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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.

Status of this Memo

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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 [PCEP-GMPLS].

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 [PCEP-GMPLS].

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 [PCEP-GMPLS], 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.

[PCEP-GMPLS] defines GMPLS-technology specific Objects/TLVs 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], and the GMPLS capability TLV as per [PCEP-GMPLS] MUST be advertised as well. This document assumes that STATEFUL-PCE-CAPABILITY TLV specified in [RFC8231] can be used for GMPLS Stateful PCE capability advertisement and there is no further extensions.

- o Active LSP update is covered in Section 6.2 of [RFC8231]. Section 5.1 of this document provides extension for its application in GMPLS-controlled networks.

- o LSP state synchronization and LSP state report. This is a generic requirement already covered in Section 5.6. of [RFC8231]. However, there are further extensions required specifically for GMPLS-controlled networks and discussed in Section 5.2.

- o LSP delegation is already covered in Section 5.7 of [RFC8231]. The delegation procedure is reused in this document without any further extensions. Statement can be found in section 5.3 in this document.

- o All the PCEP messages need to be capable to indicate GMPLS-specific switching capabilities per TE link basis. GMPLS LSP creation requires knowledge of LSP switching capability (e.g.,

TDM, L2SC, OTN-TDM, LSC, etc.) to be used according to [RFC3471], [RFC3473].

- In order to create/modify/delete GMPLS LSPs, the PCEP messages also need to indicate knowledge of the encoding type (e.g., WSON, Ethernet, SONET/ SDH, OTN, etc.) to be used by the LSP according to [RFC3471], [RFC3473].

- GMPLS LSP creation/modification/deletion requires information of the generalized payload (G-PID) to be carried by the LSP per [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.

- GMPLS extends the addressing to include unnumbered interface identifiers, as defined in [RFC3477].

- 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. Stateful 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 TLV". GMPLS-CAPABILITY TLV has been defined in [PCEP-GMPLS], and would be useful for stateful PCEP in GMPLS network as well.

Besides the above, this document does not have additional extension regarding the capability advertisement.

5.2. LSP Synchronization in GMPLS-controlled Networks

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].

[RFC8231] describes mechanisms for LSP synchronization using the Path Computation State Report (PCRpt) message, but does not cover reporting of technology-specific attributes. As stated in [RFC8231], the <path> construct is further composed of a compulsory Explicit Route Object (ERO) and a compulsory attribute-list and an optional Record Route Object (RRO). In order to report LSP states in GMPLS networks, this specification allows the use within a PCRpt message both of technology- and GMPLS-specific attribute objects and TLVs defined in [PCEP-GMPLS] as follows:

- o Include Route Object (IRO)/ Exclude Route Object (XRO) Extensions to support the inclusion/exclusion of labels and label sub-objects for GMPLS. (See Section 2.6 and 2.7 in [PCEP-GMPLS])

- o END-POINTS (Generalized END-POINTS Object Type. See Section 2.5 in [PCEP-GMPLS])

- o BANDWIDTH (Generalized BANDWIDTH Object Type. See Section 2.3 in [PCEP-GMPLS])

- o LSPA (PROTECTION ATTRIBUTE TLV, See Section 2.8 in [PCEP-GMPLS].

The END-POINTS object SHOULD be carried within the attribute-list to specify the endpoints pertaining to the reported LSP. The XRO object MAY be carried to specify the network resources that the reported LSP avoids and a PCE SHOULD consider avoid these network resources during the process of re-optimizing after this LSP is delegated to the PCE. To be more specific, the <attribute-list> is updated as follows using the notations of [RFC5511]:

```
<attribute-list> ::= [<END-POINTS>]
              [<LSPA>]
                     [<BANDWIDTH>]
```

```
                        [<metric-list>]
                                  [<IRO>]
                 [<XRO>]

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

If the LSP being reported protects another LSP, the PROTECTION-ATTRIBUTE TLV [PCEP-GMPLS] MUST be included in the LSPA object to describe its attributes and restrictions. Moreover, if the status of the protecting LSP changes from non-operational to operational, the PCC SHOULD synchronize the state change of the LSPs to the stateful PCE using a PCRpt message. This use case arises, for example, when the protecting LSP becomes operational due to the failure of the primary LSP.

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.

5.4.1. LSP Update in GMPLS-controlled Networks

[RFC8231] defines the Path Computation LSP Update Request (PCUpd) message to enable to update the attributes of an LSP. However, [RFC8231] does not define technology-specific parameters.

A key element of the PCUpd message is the attribute-list construct defined in [RFC5440] and extended by many other PCEP specifications.

For GMPLS purposes we note that the BANDWIDTH object used in the attribute-list is defined in [PCEP-GMPLS]. Furthermore, additional TLVs are defined for the LSPA object in [PCEP-GMPLS] and MAY be included to indicate technology-specific attributes. There are other technology-specific attributes that need to be conveyed in the <intended-attribute-list> of the <path> construct in the PCUpd message. Note that these path details in the PCUpd message are the same as the <attribute-list> of the PCRep message. See Section 5.3 for the details.

5.4.2. LSP Initiation in GMPLS-controlled Networks

PCInitiate message defined in [RFC8281] needs to be extended in GMPLS network to support the LSP initiation. The extension includes the following objects:

6. Modification of Existing PCEP Messages and Procedures

[Editor Notes]: the whole section would need re-working, the objective is to indicate the RBNF model for the PCEP extension, especially where new objects and TLVs are specified.

One of the advantages mentioned in [RFC8051] is that the stateful nature of a PCE simplifies the information conveyed in PCEP messages, notably between PCC and PCE, since it is possible to refer to PCE managed state for active LSPs. To be more specific, with a stateful PCE, it is possible to refer to an LSP with a unique identifier in the scope of the PCC-PCE session and thus use such identifier to refer to that LSP. Note this is also applicable to packet networks.

6.1. Modification for LSP Re-optimization

The Request Parameters (RP) object on a Path Computation Request (PCReq) message carries the R bit. When set, this indicates that the PCC is requesting re-optimization of an existing LSP. Upon receiving such a PCReq, a stateful PCE SHOULD perform the re-optimization in the following cases:

- o The existing bandwidth and route information of the LSP to be re-optimized is provided in the PCReq message using the BANDWIDTH object and the ERO.

- o The existing bandwidth and route information is not supplied in the PCReq message, but can be found in the PCE's LSP-DB. In this case, the LSP MUST be identified using an LSP identifier carried in the PCReq message, and that fact requires that the LSP identifier was previously supplied either by the PCC in a PCRpt message or by the PCE in a PCRep message. [RFC8231] defines how this is achieved using a combination of the per-node LSP identifier (PLSP-ID) and the PCC's address.

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 = TBD1, Error value= TBD2).

6.2. Modification for Route Exclusion

[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. 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 = TBD1, Error-value = TBD4). Optionally, it may provide with the unrecognized identifier information to the requesting PCC using the error reporting techniques described in [RFC5440].

6.2.1. Modification for SRP Object to indicate Bi-directional LSP

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 TBD5 as assigned by IANA (see Section 5.3)

7. PCEP Object Extensions

7.1. Generalized Endpoint

This document does not modify the usage of END-POINTS object for PCE initiated LSPs as specified in [RFC8281] . It augments the usage as specified below.

END-POINTS object has been extended by [PCEP-GMPLS] 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.

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= TBA (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).

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 [PCEP-GMPLS].

7.2. GENERALIZED-BANDWIDTH object

LSP initiate message defined in [RFC8281] can optionally include the BANDWIDTH object. However, the following possibilities cannot be represented in the BANDWIDTH object:

- 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.) are not supported.

GENERALIZED-BANDWIDTH object has been defined in [PCEP-GMPLS] to address the above-mentioned limitation of the BANDWIDTH object.

This document specifies the use of GENERALIZED-BANDWIDTH object in PCInitiate message. Specifically, GENERALIZED-BANDWIDTH object MAY be included in the PCInitiate message. The GENERALIZED-BANDWIDTH object in PCInitiate message is used to specify technology specific Tspec and asymmetrical bandwidth values for the LSP being instantiated by the PCE.

7.3. The LSP Protection Information

LSPA in the PCEP message can be used to specify protection attributes of the LSP being instantiated by the stateful PCE.

7.4. ERO Extension

GMPLS network does not have special requirement on modifying the usage of ERO object for stateful PCEP in [RFC8231] and PCE initiated LSPs as specified in [RFC8281]. It augments the usage as specified in the following sections.

7.4.1. ERO with explicit label control

As mentioned earlier, there are technologies and scenarios where active stateful PCE requires explicit label control in order to instantiate an LSP.

Explicit label control (ELC) is a procedure supported by RSVP-TE, where the outgoing label(s) is (are) encoded in the ERO. [PCEP-GMPLS] extends the ERO object of PCEP to include explicit label control. The ELC procedure enables the PCE to provide such label(s) directly in the path ERO.

The extended ERO object in PCInitiate message can be used to specify label along with ERO to PCC for the LSP being instantiated by the active stateful PCE.

7.4.2. ERO with Path Keys

There are many scenarios in packet and optical networks where the route information of an LSP may not be provided to the PCC for confidentiality reasons. A multi-domain or multi-layer network is an example of such networks. Similarly, a GMPLS User- Network Interface (UNI) [RFC4208] is also an example of such networks.

In such scenarios, ERO containing the entire route cannot be provided to PCC (by PCE). Instead, PCE provides an ERO with Path Keys to the PCC. For example, in the case UNI interface between the router and the optical nodes, the ERO in the LSP Initiate Message may be constructed as follows:

- o The first hop is a strict hop that provides the egress interface information at PCC. This interface information is used to get to a network node that can extend the rest of the ERO. (Please note that in the cases where the network node is not directly connected with the PCC, this part of ERO may consist of multiple hops and may be loose).

- o The following(s) hop in the ERO may provide the network node with the path key [RFC5520] that can be resolved to get the contents of the route towards the destination.

- o There may be further hops but these hops may also be encoded with the path keys (if needed).

This document does not change encoding or processing roles for the path keys, which are defined in [RFC5520].

7.5. Switch Layer Object

[RFC8282] specifies the SWITCH-LAYER object which defines and specifies the switching layer (or layers) in which a path MUST or MUST NOT be established. A switching layer is expressed as a switching type and encoding type. [PCEP-GMPLS], which defines the GMPLS extensions for PCEP, suggests using the SWITCH-LAYER object. Thus, SWITCH-LAYER object can be used in the PCInitiate message to specify the switching layer (or layers) of the LSP being remotely initiated.

8. IANA Considerations

8.1. 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
TBD1	LSP state information missing	[This.I-D]
Error-value TBD2:	LSP state information unavailable for the LSP re-optimization	[This.I-D]
Error-value TBD4:	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 TBD5: Label Request TLV missing	[This.I-D]

8.2. 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]

8.3. 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
TDB5	Bi-directional co-routed LSP	[This.I-D]

9. 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.

Additional considerations are presented in the next section.

9.1. 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.

10. 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.

11. Acknowledgement

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