

PCE Working Group
Internet-Draft
Intended status: Standards Track

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Expires: January 05, 2016

July 06, 2015

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

[draft-ietf-pce-pcep-stateful-pce-gmpls-03.txt](#)

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.

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Conventions used in this document

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

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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 [RFC 5440] 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 [Stateful-APP]. Further discussion of concept of a stateful PCE can be found in [RFC7399]. In order for these applications to be able to exploit the capability of stateful PCEs, extensions to PCEP are required.

[Stateful-PCE] provides the fundamental extensions needed for stateful PCE to support general functionality, but leaves out the specification for technology-specific objects/TLVs. This document focuses on the extensions that are necessary in order for the deployment of stateful PCEs in GMPLS-controlled networks.

[2. PCEP Extensions](#)

[2.1. Overview of 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 [[Stateful-APP](#)]. 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 [[Stateful-PCE](#)]. 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 basic requirements are as follows:

- o Advertisement of the stateful PCE capability. This generic requirement is covered in Section 7.1.1. of [[Stateful-PCE](#)]. This document does not provide any further extensions.
- o LSP delegation is already covered in [Section 5.5](#). of [[Stateful-PCE](#)]. [Section 2.3](#). of this document provides extension for its application in GMPLS-controlled networks. Moreover, further discussion of some generic details that need additional consideration is provided.
- o LSP state synchronization and LSP state report. This is a generic requirement already covered in Section 5.4. of [[Stateful-PCE](#)]. However, there are further extensions required specifically for GMPLS-controlled networks and discussed in [Section 2.4](#). Reference to LSPs by identifiers is discussed in [Section 7.3](#). of [[Stateful-PCE](#)]. This feature can be applied to reduce the data carried in PCEP messages. Use cases and additional Error Codes are necessary, as described in [Section 2.5](#). of this document.

[2.2. LSP Delegation in GMPLS-controlled Networks](#)

[[Stateful-PCE](#)] defines the Path Computation LSP Update Request (PCUpd) message to enable to update the attributes of an LSP. However, that document 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.

LSP parameter update controlled by a stateful PCE in a multi-domain network is complex and requires well-defined operational procedures as well as protocol design and is out of scope of this document and left for further study.

2.3. 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 [\[Stateful-PCE\]](#), 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 [\[Sync-OPT\]](#).

[\[Stateful-PCE\]](#) 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 [\[Stateful-PCE\]](#), the <path> construct is further composed of a compulsory ERO object and a compulsory attribute-list and a optional RRO object. In order to report LSP states in GMPLS networks, this specification allows the use within a PCRpt message of technology- and GMPLS-specific attribute objects and TLVs defined in [\[PCEP-GMPLS\]](#) as follows:

- o Extensions to the ERO, RRO, IRO, and XRO to carry label sub-objects for SDH/SONET, OTN, and DWDM networks.
- o Extended objects to support the inclusion of the label and unnumbered links.
- o END-POINTS (Generalized END-POINTS Object Type)
- o BANDWIDTH (Generalized BANDWIDTH Object Type)
- o PROTECTION ATTRIBUTE TLV
- o IF_ID_ERROR_SPEC (extending [\[Stateful-PCE\]](#) [section 7.3.4](#) that only considers the use of RSVP ERROR_SPEC)

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:

```
<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, this SHOULD to be synchronized to the stateful PCE using a PCRpt message.

[2.4.](#) Modification of Existing PCEP Messages and Procedures

One of the advantages mentioned in [[Stateful-APP](#)] 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 a LSP with a unique identifier in the scope of the PCC-PCEP session and thus use such identifier to refer to that LSP.

2.4.1. 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 reoptimization of an existing LSP. Upon receiving such a PCReq, a stateful PCE SHOULD perform the reoptimization in the following cases:

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

If no LSP state information is available to carry out reoptimization, the stateful PCE should report the error "LSP state information unavailable for the LSP reoptimization" (Error Type = TBD1, Error value= TBD2).

2.4.2. Modification for Route Exclusion

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											
+-+-+...+-+-+																																									
										PLSP-ID																				Reserved											
+-+-+...+-+-+																																									

X bit: indicates whether the exclusion is mandatory (X=1) and MUST be accommodated, or desired (X=0) and SHOULD be accommodated.

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.

PLSP-ID: This is the identifier given to a LSP and is unique in the context of the PCC address as defined in [Stateful-PCE].

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 it 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].

2.5. Object Encoding

Note that, as is stated in Section 7 of [Stateful-PCE], the P flag and the I flag of the PCEP objects used on PCUpd and PCRpt messages SHOULD be set to 0 on transmission and SHOULD be ignored on receipt since these flags are exclusively related to path computation requests.

3. IANA Considerations

IANA is requested to allocate new Types for the TLV/Object defined in this document.

3.1. 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]

3.2. 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]

4. 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 [\[Stateful-PCE\]](#) should also be considered.

Additional considerations are presented in the next sections.

4.1. 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 require the ingress node of an LSP carry the RRO object in order to enable the collection of such information.

5. Security Considerations

The security issues presented in [\[RFC5440\]](#) and [\[Stateful-PCE\]](#) apply to this document.

6. Acknowledgement

We would like to thank Adrian Farrel and Cyril Margaria for the useful comments and discussions.

7. References

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