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RSVP Extensions for Reoptimization of Loosely Routed Point-to-Multipoint Traffic Engineering Label Switched Paths (LSPs)

Abstract

The reoptimization of a Point-to-Multipoint (P2MP) Traffic Engineering (TE) Label Switched Path (LSP) may be triggered based on the need to reoptimize an individual source-to-leaf (S2L) sub-LSP or a set of S2L sub-LSPs, both using the Sub-Group-based reoptimization method, or the entire P2MP-TE LSP tree using the Make-Before-Break (MBB) method. This document discusses the application of the existing mechanisms for path reoptimization of loosely routed Point-to-Point (P2P) TE LSPs to the P2MP-TE LSPs, identifies issues in doing so, and defines procedures to address them. When reoptimizing a large number of S2L sub-LSPs in a tree using the Sub-Group-based reoptimization method, the S2L sub-LSP descriptor list may need to be semantically fragmented. This document defines the notion of a fragment identifier to help recipient nodes unambiguously reconstruct the fragmented S2L sub-LSP descriptor list.

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1. Introduction

This document defines Resource Reservation Protocol - Traffic Engineering (RSVP-TE) [RFC2205] [RFC3209] signaling extensions for reoptimizing loosely routed Point-to-Multipoint (P2MP) Traffic Engineering (TE) Label Switched Paths (LSPs) [RFC4875] in a Multiprotocol Label Switching (MPLS) or Generalized MPLS (GMPLS) [RFC3473] network.

A P2MP-TE LSP is comprised of one or more source-to-leaf (S2L) sub-LSPs. A loosely routed P2MP-TE S2L sub-LSP is defined as one whose path does not contain the full explicit route identifying each node along the path to the egress node at the time of its signaling by the ingress node. Such an S2L sub-LSP is signaled with no Explicit Route Object (ERO) [RFC3209], with an ERO that contains at least one "loose next hop", or with an ERO that contains an abstract node that identifies more than one node. This is often the case with inter-domain P2MP-TE LSPs where a Path Computation Element (PCE) is not used [RFC5440].

As per [RFC4875], an ingress node may reoptimize the entire P2MP-TE LSP tree by re-signaling all its S2L sub-LSPs using the Make-Before-Break (MBB) method, or it may reoptimize an individual S2L sub-LSP or a set of S2L sub-LSPs, i.e., an individual destination or a set of destinations, both using the Sub-Group-based reoptimization method.

[RFC4736] defines an RSVP signaling procedure for reoptimizing the path(s) of loosely routed Point-to-Point (P2P) TE LSP(s). The mechanisms listed in [RFC4736] include a method for the ingress node to trigger a new path re-evaluation request and a method for the midpoint node to send a notification regarding the availability of a preferred path. This document discusses the application of those mechanisms to the reoptimization of loosely routed P2MP-TE LSPs, identifies issues in doing so, and defines procedures to address them.

For reoptimizing a group of S2L sub-LSPs in a tree using the Sub-Group-based reoptimization method, an S2L sub-LSP descriptor list can be used to signal one or more S2L sub-LSPs in an RSVP message. This RSVP message may need to be semantically fragmented when a large number of S2L sub-LSPs are added to the descriptor list. This document defines the notion of a fragment identifier to help recipient nodes unambiguously reconstruct the fragmented S2L sub-LSP descriptor list.

2. Conventions Used in This Document

2.1. Key Word Definitions

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

2.2. Abbreviations

ABR: Area Border Router.

ERO: Explicit Route Object.

LSP: Label Switched Path.

LSR: Label Switching Router.

RRO: Record Route Object.

S2L sub-LSP: Source-to-leaf sub-LSP.

TE LSP: Traffic Engineering LSP.

2.3. Terminology

This document defines the following terms:

- Ingress node: Head-end / source node of the TE LSP.

- Egress node: Tail-end / destination node of the TE LSP.

It is assumed that the reader is also familiar with the terminology in [RFC4736] and [RFC4875].

3. Overview

[RFC4736] defines RSVP signaling extensions for reoptimizing loosely routed P2P TE LSPs as follows:

- A midpoint LSR that expands loose next hop(s) sends a solicited or unsolicited PathErr with Notify error code 25 (as defined in [RFC3209]), with sub-code 6 to indicate "Preferable Path Exists" to the ingress node.

- An ingress node triggers a path re-evaluation request at all midpoint LSRs that expand loose next hop(s) by setting the "Path Re-evaluation Request" flag (0x20) in the SESSION_ATTRIBUTES object in the Path message.

- The ingress node, upon receiving this PathErr with the Notify error code (either solicited or unsolicited), initiates the reoptimization of the LSP, using the MBB method with a different LSP-ID.

The following sections discuss the issues that may arise when applying the mechanisms defined in [RFC4736] for reoptimizing loosely routed P2MP-TE LSPs.

3.1. Loosely Routed Inter-domain P2MP-TE LSP Tree

An example of a loosely routed inter-domain P2MP-TE LSP tree is shown in Figure 1. In this example, the P2MP-TE LSP tree consists of three S2L sub-LSPs, to destinations (i.e., leafs) R10, R11, and R12 from the ingress node (i.e., source) R1. Nodes R2 and R5 are branch nodes, and nodes ABR3, ABR4, ABR7, ABR8, and ABR9 are ABRs. For the S2L sub-LSP to destination R10, nodes ABR3, ABR7, and R10 are defined as loose next hops. For the S2L sub-LSP to destination R11, nodes ABR3, ABR8, and R11 are defined as loose next hops. For the S2L sub-LSP to destination R12, nodes ABR4, ABR9, and R12 are defined as loose next hops.

```
         <--area1--><--area0--><-area2->

                             ABR7---R10
                            /
                           /
                  ABR3---R5
                 /         \
                /           \
          R1---R2            ABR8---R11
                \
                 \
                  ABR4---R6
                           \
                            \
                             ABR9---R12
```

Figure 1: Example of Loosely Routed Inter-domain P2MP-TE LSP Tree

3.2. Existing Mechanism for Tree-Based P2MP-TE LSP Reoptimization

The mechanisms defined in [RFC4736] can be easily applied to trigger the reoptimization of an individual S2L sub-LSP or a group of S2L sub-LSPs. However, to apply those mechanisms for triggering the reoptimization of a P2MP-TE LSP tree, an ingress node needs to send path re-evaluation requests on all (typically hundreds) of the S2L sub-LSPs, and the midpoint LSR needs to send PathErrs with the Notify error code for all S2L sub-LSPs. Such mechanisms may lead to the following issues:

- o A midpoint LSR that expands loose next hop(s) may have to accumulate the received path re-evaluation request(s) for all S2L sub-LSPs (e.g., by using a wait timer) and interpret them as a reoptimization request for the whole P2MP-TE LSP tree. Otherwise, a midpoint LSR may prematurely send a "Preferable Path Exists" notification for one S2L sub-LSP or a subset of S2L sub-LSPs.

- o Similarly, the ingress node may have to heuristically determine when to perform P2MP-TE LSP tree reoptimization and when to perform S2L sub-LSP reoptimization. For example, an implementation may choose to delay reoptimization long enough to allow all PathErrs to be received. Such timer-based procedures may produce undesired results.

- o The ingress node that receives (un)solicited PathErr(s) with the Notify error code for one or more individual S2L sub-LSPs may prematurely start reoptimizing the subset of S2L sub-LSPs. However, as mentioned in [RFC4875], Section 14.2, such a Sub-Group-based reoptimization procedure may result in data duplication that can be avoided if the entire P2MP-TE LSP tree is reoptimized using the MBB method with a different LSP-ID, especially if the ingress node eventually receives PathErrs with the Notify error code for all S2L sub-LSPs of the P2MP-TE LSP tree.

In order to address the above-mentioned issues and to align the reoptimization of P2MP-TE LSPs with P2P LSPs [RFC4736], a mechanism is needed to trigger the reoptimization of the LSP tree by re-signaling all S2L sub-LSPs with a different LSP-ID. To meet this requirement, this document defines RSVP-TE signaling extensions for the ingress node to trigger the re-evaluation of the P2MP LSP tree on every hop that has a next hop defined as a loose or abstract hop for one or more S2L sub-LSP paths, and a midpoint LSR to signal to the ingress node that a preferable LSP tree exists (compared to the current path) or that the whole P2MP-TE LSP must be reoptimized (because of maintenance required on the TE LSP path) (see Section 4.1).

3.3. Existing Mechanism for Sub-Group-Based P2MP-TE LSP Reoptimization

Applying the procedures discussed in [RFC4736] in conjunction with the Sub-Group-based reoptimization procedures ([RFC4875], Section 14.2), an ingress node MAY trigger path re-evaluation requests for a set of S2L sub-LSPs in a single Path message using an S2L sub-LSP descriptor list. Similarly, a midpoint LSR may send a PathErr with Notify error code 25 and sub-code 6 ("Preferable Path Exists") containing a list of S2L sub-LSPs transiting through the LSR using an S2L sub-LSP descriptor list to notify the ingress node. This method can be used for reoptimizing a sub-group of S2L sub-LSPs within an LSP tree using the same LSP-ID. This method can alleviate the scaling issue associated with sending RSVP messages for individual S2L sub-LSPs. However, this procedure can lead to the following issues when used to reoptimize the LSP tree:

- o A Path message that is intended to carry the path re-evaluation request as defined in [RFC4736] with a full list of S2L sub-LSPs in an S2L sub-LSP descriptor list will be decomposed at branching LSRs, and only a subset of the S2L sub-LSPs that are routed over the same next hop will be added in the descriptor list of the Path message propagated to downstream midpoint LSRs. Consequently, when a preferable path exists at such midpoint LSRs, the PathErr with the Notify error code can only include the subset of S2L sub-LSPs traversing the LSR. In this case, at the ingress node there is no way to distinguish which mode of reoptimization to invoke, i.e., Sub-Group-based reoptimization using the same LSP-ID or tree-based reoptimization using a different LSP-ID.

o An LSR may semantically fragment a large RSVP message (when a combined message may not be large enough to fit all S2L sub-LSPs). In this case, the ingress node may receive multiple PathErrs with subsets of S2L sub-LSPs in each (due to either the combined Path message getting fragmented or the combined PathErr message getting fragmented) and would require additional logic to determine how to reoptimize the LSP tree (for example, waiting for some time to aggregate all possible PathErr messages before taking an action). When fragmented, RSVP messages may arrive out of order, and the receiver has no way of knowing the beginning and end of the S2L sub-LSP list.

In order to address the above-mentioned issues caused by semantic fragmentation of an RSVP message, this document defines a new fragment identifier object for the S2L sub-LSP descriptor list when combining a large number of S2L sub-LSPs in an RSVP message (see Section 4.2).

4. Signaling Extensions for Loosely Routed P2MP-TE LSP Reoptimization

4.1. Tree-Based Reoptimization

To evaluate a P2MP-TE LSP tree on midpoint LSRs that expand loose next hop(s), an ingress node MAY send a Path message with the "P2MP-TE Tree Re-evaluation Request" flag set (bit number 14 in the Attribute Flags TLV) as defined in this document. The ingress node selects one of the S2L sub-LSPs of the P2MP-TE LSP tree transiting a midpoint LSR to trigger the re-evaluation request. The ingress node MAY send a re-evaluation request to each border LSR on the path of the LSP tree.

A midpoint LSR that expands loose next hop(s) for one or more S2L sub-LSP paths does the following upon receiving a Path message with the "P2MP-TE Tree Re-evaluation Request" flag set:

o The midpoint LSR MUST check for a preferable P2MP-TE LSP tree by re-evaluating all S2L sub-LSPs that are expanded paths of the loose next hops of the P2MP-TE LSP.

o If a preferable P2MP-TE LSP tree is found, the midpoint LSR MUST send to the ingress node an RSVP PathErr with Notify error code 25 [RFC3209] and sub-code 13 ("Preferable P2MP-TE Tree Exists)" as defined in this document. The midpoint LSR, in turn, SHOULD NOT propagate the "P2MP-TE Tree Re-evaluation Request" flag in the subsequent RSVP Path messages sent downstream for the re-evaluated P2MP-TE LSP.

o If no preferable tree for P2MP-TE LSPs can be found, the midpoint LSR that expands loose next hop(s) for one or more S2L sub-LSP paths MUST propagate the request downstream by setting the "P2MP-TE Tree Re-evaluation Request" flag in the LSP_ATTRIBUTES object of the RSVP Path message.

A midpoint LSR MAY send an unsolicited PathErr with the Notify error code and the "Preferable P2MP-TE Tree Exists" sub-code to the ingress node to notify the ingress node of a preferred P2MP-TE LSP tree when it determines that it exists. In this case, the midpoint LSR that expands loose next hop(s) for one or more S2L sub-LSP paths selects one of the S2L sub-LSPs of the P2MP-TE LSP tree to send this PathErr message to the ingress node. The midpoint LSR SHOULD consider how frequently it chooses to send such a PathErr, considering that both (1) a PathErr may be lost during its transit to the ingress node and (2) the ingress node may choose not to reoptimize the LSP when such a PathErr is received.

The sending of an RSVP PathErr with the Notify error code and the "Preferable P2MP-TE Tree Exists" sub-code to the ingress node notifies the ingress node of the existence of a preferable P2MP-TE LSP tree, and upon receiving this PathErr, the ingress node SHOULD trigger the reoptimization of the LSP, using the MBB method with a different LSP-ID.

4.2. Sub-Group-Based Reoptimization Using Fragment Identifier

It might be preferable, as per [RFC4875], to reoptimize the entire P2MP-TE LSP by re-signaling all of its S2L sub-LSPs (Section 14.1 ("Make-before-Break") in [RFC4875]) or to reoptimize an individual S2L sub-LSP or a group of S2L sub-LSPs, i.e., an individual destination or a group of destinations (Section 14.2 ("Sub-Group-Based Re-Optimization") in [RFC4875]), both using the same LSP-ID. For loosely routed S2L sub-LSPs, this can be achieved by using the procedures defined in [RFC4736] to reoptimize one or more S2L sub-LSPs of the P2MP-TE LSP.

An ingress node may trigger path re-evaluation requests using the procedures defined in [RFC4736] for a set of S2L sub-LSPs by combining multiple Path messages using an S2L sub-LSP descriptor list [RFC4875]. An S2L sub-LSP descriptor list is created using a series of S2L_SUB_LSP objects as defined in [RFC4875]. Similarly, a midpoint LSR may send a PathErr with Notify error code 25 and sub-code 6 ("Preferable Path Exists") containing a list of S2L sub-LSPs transiting through the LSR using an S2L sub-LSP descriptor list to notify the ingress node of preferable paths available.

The S2L_SUB_LSP_FRAG object defined in this document is optional, with the following exceptions:

- o As per [RFC4875], Section 5.2.3 ("Transit Fragmentation of Path State Information"), when a Path message is not large enough to fit all S2L sub-LSPs in the descriptor list, an LSR may semantically fragment the message. In this case, the LSR MUST add the S2L_SUB_LSP_FRAG object defined in this document for each fragment in the S2L sub-LSP descriptor to be able to rebuild the list from the received fragments that may arrive out of order.

- o In any other situation where an RSVP message needs to be fragmented, an LSR MUST add the S2L_SUB_LSP_FRAG object for each fragment in the S2L sub-LSP descriptor.

A midpoint LSR SHOULD wait to accumulate all S2L sub-LSPs before attempting to re-evaluate a preferable path when a Path message for "Path Re-evaluation Request" is received with the S2L_SUB_LSP_FRAG object. If a midpoint LSR does not receive all fragments of the Path message (for example, when fragments are lost) within a configurable time interval, it SHOULD trigger the re-evaluation of all S2L sub-LSPs of the P2MP-TE LSP transiting on the node. A midpoint LSR MUST receive at least one fragment of the Path message to trigger this behavior.

An ingress node SHOULD wait to accumulate all S2L sub-LSPs before attempting to trigger reoptimization when a PathErr with the Notify error code and the "Preferable Path Exists" sub-code is received with an S2L_SUB_LSP_FRAG object. If an ingress node does not receive all fragments of the PathErr message (for example, when fragments are lost) within a configurable time interval, it SHOULD trigger the reoptimization of all S2L sub-LSPs of the P2MP-TE LSP transiting on the midpoint node that had sent the PathErr message. An ingress node MUST receive at least one fragment of the PathErr message to trigger this behavior.

The S2L_SUB_LSP_FRAG object defined in this document has a wider applicability in addition to the P2MP-TE LSP reoptimization. It can also be used (in Path and Resv messages) to set up a new P2MP-TE LSP and to send other PathErr messages as well as Path Tear and Resv Tear messages for a set of S2L sub-LSPs. This is outside the scope of this document.

5. Message and Object Definitions

5.1. "P2MP-TE Tree Re-evaluation Request" Flag

In order to trigger a tree re-evaluation request, a new flag in the Attribute Flags TLV of the LSP_ATTRIBUTES object [RFC5420] is defined by this document:

Bit Number 14: "P2MP-TE Tree Re-evaluation Request" flag

The "P2MP-TE Tree Re-evaluation Request" flag is meaningful in a Path message of a P2MP-TE S2L sub-LSP and is inserted by the ingress node using the message format defined in [RFC6510].

5.2. "Preferable P2MP-TE Tree Exists" Path Error Sub-code

In order to indicate to an ingress node that a preferable P2MP-TE LSP tree exists, the following new sub-code for PathErr messages with Notify error code 25 [RFC3209] is defined by this document:

Sub-code 13: "Preferable P2MP-TE Tree Exists" sub-code

When a preferable path for a P2MP-TE LSP tree exists, the midpoint LSR sends a solicited or unsolicited "Preferable P2MP-TE Tree Exists" sub-code with a PathErr message with Notify error code 25 to the ingress node of the P2MP-TE LSP.

5.3. Fragment Identifier for S2L Sub-LSP Descriptor

The S2L_SUB_LSP object [RFC4875] identifies a particular S2L sub-LSP belonging to the P2MP-TE LSP. An S2L sub-LSP descriptor list is created using a series of S2L_SUB_LSP objects as defined in [RFC4875]. The RSVP message may need to be semantically fragmented [RFC4875] due to a large number of S2L sub-LSPs added in the descriptor list, and such fragments may be received out of order. To be able to rebuild the fragmented S2L sub-LSP descriptor list correctly, the following object is defined to identify the fragments:

S2L_SUB_LSP_FRAG: Class Number 204

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Length (8 bytes)     | Class Num 204 |   C-Type 1    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            Fragment ID        | Fragments Tot.| Fragment Num. |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Fragment ID: 16-bit integer in the range of 1 to 65535.

This value is incremented for each new RSVP message that needs to be semantically fragmented. The fragment ID is reset to 1 when it reaches the maximum value of 65535. The scope of the fragment ID is limited to the RSVP message type (e.g., Path) carrying the fragment. In other words, fragment IDs do not have any correlation between different RSVP message types (e.g., Path and PathErr). The receiver does not check to ensure that the consecutive new RSVP messages (e.g., Path messages) are received with fragment IDs incremented by 1.

Fragments Total: 8-bit integer in the range of 1 to 255.

This value indicates the number of fragments sent for the given RSVP message. This value MUST be the same in all fragmented RSVP messages with a common fragment ID.

Fragment Number: 8-bit integer in the range of 1 to 255.

This value indicates the position of this fragment in the given RSVP message.

The format of an S2L sub-LSP descriptor message is as follows:

```
<S2L sub-LSP descriptor> ::=
                  [ <S2L_SUB_LSP_FRAG> ]
                    <S2L_SUB_LSP>
                  [ <P2MP SECONDARY_EXPLICIT_ROUTE> ]
```

The S2L_SUB_LSP_FRAG object is added before adding the S2L_SUB_LSP object in the semantically fragmented RSVP message.

6. Compatibility

The LSP_ATTRIBUTES object has been defined in [RFC5420] and its message formats in [RFC6510] with class numbers in the form 11bbbbbb, which ensures compatibility with non-supporting nodes. Per [RFC2205], nodes not supporting this extension will ignore the new flag defined for this object in this document and will forward it without modification.

The S2L_SUB_LSP_FRAG object has been defined with class numbers in the form 11bbbbbb, which ensures compatibility with non-supporting nodes. Per [RFC2205], nodes not supporting this object will ignore the object and will forward it without modification.

7. IANA Considerations

IANA has performed the actions described below.

7.1. "P2MP-TE Tree Re-evaluation Request" Flag

IANA maintains the "Resource Reservation Protocol-Traffic Engineering (RSVP-TE) Parameters" registry (see <http://www.iana.org/assignments/rsvp-te-parameters>). Per Section 5.1 of this document, IANA has registered a new flag in the "Attribute Flags" registry. This new flag is defined for the Attribute Flags TLV in the LSP_ATTRIBUTES object [RFC5420].

Bit No	Name	Attribute Flags Path	Attribute Flags Resv	RRO	ERO	Reference
14	P2MP-TE Tree Re-evaluation Request	Yes	No	No	No	This document

7.2. "Preferable P2MP-TE Tree Exists" Path Error Sub-code

IANA maintains the "Resource Reservation Protocol (RSVP) Parameters" registry (see <http://www.iana.org/assignments/rsvp-parameters>). Per Section 5.2 of this document, IANA has registered a new error code in the "Sub-Codes - 25 Notify Error" sub-registry of the "Error Codes and Globally-Defined Error Value Sub-Codes" registry.

As defined in [RFC3209], error code 25 in the ERROR_SPEC object corresponds to a PathErr with the Notify error. This document adds a new "Preferable P2MP-TE Tree Exists" sub-code for this PathErr as follows:

Value	Description	PathErr Code	PathErr Name	Reference
13	Preferable P2MP-TE Tree Exists	25	Notify Error	This document

7.3. Fragment Identifier for S2L Sub-LSP Descriptor

IANA maintains the "Resource Reservation Protocol (RSVP) Parameters" registry (see <http://www.iana.org/assignments/rsvp-parameters>). Per Section 5.3 of this document, IANA has registered a new class number in the "Class Names, Class Numbers, and Class Types" registry.

Class Number	Class Name	Reference
204	S2L_SUB_LSP_FRAG	This document

IANA has also created the "Class Types or C-Types - 204 S2L_SUB_LSP_FRAG" registry and populated it as follows:

Value	Description	Reference
1	S2L_SUB_LSP_FRAG	This document

8. Security Considerations

This document defines RSVP-TE signaling extensions to allow an ingress node of a P2MP-TE LSP to request the re-evaluation of the LSP tree downstream of a node and to allow a midpoint LSR to notify the ingress node of the existence of a preferable tree by sending a PathErr message. As per [RFC4736], in the case of a P2MP-TE LSP S2L sub-LSP spanning multiple domains, it may be desirable for a midpoint LSR to modify the RSVP PathErr message to preserve confidentiality across domains.

This document also defines a fragment identifier for the S2L sub-LSP descriptor when combining a large number of S2L sub-LSPs in an RSVP message and the message needs to be semantically fragmented. The introduction of the fragment identifier, by itself, introduces no additional information to signaling. For a general discussion on security issues related to MPLS and GMPLS, see the MPLS/GMPLS security framework [RFC5920].

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