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Resilient MPLS Rings
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Abstract

This document describes the use of the MPLS control and data planes on ring topologies. It describes the special nature of rings, and proceeds to show how MPLS can be effectively used in such topologies. It describes how MPLS rings are configured, auto-discovered and signaled, as well as how the data plane works. Companion documents describe the details of discovery and signaling for specific protocols.

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].

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1. Introduction

Rings are a very common topology in transport networks. A ring is the simplest topology offering link and node resilience. Rings are nearly ubiquitous in access and aggregation networks. As MPLS

increases its presence in such networks, and takes on a greater role in transport, it is imperative that MPLS handles rings well; this is not the case today.

This document describes the special nature of rings, and the special needs of MPLS on rings. It then shows how these needs can be met in several ways, some of which involve extensions to protocols such as IS-IS [RFC5305], OSPF[RFC3630], RSVP-TE [RFC3209] and LDP [RFC5036]. RMR LSPs can also be signaled with SPRING [RFC8402]; that will be described in a future document.

The intent of this document is to handle rings that "occur naturally". Many access and aggregation networks in metros have their start as a simple ring. They may then grow into more complex topologies, for example, by adding parallel links to the ring, or by adding "express" links. The goal here is to discover these rings (with some guidance), and run MPLS over them efficiently. The intent is not to construct rings in a mesh network, and use those for protection.

1.1. Definitions

A (directed) graph G = (V, E) consists of a set of vertices (or nodes) V and a set of edges (or links) E. An edge is an ordered pair of nodes (a, b), where a and b are in V. (In this document, the terms node and link will be used instead of vertex and edge.)

A ring is a subgraph of G. A ring consists of a subset of n nodes {R_i, 0 <= i < n} of V. The directed edges {(R_i, R_i+1) and (R_i+1, R_i), 0 <= i < n-1} must be a subset of E (note that index arithmetic is done modulo n). We define the direction from node R_i to R_i+1 as "clockwise" (CW) and the reverse direction as "anticlockwise" (AC). As there may be several rings in a graph, we number each ring with a distinct ring ID RID.

```
                    R0 . . . R1
                  .             .
               R7                 R2
     Anti-     |  .       Ring       .  |
     Clockwise |  .                  .  | Clockwise
               v  .     RID = 17     .  v
               R6                 R3
                  .             .
                    R5 . . . R4
```

Figure 1: Ring with 8 nodes

The following terminology is used for ring LSPs:

Ring ID (RID): A non-negative number. When the RID identifies a ring, it must be positive and unique in some scope of a Service Provider's network. An RID of zero, when assigned to a node, indicates that the node must behave in "promiscuous mode" (see Section 3.2). A node may belong to multiple rings.

Ring node: A member of a ring. Note that a device may belong to several rings.

Node index: A logical numbering of nodes in a ring, from zero up to one less than the ring size. Used purely for exposition in this document.

Ring master: The ring master initiates the ring identification process. Mastership is indicated in the IGP by a two-bit field.

Ring neighbors: Nodes whose indices differ by one (modulo ring size).

Ring links: Links that connect ring neighbors.

Express links: Links that connect non-neighboring ring nodes.

Ring direction: A two-bit field in the IGP indicating the direction of a link. The choices are:

UN: 00 undefined link

CW: 01 clockwise ring link

AC: 10 anticlockwise ring link

EX: 11 express link

Ring Identification: The process of discovering ring nodes, ring links, link directions, and express links.

The following notation is used for ring LSPs:

R_k: A ring node with index k. R_k has AC neighbor R_(k-1) and CW neighbor R_(k+1).

RL_k: A (unicast) Ring LSP anchored on node R_k.

CL_jk: A label allocated by R_j for RL_k in the CW direction.

AL_jk: A label allocated by R_j for RL_k in the AC direction.

2. Motivation

A ring is the simplest topology that offers resilience. This is perhaps the main reason to lay out fiber in a ring. Thus, effective mechanisms for fast failover on rings are needed. Furthermore, there are large numbers of rings. Thus, configuration of rings needs to be as simple as possible. Finally, bandwidth management on access rings is very important, as bandwidth is generally quite constrained here.

The goals of this document are to present mechanisms for improved MPLS-based resilience in ring networks (using ideas that are reminiscent of Bidirectional Line Switched Rings), for automatic bring-up of LSPs, better bandwidth management and for auto-hierarchy. These goals can be achieved using extensions to existing IGP and MPLS signaling protocols, using central provisioning, or in other ways.

3. Theory of Operation

Say a ring has ring ID RID. The ring is provisioned by choosing one or more ring masters for the ring and assigning them the RID. Other nodes in the ring may also be assigned this RID, or may be configured as "promiscuous". Ring discovery then kicks in. When each ring node knows its CW and AC ring neighbors and its ring links, and all express links have been identified, ring identification is complete.

Once ring identification is complete, each node signals one or more ring LSPs RL_i. RL_i, anchored on node R_i, consists of two counter-rotating unicast LSPs that start and end at R_i. A ring LSP is "multipoint": any node R_j can use RL_i to send traffic to R_i; this can be in either the CW or AC directions, or both (i.e., load balanced). Both of these counter-rotating LSPs are "active"; the choice of direction to send traffic to R_i is determined by policy at the node where traffic is injected into the ring. The default policy is to send traffic along the shortest path. Bidirectional connectivity between nodes R_i and R_j is achieved by using two different ring LSPs: R_i uses RL_j to reach R_j, and R_j uses RL_i to reach R_i.

3.1. Provisioning

The goal here is to provision rings with the absolute minimum configuration. The exposition below aims to achieve that using auto-discovery via a link-state IGP (see Section 4). Of course, auto-discovery can be overriden by configuration. For example, a link that would otherwise be classified by auto-discovery as a ring link might be configured not to be used for ring LSPs.

3.2. Ring Nodes

Ring nodes have a loopback address, and run a link-state IGP and an MPLS signaling protocol. To provision a node as a ring node for ring RID, the node is simply assigned that RID. A node may be part of several rings, and thus may be assigned several ring IDs.

To simplify ring provisioning even further, a node N may be made "promiscuous" by being assigned an RID of 0. A promiscuous node listens to RIDs in its IGP neighbors' link-state updates. For every non-zero RID N hears from a neighbor, N joins the corresponding ring by taking on that RID. In many situations, the use of promiscuous mode means that only one or two nodes in a ring needs to be provisioned; everything else is auto-discovered.

A ring node indicates in its IGP updates the ring LSP signaling protocols it supports. This can be LDP and/or RSVP-TE. Ideally, each node should support both.

3.3. Ring Links and Directions

Ring links must be MPLS-capable. They are by default unnumbered, point-to-point (from the IGP point of view) and "auto-bundled". The "auto-bundled" attribute means that parallel links between ring neighbors are considered as a single link, without the need for explicit configuration for bundling (such as a Link Aggregation Group). Note that each component may be advertised separately in the IGP; however, signaling messages and labels across one component link apply to all components. Parallel links between a pair of ring nodes is often the result of having multiple lambdas or fibers between those nodes. RMR is primarily intended for operation at the packet layer; however, parallel links at the lambda or fiber layer result in parallel links at the packet layer.

A ring link is not provisioned as belonging to the ring; it is discovered to belong to ring RID if both its adjacent nodes belong to RID. A ring link's direction (CW or AC) is also discovered; this process is initiated by the ring's ring master. Note that the above two attributes can be overridden by provisioning if needed; it is then up to the provisioning system to maintain consistency across the ring.

3.3.1. Express Links

Express links are discovered once ring nodes, ring links and directions have been established. As defined earlier, express links are links joining non-neighboring ring nodes; often, this may be the result of optically bypassing ring nodes.

3.4. Ring LSPs

Ring LSPs are not provisioned. Once a ring node R_i knows its RID, its ring links and directions, it kicks off ring LSP signaling automatically. R_i allocates CW and AC labels for each ring LSP RL_k. R_i also initiates the creation of RL_i. As the signaling propagates around the ring, CW and AC labels are exchanged. When R_i receives CW and AC labels for RL_k from its ring neighbors, primary and fast reroute (FRR) paths for RL_k are installed at R_i. More details are given in Section 5.

For RSVP-TE LSPs, bandwidths may be signaled in both directions. However, these are not provisioned either; rather, one does "reverse call admission control". When a service needs to use an LSP, the ring node where the traffic enters the ring attempts to increase the bandwidth on the LSP to the egress. If successful, the service is admitted to the ring.

3.5. Installing Primary LFIB Entries

In setting up RL_k, a node R_j sends out two labels: CL_jk to R_j-1 and AL_jk to R_j+1. R_j also receives two labels: CL_j+1,k from R_j+1, and AL_j-1,k from R_j-1. R_j can now set up the forwarding entries for RL_k. In the CW direction, R_j swaps incoming label CL_jk with CL_j+1,k with next hop R_j+1; these allow R_j to act as LSR for RL_k. R_j also installs an LFIB entry to push CL_j+1,k with next hop R_j+1 to act as ingress for RL_k. Similarly, in the AC direction, R_j swaps incoming label AL_jk with AL_j-1,k with next hop R_j-1 (as LSR), and an entry to push AL_j-1,k with next hop R_j-1 (as ingress).

Clearly, R_k does not act as ingress for its own LSPs. However, R_k can send OAM messages, for example, an MPLS ping or traceroute ([I-D.ietf-mpls-rfc4379bis]), using labels CL_k,k+1 and AL_k-1,k, to test the entire ring LSP anchored at R_k in both directions. Furthermore, if these LSPs use Ultimate Hop Popping, then R_k installs LFIB entries to pop CL_k,k for packets received from R_k-1 and to pop AL_k,k for packets received from R_k+1.

3.6. Protection

In this scheme, there are no protection LSPs as such -- no node or link bypass LSPs, no standby LSPs, no detours, and no LFA-type protection. Protection is via the "other" direction around the ring, which is why ring LSPs are in counter-rotating pairs. Protection works in the same way for link, node and ring LSP failures.

If a node R_j detects a failure from R_j+1 -- either all links to R_j+1 fail, or R_j+1 itself fails, R_j switches traffic on all CW ring LSPs to the AC direction using the FRR LFIB entries. If the failure is specific to a single ring LSP, R_j switches traffic just for that LSP. In either case, this switchover can be very fast, as the FRR LFIB entries can be preprogrammed. Fast detection and fast switchover lead to minimal traffic loss.

R_j then sends an indication to R_j-1 that the CW direction is not working, so that R_j-1 can similarly switch traffic to the AC direction. For RSVP-TE, this indication can be a PathErr or a Notify; other signaling protocols have similar indications. These indications propagate AC until each traffic source on the ring AC of the failure uses the AC direction. Thus, within a short period, traffic will be flowing in the optimal path, given that there is a failure on the ring. This contrasts with (say) bypass protection, where until the ingress recomputes a new path, traffic will be suboptimal.

Note that the failure of a node or a link will not necessarily affect all ring LSPs. Thus, it is important to identify the affected LSPs (and switch them), but to leave the rest alone.

One point to note is that when a ring node, say R_j, fails, RL_j is clearly unusable. However, the above protection scheme will cause a traffic loop: R_j-1 detects a failure CW, and protects by sending CW traffic on RL_j back all the way to R_j+1, which in turn sends traffic to R_j-1, etc. There are three proposals to avoid this:

1. Each ring node acting as ingress sends traffic with a TTL of at most 2*n, where n is the number of nodes in the ring.

2. A ring node sends protected traffic (i.e., traffic switched from CW to AC or vice versa) with TTL just large enough to reach the egress.

3. A ring node sends protected traffic with a special purpose label below the ring LSP label. A protecting node first checks for the presence of this label; if present, it means that the traffic is looping and MUST be dropped.

It is recommended that (2) be implemented. The other methods are optional.

3.7. Installing FRR LFIB Entries

At the same time that R_j sets up its primary CW and AC LFIB entries, it can also set up the protection forwarding entries for RL_k. In the CW direction, R_j sets up an FRR LFIB entry to swap incoming label CL_jk with AL_j-1,k with next hop R_j-1. In the AC direction, R_j sets up an FRR LFIB entry to swap incoming label AL_jk with CL_j+1,k with next hop R_j+1. Again, R_k does not install FRR LFIB entries in this manner.

4. Autodiscovery

4.1. Overview

Auto-discovery proceeds in three phases. The first phase is the announcement phase. The second phase is the mastership phase. The third phase is the ring identification phase.

```
               S1
              /   \
             |     R0 . . . R1          R0 has MV = 11
             |  .    \        .         R1 has MV = 10
             R7       \________ R2      All other nodes have MV = 00
Anti-     |  .                   .  |
clockwise |  .        Ring       .  | Clockwise
          v  .      RID = 17     .  v
             R6                  R3
                .             .
                  R5 . . . R4
                    \      /
                     \    /
                       An
```

Figure 2: Ring with non-ring nodes and links

The format of an RMR Node Type-Length-Value (TLV) is given below. It consists of information pertaining to the node and optionally, sub-TLVs. A Neighbor sub-TLV contains information pertaining to the node's neighbors. Other sub-TLVs may be defined in the future. Details of the format specific to IS-IS and OSPF will be given in the corresponding IGP documents.

```
[RMR Node Type][RMR Node Length][RID][Node Flags][sub-TLVs]
```

Ring Node TLV Format

```
          [RMR Nbr Type][RMR Nbr Length][Nbr Address][Nbr Flags]

                       Ring Neighbor Sub-TLV Format

     0                   1
     0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |MV | SS  | SO  |  MBZ    |SU |M|
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    MV: Mastership Value
    SS: Supported Signaling Protocols
        (100 = RSVP-TE; 010 = LDP; 001 = SPRING)
    MBZ: Must be zero
    SO: Supported OAM Protocols (100 = BFD; 010 = CFM; 001 = EFM)
    SU: Signaling Protocol to Use  (00 = none; 01 = LDP; 10 = RSVP-TE)
    M : Elected Master (0 = no, 1 = yes)

                         Flags for a Ring Node TLV

     0                   1
     0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |RD |OAM|          MBZ          |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    RD:  Ring Direction
    OAM: OAM Protocol to use (00 = none; 01 = BFD; 10 = CFM; 11 = EFM)
    MBZ: Must be zero

                       Flags for a Ring Neighbor TLV
```

4.2. Ring Announcement Phase

Each node participating in an MPLS ring is assigned an RID; in the example, RID = 17. A node is also provisioned with a mastership value. Each node advertises a ring node TLV for each ring it is participating in, along with the associated flags. It then starts timer T1; this timer is to allow each node time to hear from all other nodes in the ring.

A node in promiscuous mode doesn't advertise any ring node TLVs. However, when it hears a ring node TLV from an IGP neighbor, it joins that ring, and sends its own ring node TLV with that RID.

The announcement phase allows a ring node to discover other ring nodes in the same ring so that a ring master can be elected.

4.3. Mastership Phase

When timer T1 fires, a node enters the mastership phase. In this phase, each ring node N starts timer T2 and checks if it is master. If it is the node with the lowest loopback address of all nodes with the highest mastership values, N declares itself master by readvertising its ring node TLV with the M bit set.

When timer T2 fires, each node examines the ring node TLVs from all other nodes in the ring to identify the ring master. There should be exactly one; if not, each node restarts timer T2 and tries again.

Barring software bugs or malicious code, the principal reason for multiple nodes for setting their M bit is late-arriving ring announcements. Say nodes N1 and N2 have the highest mastership values, and N1 has the lowest loopback address, while N2 has the second lowest loopback address. If N1 makes its ring announcement just as N2's T1 timer fires, both N1 and N2 will think they are the master (since N2 will not have heard N1's announcment in time). However, in the next round, N2 will realize that N1 is indeed the master. In the worst case, the mastership phase will occur as many times as there are nodes in the ring.

4.4. Ring Identification Phase

When there is exactly one ring master M, M enters the Ring Identification Phase. M indicates that it has successfully completed this phase by advertising ring link TLVs. This is the trigger for M's CW neighbor to enter the Ring Identification Phase. This phase passes CW until all ring nodes have completed ring identification.

In the Ring Identification Phase, a node X that has two or more IGP neighbors that belong to the ring picks one of them to be its CW ring neighbor. If X is the ring master, it also picks a node as its AC ring neighbor. If there are exactly two such nodes, this step is trivial. If not, X computes a ring that includes all nodes that have completed the Ring Identification Phase (as seen by their ring link TLVs) and further contains the maximal number of nodes that belong to the ring. Based on that, X picks a CW neighbor and inserts ring link TLVs with ring direction CW for each link to its CW neighbor; X also inserts a ring link TLV with direction AC for each link to its AC neighbor. Then, X determines its express links. These are links connected to ring nodes that are not ring neighbors. X advertises ring link TLVs for express links by setting the link direction to "express link".

4.5. Ring Changes

The main changes to a ring are:

ring link addition;

ring link deletion;

ring node addition; and

ring node deletion.

The main goal of handling ring changes is (as much as possible) not to perturb existing ring operation. Thus, if the ring master hasn't changed, all of the above changes should be local to the point of change. Link adds just update the IGP; signaling should take advantage of the new capacity as soon as it learns. Link deletions in the case of parallel links also show up as a change in capacity (until the last link in the bundle is removed.)

The removal of the last ring link between two nodes, or the removal of a ring node is an event that triggers protection switching. In a simple ring, the result is a broken ring. However, if a ring has express links, then it may be able to converge to a smaller ring with protection.

The addition of a new ring node can also be handled incrementally.

5. Ring Signaling

The ring LSP signaling procedures will be described in separate documents describing signaling solution options.

6. Ring OAM

Each ring node should advertise in its ring node TLV the OAM protocols it supports. Each ring node is expected to run a link-level OAM over each ring link. This should be an OAM protocol that both neighbors agree on. The default hello time is 3.3 millisecond.

Each ring node also sends OAM messages over each direction of its ring LSP. This is a multi-hop OAM to check LSP liveness; typically, BFD would be used for this. The node chooses the hello interval; the default is once a second.

7. Advanced Topics

7.1. Half-rings

In some cases, a ring H may be incomplete, either because H is permanently missing a link (not just because of a failure), or because the link required to complete H is in a different IGP area. Either way, the ring discovery algorithm will fail. We call such a ring a "half-ring". Half-rings are sufficiently common that finding a way to deal with them effectively is a useful problem to solve. This topic will not be addressed in this document; that task is left for a future document.

7.2. Hub Node Resilience

Let's call the node(s) that connect a ring to the rest of the network "hub node(s)" (usually, there are a pair of hub nodes.) Suppose a ring has two hub nodes H1 and H2. Suppose further that a non-hub ring node X wants to send traffic to some node Z outside the ring. This could be done, say, by having targeted LDP (T-LDP) sessions from H1 and H2 to X advertising LDP reachability to Z via H1 (H2); there would be a two-label stack from X to reach Z. Say that to reach Z, X prefers H1; thus, traffic from X to Z will first go to H1 via a ring LSP, then to Z via LDP.

If H1 fails, traffic from X to Z will drop until the T-LDP session from H1 to Z fails, the IGP reconverges, and H2's label to Z is chosen. Thereafter, traffic will go from X to H2 via a ring LSP, then to Z via LDP. However, this convergence could take a long time. Since this is a very common and important situation, it is again a useful problem to solve. However, this topic too will not be addressed in this document; that task is left for a future document.

8. Security Considerations

This document presents a new method of using MPLS in rings. The use of MPLS in rings is not new, so this per se does not pose security concerns. The question is, rather, whether the extensions to protocols suggested here do so. IS-IS and OSPF have security mechanisms that ensure secure exchange of information, as do RSVP-TE and LDP. The extensions proposed here are protected by the same mechanisms.

One can also ask whether the semantic content of these extensions can be used to compromise a network or initiate a denial-of-service attack. To do so would require either compromising the control plane processing these requests, or manipulating the content of the messages. The former is outside the scope of this document; the

latter is addressed by the security mechanisms of the underlying protocols.

9. Acknowledgments

Many thanks to Pierre Bichon whose exemplar of self-organizing networks and whose urging for ever simpler provisioning led to the notion of promiscuous nodes.

10. IANA Considerations

There are no requests as yet to IANA for this document.

11. References

11.1. Normative References

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