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LDP Extensions for Pseudowire
Binding to Label Switched Path (LSP) Tunnels

Abstract

Many transport services require that user traffic, in the form of Pseudowires (PWs), be delivered via either a single co-routed bidirectional tunnel or two unidirectional tunnels that share the same routes. This document defines an optional extension to the Label Distribution Protocol (LDP) that enables the binding between PWs and the underlying Traffic Engineering (TE) tunnels. The extension applies to both single-segment and multi-segment PWs.

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1. Introduction

Pseudo Wire Emulation Edge-to-Edge (PWE3) [RFC3985] is a mechanism to emulate Layer 2 services, such as Ethernet Point-to-Point circuits. Such services are emulated between two Attachment Circuits, and the Pseudowire-encapsulated Layer 2 service payload is transported via Packet Switching Network (PSN) tunnels between Provider Edges (PEs). PWE3 typically uses the Label Distribution Protocol (LDP) [RFC5036] or Resource Reservation Protocol - Traffic Engineering (RSVP-TE) [RFC3209] Label Switched Paths (LSPs) as PSN tunnels. The PEs select and bind the Pseudowires to PSN tunnels independently. Today, there is no standardized protocol-based provisioning mechanism to associate PWs with PSN tunnels; such associations must be managed via provisioning or other private methods.

PW-to-PSN Tunnel Binding has become increasingly common and important in many deployment scenarios, as it allows service providers to offer service level agreements to their customers for such traffic attributes as bandwidth, latency, and availability.

The requirements for explicit control of PW-to-LSP mapping are described in Section 5.3.2 of [RFC6373]. Figure 1 illustrates how PWs can be bound to particular LSPs.

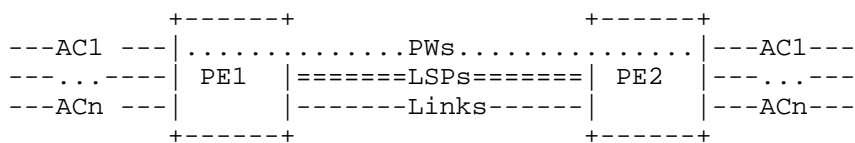


Figure 1: Explicit PW-to-LSP Binding Scenario

There are two PEs (PE1 and PE2) connected through multiple parallel links that may be on different physical fibers. Each link is managed and controlled as a bidirectional LSP. At each PE, there are a large number of bidirectional user flows from multiple Ethernet interfaces (access circuits in the figure). Each user flow utilizes a pair of unidirectional PWs to carry bidirectional traffic. The operators need to make sure that the user flows (that is, the PW-pairs) are carried on the same fiber or bidirectional LSP.

There are a number of reasons behind this requirement. First, due to delay and latency constraints, traffic going over different fibers may require a large amount of expensive buffer memory to compensate for the differential delay at the head-end nodes. Further, the operators may apply different protection mechanisms on different parts of the network (e.g., to deploy 1:1 protection in one part and 1+1 protection in other parts). As such, operators may prefer to

have a user's traffic traverse the same fiber. That implies that both forwarding and reserve direction PWs that belong to the same user flow need to be mapped to the same co-routed bidirectional LSP or two LSPs with the same route.

Figure 2 illustrates a scenario where PW-LSP binding is not applied.

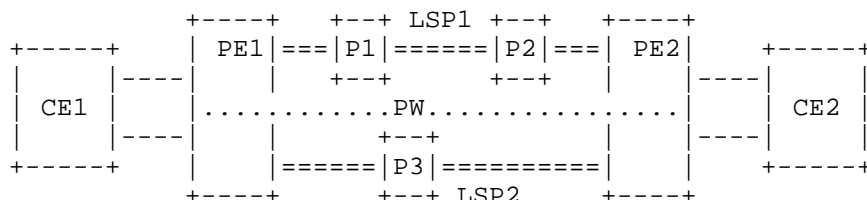


Figure 2: Inconsistent SS-PW-to-LSP Binding Scenario

LSP1 and LSP2 are two bidirectional connections on diverse paths. The operator needs to deliver a bidirectional flow between PE1 and PE2. Using existing mechanisms, it's possible that PE1 may select LSP1 (PE1-P1-P2-PE2) as the PSN tunnel for traffic from PE1 to PE2, while selecting LSP2 (PE2-P3-PE1) as the PSN tunnel for traffic from PE2 to PE1.

Consequently, the user traffic is delivered over two disjointed LSPs that may have very different service attributes in terms of latency and protection. This may not be acceptable as a reliable and effective transport service to the customer.

A similar problem may also exist in multi-segment PWs (MS-PWs), where user traffic on a particular PW may hop over different networks in forward and reverse directions.

One way to solve this problem is by introducing manual provisioning at each PE to bind the PWs to the underlying PSN tunnels. However, this is prone to configuration errors and does not scale.

This document introduces an automatic solution by extending Forwarding Equivalence Class (FEC) 128/129 PW based on [RFC4447].

2. Requirements Language

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].

3. LDP Extensions

This document defines a new optional TLV, the PSN Tunnel Binding TLV, to communicate tunnel/LSP selection and binding requests between PEs. The TLV carries a PW's binding profile and provides explicit or implicit information for the underlying PSN Tunnel Binding operation.

The binding operation applies in both single-segment (SS) and multi-segment (MS) scenarios.

The extension supports two types of binding requests:

1. Strict binding: The requesting PE will choose and explicitly indicate the LSP information in the requests; the receiving PE MUST obey the requests; otherwise, the PW will not be established.
2. Co-routed binding: The requesting PE will suggest an underlying LSP to a remote PE. Upon receipt, the remote PE has the option to use the suggested LSP or reply to the information for an alternative.

In this document, the term "tunnel" is identical to the "TE Tunnel" defined in Section 2.1 of [RFC3209], which is uniquely identified by a SESSION object that includes the Tunnel endpoint address, the Tunnel ID, and the Extended Tunnel ID. The term "LSP" is identical to the "LSP tunnel" defined in Section 2.1 of [RFC3209], which is uniquely identified by the SESSION object together with the SENDER_TEMPLATE (or FILTER_SPEC) object that consists of the LSP ID and the Tunnel endpoint address.

3.1. PSN Tunnel Binding TLV

The PSN Tunnel Binding TLV is an optional TLV and MUST be carried in the LDP Label Mapping message [RFC5036] if PW-to-LSP binding is required. The format 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
+-----+-----+-----+-----+-----+-----+-----+-----+
|U|F| PSN Tunnel Binding(0x0973)|                               Length|
+-----+-----+-----+-----+-----+-----+-----+-----+
|C|S|T|   Unallocated flags   |                               Reserved|
+-----+-----+-----+-----+-----+-----+-----+-----+
~                               PSN Tunnel Sub-TLV                               ~
+-----+-----+-----+-----+-----+-----+-----+-----+

```

Figure 3: PSN Tunnel Binding TLV

The U-bit and F-bit are defined in Section 3.3 [RFC5036]. Since the PSN Tunnel Binding TLV is an optional TLV, the U-bit MUST be set to 1 so that a receiver MUST silently ignore this TLV if unknown to it, and continue processing the rest of the message.

A receiver of this TLV is not allowed to forward the TLV further when it does not know the TLV. So, the F-bit MUST be set to 0.

The PSN Tunnel Binding TLV type is 0x0973.

The Length field is 2 octets long. It defines the length in octets of the value field (including Flags, Reserved, and sub-TLV fields).

The Flags field is 2 octets in length and three flags are defined in this document. The rest of the unallocated flags MUST be set to zero when sending and MUST be ignored when received.

C (Co-routed path) bit: This bit informs the remote T-PE/S-PEs about the properties of the underlying LSPs. When set, the remote T-PE/S-PEs SHOULD select the co-routed LSP (as the forwarding tunnel) as the reverse PSN tunnel. If there is no such tunnel available, it may trigger the remote T-PE/S-PEs to establish a new LSP.

S (Strict) bit: This bit instructs the PEs with respect to the handling of the underlying LSPs. When set, the remote PE MUST use the tunnel/LSP specified in the PSN Tunnel Sub-TLV as the PSN tunnel on the reverse direction of the PW, or the PW will fail to be established.

Either the C-bit or the S-bit MUST be set. The C-bit and S-bit are mutually exclusive from each other, and they cannot be set in the same message. If a status code set to "both C-bit and S-bit are set" or "both C-bit and S-bit are clear" is received, a Label Release message with the status code set to "The C-bit or S-bit unknown" (0x0000003C) MUST be the reply, and the PW will not be established.

T (Tunnel Representation) bit: This bit indicates the format of the LSP tunnels. When the bit is set, the tunnel uses the tunnel information to identify itself, and the LSP Number fields in the PSN Tunnel sub-TLV (Section 3.1.1) MUST be set to zero. Otherwise, both the tunnel and LSP information of the PSN tunnel are required. The default is set. The motivation for the T-bit is to support the MPLS protection operation where the LSP Number fields may be ignored.

The Reserved field is 2 octets in length and is left for future use.

3.1.1.1. PSN Tunnel Sub-TLV

PSN Tunnel Sub-TLVs are designed for inclusion in the PSN Tunnel Binding TLV to specify the tunnel/LSPs to which a PW is required to bind.

Two sub-TLVs are defined: The IPv4 and IPv6 Tunnel sub-TLVs.

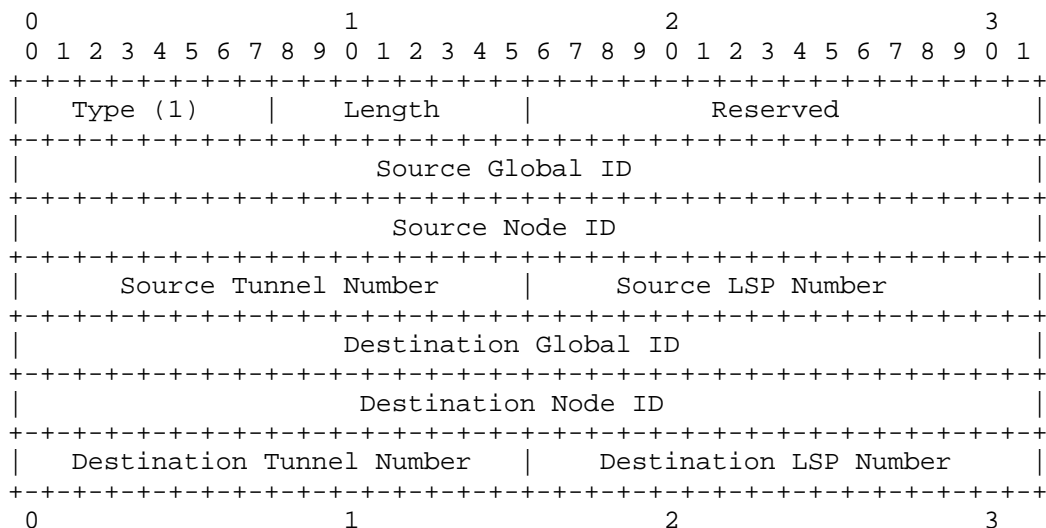


Figure 4: IPv4 PSN Tunnel Sub-TLV Format

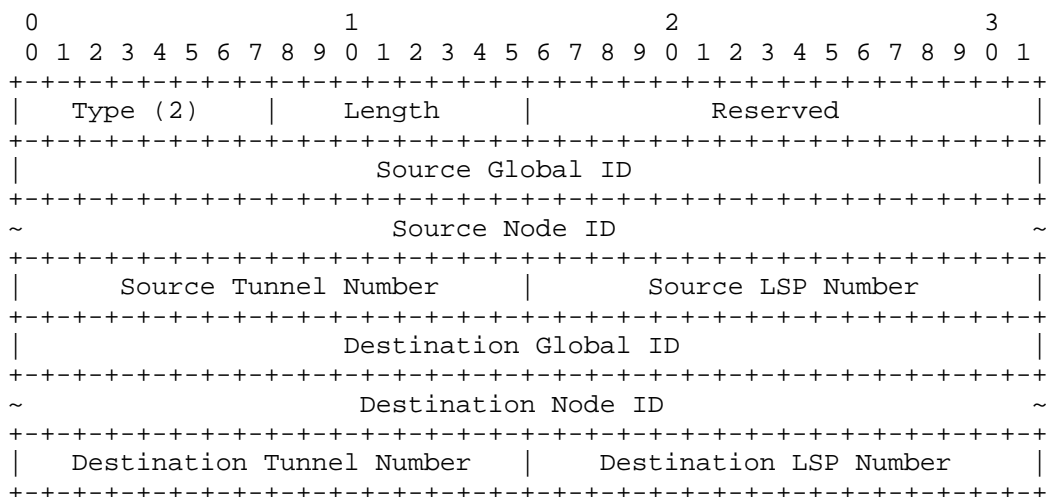


Figure 5: IPv6 PSN Tunnel Sub-TLV Format

The definition of the Source and Destination Global/Node IDs and Tunnel/LSP Numbers are derived from [RFC6370]. This describes the underlying LSPs. Note that the LSPs in this notation are globally unique. The ITU-T style identifiers [RFC6923] are not used in this document.

As defined in Sections 4.6.1.1 and 4.6.1.2 of [RFC3209], the "Tunnel endpoint address" is mapped to the Destination Node ID, and the "Extended Tunnel ID" is mapped to the Source Node ID. Both IDs can be either IPv4 or IPv6 addresses. The Node IDs are routable addresses of the ingress LSR and egress LSR of the Tunnel/LSP.

A PSN Tunnel sub-TLV could be used to identify either a tunnel or a specific LSP. The T-bit in the Flags field defines the distinction as such that, when the T-bit is set, the Source/Destination LSP Number fields MUST be zero and ignored during processing. Otherwise, both Source/Destination LSP Number fields MUST have the actual LSP IDs of specific LSPs.

Each PSN Tunnel Binding TLV MUST only have one such sub-TLV. When sending, only one sub-TLV MUST be carried. When received, if there are more than one sub-TLVs carried, only the first sub-TLV MUST be used, the rest of the sub-TLVs MUST be ignored.

4. Theory of Operation

During PW setup, the PEs may choose to select the desired forwarding tunnels/LSPs and inform the remote T-PE/S-PEs about the desired reverse tunnels/LSPs.

Specifically, to set up a PW (or PW Segment), a PE may select a candidate tunnel/LSP to act as the PSN tunnel. If no candidate is available or none satisfy the constraints, the PE will trigger and establish a new tunnel/LSP. The selected tunnel/LSP information is carried in the PSN Tunnel Binding TLV and sent with the Label Mapping message to the target PE.

Upon the reception of the Label Mapping message, the receiving PE will process the PSN Tunnel Binding TLV, determine whether it can accept the suggested tunnel/LSP or to find the reverse tunnel/LSP that meets the request, and respond with a Label Mapping message, which contains the corresponding PSN Tunnel Binding TLV.

It is possible that two PEs request PSN Binding to the same PW or PW segment over different tunnels/LSPs at the same time. This may cause collisions of tunnel/LSPs selection as both PEs assume the active role.

As defined in (Section 7.2.1, [RFC6073]), each PE may be categorized into active and passive roles:

1. Active PE: The PE that initiates the selection of the tunnel/LSPs and informs the remote PE;
2. Passive PE: The PE that obeys the active PE's suggestion.

In the rest of this document, we will elaborate upon the operation for SS-PW and MS-PW:

1. SS-PW: In this scenario, both PEs for a particular PW may assume the active roles.
2. MS-PW: One PE is active, while the other is passive. The PWs are set up using FEC 129.

5. PSN Binding Operation for SS-PW

As illustrated in Figure 6, both PEs (e.g., PE1 and PE2) of a PW may independently initiate the setup. To perform PSN Binding, the Label Mapping messages MUST carry a PSN Tunnel Binding TLV, and the PSN Tunnel sub-TLV MUST contain the desired tunnel/LSPs of the sender.

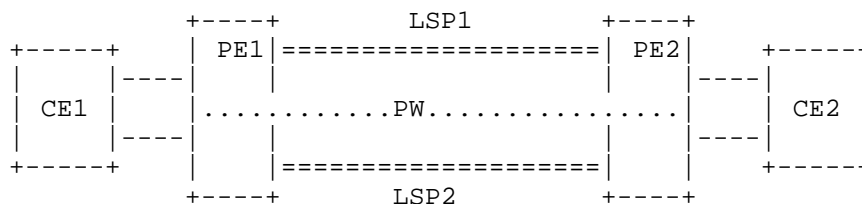


Figure 6: PSN Binding Operation in SS-PW Environment

As outlined previously, there are two types of binding requests: co-routed and strict.

In strict binding, a PE (e.g., PE1) will mandate that the other PE (e.g., PE2) use a specified tunnel/LSP (e.g., LSP1) as the PSN tunnel on the reverse direction. In the PSN Tunnel Binding TLV, the S-bit MUST be set, the C-bit MUST be cleared, and the Source and Destination IDs/Numbers MUST be filled.

Upon receipt, if the S-bit is set, as well as following the processing procedure defined in Section 5.3.3 of [RFC4447], the receiving PE (i.e., PE2) needs to determine whether to accept the indicated tunnel/LSP in PSN Tunnel Sub-TLV.

The receiving PE (PE2) may also be an active PE, and it may have initiated the PSN Binding requests to the other PE (PE1); if the received PSN tunnel/LSP is the same as was sent in the Label Mapping message by PE2, then the signaling has converged on a mutually agreed upon Tunnel/LSP. The binding operation is completed.

Otherwise, the receiving PE (PE2) MUST compare its own Node ID against the received Source Node ID as unsigned integers. If the received Source Node ID is larger, the PE (PE2) will reply with a Label Mapping message to complete the PW setup and confirm the binding request. The PSN Tunnel Binding TLV in the message MUST contain the same Source and Destination IDs/Numbers as in the received binding request, in the appropriate order (where the source is PE2 and PE1 becomes the destination). On the other hand, if the receiving PE (PE2) has a Node ID that is larger than the Source Node ID carried in the PSN Tunnel Binding TLV, it MUST reply with a Label Release message with the status code set to "Reject - unable to use the suggested tunnel/LSPs", and the received PSN Tunnel Binding TLV, and the PW will not be established.

To support co-routed binding, the receiving PE can select the appropriate PSN tunnel/LSP for the reverse direction of the PW, so long as the forwarding and reverse PSNs share the same route (links and nodes).

Initially, a PE (PE1) sends a Label Mapping message to the remote PE (PE2) with the PSN Tunnel Binding TLV, with C-bit set, S-bit cleared, and the appropriate Source and Destination IDs/Numbers. In case of unidirectional LSPs, the PSN Tunnel Binding TLV may only contain the Source IDs/Numbers; the Destination IDs/Numbers are set to zero and left for PE2 to complete when responding to the Label Mapping message.

Upon receipt, since PE2 is also an active PE, and may have initiated the PSN Binding requests to the other PE (PE1), if the received PSN tunnel/LSP has the same route as the one that has been sent in the Label Mapping message to PE1, then the signaling has converged. The binding operation is completed.

Otherwise, PE2 needs to compare its own Node ID against the received Source Node ID as unsigned integers. If the received Source Node ID is larger, PE2 needs to find/establish a tunnel/LSP that meets the co-routed constraint, and reply with a Label Mapping message that has a PSN Binding TLV that contains the Source and Destination IDs/Numbers of the tunnel/LSP. On the other hand, if the receiving PE (PE2) has a Node ID that is larger than the Source Node ID carried in the PSN Tunnel Binding TLV, it MUST reply with a Label Release message that has a status code set to "Reject - unable to use the

suggested tunnel/LSPs" (0x0000003B) and the received PSN Tunnel Binding TLV.

In addition, if the received PSN tunnel/LSP endpoints do not match the PW endpoints, PE2 MUST reply with a Label Release message with the status code set to "Reject - unable to use the suggested tunnel/LSPs" (0x0000003B) and the received PSN Tunnel Binding TLV MUST also be carried.

In both strict and co-routed bindings, if the T-bit is set, the LSP Number field MUST be set to zero. Otherwise, the field MUST contain the actual LSP number for the related PSN LSP.

After a PW is established, the operators may choose to move the PWs from the current tunnel/LSPs to other tunnel/LSPs. Also, the underlying PSN tunnel may break due to a network failure. When either of these scenarios occur, a new Label Mapping message MUST be sent to notify the remote PE of the changes. Note that when the T-bit is set, the working LSP broken will not provide this update if there are protection LSPs in place.

The message may carry a new PSN Tunnel Binding TLV, which contains the new Source and Destination Numbers/IDs. The handling of the new message should be identical to what has been described in this section.

However, if the new Label Mapping message does not contain the PSN Tunnel Binding TLV, it declares the removal of any co-routed/strict constraints. The current independent PW-to-PSN Binding will be used.

Further, as an implementation option, the PEs may choose not to remove the traffic from an operational PW until the completion of the underlying PSN tunnel/LSP changes.

6. PSN Binding Operation for MS-PW

MS-PW uses FEC 129 for PW setup. We refer to Figure 7 for this operation.

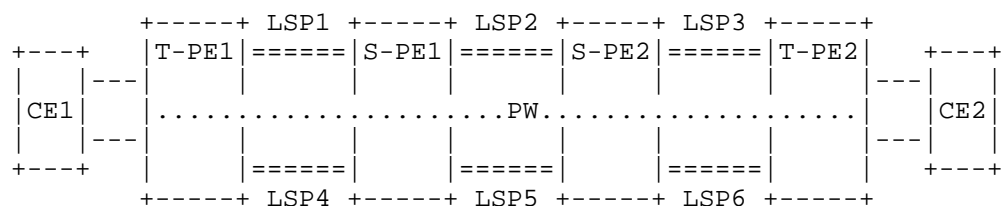


Figure 7: PSN Binding Operation in MS-PW Environment

When an active PE (that is, T-PE1) starts to signal an MS-PW, a PSN Tunnel Binding TLV MUST be carried in the Label Mapping message and sent to the adjacent S-PE (that is, S-PE1). The PSN Tunnel Binding TLV includes the PSN Tunnel sub-TLV that carries the desired tunnel/LSP of T-PE1.

For strict binding, the initiating PE MUST set the S-bit, clear the C-bit, and indicate the binding tunnel/LSP to the next-hop S-PE.

When S-PE1 receives the Label Mapping message, it needs to determine if the signaling is for the forward or reverse direction, as defined in Section 4.2.3 of [RFC7267].

If the Label Mapping message is for the forward direction, and S-PE1 accepts the requested tunnel/LSPs from T-PE1, S-PE1 MUST save the tunnel/LSP information for reverse-direction processing later on. If the PSN Binding request is not acceptable, S-PE1 MUST reply with a Label Release Message to the upstream PE (T-PE1) with the status code set to "Reject - unable to use the suggested tunnel/LSPs" (0x0000003B).

Otherwise, S-PE1 relays the Label Mapping message to the next S-PE (that is, S-PE2), with the PSN Tunnel sub-TLV carrying the information of the new PSN tunnel/LSPs selected by S-PE1. S-PE2 and subsequent S-PEs will repeat the same operation until the Label Mapping message reaches to the remote T-PE (that is, T-PE2).

If T-PE2 agrees with the requested tunnel/LSPs, it will reply with a Label Mapping message to initiate the binding process in the reverse direction. The Label Mapping message contains the received PSN Tunnel Binding TLV for confirmation purposes.

When its upstream S-PE (S-PE2) receives the Label Mapping message, the S-PE relays the Label Mapping message to its upstream adjacent S-PE (S-PE1), with the previously saved PSN tunnel/LSP information in the PSN Tunnel sub-TLV. The same procedure will be applied on subsequent S-PEs, until the message reaches T-PE1 to complete the PSN Binding setup.

During the binding process, if any PE does not agree to the requested tunnel/LSPs, it can send a Label Release Message to its upstream adjacent PE with the status code set to "Reject - unable to use the suggested tunnel/LSPs" (0x0000003B). In addition, if the received PSN tunnel/LSP endpoints do not match the PW Segment endpoints, the receiving PE MUST reply with a Label Release message with the status code set to "Reject - unable to use the suggested tunnel/LSPs" (0x0000003B) and the received PSN Tunnel Binding TLV MUST also be carried.

For co-routed binding, the initiating PE (T-PE1) MUST set the C-bit, reset the S-bit, and indicate the suggested tunnel/LSP in the PSN Tunnel sub-TLV to the next-hop S-PE (S-PE1).

During the MS-PW setup, the PEs have the option of ignoring the suggested tunnel/LSP, and to select another tunnel/LSP for the segment PW between itself and its upstream PE in reverse direction only if the tunnel/LSP is co-routed with the forward one. Otherwise, the procedure is the same as the strict binding.

The tunnel/LSPs may change after a MS-PW has been established. When a tunnel/LSP has changed, the PE that detects the change SHOULD select an alternative tunnel/LSP for temporary use while negotiating with other PEs following the procedure described in this section.

7. PSN Tunnel Select Considerations

As stated in Section 1, the PSN tunnel that is used for binding can be either a co-routed bidirectional LSP or two LSPs with the same route. The co-routed bidirectional LSP has the characteristics that both directions not only cross the same nodes and links, but have the same life span. But for the two LSPs case, even if they have the same route at the beginning, it cannot be guaranteed that they will always have the same route all the time. For example, when Fast ReRoute (FRR) [RFC4090] is deployed for the LSPs, link or node failure may make the two LSPs use different routes. So, if the network supports co-routed bidirectional LSPs, it is RECOMMENDED that a co-routed bidirectional LSP should be used; otherwise, two LSPs with the same route may be used.

8. Security Considerations

The ability to control which LSP is used to carry traffic from a PW can be a potential security risk both for denial of service and traffic interception. It is RECOMMENDED that PEs not accept the use of LSPs identified in the PSN Tunnel Binding TLV unless the LSP endpoints match the PW or PW segment endpoints. Furthermore, it is RECOMMENDED that PEs implement the LDP security mechanisms described in [RFC5036] and [RFC5920].

9. IANA Considerations

9.1. LDP TLV Types

This document defines a new TLV (Section 3.1) for inclusion in the LDP Label Mapping message. IANA has assigned TLV type value 0x0973 from the "LDP TLV Type Name Space" registry.

9.1.1. PSN Tunnel Sub-TLVs

This document defines two sub-TLVs (Section 3.1.1) for the PSN Tunnel Binding TLV. IANA has created a new PWE3 subregistry titled "PSN Tunnel Sub-TLV Name Space" for PSN Tunnel sub-TLVs and has assigned Sub-TLV type values to the following sub-TLVs:

IPv4 PSN Tunnel sub-TLV - 1

IPv6 PSN Tunnel sub-TLV - 2

In addition, the values 0 and 255 in this new registry should be reserved, and values 1-254 will be allocated by IETF Review [RFC5226].

9.2. LDP Status Codes

This document defines two new LDP status codes, IANA has assigned status codes to these new defined codes from the "LDP Status Code Name Space" registry.

"Reject - unable to use the suggested tunnel/LSPs" - 0x0000003B

"The C-bit or S-bit unknown" - 0x0000003C

The E bit is set to 1 for both new codes.

10. References

10.1. Normative References

- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<http://www.rfc-editor.org/info/rfc2119>>.
- [RFC4447] Martini, L., Ed., Rosen, E., El-Aawar, N., Smith, T., and G. Heron, "Pseudowire Setup and Maintenance Using the Label Distribution Protocol (LDP)", RFC 4447, DOI 10.17487/RFC4447, April 2006, <<http://www.rfc-editor.org/info/rfc4447>>.
- [RFC6370] Bocci, M., Swallow, G., and E. Gray, "MPLS Transport Profile (MPLS-TP) Identifiers", RFC 6370, DOI 10.17487/RFC6370, September 2011, <<http://www.rfc-editor.org/info/rfc6370>>.

10.2. Informative References

- [RFC3209] Awduche, D., Berger, L., Gan, D., Li, T., Srinivasan, V., and G. Swallow, "RSVP-TE: Extensions to RSVP for LSP Tunnels", RFC 3209, DOI 10.17487/RFC3209, December 2001, <<http://www.rfc-editor.org/info/rfc3209>>.
- [RFC3985] Bryant, S., Ed. and P. Pate, Ed., "Pseudo Wire Emulation Edge-to-Edge (PWE3) Architecture", RFC 3985, DOI 10.17487/RFC3985, March 2005, <<http://www.rfc-editor.org/info/rfc3985>>.
- [RFC4090] Pan, P., Ed., Swallow, G., Ed., and A. Atlas, Ed., "Fast Reroute Extensions to RSVP-TE for LSP Tunnels", RFC 4090, DOI 10.17487/RFC4090, May 2005, <<http://www.rfc-editor.org/info/rfc4090>>.
- [RFC5036] Andersson, L., Ed., Minei, I., Ed., and B. Thomas, Ed., "LDP Specification", RFC 5036, DOI 10.17487/RFC5036, October 2007, <<http://www.rfc-editor.org/info/rfc5036>>.
- [RFC5226] Narten, T. and H. Alvestrand, "Guidelines for Writing an IANA Considerations Section in RFCs", BCP 26, RFC 5226, DOI 10.17487/RFC5226, May 2008, <<http://www.rfc-editor.org/info/rfc5226>>.
- [RFC5920] Fang, L., Ed., "Security Framework for MPLS and GMPLS Networks", RFC 5920, DOI 10.17487/RFC5920, July 2010, <<http://www.rfc-editor.org/info/rfc5920>>.
- [RFC6073] Martini, L., Metz, C., Nadeau, T., Bocci, M., and M. Aissaoui, "Segmented Pseudowire", RFC 6073, DOI 10.17487/RFC6073, January 2011, <<http://www.rfc-editor.org/info/rfc6073>>.
- [RFC6373] Andersson, L., Ed., Berger, L., Ed., Fang, L., Ed., Bitar, N., Ed., and E. Gray, Ed., "MPLS Transport Profile (MPLS-TP) Control Plane Framework", RFC 6373, DOI 10.17487/RFC6373, September 2011, <<http://www.rfc-editor.org/info/rfc6373>>.
- [RFC6923] Winter, R., Gray, E., van Helvoort, H., and M. Betts, "MPLS Transport Profile (MPLS-TP) Identifiers Following ITU-T Conventions", RFC 6923, DOI 10.17487/RFC6923, May 2013, <<http://www.rfc-editor.org/info/rfc6923>>.

[RFC7267] Martini, L., Ed., Bocci, M., Ed., and F. Balus, Ed.,
"Dynamic Placement of Multi-Segment Pseudowires",
RFC 7267, DOI 10.17487/RFC7267, June 2014,
<<http://www.rfc-editor.org/info/rfc7267>>.

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The coauthors of this document, the working group chairs, the responsible AD, and the PALS working group wish to dedicate this RFC to the memory of our friend and colleague Ping Pan, in recognition for his devotion and hard work at the IETF.

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