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                  SR-TE Path Midpoint Restoration

Abstract

   Segment Routing Traffic Engineering (SR-TE) supports explicit paths
   using segment lists containing adjacency-SIDs, node-SIDs and
   binding-SIDs. The current SR FRR such as TI-LFA provides fast re-
   route protection for the failure of a node along a SR-TE path by the
   direct neighbor or say point of local repair (PLR) to the failure.
   However, once the IGP converges, the SR FRR is no longer sufficient
   to forward traffic of the path around the failure, since the non-
   neighbors of the failure will no longer have a route to the failed
   node. This document describes a mechanism for the restoration of the
   routes to the failure of a SR-MPLS TE path after the IGP converges.
   It provides the restoration of the routes to an adjacency segment, a
   node segment and a binding segment of the path. With the restoration
   of the routes to the failure, the traffic is continuously sent to
   the neighbor of the failure after the IGP converges. The neighbor as
   a PLR fast re-routes the traffic around the failure.

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] [RFC8174]
   when, and only when, they appear in all capitals, as shown here.

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1. Introduction

   Segment Routing Traffic Engineering (SR-TE) is a technology that
   implements traffic engineering using a segment list. SR-TE supports
   the creation of explicit paths using adjacency-SIDs, node-SIDs,

anycast-SIDs, and binding-SIDs. A node-SID in the segment list defining an SR-TE path indicates a loose hop that the SR-TE path should pass through. When the node fails, the network may no longer be able to properly forward traffic on that SR-TE path.

[I-D.ietf-rtgwg-segment-routing-ti-lfa] describes an SR FRR mechanism that provides fast re-route protection for the failure of a node on a SR-TE path by the direct neighbor or say point of local repair (PLR) to the failure. However, once the IGP converges, the SR FRR is no longer sufficient to forward traffic of the path around the failure, since the non-neighbors of the failure will no longer have a route to the failed node and drop the traffic.

To solve this problem, [I-D.ietf-spring-segment-protection-sr-te-paths] proposes that a hold timer should be configured on every router in a network. After the IGP converges on the event of a node failure, if the node-SID of the failed node becomes unreachable, the forwarding changes should not be communicated to the forwarding planes on all configured routers (including PLRs for the failed node) until the hold timer expires. This solution may not work for some cases such as some of nodes in the network not supporting this solution.

This document describes a proxy forwarding mechanism for the restoration of the routes to the failure of a SR-MPLS TE path after the IGP converges. It provides the restoration of the routes to an adjacency segment, a node segment and a binding segment on a failed node along the path. With the restoration of the routes to the failure, the traffic for the SR-MPLS TE path is continuously sent to the neighbor of the failure after the IGP converges. The neighbor as a PLR fast re-routes the traffic around the failure.

1.1. Terminology

SR: Segment Routing.

PLR: Point of Local Repair.

LSP: Link State Protocol Data Unit (PDU) in IS-IS.

LSA: Link State Advertisement in OSPF.

LS: Link State, which is LSP or LSA.

2. Proxy Forwarding

In the proxy forwarding mechanism, each neighbor of a possible failed node advertises its SR proxy forwarding capability in its network domain when it has the capability. This capability indicates that the neighbor (the Proxy Forwarder) will forward traffic on

behalf of the failed node. A router receiving the SR Proxy
Forwarding capability from the neighbors of a failed node will send
traffic using the node-SID of the failed node to the nearest Proxy
Forwarder after the IGP converges on the event of the failure.

Once the affected traffic reaches a Proxy Forwarder, it sends the
traffic on the post-failure shortest path to the node immediately
following the failed node in the segment list.

For a binding segment of a possible failed node, the node advertises
the information about the binding segment, including the binding SID
and the list of SIDs associated with the binding SID, to its direct
neighbors only. Note that the information is not advertised in the
network domain.

After the node fails and the IGP converges on the failure, the
traffic with the binding SID of the failed node will reach its
neighbor having SR Proxy Forwarding capability. Once receiving the
traffic, the neighbor swaps the binding SID with the list of SIDs
associated with the binding SID and sends the traffic along the
post-failure shortest path to the first node in the segment list.

3. Protocol Extensions for Proxy Forwarding

This section describes the semantic of protocol extensions/re-use
for advertising the SR proxy forwarding capability of a node in a
network domain and the information about each binding segment
(including its binding SID and the list of SIDs associated) of a
node to its direct neighbors.

3.1. Advertising Proxy Forwarding

When a node P is able to do SR proxy forwarding for its neighboring
nodes for protecting the failures of these nodes, P advertises its
SR proxy forwarding capability for these nodes. The mirror SID
[RFC8402][RFC8667] for a node N (Neighbor of P) advertised by P
indicates the capability of P for N.

For a node X in the network, it learns the prefix/node SID of node
N, which is originated and advertised by node N. It creates a proxy
prefix/node SID of node N for node P if node P is capable of doing
SR proxy forwarding for node N. The proxy prefix/node SID of node N
for node P is a copy of the prefix/node SID of node N originated by
node N, but stored under (or say, associated with) node P. The route
to the proxy prefix/node SID is through proxy forwarding capable
nodes.

In normal operations, node X prefers to use the prefix/node SID of
node N. When node N fails, node X prefers to use the proxy prefix/
node SID of node N. Thus node X will forward the traffic targeting

to the prefix/node SID of node N to node P when node N fails, and
node P will do a SR proxy forwarding for node N and forward the
traffic towards its final destination without going through node N.

Note that the behaviors of normal IP forwarding and routing
convergences in a network are not changed at all by the SR proxy
forwarding. For example, the next hop used by BGP is an IP address
(or prefix). The IGP and BGP converge in normal ways for changes in
the network. The packet with its IP destination to this next hop is
forwarded according to the IP forwarding table (FIB) derived from
IGP and BGP routes.

Alternatively, P advertises its capability in its LS. For OSPF, P
advertises its information opaque LSA with one bit (called PF bit)
set to one indicating that P has the capability for all its
neighbors. For IS-IS, P advertises its LSP with PF bit.

If node P can not do a SR proxy forwarding for all its neighboring
nodes, but for some of them, then it advertises the node SID of each
of the nodes as a proxy node SID, indicating that it is able to do
proxy forwarding for the node SID.

3.2. Advertising Binding Segment

For a binding segment (or binding for short) on a node A, which
consists of a binding SID and a list of segments, node A advertises
an LS containing the binding (i.e., the binding SID and the list of
the segments) in a binding segment TLV. The LS is advertised only to
each of the node A's neighboring nodes. For OSPFv2, the LS is a
opaque LSA of LS type 9 (i.e., a link local scope LSA). For IS-IS,
the TLV is advertised in Circuit Scoped Link State PDUs (CS-LSP)
[RFC7356].

Alternatively, when a protocol (such as PCE or BGP running on a
controller) supports sending a binding on a node A to A, this
protocol may be extended to send the binding with node A to A's
neighbors if the controller knows the neighbors and there are
protocol (PCE or BGP) sessions between the controller and the
neighbors.

4. Proxy Forwarding Example

This section illustrates the proxy forwarding for a binding SID
through an example. The proxy forwarding for a node SID and an
adjacency SID can refer to [I-D.ietf-spring-segment-protection-sr-
te-paths] or Appendix. Figure 1 is an example network topology used
to illustrate the proxy forwarding mechanism for a binding SID. Each
node N has SRGB = [N000-N999]. RT1 is an ingress node of SR domain.
RT3 is a failure node. RT2 is a Point of Local Repair (PLR) node,
i.e., a proxy forwarding node. Label Stack 1 uses a node-SID and a

binding SID. The Binding-SID with label=100 at RT3 represents the ECMP-aware path RT3->RT4->RT5. So Label Stack 1, which consists of the node-SID for RT3 following by Binding-SID=100, represents the ECMP-aware path RT1->RT3->RT4->RT5.

```
              Node SID:2        Node SID:3
                +-----+           +-----+
                |     |-----------+     |
               / |RT2  |          | RT3 |\
              /  +-----+          +-----+ \
             /      | \             /|     \
            /       |  \           / |      \
           /        |   \         /  |       \
          /         |    \       /   |        \
         /          |     \     /    |         \
   Node SID:1       |      \   /     |        \Node SID:4   Node SID:5
   +-----+          |       \ /      |          +-----+       +-----+
   |     |          |        X       |          |     |       |     |
   | RT1 |          |       / \      |          | RT4 |-------|     |
   +-----+          |      /   \     |          +-----+       | RT5 |
      \             |     /     \    |           /            +-----+
       \            |    /       \   |          /
        \           |   /         \  |         /
         \          |  /           \ |        /
          \         | /             \|       /
           \        |/               |      /
            \    +-----+           +-----+ /
             \   |     |           |     ||/
              \  | RT6 |-----------| RT7 |
                 +-----+           +-----+
              Node SID:6        Node SID:7

   +----------------+  +--------------+
   |   Node SRGB    |  | Adj-SID      |   +-------+  +-------+  +-------+
   +----------------+  +--------------+   |Label  |  |Label  |  |Label  |
   | RT1:[1000-1999]|  |RT1->RT2:10012|   |Stack 3|  |Stack 2|  |Stack 1|
   +----------------+  +--------------+   +-------+  +-------+  +-------+
   | RT2:[2000-2999]|  |RT2->RT3:20023|   | 10012 |  | 1003  |  | 1003  |
   +----------------+  +--------------+   +-------+  +-------+  +-------+
   | RT3:[3000-3999]|  |RT3->RT6:30036|   | 20023 |  | 3004  |  | 100   |
   +----------------+  +--------------+   +-------+  +-------+  +-------+
   | RT4:[4000=4999]|  |RT3->RT7:30037|   | 30034 |  | 4005  |    100 is
   +----------------+  +--------------+   +-------+  +-------+  binding SID
   | RT5:[5000-5999]|  |RT3->RT4:30034|   | 40045 |              to
   +----------------+  +--------------+   +-------+           {30034,40045
   | RT6:[6000-6999]|  |RT7->RT4:70074|
   +----------------+  +--------------+
   | RT7:[7000-7999]|  |RT4->RT5:40045|
   +----------------+  +--------------+

                    Figure 1: Topology of SR-TE Path
```
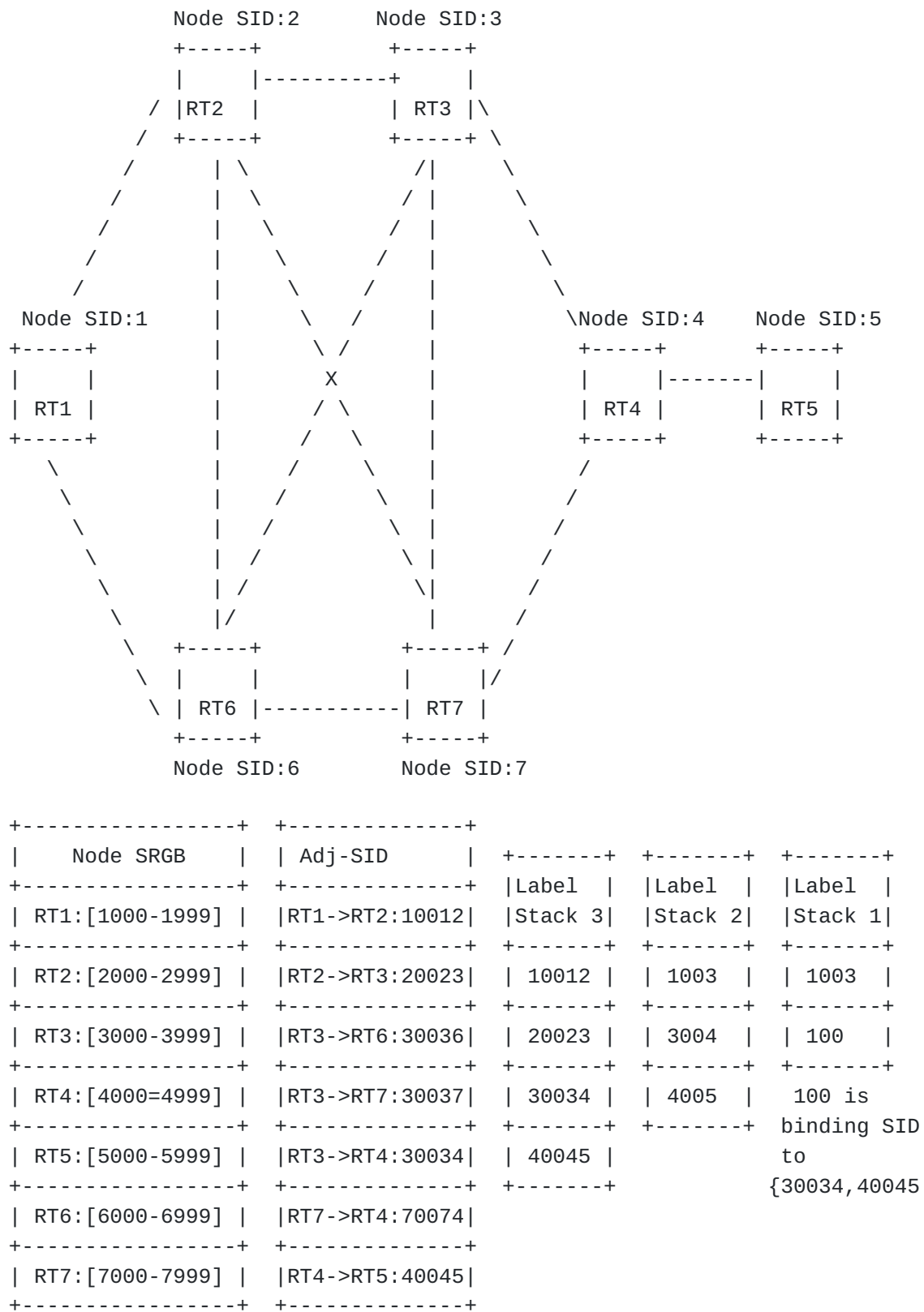
4.1. Advertising Proxy Forwarding

If the Point of Local Repair (PLR), for example, RT2, has the capability to do SR proxy forwarding for its neighboring nodes such as RT3, it must advertise this capability. When RT3 fails, RT2 needs to maintain its SR proxy forwarding capability for a period of time. When the proxy forwarding table corresponding to the fault node is deleted, the capability is withdrawn. The nodes in the network (for example, RT1) learn the prefix/node SID advertised by RT3 and the proxy forwarding capability for RT3 advertised by RT2. When RT3 is normal, the nodes prefer prefix/node SID. When the RT3 fails, the proxy prefix/node SIDs of RT3 for RT2 is preferred.

For binding-SID 100, which is associated with segment list {30034, 40045}, RT3 advertises the binding (i.e., 100 bond to {30034, 40045}) to its neighbors RT2, RT4 and RT7. RT2 as PLR uses the binding to build an entry for proxy forwarding for binding-SID 100 in its Proxy Forwarding Table for RT3. The entry is used when RT3 fails.

4.2. Building Proxy Forwarding Table

A SR proxy node P needs to build an independent proxy forwarding table for each neighbor N. The proxy forwarding table for node N contains the following information:

1: Node N's SRGB range and the difference between the SRGB start value of node P and that of node N;

2: Every adjacency-SID of N and Node-SID of the node pointed to by node N's adjacency-SID.

3: Every binding-SID of N and the label stack associated with the binding-SID.

Node P (PLR) uses a proxy forwarding table based on the next segment to find a node N as a backup forwarding entry to the adjacency-SID and Node-SID of node N. When node N fails, the proxy forwarding table needs to be maintained for a period of time, which is recommended for 30 minutes.

Node RT3 in Figure 1 is node N, and node RT2 is node P (PLR). RT2 builds the proxy forwarding table for RT3. RT2 calculates the proxy forwarding table for RT3, as shown in Figure 2.

```
+==========+==============+============+=============+==============+
| In-label | SRGBDiffValue | Next Label |   Action    |  Map Label   |
+==========+==============+============+=============+==============+
| 2003     |    -1000      |   30034    | Fwd to RT4  |    2004      |
+----------+--------------+------------+-------------+--------------+
                          |   30036    | Fwd to RT6  |    2006      |
                          +------------+-------------+--------------+
                          |   30037    | Fwd to RT7  |    2007      |
                          +------------+-------------+--------------+
                          |    100     | Swap to { 30034, 40045 }   |
                          +------------+-------------+--------------+
```

              Figure 2: RT2's Proxy Forwarding Table for RT3

4.3. Proxy Forwarding for Binding Segment

   This Section shows through example how a proxy node uses the SR
   proxy forwarding mechanism to forward traffic to the destination
   node when a node fails and the next segment of label stack is a
   binding-SID.

   As shown in [Figure 1](#), Label Stack 1 {1003, 100} represents SR-TE
   loose path RT1->RT3->RT4->RT5, where 100 is a Binding-SID, which
   represents segment list {30034, 40045}.

   When the node RT3 fails, the proxy forwarding SID implied or
   advertised by the RT2 is preferred to forward the traffic of the RT1
   to the PLR node RT2. Node RT2 acts as a PLR node and uses Binding-
   SID to query the proxy forwarding table locally built for RT3. The
   path returned is the label forwarding path to RT3's next hop node
   (RT4), which bypasses RT3. The specific steps are as follows:

   a. RT1 swaps label 1003 to out-label 2003 to RT3.

   b. RT2 receives the label forwarding packet whose top label of label
   stack is 2003, and searches for the local Routing Table, the
   behavior found is to lookup Proxy Forwarding table due to RT3
   failure.

   c. RT2 uses Binding-SID:100 (label 2003 has pop) as the in-label to
   lookup the Next Label record of the Proxy Forwarding Table, the
   behavior found is to swap to Segment list {30034, 40045}.

   d. RT2 swaps Binding-SID:100 to Segment list {30034, 40045}, and
   uses the 30034 to lookup the Next Label record of the Proxy
   Forwarding table again. The behavior found is to forward the packet
   to RT4.

   e. RT2 queries the Routing Table to RT4, using primary or backup
   path to RT4. The next hop is RT7.

f. RT2 forwards packets to RT7. RT7 queries the local routing table to forward the packet to RT4.

5. Security Considerations

The extensions to OSPF and IS-IS described in this document result in two types of behaviors in data plane when a node in a network fails. One is that for a node, which is a upstream (except for the direct upstream) node of the failed node along a SR-TE path, it continues to send the traffic to the failed node along the SR-TE path for an extended period of time. The other is that for a node, which is the direct upstream node of the failed node, it fast re-routes the traffic around the failed node to the direct downstream node of the failed node along the SR-TE path. These behaviors are internal to a network and should not cause extra security issues.

6. IANA Considerations

7. Acknowledgements

The authors would like to thank Peter Psenak, Acee Lindem, Les Ginsberg, Bruno Decraene and Jeff Tantsura for their comments to this work.

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Appendix A. Proxy Forwarding for Adjacency and Node Segment

This Section shows through example how a proxy node forward traffic
to the destination node when a node fails and the next segment of
label stack is an adjacency-SID or node-SID.

A.1. Next Segment is an Adjacency Segment

As shown in Figure 1, Label Stack 3 {10012, 20023, 30034, 40045}
uses only adjacency-SIDs and represents the SR-TE strict explicit
path RT1->RT2->RT3->RT4->RT5. When RT3 fails, node RT2 acts as a
PLR, and uses next adjacency-SID (30034) of the label stack to
lookup the proxy forwarding table built by RT2 locally for RT3. The
path returned is the label forwarding path to RT3's next hop node
RT4, which bypasses RT3. The specific steps are as follows:

a. RT1 pops top adjacency-SID 10012, and forwards the packet to RT2;

b. RT2 uses the label 20023 to identify the next hop node RT3, which
has failed. RT2 pops label 20023 and queries the Proxy Forwarding
Table corresponding to RT3 with label 30034. The query result is

2004. RT2 uses 2004 as the incoming label to query the label forwarding table. The next hop is RT7, and the incoming label is changed to 7004.

c. So the packet leaves RT2 out the interface to RT7 with label stack {7004, 40045}. RT7 forwards it to RT4, where the original path is rejoined.

d. RT2 forwards packets to RT7. RT7 queries the local routing table to forward the packet to RT4.

A.2. Next Segment is a Node Segment

As shown in [Figure 1](#), Label Stack 2 {1003, 3004, 4005} uses only node-SIDs and represents the ECMP-aware path RT1->RT3->RT4->RT5, where 1003 is the node SID of RT3.

When the node RT3 fails, the proxy forwarding TLV advertised by the RT2 is preferred to direct the traffic of the RT1 to the PLR node RT2. Node RT2 acts as a PLR node and queries the proxy forwarding table locally built for RT3. The path returned is the label forwarding path to RT3's next hop node RT4, which bypasses RT3. The specific steps are as follows:

a. RT1 swaps label 1003 to out-label 2003 to RT3.

b. RT2 receives the label forwarding packet whose top label of label stack is 2003, and searches for the local Routing Table, the behavior found is to lookup Proxy Forwarding table due to RT3 failure, RT2 pops label 2003.

c. RT2 uses 3004 as the in-label to lookup Proxy Forwarding table, The value of Map Label calculated based on SRGBDiffValue is 2004. and the query result is forwarding the packet to RT4.

d. Then RT2 queries the Routing Table to RT4, using the primary or backup path to RT4. The next hop is RT7.

e. RT2 forwards the packet to RT7. RT7 queries the local routing table to forward the packet to RT4.

f. After RT1 convergences, node SID 1003 is preferred to the proxy SID implied/advertised by RT2.

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