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# Path Computation Element (PCE) Protocol Extensions for Stateful PCE Usage in GMPLS-controlled Networks

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## Abstract

The Path Computation Element (PCE) facilitates Traffic Engineering (TE) based path calculation in large, multi-domain, multi-region, or multi-layer networks. The PCE communication Protocol (PCEP) has been extended to support stateful PCE functions where the PCE retains information about the paths already present in the network, but those extensions are technology-agnostic. This memo provides extensions required for PCEP so as to enable the usage of a stateful PCE capability in GMPLS-controlled networks.

This Internet-Draft will expire on June 29, 2021.

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## 1. Introduction

[RFC4655] presents the architecture of a Path Computation Element (PCE)-based model for computing Multiprotocol Label Switching (MPLS) and Generalized MPLS (GMPLS) Traffic Engineering Label Switched Paths (TE LSPs). To perform such a constrained computation, a PCE stores the network topology (i.e., TE links and nodes) and resource information (i.e., TE attributes) in its TE Database (TED). Such a PCE is usually referred as a stateless PCE. To request path computation services to a PCE, [RFC5440] defines the PCE communication Protocol (PCEP) for interaction between a Path Computation Client (PCC) and a PCE, or between two PCEs. PCEP as specified in [RFC5440] mainly focuses on MPLS networks and the PCEP extensions needed for GMPLS-controlled networks are provided in [RFC8779].

Stateful PCEs are shown to be helpful in many application scenarios, in both MPLS and GMPLS networks, as illustrated in [RFC8051]. Further discussion of concept of a stateful PCE can be found in [RFC7399]. In order for these applications to able to exploit the capability of stateful PCEs, extensions to PCEP are required.

[RFC8051] describes how a stateful PCE can be applicable to solve various problems for MPLS-TE and GMPLS networks and the benefits it brings to such deployments.

[RFC8231] provides the fundamental extensions needed for stateful PCE to support general functionality. Furthermore, [RFC8281] describes the setup and teardown of PCE-initiated LSPs under the active stateful PCE model, without the need for local configuration on the PCC. However, both the documents left out the specification for technology-specific objects/TLVs, and does not cover the GMPLS networks (e.g., WSON, OTN, SONET/ SDH, etc. technologies). This document focuses on the extensions that are necessary in order for the deployment of stateful PCEs and the requirements for remote-initiated LSPs in GMPLS-controlled networks. Section 3 provides General context of Stateful PCE and PCEP for GMPLS are provided in Section 3, and PCE initiation requirement for GMPLS is provided in section 4. Protocol extensions is included in section 5, as a solution to address such requirements.

## 2. Conventions used in this document

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.

## 3. General Context of Stateful PCE and PCEP for GMPLS

This section is built on the basis of Stateful PCE in [RFC8231] and PCEP for GMPLS in [RFC8779].

The operation for Stateful PCE on LSPs can be divided into two types, active stateful PCE and passive stateful PCE.

For active stateful PCE, PCUpd message is sent from PCE to PCC to update the LSP state for the LSP delegated to PCE. Any changes to the delegated LSPs generate a PCRpt message by the PCC to PCE to convey the changes of the LSP. Any modifications to the Objects/TLVs that are identified in this document to support GMPLS technology-specific attributes will be carried in the PCRpt and PCUpd messages.

For passive stateful PCEs, PCReq/PCRep messages are used to convey path computation instructions. GMPLS-technology specific Objects and TLVs are defined in [RFC8779], so this document just points at that work and only adds the stateful PCE aspects where applicable.

Passive Stateful PCE makes use of PCRpt messages when reporting LSP State changes sent by PCC to PCEs. Any modifications to the Objects/TLVs that are identified in this document to support GMPLS technology-specific attributes will be carried in the PCRpt message.

Furthermore, the Initiation of PCEP are defined in [RFC8281] to allow the PCE to initiate the LSP establishment after the path is computed. PCInitiate messages are used to trigger the end node to set up the LSP. Any modifications to the Objects/TLVs that are identified in this document to support GMPLS technology-specific attributes will be carried in the PCInitiate messages.

[RFC8779] defines GMPLS-technology specific Objects/TLVs in stateless PCEP, and this document makes use of these Objects/TLVs without modifications where applicable. Some of these Objects/TLVs may require modifications to incorporate stateful PCE where applicable. The remote-initiated LSP would follow the principle specified in [RFC8281], and GMPLS-specific extensions are also included in this document.

## 4. Main Requirements

This section notes the main functional requirements for PCEP extensions to support stateful PCE for use in GMPLS-controlled networks, based on the description in [RFC8051]. Many requirements are common across a variety of network types (e.g., MPLS-TE networks and GMPLS networks) and the protocol extensions to meet the requirements are already described in [RFC8231]. This document does not repeat the description of those protocol extensions. This document presents protocol extensions for a set of requirements which are specific to the use of a stateful PCE in a GMPLS-controlled network.

The requirements for GMPLS-specific stateful PCE are as follows:

- o Advertisement of the stateful PCE capability. This generic requirement is covered in Section 5.4 of [RFC8231]. The GMPLS CAPABILITY TLV in section 2.1 of [RFC8779] and its extension in this document MUST be advertised as well.

- o LSP operations, including LSP update, delegation and state synchronization/report were covered in [RFC8231]. This document provides extension for its application in GMPLS-controlled networks.

- o All the PCEP messages need to be capable to indicate GMPLS-specific switching capabilities per TE link basis. GMPLS LSP creation/modification/deletion requires knowledge of LSP

switching capability (e.g., TDM, L2SC, OTN-TDM, LSC, etc.) and the generalized payload (G-PID) to be used according to [RFC3471], [RFC3473]. It also requires the specification of data flow specific traffic parameters (also known as TSpec), which are technology specific. Such information would be needed for PCEP message.

- In some technologies path calculation is tightly coupled with label selection along the route. For example, path calculation in a WDM network may include lambda continuity and/or lambda feasibility constraints and hence a path computed by the PCE is associated with a specific lambda (label). Hence, in such networks, the label information needs to be provided to a PCC in order for a PCE to initiate GMPLS LSPs under the active stateful PCE model, i.e., explicit label control may be required.

- Stateful PCEP message also need to indicate the protection context information for the LSP specified by GMPLS, as defined in [RFC4872], [RFC4873].

## 5. Overview of PCEP Extensions for GMPLS Networks

### 5.1. Capability Advertisement for Stateful PCEP in GMPLS

Capability Advertisement has been specified in [RFC8231], and can be achieved by using the "STATEFUL-PCE-CAPABILITY" in the PCEP TLV Type Indicators. Another GMPLS-CAPABILITY TLV in the PCEP TLV Type Indicators has been defined in [RFC8779]. According to [RFC8779], IANA created a registry to manage the value of the GMPLS-CAPABILITY TLV's Flag field. New bits, LSP-UPDATE-CAPABILITY (TBD1) and LSP-INSTANTIATION-CAPABILITY (TBD2), are introduced as flag to indicate the capability for LSP update and remote LSP initiation in GMPLS networks.

### 5.2. LSP Synchronization

PCCs need to report the attributes of LSPs to the PCE to enable stateful operation of a GMPLS network. This process is known as LSP state synchronization. The LSP attributes include bandwidth, associated route, and protection information etc., are stored by the PCE in the LSP database (LSP-DB). Note that, as described in [RFC8231], the LSP state synchronization covers both the bulk reporting of LSPs at initialization as well the reporting of new or modified LSP during normal operation. Incremental LSP-DB synchronization may be desired in a GMPLS-controlled network and it is specified in [RFC8232].

The END-POINTS object is extended for GMPLS in [RFC8779]. The END-POINTS object is carried in the PCRpt message as specified in [RFC8623]. The END-POINTS object type for GMPLS is included in the PCRpt message as per the same.

The BANDWIDTH, LSPA, IRO and XRO objects are extended for GMPLS in [RFC8779]. These objects are carried in the PCRpt message as specified in [RFC8231] (as the attribute-list defined in Section 6.5 of [RFC5440] and extended by PCEP extensions).

The SWITCH-LAYER object is defined in [RFC8282]. This object is carried in PCRpt message as specified in section 3.2 of [RFC8282].

### 5.3. LSP Delegation and Cleanup

LSP delegation and cleanup procedure specified in [RFC8231] are equally applicable to GMPLS LSPs and this document does not modify the associated usage.

### 5.4. LSP Operations in Stateful PCEP for GMPLS-controlled Networks

Both passive and active stateful PCE mechanism in [RFC8231] are applicable in GMPLS-controlled networks. Remote LSP Initiation in [RFC8281] is also applicable in GMPLS-controlled networks.

## 6. Extension of Existing PCEP Messages

### 6.1. The PCRpt Message

According to [RFC8231], the PCRpt Message is used to report the current state of LSP. This document extends the message in reporting the status of LSPs with GMPLS characteristics.

The format of the PCRpt message is as follows:

```
<PCRpt Message> ::= <Common Header>

                    <state-report-list>

Where:

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

<state-report> ::= [<SRP>]

                   <LSP>

                   <path>
```

```
Where:

  <path>::= <intended-path>

            [<actual-attribute-list><actual-path>]

            <intended-attribute-list>


  <actual-attribute-list>::=[<BANDWIDTH>]

                             [<metric-list>]
```

Where:

<intended-path> is represented by the ERO object defined in Section 7.9 of [RFC5440], augmented in [RFC8779] with explicit label control (ELC) and Path Keys.

<actual-attribute-list> consists of the actual computed and signaled values of the <BANDWIDTH> and <metric-lists> objects defined in [RFC5440]. GENERALIZED-BANDWIDTH object has been defined in [RFC8779] to address the limitation of the BANDWIDTH object, with supporting the following:

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

o Technology specific GMPLS parameters (e.g., TSpec for SDH/SONET, G.709, ATM, MEF, etc.).

<actual-path> is represented by the RRO object defined in Section 7.10 of [RFC5440].

<intended-attribute-list> is the attribute-list defined in Section 6.5 of [RFC5440] and extended by PCEP extensions.

The SRP object is OPTIONAL, and the usage is extended in the section 7.2.3 of this document.

### 6.2. The PCUpd Message

The format of a PCUpd message is as follows:

```
<PCUpd Message> ::= <Common Header>

                    <update-request-list>
```

Where:

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

<update-request> ::= <SRP>

                     <LSP>

                     <path>
```

Where:

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

Where:

<intended-path> is represented by the ERO object defined in Section 7.9 of [RFC5440], augmented in [RFC8779] with explicit label control (ELC) and Path Keys.

<intended-attribute-list> is the attribute-list defined in [RFC5440] and extended by PCEP extensions.

### 6.3. The PCInitiate Message

According to [RFC8281], the PCInitiate Message is used allow remote LSP Initiation. This document extends the message in initiating LSPs with GMPLS characteristics. The format of a PCInitiate message is as follows:

```
<PCInitiate Message> ::= <Common Header>

                         <PCE-initiated-lsp-list>
```

Where:

<Common Header> is defined in [RFC5440].

```
<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>
```

END-POINTS object has been extended by [RFC8779] to include a new object type called "Generalized Endpoint". PCInitiate message sent by a PCE to a PCC to trigger a GMPLS LSP instantiation MUST include the END-POINTS with Generalized Endpoint object type. Furthermore, the END-POINTS object MUST contain "label request" TLV. The label request TLV is used to specify the switching type, encoding type and G-PID of the LSP being instantiated by the PCE.

The unnumbered endpoint TLV can be used to specify unnumbered endpoint addresses for the LSP being instantiated by the PCE. The END-POINTS MAY contain other TLVs defined in [RFC8779].

## 7. PCEP Object Extensions

### 7.1. Existing Extensions used for Stateful GMPLS

Existing extensions defined in [RFC8779] can be used in the Stateful PCEP with no changes or slightly changes for GMPLS network control, including the following:

o END-POINTS: Generalized END-POINTS was specified in [RFC8779] to include GMPLS capabilities. Stateful PCEP messages MUST include the END-POINTS with Generalized Endpoint object type, containing the "label request" TLV.

o BANDWIDTH: Generalized BANDWIDTH was specified in [RFC8779] to represent GMPLS features, including asymmetric bandwidth and G-PID information.

o LSPA: LSPA Extensions in Section 2.8 of [RFC8779] is applicable in Stateful PCEP for GMPLS networks.

o IRO: IRO Extensions in Section 2.6 of [RFC8779] is applicable in Stateful PCEP for GMPLS networks.

o XRO: XRO Extensions in Section 2.7 of [RFC8779] is applicable in Stateful PCEP for GMPLS networks. A new flag is defined in section 7.2.2 of this document.

o ERO: The ERO was not extended in [RFC8779], and not in this document as well.

o SWITCH-LAYER: SWITCHING-LAYER definition in Section 3.2 of [RFC8282] is applicable in Stateful PCEP messages for GMPLS networks.

## 7.2. New Extensions

### 7.2.1. OPEN Object Extension GMPLS-CAPABILITY TLV

In [RFC8779], IANA has allocated value 45 (GMPLS-CAPABILITY) from the "PCEP TLV Type Indicators" sub-registry. The TLV is extended with two flags to indicate the Stateful and remote initiate capability.

```
 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=45         |           Length              |

+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

|                             Flags                           |I|S|

+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

S (LSP-UPDATE-CAPABILITY -- 1 bit): if set to 1 by a PCC, the S flag indicates that the PCC allows modification of LSP parameters; if set to 1 by a PCE, the S flag indicates that the PCE is capable of updating LSP parameters. The LSP-UPDATE-CAPABILITY flag must be advertised by both a PCC and a PCE for PCUpd messages to be allowed on a PCEP session.

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 supports instantiating LSPs. The LSP-INSTANTIATION-CAPABILITY flag must be set by both the PCC and PCE in order to enable PCE-initiated LSP instantiation.

### 7.2.2. XRO Subobject

[RFC5521] defines a mechanism for a PCC to request or demand that specific nodes, links, or other network resources are excluded from paths computed by a PCE. A PCC may wish to request the computation of a path that avoids all link and nodes traversed by some other LSP.

To this end this document defines a new sub-object for use with route exclusion defined in [RFC5521]. The LSP exclusion sub-object 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|X|Type (TBD3) |     Length    |   Attributes  |    Flag       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
//                    Symbolic Path Name                       //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

X bit and Attribute fields are defined in [RFC5521].

Type: Subobject Type for an LSP exclusion sub-object. Value of TBD3. To be assigned by IANA.

Length: The Length contains the total length of the subobject in bytes, including the Type and Length fields.

Flags: This field may be used to further specify the exclusion constraint with regard to the LSP. Currently, no values are defined.

Symbolic Path Name: This is the identifier given to an LSP and is unique in the context of the PCC address as defined in [RFC8231].

Reserved: MUST be transmitted as zero and SHOULD be ignored on receipt.

This sub-object is OPTIONAL in the exclude route object (XRO) and can be present multiple times. When a stateful PCE receives a PCReq message carrying this sub-object, it SHOULD search for the identified LSP in its LSP-DB and then exclude from the new path computation all resources used by the identified LSP.

#### 7.2.3. SRP Extension

The format of the SRP object is defined in [RFC8231]. The object is used in PCUpd and PCInitiate messages for GMPLS.

This document defines a new flag to be carried in the Flags field of the SRP object. This flag indicates a bidirectional co-routed LSP setup operation initiated by the PCE as follows:

o B (Bidirectional LSP -- 1 bit): If set to 0, it indicates a request to create a uni-directional LSP. If set to 1, it indicates a request to create a bidirectional co-routed LSP.

The bit position is TBD6 as assigned by IANA.

## 8. Update to Error Handling

A PCEP-ERROR object is used to report a PCEP error and is characterized by an Error-Type that specifies the type of error and an Error-value that provides additional information about the error. In this document the following Error-Type and Error-Value are introduced.

### 8.1. Error Handling in LSP Re-optimization

When setting the R bit in RP object, the PCC is requesting re-optimization of an existing LSP. A stateful PCE SHOULD perform the re-optimization.

If no LSP state information is available to carry out re-optimization, the stateful PCE should report the error "LSP state information unavailable for the LSP re-optimization" (Error Type = TBD5, Error value= TBD6).

### 8.2. Error Handling in Route Exclusion

This sub-object in XRO defined in section 7.2.2 of this document is OPTIONAL and can be present multiple times. When a stateful PCE receives a PCReq message carrying this sub-object, it SHOULD search for the identified LSP in its LSP-DB and then exclude from the new path computation all resources used by the identified LSP.

If the stateful PCE cannot recognize one or more of the received LSP identifiers, it should send an error message PCErr reporting "The LSP state information for route exclusion purpose cannot be found"

(Error-type = TBD5, Error-value = TBD7). Optionally, it may provide with the unrecognized identifier information to the requesting PCC using the error reporting techniques described in [RFC5440].

### 8.3. Error Handling for generalized END-POINTS

If the END-POINTS Object of type Generalized Endpoint is missing the label request TLV, the PCC MUST send a PCErr message with Error-type=6 (Mandatory Object missing) and Error-value= TBD8 (label request TLV missing).

If the PCC does not support the END-POINTS Object of type Generalized Endpoint, the PCC MUST send a PCErr message with Error-type = 3(Unknown Object), Error-value = 2(unknown object type).

## 9. Implementation

[NOTE TO RFC EDITOR : This whole section and the reference to RFC 7942 is to be removed before publication as an RFC]

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 [RFC7942]. 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 [RFC7942], "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".

### 9.1. Huawei Technologies

- o Organization: Huawei Technologies, Co. LTD

- o Implementation: Huawei NCE-T

- o Description: PCRpt, PCUpd and PCInitiate messages for GMPLS Network

- o Maturity Level: Production

- o Coverage: Full

- o Contact: zhenghaomian@huawei.com

## 10. IANA Considerations

### 10.1. New GMPLS-CAPABILITY

[RFC8231] defines the STATEFUL-PCE-CAPABILITY TLV; per that RFC, IANA created a registry to manage the value of the STATEFUL-PCE-CAPABILITY TLV's Flag field. IANA has allocated a new bit in the STATEFUL-PCE-CAPABILITY TLV Flag Field registry, as follows:

| Bit | Description | Reference |
|---|---|---|
| TBD1 | LSP-UPDATE-CAPABILITY (S) | [This.I-D] |
| TBD2 | LSP-INSTANTIATION-CAPABILITY (I) | [This.I-D] |

### 10.2. New Subobject for the Exclude Route Object

IANA maintains the "PCEP Parameters" registry containing a subregistry called "PCEP Objects". This registry has a subregistry for the XRO (Exclude Route Object) listing the sub-objects that can be carried in the XRO. IANA is requested to assign a further sub-object that can be carried in the XRO as follows:

| Value | Description | Reference |
|---|---|---|
| TBD3 | LSP identifier sub-object | [This.I-D] |

### 10.3. New "B" Flag in the SRP Object

IANA maintains a subregistry, named the "SRP Object Flag Field", within the "Path Computation Element Protocol (PCEP) Numbers" registry, to manage the Flag field of the SRP object.

IANA is requested to make an assignment from this registry as follows:

| Bit | Description | Reference |
|---|---|---|
| TBD4 | Bi-directional co-routed LSP | [This.I-D] |

### 10.4. New PCEP Error Codes

IANA is requested to make the following allocation in the "PCEP-ERROR Object Error Types and Values" registry.

| Error Type | Meaning | Reference |
|---|---|---|
| TBD5 | LSP state information missing | [This.I-D] |
| Error-value TBD6: | LSP state information unavailable for the LSP re-optimization | [This.I-D] |
| Error-value TBD7: | LSP state information for route exclusion purpose cannot be found | [This.I-D] |

This document defines the following new Error-Value:

| Error-Type | Error-Value | Reference |
|---|---|---|
| 6 | Error-value TBD8: Label Request TLV missing | [This.I-D] |

## 11. Manageability Considerations

The description and functionality specifications presented related to stateful PCEs should also comply with the manageability specifications covered in Section 8 of [RFC4655]. Furthermore, a further list of manageability issues presented in [RFC8231] should also be considered.

### 11.1. Requirements on Other Protocols and Functional Components

When the detailed route information is included for LSP state synchronization (either at the initial stage or during LSP state report process), this requires the ingress node of an LSP carry the RRO object in order to enable the collection of such information.

## 12. Security Considerations

This draft provides additional extensions to PCEP so as to facilitate stateful PCE usage in GMPLS-controlled networks, on top

of [RFC8231]. The PCEP extensions to support GMPLS-controlled networks should be considered under the same security as for MPLS networks, as noted in [RFC7025]. Therefore, the security considerations elaborated in [RFC5440] still apply to this draft. Furthermore, [RFC8231] provides a detailed analysis of the additional security issues incurred due to the new extensions and possible solutions needed to support for the new stateful PCE capabilities and they apply to this document as well.

## 13. Acknowledgement

We would like to thank Adrian Farrel, Cyril Margaria, George Swallow and Jan Medved for the useful comments and discussions.

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