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Point-to-Multipoint Transport Using Chain Replication in Segment Routing
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Abstract

This document specifies a point-to-multipoint (P2MP) transport mechanism based on chain replication. It can be used in segment routing to achieve traffic optimization for multicast.

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1. Introduction

The Segment Routing Architecture [RFC8402] describes segment routing (SR) and its instantiation in two data planes, i.e. MPLS and IPv6. In SR, point-to-multipoint (P2MP) transport is currently achieved by using ingress replication, where a point-to-point (P2P) SR tunnel is constructed from a root node to each leaf node, and every ingress packet is replicated and sent via a bundle of such P2P SR tunnels to all the leaf nodes. Although this approach provides P2MP reachability, it does not consider traffic optimization across the tunnels, as the path of each tunnel is computed or decided independently.

An alternative approach would be to use P2MP-tree based transport. Such approach can achieve maximum traffic optimization, but it relies a controller or path computation element (PCE) to provision and manage "replication segments" on branch nodes. The replication segments are essentially P2MP-tree state (i.e. transport tunnel state) on transit routers. Therefore, this approach is not fully aligned with SR's principles of single-point provisioning (at ingress routers and border routers) and stateless core network.

This document introduces a new solution for P2MP transport in SR, based on "chain replication". In this solution, P2MP transport is achieved by constructing a set of "P2MP chain tunnels" (or simply "P2MP chains") from a root node to leaf nodes. Each P2MP chain is a single-path tunnel, with a leaf node at tail end and some transit leaf nodes along the path, resembling a chain. The leaf node at the tail end behaves as a normal receiver. Each transit leaf node replicates a packet once for local processing off the chain, and also forwards the original packet down the chain. The root node replicates and sends packets via the set of P2MP chains to all the leaf nodes.

As a P2MP chain can reach multiple leaf nodes, it is considered more optimal than the multiple P2P tunnels which would be needed by ingress replication. Compared with ingress replication and the P2MP-tree based approach, this solution can achieve transport efficiency in general, while maintaining the simplicity of SR, including single-point provisioning and stateless core.

2. Specification of Requirements

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] and [RFC8174].

3. Applicability

The P2MP transport mechanism in this document is generally applicable to all networks. However, it benefits more for certain types of topologies than others. These topologies include ring topologies, linear topologies, topologies with leaf nodes concentrated in geographical sites which can be modeled as leaf groups, etc.

The mechanism is stateless in the core of a network. It is transparent to all transit routers. Leaf nodes intended to take advantage of the mechanism will need to support the new forwarding behavior specified in this document. For other leaf nodes, the mechanism has a backward compatibility to allow them to be reached by P2P tunnels using ingress replication. Path computation and P2MP chain construction will need to be supported by a controller or root nodes, depending on where they are performed.

The mechanism is applicable to both SR-MPLS [RFC8660] and SRv6 [SRv6-SRH], [SRv6-Programming].

The mechanism does not create any state of P2MP tunnel or P2MP tree on routers. Therefore, if leaf nodes need to know the service level

context (e.g. source, VPN) of a P2MP stream, they must rely on the information contained in packet headers (or inner headers). In SR-MPLS, service labels may be allocated from a domain-wide common block (DCB) to serve as globally unique context indicators. In SRv6, a root node's IP address or an upstream-assigned context indicator may be encoded in the source address of IPv6 header, or a downstream-assigned context indicator may be encoded in the ARG portion of a service SID.

This document introduces a new type of segments, called bud segments (Section 4.1). The segments are generic in nature. They may be used in cases other than P2MP transport, such as traffic mirroring and monitoring, OAM, etc. These use cases are out of the scope of this document.

4. P2MP Transport Using Chain Replication

In this document, a P2MP stream associated with a root node and a set of leaf nodes is denoted as {root node, leaf nodes}. It is achieved by using a bundle of P2MP chains covering all the leaf nodes. Each P2MP chain is a single-path tunnel starting from the root node and reaching one or multiple leaf nodes along the path. The tail-end node of the P2MP chain is a leaf node, called a "tail-end" leaf node. Each leaf node traversed by the P2MP chain is called a "transit" leaf node. As a special case, a P2MP chain may have no transit leaf node, but only a tail-end leaf node, essentially becoming a P2P tunnel of ingress replication.

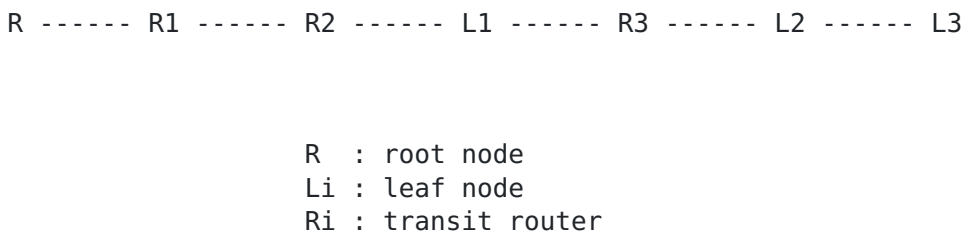

Figure 1

A tail-end leaf node and a transit leaf nodes have different behaviors when processing a received packet. In particular, a tail-end leaf node processes the packet as a normal receiver. A transit leaf node not only processes the packet as a receiver, but also forwards it downstream along the P2MP chain, hence acting as a "bud node". To achieve this, the transit leaf node needs to replicate the packet, producing two packets, one for forwarding and the other for local processing. Such packet replication happens on every transit

leaf node along a P2MP chain. Therefore, it is called "chain replication".

This document introduces a new type of segments, called "bud segments", to facilitate the above packet processing on transit leaf nodes. The segment ID (SID) of a bud segment is a "bud-SID".

4.1. Bud Segment

On a transit leaf node, a bud segment represents the following instructions for forwarding hardware to execute on a received packet P. They apply when the active SID of the packet P is the bud-SID of this bud segment.

[1] Replicate the packet P to generate a copy P1.

[2] For P, perform a NEXT operation on the bud-SID, make the next SID active, and forward the packet based on that SID.

[3] For P1, perform a sequence of NEXT operations on the bud-SID and all the subsequent SIDs of the P2MP chain, and process the packet locally. (The SIDs of the P2MP chain are not useful for processing P1 locally. Hence, they are removed before the processing.)

Bud segments are global segments of leaf nodes. They are routable segments via topological shortest-paths. Bud-SIDs are allocated from SRGB (SR global block). Only one bud segment is needed per leaf node, and per SR-MPLS or SRv6. It is used only when the leaf node is a transit leaf node on a P2MP chain.

In SR-MPLS, bud-SIDs are labels, and penultimate hop popping (PHP) MUST be disabled for bud-SID labels. In SRv6, bud-SIDs are IPv6 addresses explicitly associated with bud segments. Therefore, the above instructions [1] to [3] are achieved in different ways in SR-MPLS and SRv6:

(a) In SR-MPLS, the packet may have a service label(s) after P2MP chain labels in MPLS header, e.g. a VPN label, a bridge domain label, a source Ethernet segment label, etc. Therefore, the bud segment MUST have a way to identify the position of the last P2MP chain label, in order to execute [3] above. This document introduces an "end-of-chain" (EoC) label to facilitate the process. The EoC label is an extended special-purpose label (ESPL) [RFC 7274] with value TDB. When a root node constructs an MPLS header for a packet, if the packet has a service label(s), the root node MUST push the Extension Label (XL, value 15) and the EoC label, after pushing the service label(s) and before pushing

P2MP chain labels. Hence, [XL, EoC] serve as a recognizable pattern to indicate the end of the P2MP chain labels. If the packet does not have a service label(s), its MPLS header will contain P2MP chain labels only, and the root node SHOULD NOT push [XL, EoC] to the MPLS header. In any case, in [3] above, the bud segment MUST pop labels until [XL, EoC] are popped or all labels have been popped.

(b) In SRv6, the packet is encapsulated with an outer IPv6 header corresponding to the P2MP chain, optionally followed by a segment routing header (SRH) containing the SIDs of the P2MP chain, and followed by an inner header (of IPv4, IPv6, MPLS, layer-2, etc.) associated with a service. In [3] above, the bud segment SHOULD simply remove the outer IPv6 header and the SRH (if any), and leave the packet with the inner header to local processing.

Bud segments are shared by all P2MP streams, i.e. all combinations of {root node, leaf nodes}. A leaf node SHOULD advertise a bud segment for SR-MPLS, if its forwarding hardware supports the above SR-MPLS processing. Likewise, it SHOULD advertise a bud segment for SRv6, if its forwarding hardware supports the above SRv6 processing. The advertisement may be via a protocol, e.g. ISIS, OSPF, or BGP. The advertisement allows the leaf node to be considered as a transit leaf node on a P2MP chain. If a leaf node does not advertise a bud segment, it can only be considered as a tail-end leaf node on a P2MP chain, or reached via a P2P tunnel using ingress replication.

4.2. P2MP Chain

Construction of P2MP chains for a P2MP stream is performed by a controller or the root node based on configuration or path computation (Section 5). This decides the number of P2MP chains to use, and the set of leaf nodes that each P2MP chain reaches. In general, if the leaf nodes of the P2MP stream cannot be covered by using a single P2MP chain, multiple P2MP chains MUST be used, and the root node MUST replicate ingress packets over the P2MP chains.

The path of a P2MP chain is a single path traversing one or multiple transit leaf nodes and terminating at a tail-end leaf node. Between the root node and the first transit leaf node, and between two consecutive leaf nodes, there may be none, one, or multiple transit routers.

The path is then translated to a SID list to be programmed on the root node. In the SID list, each transit leaf node has its bud-SID in a corresponding position. Given a P2MP chain to a set of leaf nodes in the order of L1, L2, ..., Ln, the SID list may be represented as:

<SID_11, SID_12, ...>, bud-SID of L1, ..., <SID_i1, SID_i2, ...>, bud-SID of Li, ..., <SID_n1, SID_n2, ...>

Where:

- <SID_11, SID_12, ...> is the sub-path from the root node to L1.
- <SID_i1, SID_i2, ...> is the sub-path from Li-1 to Li.
- <SID_n1, SID_n2, ...> is the sub-path from Ln-1 to Ln. There is no need for Ln's bud-SID to be at the end of the SID list, because the tail-end leaf node does not perform a chain replication.

Each of the above sub-paths is a regular point-to-point path. The SIDs in the sub-path are regular SIDs, such as adjacency-SIDs, node-SIDs, binding-SIDs, etc. A sub-path from Li-1 to Li may have an empty SID list, if the sub-path takes the shortest path indicated by the bud-SID of Li.

The root node then applies the SID list to packets, by using the encapsulation procedure of SR-MPLS or SRv6. Note that in an SR-MPLS case where a service label(s) applies, the service label(s) is pushed to an MPLS header first, then [XL, EoC] are pushed, and finally the labels of the SID list are pushed. This also places a requirement on the tail-end leaf node to handle [XL, EoC]. On the tail-end leaf node, a received MPLS header may have either [XL, EoC] at the top, or the node's node-SID label at the top, followed by [XL, EoC]. In the latter case, [XL, EoC] will be exposed to the top after the node-SID label is popped. In either case, the node MUST pop [XL, EoC] and continue to process the next label, i.e. the service label.

4.3. Example

In the following example, P2MP transport is needed from the root node R, to leaf nodes L1, L2, L3 and L4.

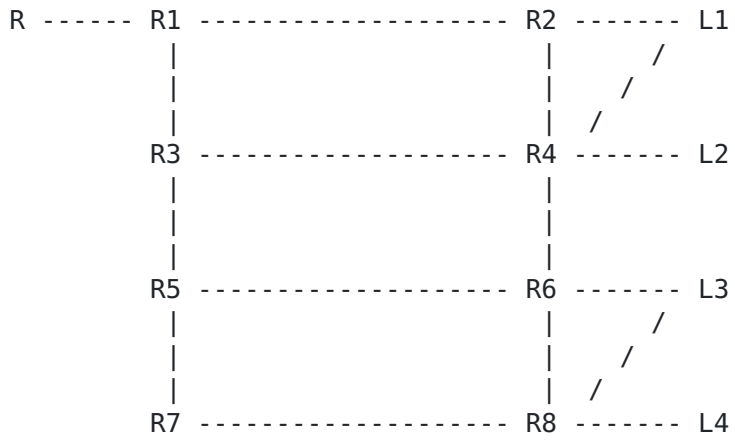

Figure 2

Path computation results in two P2MP chains:

P2MP chain 1:

Path: R -> R1 -> R2 -> L1 -> R4 -> L2, where L1 is a transit leaf node, and L2 is the tail-end leaf node.

Assuming that the sub-path R -> R1 -> R2 -> L1 is not the shortest path from R to L1, so that an explicit sub-path must be used. Also assuming that the sub-path L1 -> R4 -> L2 is the shortest path from L1 to L2, so that the node-SID of L2 can be used to represent this sub-path. The segment list applied to packets on R is:

adj-SID 100 - link from R to R1

adj-SID 200 - link from R1 to R2

adj-SID 300 - link from R2 to L1

bud-SID 1000 - L1

node-SID 2000 - L2

P2MP chain 2:

Path: R -> R1 -> R3 -> R5 -> R6 -> L3 -> R8 -> L4, where L3 is a transit leaf node, and L4 is the tail-end leaf node.

Assuming that the sub-path R -> R1 -> R3 -> R5 -> R6 -> L3 is the shortest path from R to L3, so that the bud-SID of L3 can

be used to represent this sub-path. Also assuming that the sub-path L3 -> R8 -> L4 is not the shortest path from L3 to L4, so that an explicit sub-path must be used. The segment list applied to packets on R is:

bud-SID 3000 - L3

adj-SID 600 - link from L3 to R8

adj-SID 700 - link from R8 to L4

node-SID 4000 - L4

5. Path Computation for P2MP Chains

P2MP chain path computation for a P2MP stream {root node, leaf nodes} may be performed by a controller or the root node. P2MP chains are single-path tunnels. In general, any P2P path computation algorithm may be extended to serve the purpose. This document does not enforce a particular algorithm.

The path computation may consider general metric for shortest paths, or traffic engineering (TE) constraints for TE paths. In addition, this document also considers the following constraints:

- Maximum hops per P2MP chain. This SHOULD be based on the maximum delay allowed for a packet to accumulate before reaching a tail-end leaf node.

- Maximum length of SID list. This SHOULD be based on the maximum header size which a root node may apply to a packet. This is typically a limit of forwarding hardware. Note that a SID list is translated from a computed path. Hence, the SID list's length and the path's hop count are not necessarily the same.

- Maximum leaf nodes per P2MP chain. This may be used to restrict the length of each P2MP chain.

- Maximum hops between two consecutive leaf nodes. This may be used avoid a sparse chain, where an excessive distance between two consecutive leaf nodes will cause a P2MP chain's efficiency to degrade.

- Maximum number of times that a node or link may be traversed by a P2MP chain. This may be used to prevent a node or link from being congested by duplicate traffic.

The path computation is generally deterministic in a ring or linear topology. In an arbitrary topology, the path computation may be more controllable by dividing leaf nodes into groups based on geographic location or policies, and computing a separate path for each group. A leaf group may be defined as a sequence (i.e. ordered) or set (i.e. unordered) of leaf nodes, which are treated as loose hops in path computation.

6. Protocol Extensions for Bud Segment

The protocol extensions of ISIS, OSPF, and BGP for bud segment advertisement will be specified in the next version of this document.

7. Special Purpose Bud Segments

So far, the discussion in this document has been focusing on bud segments that are created on a per SR-MPLS or SRv6 basis on each leaf node. These bud segments indicate generic local processing which is completely based on the inner header of a packet, i.e. after all the SIDs of a P2MP chain are removed by the instruction [3] in Section 4.1. They are applicable to common P2MP transport cases, and hence are considered as the default and general purpose bud segments.

The concept of bud segment can also be extended to other cases, where a transit leaf node needs to perform a special kind of local processing for packets, but cannot derive the context from the inner headers of the packets. For example, the node may need to forward the packets over a particular interface or tunnel to some device(s), or to process the packets based on a particular forwarding table or policy, and so on. In such cases, a dedicated bud segment may be created for each special local processing, indicating the context. The bud segment is called a special purpose bud segment.

Note that the scaling of special purpose bud segments per leaf node SHOULD be a consideration in network design, as well as the requirement for a controller or ingress router to learn all the special purpose bud segments in a network and apply them in P2MP chain construction.

8. IANA Considerations

This document requires IANA to allocate a value from the "Extended Special-Purpose MPLS Label Values" registry for the EoC label.

The document also requires IANA registration and allocation for the ISIS, OSPF and BGP extensions for bud segment advertisement. The details will be provided in the next version of this document.

9. Security Considerations

This document introduces bud segments for leaf nodes to act as both packet receivers and transit routers. A security attack may target on a leaf node by constructing malicious packets with the node's bud-SID. Such kind of attacks can be defeated by restricting bud segment distribution and P2MP chain construction within the scope of a controller and a given network.

10. Acknowledgements

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