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RFC 8697
Path Computation Element Communication Protocol (PCEP) Extensions for Establishing Relationships between Sets of Label Switched Paths (LSPs)

Abstract

This document introduces a generic mechanism to create a grouping of Label Switched Paths (LSPs) in the context of a Path Computation Element (PCE). This grouping can then be used to define associations between sets of LSPs or between a set of LSPs and a set of attributes (such as configuration parameters or behaviors), and it is equally applicable to the stateful PCE (active and passive modes) and the stateless PCE.

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 7841.

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1. Introduction

[RFC5440] describes the Path Computation Element (PCE) Communication Protocol (PCEP). PCEP enables communication between a Path Computation Client (PCC) and a PCE, or between a PCE and another PCE, for the purpose of the computation of Multiprotocol Label Switching (MPLS) as well as Generalized MPLS (GMPLS) Traffic Engineering Label Switched Path (TE LSP) characteristics.

[RFC8231] specifies a set of extensions to PCEP to enable stateful control of TE LSPs within and across PCEP sessions in compliance with [RFC4657]. It includes mechanisms to effect LSP State Synchronization between PCCs and PCEs, delegation of control over LSPs to PCEs, and PCE control of timing and sequence of path computations within and across PCEP sessions. The operational model whereby LSPs are initiated from the PCE is described in [RFC8281].

[RFC4872] defines the RSVP ASSOCIATION object, which was defined in the context of GMPLS-controlled LSPs to be used to associate recovery LSPs with the LSP they are protecting. This object also has broader applicability as a mechanism to associate RSVP state. [RFC6780] describes how the ASSOCIATION object can be more generally applied by defining the Extended ASSOCIATION object.

This document introduces a generic mechanism to create a grouping of LSPs. This grouping can then be used to define associations between sets of LSPs or between a set of LSPs and a set of attributes (such as configuration parameters or behaviors), and it is equally applicable to the stateful PCE (active and passive modes) and the stateless PCE. The associations could be created dynamically and conveyed to a PCEP peer within PCEP, or they could be configured manually by an operator on the PCEP peers. Refer to Section 3.3 for more details.

1.1. 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.

2. Terminology

This document uses the following terms defined in [RFC5440]:

- PCC
- PCE
- PCEP Peer
- Path Computation Request (PCReq)
- Path Computation Reply (PCRep)
- PCEP Error (PCErr)

This document uses the following terms defined in [RFC8051]:

- Stateful PCE
- Active Stateful PCE
- Passive Stateful PCE
- Delegation

This document uses the following terms defined in [RFC8231]:

- LSP State Report (PCRpt)
- LSP Update Request (PCUpd)
- State Timeout Interval

This document uses the following terms defined in [RFC8281]:

- PCE-initiated LSP
- LSP Initiate Request (PCInitiate)

3. Architectural Overview

3.1. Motivations

A stateful PCE provides the ability to update existing LSPs and to instantiate new ones. There are various situations where several LSPs need to share common information. For example, to support PCE-controlled make-before-break, an association between the original path and the reoptimized path is desired. Similarly, for end-to-end protection, an association between working and protection LSPs is required (see [PCE-PROTECTION]). For diverse paths, an association between a group of LSPs could be used (see [PCE-DIVERSITY]). Another use for an LSP grouping would be to apply a common set of configuration parameters or behaviors to a set of LSPs.

For a stateless PCE, it might be useful to associate a PCReq message to an association group, thus enabling it to associate a common set of policies, configuration parameters, or behaviors with the request.

Some associations could be created dynamically, such as an association between the working and protection LSPs of a tunnel, whereas some associations could be created by the operator manually, such as a policy-based association where the LSP could join an operator-configured existing association.

Rather than creating separate mechanisms for each use case, this document defines a generic mechanism that can be reused as needed.

3.2. Relationship to the SVEC List

Note that [RFC5440] defines a mechanism for the synchronization of a set of PCReq messages by using the SVEC (Synchronization VECtor) object, which specifies the list of synchronized requests that can be either dependent or independent. The SVEC object identifies the relationship between the set of PCReq messages, identified by "Request-ID-number" in the RP (Request Parameters) object. [RFC6007] further clarifies the use of the SVEC list for synchronized path computations when computing dependent requests, and it describes a number of usage scenarios for SVEC lists within single-domain and multi-domain environments.

The motivations behind the association group defined in this document and the SVEC object are quite different, though some use cases may overlap. PCEP extensions that define a new Association Type should clarify the relationship between the SVEC object and the Association Type, if any.

3.3. Operational Overview

LSPs are associated with other LSPs with which they interact by adding them to a common association group. Association groups as defined in this document can be applied to LSPs originating at the same headend or different headends.

Some associations could be created dynamically by a PCEP speaker, and the associations (along with the set of LSPs) are conveyed to a PCEP peer. Whereas some associations are configured by the operator beforehand on the PCEP peers in question, a PCEP speaker could then ask an LSP to join the Operator-configured Association. Usage of dynamic and configured associations is usually dependent on the type of association.

For Operator-configured Associations, the association parameters, such as the Association Identifier (Association ID), Association Type, and the Association Source IP address, are manually configured by the operator. In the case of a dynamic association, the association parameters, such as the Association ID, are allocated dynamically by the PCEP speaker. The Association Source is set as the local PCEP speaker address unless local policy dictates otherwise, in which case the Association Source is set based on the local policy.

The dynamically created association can be reported to the PCEP peer via the PCEP messages as per the stateful extensions. When the Operator-configured Association is known to the PCEP peer beforehand, a PCEP peer could ask an LSP to join the Operator-configured Association via the stateful PCEP messages.

The associations are properties of the LSP and thus could be stored in the LSP state database. The dynamic association exists as long as the LSP state exists. In the case of PCEP session termination, the LSP state cleanup **MUST** also take care of associations.

Multiple types of associations can exist, each with its own Association ID space. The definition of the different Association Types and their behaviors is outside the scope of this document. The establishment and removal of the association relationship can be done on a per-LSP basis. An LSP may join multiple association groups that have the same Association Type or different Association Types.

3.4. Operator-Configured Association Range

Some Association Types are dynamic, some are operator configured, and some could be both. For the Association Types that could be both dynamic and operator configured and use the same Association Source, it is necessary to distinguish a range of Association IDs that are marked for Operator-configured Associations, to avoid any Association ID clashes within the scope of the Association Source. This document assumes that these two ranges are configured.

A range of Association IDs for each Association Type (and Association Source) is kept for the Operator-configured Associations. Dynamic associations **MUST NOT** use the Association ID from this range.

This range, as set at the PCEP speaker (a PCC or PCE, as an Association Source), needs to be communicated to a PCEP peer in the Open message. A new TLV is defined in this specification for this purpose (Section 5). See Appendix A for an example.

The Association ID range for sources other than the PCEP speaker (for example, a Network Management System (NMS)) is not communicated in PCEP, and the procedure for Operator-configured Association Range settings is outside the scope of this document.

4. Discovery of Supported Association Types

This section defines PCEP extensions so as to support the capability advertisement of the Association Types supported by a PCEP speaker.

A new PCEP ASSOC-Type-List (Association Types list) TLV is defined. The PCEP ASSOC-Type-List TLV is carried within an OPEN object. This way, during the PCEP session-setup phase, a PCEP speaker can advertise to a PCEP peer the list of supported Association Types.

4.1. ASSOC-Type-List TLV

The PCEP ASSOC-Type-List TLV is **OPTIONAL**. It **MAY** be carried within an OPEN object sent by a PCEP speaker in an Open message to a PCEP peer so as to indicate the list of supported Association Types.

The PCEP ASSOC-Type-List TLV format is compliant with the PCEP TLV format defined in [RFC5440]. That is, the TLV is composed of 2 octets for the type, 2 octets specifying the TLV length, and a Value field. The Length field defines the length of the value portion in octets. The TLV is padded to 4-octet alignment, and padding is not included in the Length field (e.g., a 3-octet value would have a length of three, but the total size of the TLV would be 8 octets).

The PCEP ASSOC-Type-List TLV has the following format:

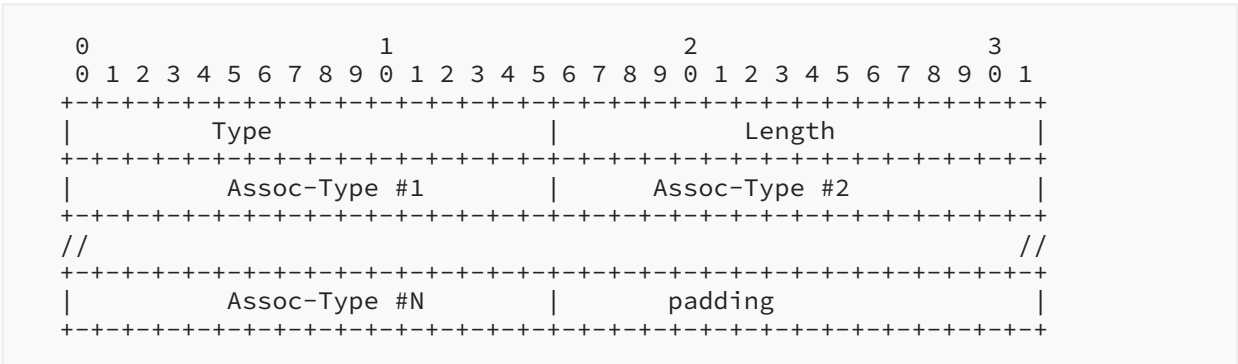

Figure 1: The ASSOC-Type-List TLV Format

Type: 35

Length: N * 2 (where N is the number of Association Types).

Value: List of 2-byte Association Type code points, identifying the Association Types supported by the sender of the Open message.

Assoc-Type (2 bytes): Association Type code point identifier. IANA manages the "ASSOCIATION Type Field" code point registry (see Section 7.4).

4.1.1. Procedure

An ASSOC-Type-List TLV within an OPEN object in an Open message is included by a PCEP speaker in order to advertise a set of one or more supported Association Types. The ASSOC-Type-List TLV **MUST NOT** appear more than once in an OPEN object. If it appears more than once, the PCEP session **MUST** be rejected with Error-Type 1 and Error-value 1 (PCEP session establishment failure / Reception of an invalid Open message). As specified in [RFC5440], a PCEP peer that does not recognize the ASSOC-Type-List TLV will silently ignore it.

The Association Type (to be defined in future documents) can specify if the Association Type advertisement is mandatory for it. Thus, the ASSOC-Type-List TLV **MUST** be included if at least one mandatory Association Type needs to be advertised, and the ASSOC-Type-List TLV **MAY** be included otherwise. For an Association Type that specifies that the advertisement is mandatory, a missing Assoc-Type in the ASSOC-Type-List TLV (or a missing ASSOC-Type-List TLV) is to be interpreted as meaning that the Association Type is not supported by the PCEP speaker.

The absence of the ASSOC-Type-List TLV in an OPEN object **MUST** be interpreted as an absence of information in the list of supported Association Types (rather than an indication that the Association Type is not supported). In this case, the PCEP speaker could still use the ASSOCIATION object: if the peer does not support the association, it will react as per the procedure described in Section 6.4.

If the use of the ASSOC-Type-List TLV is triggered by support for a mandatory Association Type, then it is **RECOMMENDED** that the PCEP implementation include all supported Association Types (including optional types) to ease the operations of the PCEP peer.

5. Operator-Configured Association Range TLV

This section defines a PCEP extension to support the advertisement of the Operator-configured Association Range used for an Association Type by the PCEP speaker (as an Association Source).

A new PCEP OP-CONF-ASSOC-RANGE (Operator-configured Association Range) TLV is defined. The PCEP OP-CONF-ASSOC-RANGE TLV is carried within an OPEN object. This way, during the PCEP session-setup phase, a PCEP speaker can advertise to a PCEP peer the Operator-configured Association Range for an Association Type.

The PCEP OP-CONF-ASSOC-RANGE TLV is **OPTIONAL**. It **MAY** be carried within an OPEN object sent by a PCEP speaker in an Open message to a PCEP peer. The OP-CONF-ASSOC-RANGE TLV format is compliant with the PCEP TLV format defined in [RFC5440]. That is, the TLV is composed of 2 bytes for the type, 2 bytes specifying the TLV length, and a Value field. The Length field defines the length of the value portion in bytes.

The PCEP OP-CONF-ASSOC-RANGE TLV has the following format:

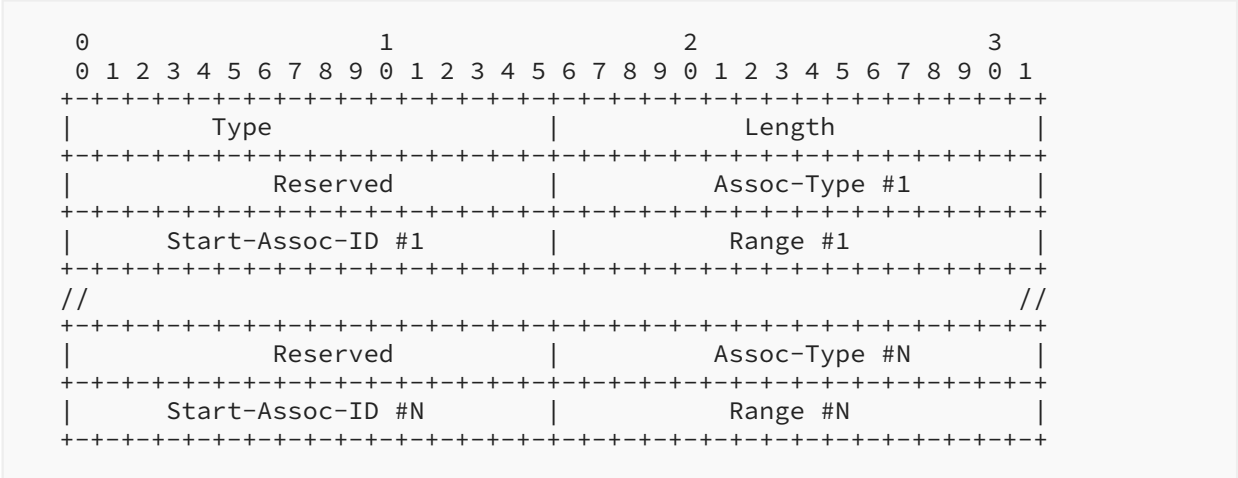

Figure 2: The OP-CONF-ASSOC-RANGE TLV Format

Type: 29

Length: N * 8 (where N is the number of Association Types).

Value: Includes the following fields, repeated for each Association Type:

Reserved (2 bytes): **MUST** be set to 0 on transmission and **MUST** be ignored on receipt.

Assoc-Type (2 bytes): The Association Type (Section 7.4). The Association Types will be defined in future documents.

Start-Assoc-ID (2 bytes): The "start association" identifier for the Operator-configured Association Range for the particular Association Type. The values 0 and 0xffff **MUST NOT** be used; on receipt of these values in the TLV, the session is rejected, and an error message is sent (see Section 5.1).

Range (2 bytes): The number of associations marked for the Operator-configured Associations. Range **MUST** be greater than 0, and it **MUST** be such that (Start-Assoc-ID + Range) does not cross the largest Association ID value of 0xffff. If this condition is not satisfied, the session is rejected, and an error message is sent (see Section 5.1).

5.1. Procedure

A PCEP speaker **MAY** include an OP-CONF-ASSOC-RANGE TLV within an OPEN object in an Open message sent to a PCEP peer in order to advertise the Operator-configured Association Range for an Association Type. The OP-CONF-ASSOC-RANGE TLV **MUST NOT** appear more than once in an OPEN object. If it appears more than once, the PCEP session **MUST** be rejected with Error-Type 1 and Error-value 1 (PCEP session establishment failure / Reception of an invalid Open message).

As specified in [RFC5440], a PCEP peer that does not recognize the OP-CONF-ASSOC-RANGE TLV will silently ignore it.

The Operator-configured Association Range **SHOULD** be included for each Association Type that could be both dynamic and operator configured. For Association Types that are only dynamic or only operator configured, this TLV **MAY** be skipped, in which case the full range of Association IDs is considered dynamic or operator configured, respectively. Each Association Type (to be defined in future documents) can specify the default value for its Operator-configured Association Range.

The absence of the OP-CONF-ASSOC-RANGE TLV in an OPEN object **MUST** be interpreted as an absence of an explicit Operator-configured Association Range at the PCEP peer. In this case, the default behavior as per each Association Type applies. If the Association Source is not a PCEP speaker, the default value for the Operator-configured Association Range is used for the Association Source.

If the Assoc-Type is not recognized or supported by the PCEP speaker, it **MUST** ignore that respective (Start-Assoc-ID + Range). If the Assoc-Type is recognized/supported but Start-Assoc-ID or Range is set incorrectly, the PCEP session **MUST** be rejected with Error-Type 1 and Error-value 1 (PCEP session establishment failure / Reception of an invalid Open message). The incorrect range includes the case when the (Start-Assoc-ID + Range) crosses the largest Association ID value of 0xffff.

A given Assoc-Type **MAY** appear more than once in the OP-CONF-ASSOC-RANGE TLV in the case of a non-contiguous Operator-configured Association Range. The PCEP speaker originating this TLV **MUST NOT** send overlapping ranges for an Association Type. If a PCEP peer receives overlapping ranges for an Association Type, it **MUST** consider the Open message malformed and **MUST** reject the PCEP session with Error-Type 1 and Error-value 1 (PCEP session establishment failure / Reception of an invalid Open message).

There may be cases where an Operator-configured Association was configured with association parameters (such as an Association ID, Association Type, and Association Source) at the local PCEP speaker, and the PCEP session is later established with the Association Source and a new operator-configured range is learned during session establishment. At this time, the local PCEP speaker **MUST** remove any associations that are not in the new operator-configured range (by disassociating any LSPs that are part of it (and notifying the PCEP peer of this change)). If a PCEP speaker receives an association for an Operator-configured Association and the Association ID is not in the Operator-configured Association Range for the Association Type and Association Source, it **MUST** generate an error (as described in Section 6.4).

6. ASSOCIATION Object

6.1. Object Definition

Association groups and their memberships are defined using a new ASSOCIATION object.

The ASSOCIATION Object-Class value is 40.

The ASSOCIATION Object-Type value is 1 for IPv4, and its format is shown in Figure 3:

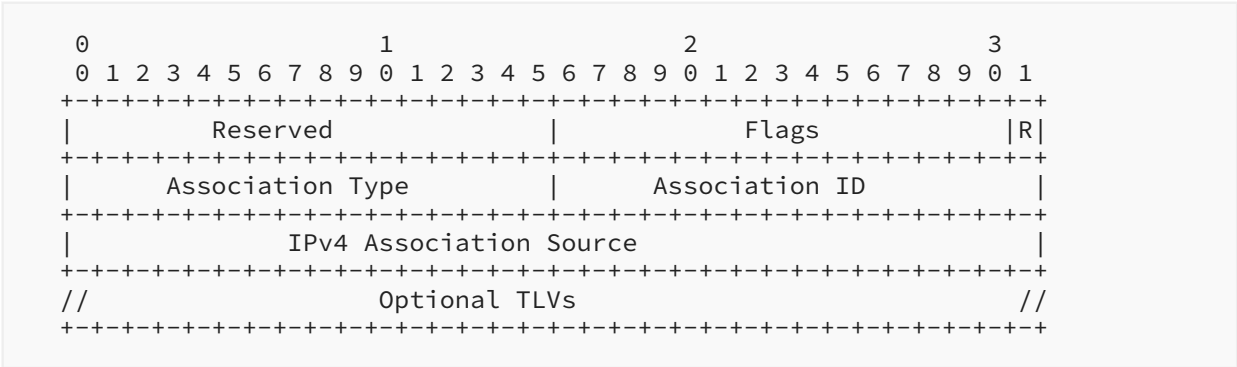

Figure 3: The IPv4 ASSOCIATION Object Format

The ASSOCIATION Object-Type value is 2 for IPv6, and its format is shown in Figure 4:

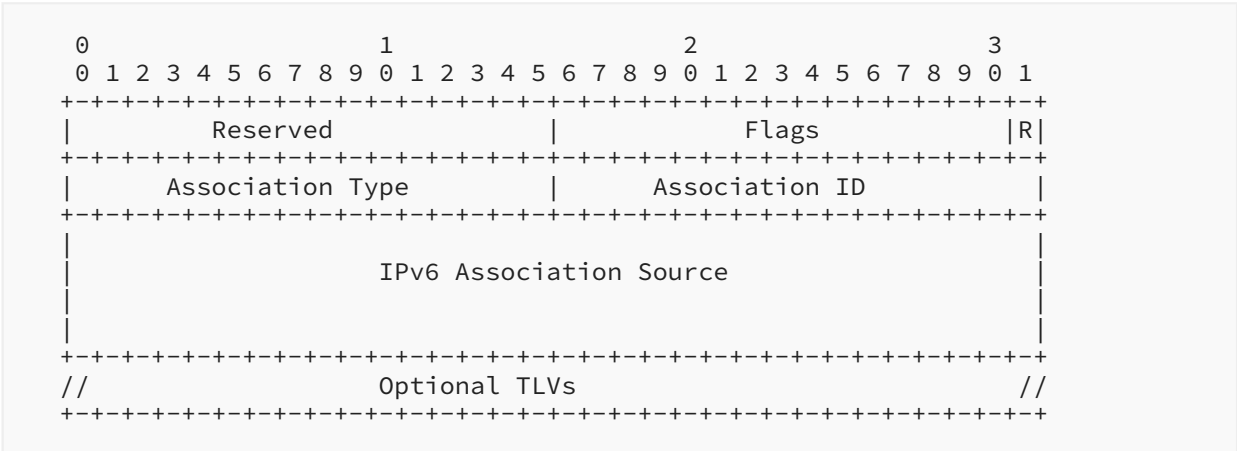

Figure 4: The IPv6 ASSOCIATION Object Format

Reserved (2 bytes): **MUST** be set to 0 and ignored upon receipt.

Flags (2 bytes): The following flag is currently defined:

R (Removal - 1 bit): When set, the requesting PCEP peer requires the removal of an LSP from the association group. When unset, the PCEP peer indicates that the LSP is added or retained as part of the association group. This flag is used for the

ASSOCIATION object in the Path Computation Report (PCRpt) and Path Computation Update (PCUpd) messages. It is ignored in other PCEP messages.

The unassigned flags **MUST** be set to 0 on transmission and **MUST** be ignored on receipt.

Association Type (2 bytes): The Association Type (Section 7.4). The Association Types will be defined in future documents.

Association ID (2 bytes): The identifier of the association group. When combined with other association parameters, such as an Association Type and Association Source, this value uniquely identifies an association group. The values 0xffff and 0x0 are reserved. The value 0xffff is used to indicate all association groups and could be used with the R flag to indicate removal for all associations for the LSP within the scope of the Association Type and Association Source.

Association Source: Contains a valid IPv4 address (4 bytes) if the ASSOCIATION Object-Type is 1 or a valid IPv6 address (16 bytes) if the ASSOCIATION Object-Type is 2. The address provides scoping for the Association ID. See Section 6.1.3 for details.

Optional TLVs: The optional TLVs follow the PCEP TLV format defined in [RFC5440]. This document defines two optional TLVs. Other documents can define more TLVs in the future.

6.1.1. Global Association Source TLV

The Global Association Source TLV is an optional TLV for use in the ASSOCIATION object. The meaning and usage of the Global Association Source TLV are as per Section 4 of [RFC6780].

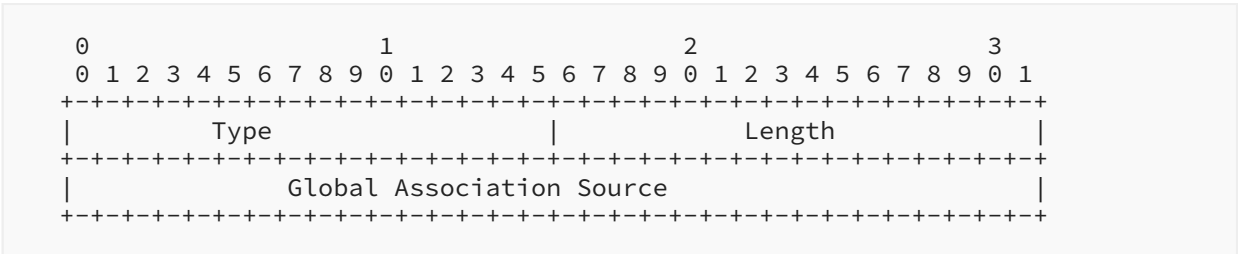

Figure 5: The Global Association Source TLV Format

Type: 30

Length: Fixed value of 4 bytes.

Global Association Source: As defined in Section 4 of [RFC6780].

6.1.2. Extended Association ID TLV

The Extended Association ID TLV is an optional TLV for use in the ASSOCIATION object. The meaning and usage of the Extended Association ID TLV are as per Section 4 of [RFC6780].

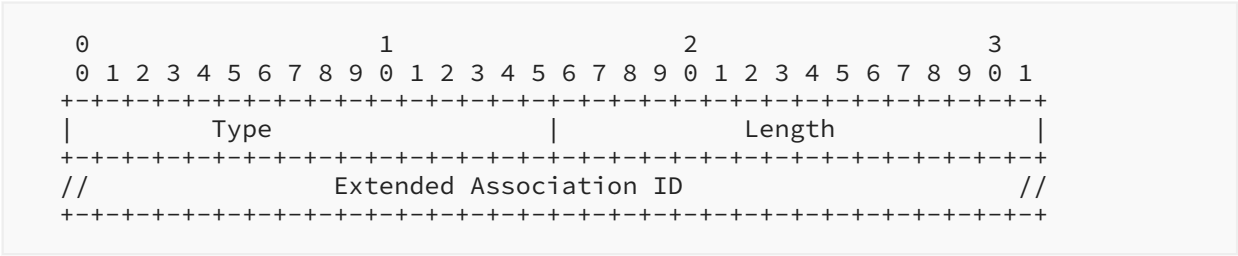

Figure 6: The Extended Association ID TLV Format

Type: 31

Length: Variable.

Extended Association ID: As defined in Section 4 of [RFC6780].

6.1.3. Association Source

The Association Source field in the ASSOCIATION object is set to a valid IP address to identify the node that originated the association. In the case of dynamic associations, the Association Source is usually set as the local PCEP speaker address unless local policy dictates otherwise, in which case the Association Source is set based on the local policy. In the case of PCE redundancy, local policy could set the source as a virtual IP address that identifies all instances of the PCE. In the case of Operator-configured Associations, the Association Source is manually configured, and it could be set as one of the PCEP speakers, an NMS, or any other valid IP address that scopes the Association ID for the Association Type.

6.1.4. Unique Identification for an Association Group

The combination of the mandatory fields Association Type, Association ID, and Association Source in the ASSOCIATION object uniquely identifies the association group. If the optional TLVs (Global Association Source and Extended Association ID) are included, then they **MUST** be included in combination with mandatory fields to uniquely identify the association group. In this document, all these fields are collectively called "association parameters". Note that the ASSOCIATION object **MAY** include other optional TLVs (not defined in this document) based on the Association Types. These TLVs provide "information" related to the Association Type. This document refers to this information as "association information".

6.2. Relationship to the RSVP ASSOCIATION Object

The format of the PCEP ASSOCIATION object defined in this document is aligned with the RSVP ASSOCIATION object [RFC6780]. Various Association Types related to RSVP association are defined in [RFC4872], [RFC4873], and [RFC7551]. The PCEP extensions that define new Association Types should clarify how the PCEP associations would work with RSVP associations and vice versa.

6.3. Object Encoding in PCEP Messages

Message formats in this document are expressed using Routing BNF (RBNF) as used in [RFC5440] and defined in [RFC5511].

6.3.1. Stateful PCEP Messages

The ASSOCIATION object **MAY** be carried in the PCUpd, PCRpt, and Path Computation Initiate (PCInitiate) messages.

When carried in a PCRpt message, this object is used to report the association group membership pertaining to an LSP to a stateful PCE. The PCRpt message is used for initial State Synchronization operations (Section 5.6 of [RFC8231]), as well as whenever the state of the LSP changes. If the LSP belongs to an association group, then the associations **MUST** be included during the State Synchronization operations.

The PCRpt message can also be used to remove an LSP from one or more association groups by setting the R flag to 1 in the ASSOCIATION object.

When an LSP is first reported to the PCE, the PCRpt message **MUST** include all the association groups that it belongs to. Any subsequent PCRpt message **SHOULD** include only the associations that are being modified or removed.

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

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

Where:

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

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

Where:

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

      <association-list> ::= <ASSOCIATION> [<association-list>]
```

When an LSP is delegated to a stateful PCE, the stateful PCE can create a new association group for this LSP or associate it with one or more existing association groups. This is done by including the ASSOCIATION object in a PCUpd message. A stateful PCE can also remove a delegated LSP from one or more association groups by setting the R flag to 1 in the ASSOCIATION object.

The PCUpd message **SHOULD** include the association groups that are being modified or removed. There is no need to include associations that remain unchanged.

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

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

Where:

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

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

Where:

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

    <association-list> ::= <ASSOCIATION> [<association-list>]
```

Unless a PCEP speaker wants to delete an association from an LSP or make changes to the association, it does not need to include the ASSOCIATION object in future stateful messages.

A PCE initiating a new LSP can also include the association groups that this LSP belongs to. This is done by including the ASSOCIATION object in a PCInitiate message. The PCInitiate message **MUST** include all the association groups that it belongs to. The PCInitiate message is defined in [RFC8281] and updated as shown 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>
                                      [<association-list>]
                                      [<attribute-list>]
```

Where:

```
<association-list> ::= <ASSOCIATION> [<association-list>]
```

6.3.2. Request Message

In the case of a passive (stateful or stateless) PCE, the ASSOCIATION object is **OPTIONAL** and **MAY** be carried in the PCReq message.

When carried in a PCReq message, the ASSOCIATION object is used to associate the path computation request to an association group. The association (and the other LSPs) should be known to the PCE beforehand. These could be operator configured or dynamically learned beforehand via stateful PCEP messages. The R flag in the ASSOCIATION object within a PCReq message **MUST** be set to 0 while sending and ignored on receipt.

The PCReq message is defined in [RFC5440] and updated in [RFC8231]. It is further updated below for association groups:

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

Where:

```
   <association-list> ::= <ASSOCIATION> [<association-list>]
```

Note that the LSP object **MAY** be present for the passive stateful PCE mode.

6.3.3. Reply Message

In the case of a passive (stateful or stateless) PCE, the ASSOCIATION object is **OPTIONAL** and **MAY** be carried in the PCRep message with the NO-PATH object. The ASSOCIATION object in the PCRep message indicates the association group that caused the PCE to fail to find a path.

The PCRep message is defined in [RFC5440] and updated in [RFC8231]. It is further updated below for association groups:

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

Where:

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

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

Where:

```
   <association-list> ::= <ASSOCIATION> [<association-list>]
```

Note that the LSP object **MAY** be present for the passive stateful PCE mode.

6.4. Processing Rules

Association groups can be operator configured on the necessary PCEP speakers, and the PCEP speakers can join the existing association groups. In addition, a PCC or a PCE can create association groups dynamically, and the PCEP speaker can also report the associations to its peer via PCEP messages. The Operator-configured Associations are created via configurations (where all association parameters are manually set) and exist until explicitly removed via configurations. The PCEP speaker can add LSPs to these configured associations and provide this information via stateful PCEP messages. The dynamic associations are created dynamically by the PCEP speaker (where all association parameters are populated dynamically). The association group is attached to the LSP state, and the association group exists until there is at least one LSP as part of the association. As described in Section 6.1.4, the association parameters are the combination of Association Type, Association ID, and Association Source, as well as the optional Global Association Source and Extended Association ID TLVs; this combination uniquely identifies an association group. The information related to the Association Types encoded via the TLVs of a particular Association Type (not described in this document) is the association information (Section 6.1.4).

If a PCEP speaker does not recognize the ASSOCIATION object in the stateful message, it will return a PCErr message with Error-Type "Unknown Object" as described in [RFC5440]. In the case of a PCReq message, the PCE would react based on the P flag as per [RFC5440]. If a PCEP speaker understands the ASSOCIATION object but does not support the Association Type, it **MUST** return a PCErr message with Error-Type 26 "Association Error" and Error-value 1 "Association Type is not supported". If any association parameters are invalid in the ASSOCIATION object, the PCEP speaker would consider this object malformed and process it as a malformed message [RFC5440]. On receiving a PCEP message with an ASSOCIATION object, if a PCEP speaker finds that too many LSPs belong to the association group, it **MUST** return a PCErr message with Error-Type 26 "Association Error" and Error-value 2 "Too many LSPs in the association group". If a PCEP speaker cannot handle a new association, it **MUST** return a PCErr message with Error-Type 26 "Association Error" and Error-value 3 "Too many association groups". These numbers **MAY** be set by the operator or chosen based on a local policy.

If a PCE peer is unwilling or unable to process the ASSOCIATION object in the stateful message, it **MUST** return a PCErr message with the Error-Type "Not supported object" and follow the relevant procedures described in [RFC5440]. In the case of a PCReq message, the PCE would react based on the P flag as per [RFC5440]. On receiving a PCEP message with an ASSOCIATION object, if a PCEP speaker could not add the LSP to the association group for any reason, it **MUST** return a PCErr message with Error-Type 26 "Association Error" and Error-value 7 "Cannot join the association group".

If a PCEP speaker receives an ASSOCIATION object for an Operator-configured Association and the Association ID is not in the Operator-configured Association Range for the Association Type and Association Source, it **MUST** return a PCErr message with Error-Type 26 "Association Error" and Error-value 8 "Association ID not in range".

If a PCEP speaker receives an ASSOCIATION object in a PCReq message and the association is not known (the association is not configured, was not created dynamically, or was not learned from a PCEP peer), it **MUST** return a PCErr message with Error-Type 26 "Association Error" and Error-value 4 "Association unknown".

If the association information (related to the association group as a whole) received from the peer does not match the local operator-configured information, it **MUST** return a PCErr message with Error-Type 26 "Association Error" and Error-value 5 "Operator-configured association information mismatch". On receiving association information (related to the association group as a whole) that does not match the association information previously received about the same association from a peer, it **MUST** return a PCErr message with Error-Type 26 "Association Error" and Error-value 6 "Association information mismatch". Note that information related to each LSP within the association as part of the association information TLVs could be different.

If a PCEP speaker receives an ASSOCIATION object with the R bit set for removal and the association group (identified by association parameters) is not known, it **MUST** return a PCErr message with Error-Type 26 "Association Error" and Error-value 4 "Association unknown".

The dynamic associations are cleared along with the LSP state information as per [RFC8231]. When a PCEP session is terminated, after expiry of the State Timeout Interval at the PCC, the LSP state associated with that PCEP session is reverted to operator-defined default parameters or behaviors. The same procedure is also followed for the association groups. On session termination at the PCE, when the LSP state reported by the PCC is cleared, the association groups are also cleared. When there are no LSPs in an association group, the association is considered empty and thus deleted.

If the LSP is delegated to another PCE on session failure, the associations (and association information) set by the PCE remain intact, unless updated by the new PCE that takes over.

Upon LSP delegation revocation, the PCC **MAY** clear the association created by the PCE, but in order to avoid traffic loss, it **SHOULD** perform this action in a make-before-break fashion (same as [RFC8231]).

7. IANA Considerations

IANA maintains the "Path Computation Element Protocol (PCEP) Numbers" registry at <https://www.iana.org/assignments/pcep>.

7.1. PCEP Object

The "Path Computation Element Protocol (PCEP) Numbers" registry contains a subregistry called "PCEP Objects". IANA has allocated the following code point in the "PCEP Objects" registry.

Object-Class Value	Name	Object-Type	Reference
40	ASSOCIATION	0: Reserved	RFC 8697

Object-Class Value	Name	Object-Type	Reference
		1: IPv4	RFC 8697
		2: IPv6	RFC 8697

Table 1: PCEP Object

7.2. PCEP TLV

IANA has allocated the following code points in the "PCEP TLV Type Indicators" registry.

Value	Meaning	Reference
29	Operator-configured Association Range	RFC 8697
30	Global Association Source	RFC 8697
31	Extended Association ID	RFC 8697

Table 2: PCEP TLV Type Indicators

IANA has corrected the capitalization in the meaning for value 31 in the above registry to "Extended Association ID"; it was previously listed as "Extended Association Id".

IANA has made a new assignment in the existing "PCEP TLV Type Indicators" registry as follows:

Value	Meaning	Reference
35	ASSOC-Type-List	RFC 8697

Table 3: ASSOC-Type-List PCEP TLV Type Indicator

7.3. Association Flags

Per this document, IANA has created a subregistry of the "Path Computation Element Protocol (PCEP) Numbers" registry for the bits carried in the Flags field of the ASSOCIATION object. The subregistry is called "ASSOCIATION Flag Field". New values are assigned by Standards Action [RFC8126]. Each bit is tracked with the following qualities:

- Bit number (counting from bit 0 as the most significant bit)
- Capability description
- Defining RFC

Bit	Description	Reference
15	R (Removal)	RFC 8697

Table 4: New ASSOCIATION Flag Field

7.4. Association Type

Per this document, IANA has created a subregistry of the "Path Computation Element Protocol (PCEP) Numbers" registry for the Association Type field of the ASSOCIATION object. The subregistry is called "ASSOCIATION Type Field". New values are assigned by Standards Action [RFC8126]. Each value is tracked with the following qualities:

- Type
- Name
- Reference

Type	Name	Reference
0	Reserved	RFC 8697

Table 5: New ASSOCIATION Type Field

Values 2-65535 are Unassigned. Future documents should request the assignment of Association Types from this subregistry.

7.5. PCEP-Error Object

IANA has allocated the following code points within the "PCEP-ERROR Object Error Types and Values" subregistry of the "Path Computation Element Protocol (PCEP) Numbers" registry as follows:

Error-Type	Meaning	Error-value	Reference
26	Association Error	0: Unassigned	RFC 8697
		1: Association Type is not supported	RFC 8697
		2: Too many LSPs in the association group	RFC 8697
		3: Too many association groups	RFC 8697
		4: Association unknown	RFC 8697
		5: Operator-configured association information mismatch	RFC 8697

Error-Type	Meaning	Error-value	Reference
		6: Association information mismatch	RFC 8697
		7: Cannot join the association group	RFC 8697
		8: Association ID not in range	RFC 8697

Table 6: PCEP-ERROR Types and Names

8. Security Considerations

The security considerations described in [RFC8231] and [RFC5440] apply to the extensions described in this document as well. Additional considerations related to a malicious PCEP speaker are introduced, as associations could be spoofed and could be used as an attack vector. An attacker could attempt to create too many associations in an attempt to load the PCEP peer. The PCEP peer responds with a PCErr message as described in Section 6.4. An attacker could impact LSP operations by creating bogus associations. Further, association groups could provide an adversary with the opportunity to eavesdrop on the relationship between the LSPs. Thus, securing the PCEP session using Transport Layer Security (TLS) [RFC8253], as per the recommendations and best current practices in [RFC7525], is **RECOMMENDED**.

Much of the information carried in the ASSOCIATION object as per this document is not extra sensitive. It often reflects information that can also be derived from the LSP database, but the association provides a much easier grouping of related LSPs and messages. Implementations and operators can, and should, use indirect values in the ASSOCIATION object as a way to hide any sensitive business relationships.

9. Manageability Considerations

All manageability requirements and considerations listed in [RFC5440] and [RFC8231] apply to PCEP protocol extensions defined in this document. In addition, requirements and considerations listed in this section apply.

9.1. Control of Function and Policy

A PCE or PCC implementation **MUST** allow Operator-configured Associations and **SHOULD** allow the setting of the Operator-configured Association Range (Section 3.4) as described in this document.

9.2. Information and Data Models

The PCEP YANG module is defined in [PCEP-YANG]. In the future, this YANG module should be extended or augmented to provide the following additional information related to association groups.

An implementation **SHOULD** allow the operator to view the associations configured or created dynamically. Future implementations **SHOULD** allow the viewing of associations reported by each peer and the current set of LSPs in the association.

It might also be useful to find out how many associations for each Association Type currently exist and to know how many free Association IDs are available for a particular Association Type and source.

9.3. Liveness Detection and Monitoring

Mechanisms defined in this document do not imply any new liveness detection and monitoring requirements in addition to those already listed in [RFC5440].

9.4. Verifying Correct Operation

Mechanisms defined in this document do not imply any new operation verification requirements in addition to those already listed in [RFC5440] and [RFC8231].

9.5. Requirements on Other Protocols

Mechanisms defined in this document do not imply any new requirements on other protocols.

9.6. Impact on Network Operations

Mechanisms defined in [RFC5440] and [RFC8231] also apply to PCEP extensions defined in this document.

10. References

10.1. Normative References

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Appendix A. Example of an Operator-Configured Association Range

Consider an Association Type T1 (which allows both dynamic and Operator-configured Associations with a default range of <0x1000, 0xffff>). Consider that, because of the needs of the network, the PCE needs to create more dynamic associations and would like to change the Association Range to <0xbffe, 0xffff> instead. During PCEP session establishment, the PCE would advertise the new range. The PCC could skip advertising, as the default values are used. If a PCC is creating a dynamic association (with the PCC as the Association Source), it needs to pick a free Association ID for type T1 in the range <0x1, 0x0fff>, whereas if a PCE is creating a dynamic association (with the PCE as the Association Source), it needs to pick a free Association ID from the range <0x1, 0xbffd>. Similarly, if an Operator-configured Association is manually configured with the PCC as the Association Source, it should be from the range <0x1000, 0xffff>, whereas if the PCE is the Association Source, it should be from the range <0xbffe, 0xffff>. If the Association Source is not a PCEP peer (for example, an NMS), then the default range of <0x1000, 0xffff> is considered.

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