST send a PCErr message indicating "LSP is not PCE initiated" (Error code 19, error value TBD). Following the removal of the LSP, the PCC MUST send a PCRpt as described in [I-D.ietf-pce-stateful-pce]. The SRP object in the PCRpt MUST include the SRP-ID-number from the

PCInitiate message that triggered the removal. The R flag in the SRP object SHOULD be set.

6. LSP delegation and cleanup

PCE-initiated LSPs are automatically delegated by the PCC to the PCE upon instantiation. The PCC MUST delegate the LSP to the PCE by setting the delegation bit to 1 in the PCRpt that includes the assigned PLSP-ID. All subsequent messages from the PCC must have the delegation bit set to 1. The PCC cannot revoke the delegation for PCE-initiated LSPs for an active PCEP session. Sending a PCRpt message with the delegation bit set to 0 results in a PCErr message of type 19 (Invalid Operation) and value TBD "Delegation for PCE-initiated LSP cannot be revoked". The PCE MAY further react by closing the session.

A PCE MAY return a delegation to the PCC, to allow for LSP transfer between PCEs. Doing so MUST trigger the State Timeout Interval timer ([I-D.ietf-pce-stateful-pce]).

In case of PCEP session failure, control over PCE-initiated LSPs reverts to the PCC at the expiration of the redelegation timeout. To obtain control of a PCE-initiated LSP, a PCE (either the original or one of its backups) sends a PCInitiate message, including just the SRP and LSP objects, and carrying the PLSP-ID of the LSP it wants to take control of. Receipt of a PCInitiate message with a non-zero PLSP-ID normally results in the generation of a PCErr. If the State Timeout timer is running, the PCC MUST NOT generate an error and redelegate the LSP to the PCE. The State Timeout timer is stopped upon the redelegation. After obtaining control of the LSP, the PCE may remove it using the procedures described in this document.

The State Timeout timer ensures that a PCE crash does not result in automatic and immediate disruption for the services using PCE-initiated LSPs. PCE-initiated LSPs are not be removed immediately upon PCE failure. Instead, they are cleaned up on the expiration of this timer. This allows for network cleanup without manual intervention. The PCC SHOULD support removal of PCE-initiated LSPs as one of the behaviors applied on expiration of the State Timeout Interval [I-D.ietf-pce-stateful-pce]. The behavior SHOULD be picked based on local policy, and can result either in LSP removal, or into reverting to operator-defined default parameters.

7. Implementation status

This section to be removed by the RFC editor.

This section records the status of known implementations of the protocol defined by this specification at the time of posting of this Internet-Draft, and is based on a proposal described in RFC 6982. The description of implementations in this section is intended to assist the IETF in its decision processes in progressing drafts to RFCs. Please note that the listing of any individual implementation here does not imply endorsement by the IETF. Furthermore, no effort has been spent to verify the information presented here that was supplied by IETF contributors. This is not intended as, and must not be construed to be, a catalog of available implementations or their features. Readers are advised to note that other implementations may exist.

According to RFC 6982, "this will allow reviewers and working groups to assign due consideration to documents that have the benefit of running code, which may serve as evidence of valuable experimentation and feedback that have made the implemented protocols more mature. It is up to the individual working groups to use this information as they see fit".

Two vendors are implementing the extensions described in this draft and have included the functionality in releases that will be shipping in the near future. An additional entity is working on implementing these extensions in the scope of research projects.

8. IANA considerations

8.1. PCEP Messages

This document defines the following new PCEP messages:

Value	Meaning	Reference
12	Initiate	This document

8.2. LSP Object

The following values are defined in this document for the Flags field in the LSP Object.

Bit	Description	Reference
24	Create	This document

8.3. PCEP-Error Object

This document defines new Error-Type and Error-Value for the following new error conditions:

```
 Error-Type  Meaning
    6        Mandatory Object missing
              Error-value=13: LSP cleanup TLV missing
              Error-value=14: SYMBOLIC-PATH-NAME TLV missing
    19       Invalid operation
              Error-value=6:  PCE-initiated LSP limit reached
              Error-value=7:  Delegation for PCE-initiated LSP cannot
                              be revoked
              Error-value=8:  Non-zero PLSP-ID in LSP initiation
                              request
    23       Bad parameter value
              Error-value=1:  SYMBOLIC-PATH-NAME in use
    24       LSP instantiation error
              Error-value=1:  Unacceptable instantiation parameters
              Error-value=2:  Internal error
              Error-value=3:  RSVP signaling error
```

9. Security Considerations

The security considerations described in [I-D.ietf-pce-stateful-pce] apply to the extensions described in this document. Additional considerations related to a malicious PCE are introduced.

9.1. Malicious PCE

The LSP instantiation mechanism described in this document allows a PCE to generate state on the PCC and throughout the network. As a result, it introduces a new attack vector: an attacker may flood the PCC with LSP instantiation requests and consume network and LSR resources, either by spoofing messages or by compromising the PCE itself.

A PCC can protect itself from such an attack by imposing a limit on either the number of LSPs or the percentage of resources that are allocated to honor PCE-initiated LSP requests. As soon as that limit is reached, the PCC MUST send a PCErr message of type 19 (Invalid Operation) and value 3 "PCE-initiated LSP limit reached" and is free to drop any incoming PCInitiate messages for LSP instantiation without additional processing.

Rapid flaps triggered by the PCE can also be an attack vector. This will be discussed in a future version of this document.

9.2. Malicious PCC

The LSP instantiation mechanism described in this document requires the PCE to keep state for LSPs that it instantiates and relies on the PCC responding (with either a state report or an error message) to requests for LSP instantiation. A malicious PCC or one that reached the limit of the number of PCE-initiated LSPs, can ignore PCE requests and consume PCE resources. A PCE can protect itself by imposing a limit on the number of requests pending, or by setting a timeout and it MAY take further action such as closing the session or removing all the LSPs it initiated.

10. Acknowledgements

We would like to thank Jan Medved, Ambrose Kwong, Ramon Casellas, Dhruv Dhody, and Raveendra Trovi for their contributions to this document.

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