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Entropy label for SPRING tunnels
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Abstract

Segment Routing (SR) leverages the source routing paradigm. A node steers a packet through an ordered list of instructions, called segments. Segment Routing can be applied to the Multi Protocol Label Switching (MPLS) data plane. Entropy label (EL) is a technique used in MPLS to improve load-balancing. This document examines and describes how ELs are to be applied to Segment Routing MPLS.

Status of This Memo

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1. Introduction

Segment Routing [I-D.ietf-spring-segment-routing] is based on source routed tunnels to steer a packet along a particular path. This path is encoded as an ordered list of segments. When applied to the MPLS dataplane [I-D.ietf-spring-segment-routing-mpls], each segment is an LSP with an associated MPLS label value. Hence, label stacking is used to represent the ordered list of segments and the label stack associated with an SR tunnel can be seen as nested LSPs (LSP hierarchy) in the MPLS architecture.

Using label stacking to encode the list of segment has implications on the label stack depth.

Traffic load-balancing over ECMP (Equal Cost MultiPath) or LAGs (Link Aggregation Groups) is usually based on a hashing function. The local node who performs the load-balancing is required to read some header fields in the incoming packets and then computes a hash based on these fields. The result of the hash is finally mapped to a list of outgoing nexthops. The hashing technique is required to perfom a per-flow load-balancing and thus prevent packet disordering. For IP traffic, the usual fields that are looked up are the source address, the destination address, the protocol type, and, if the upper layer is TCP or UDP, the source port and destination port can be added as well in the hash.

The MPLS architecture brings some challenges on the load-balancing as an LSR (Label Switch Router) should be able to look at header fields that are beyond the MPLS label stack. An LSR must perform a deeper inspection compared to an ingress router which could be challenging for some hardware. Entropy label (EL) [RFC6790] is a technique used in the MPLS data plane to provide entropy for load-balancing. The idea behind entropy label is that the ingress router computes a hash based on several fields from a given packet and place the result in an additional label, named "entropy label". When using entropy label, an LSR is only required to hash on the MPLS label stack or solely on the entropy label to get a full benefit of load-balancing; deep hashing is not required anymore.

When using LSP hierarchies, there are implications on how [RFC6790] should be applied. The current document addresses the case where a hierarchy is created at a single LSR as required by Segment Routing.

A use-case requiring load-balancing with SR is given in Section 3. A recommended solution is described in Section 7 keeping in consideration the limitations of implementations when applying [RFC6790] to deeper label stacks. Options that were considered to arrive at the recommended solution are documented for historical purposes in Section 10.

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

2. Abbreviations and Terminology

EL - Entropy Label

ELI - Entropy Label Identifier

ELC - Entropy Label Capability

ERLD - Entropy Readable Label Depth

SR - Segment Routing

ECMP - Equal Cost Multi Path

LSR - Label Switch Router

MPLS - Multiprotocol Label Switching

MSD - Maximum SID Depth

SID - Segment Identifier

RLD - Readable Label Depth

OAM - Operation, Administration and Maintenance

3. Use-case requiring multipath load-balancing

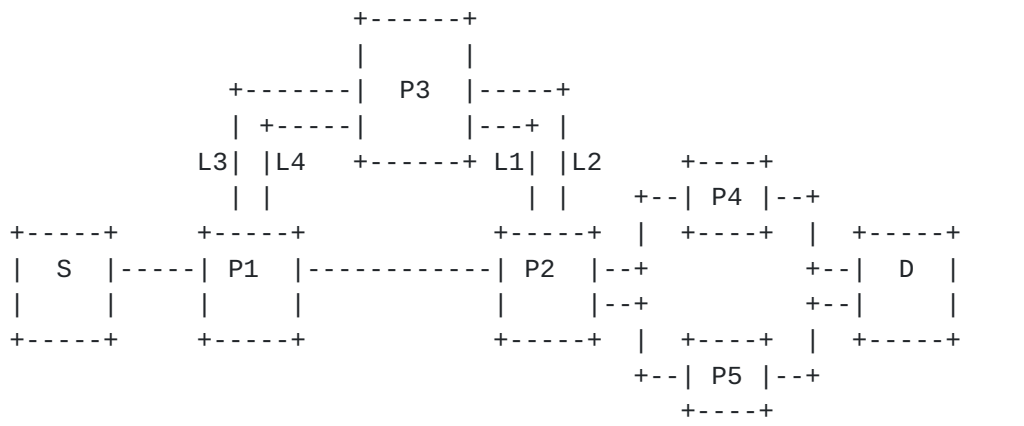


Figure 1: Traffic engineering use-case

Traffic-engineering is one of the applications of MPLS and is also a requirement for source routed tunnels with label stacks [RFC7855]. Consider the topology shown in Figure 1. The LSR S requires data to be sent to LSR D along a traffic-engineered path that goes over the link L1. Good load-balancing is also required across equal cost paths (including parallel links). To engineer traffic along a path that takes link L1, the label stack that LSR S creates consists of a label to the node SID of LSR P3, stacked over the label for the adjacency SID of link L1 and that in turn is stacked over the label to the node SID of LSR D. For simplicity lets assume that all LSRs use the same label space (SRGB) for source routed label stacks. Let L_N-Px denote the label to be used to reach the node SID of LSR Px. Let L_A-Ln denote the label used for the adjacency SID for link Ln. The LSR S must use the label stack <L_N-P3, L_A-L1, L_N-D> for traffic-engineering. However to achieve good load-balancing over the equal cost paths P2-P4-D, P2-P5-D and the parallel links L3, L4, a mechanism such as Entropy labels [RFC6790] should be adapted for source routed label stacks. Indeed, the SPRING architecture with the MPLS dataplane ([I-D.ietf-spring-segment-routing-mpls]) uses nested MPLS LSPs composing the source routed label stacks.

An MPLS node may have limitations in the number of labels it can push. It may also have a limitation in the number of labels it can inspect when looking for hash keys during load-balancing. While entropy label is normally inserted at the bottom of the transport tunnel, this may prevent an LSR to take into account the EL in its load-balancing function if the EL is too deep in the stack. In a segment routing environment, it is important to define the considerations that needs to be taken into account when inserting EL. Multiple ways to apply entropy labels were considered and are

documented in Section 10 along with their trade-offs. A recommended solution is described in Section 7.

4. Entropy Readable Label Depth

The Entropy Readable Label Depth (ERLD) is defined as the number of labels a router can both:

a. Read in an MPLS packet received on its incoming interface(s) (starting from the top of the stack).

b. Use in its load-balancing function.

The ERLD means that the router will perform load-balancing using the EL label if the EL is placed within the ERLD first labels.

A router capable of reading N labels but not using an EL located within those N labels MUST consider its ERLD to be 0. In a distributed switching architecture, each linecard may have a different capability in terms of ERLD. For simplicity, an implementation MAY use the minimum ERLD between each linecard as the ERLD value for the system.

Examples:

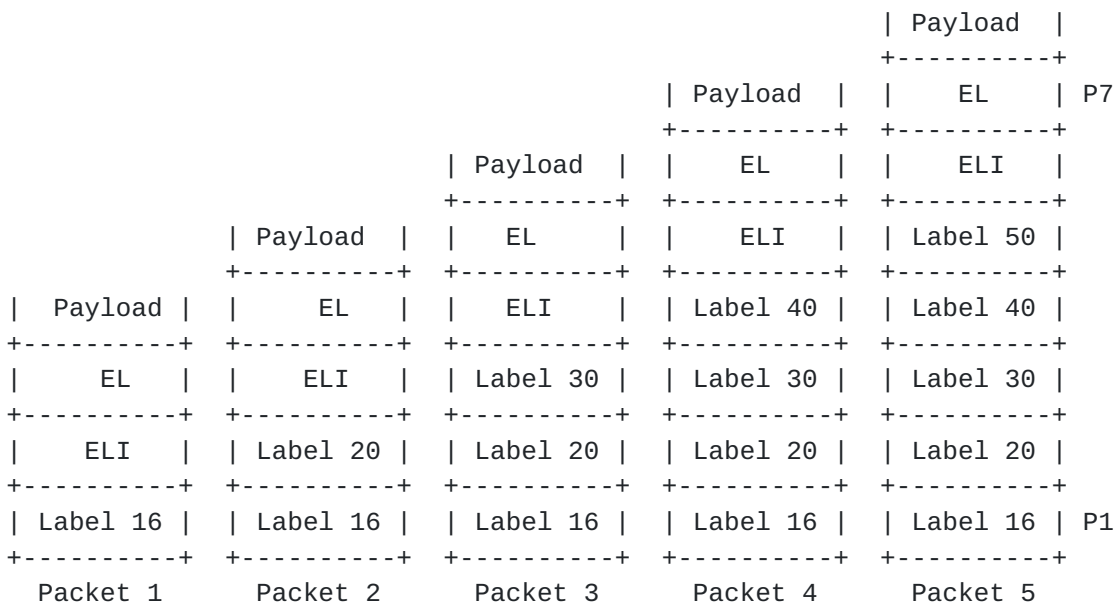


Figure 2: Label stacks with ELI/EL

In the figure 2, we consider the displayed packets received on a router interface. We consider also a single ERLD value for the router.

- If the router has an ERLD of 3, it will be able to load-balance Packet 1 displayed in Figure 2 using the EL as part of the load-balancing keys. The ERLD value of 3 means that the router can read and take into account the entropy label for load-balancing if it is placed between position 1 (top) and position 3.

- If the router has an ERLD of 5, it will be able to load-balance Packets 1 to 3 in Figure 2 using the EL as part of the load-balancing keys. Packets 4 and 5 have the EL placed at a position greater than 5, so the router is not able to read it and use as part of the load-balancing keys.

- If the router has an ERLD of 10, it will be able to load-balance all the packets displayed in Figure 2 using the EL as part of the load-balancing keys.

To allow an efficient load-balancing based on entropy labels, a router running SPRING SHOULD advertise its ERLD (or ERLDs), so all the other SPRING routers in the network are aware of its capability. How this advertisement is done is outside the scope of this document.

To advertise an ERLD value, a SPRING router:

- MUST be entropy label capable and, as a consequence, MUST apply the dataplane procedures defined in [RFC6790].

- MUST be able to read an ELI/EL which is located within its ERLD value.

- MUST take into account this EL in its load-balancing function.

5. Maximum SID Depth

The Maximum SID Depth defines the maximum number of labels that a particular node can impose on a packet. This includes any kind of labels (service, entropy, transport...). In an MPLS network, the MSD is a limit of the Ingress LSR (I-LSR) or any stitching node that would perform an imposition of additional labels on an existing label stack.

Depending of the number of MPLS operations (POP, SWAP...) to be performed before the PUSH, the MSD may vary due to the hardware or software limitations. As for the ERLD, there may also be different MSD limits based on the linecard type used in a distributed switching system.

When an external controller is used to program a label stack on a particular node, this node MAY advertise its MSD value or a subset of

its MSD value to the controller. How this advertisement is done is outside the scope of this document. As the controller does not have the knowledge of the entire label stack to be pushed by the node, the node may advertise an MSD value which is lower than its actual limit. This gives the ability for the controller to program a label stack up to the advertised MSD value while leaving room for the local node to add more labels (e.g., service, entropy, transport...) without reaching the hardware/software limit.

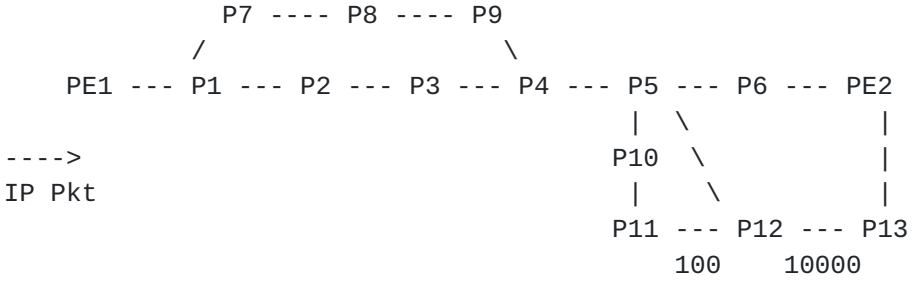


Figure 3

In the figure 3, an IP packet comes in the MPLS network at PE1. All metrics are considered equal to 1 except P12-P13 which is 10000 and P11-P12 which is 100. PE1 wants to steer the traffic using a SPRING path to PE2 along PE1->P1->P7->P8->P9->P4->P5->P10->P11->P12->P13->PE2. By using adjacency SIDs only, PE1 (acting as an I-LSR) will be required to push 10 labels on the IP packet received and thus requires an MSD of 10. If the IP packet should be carried over an MPLS service like a regular layer 3 VPN, an additional service label should be imposed, requiring an MSD of 11 for PE1. In addition, if PE1 wants to insert an ELI/EL for load-balancing purpose, PE1 will need to push 13 labels on the IP packet requiring an MSD of 13.

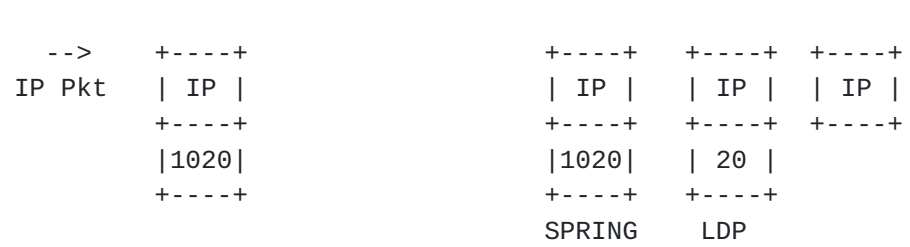
In the SPRING architecture, Node SIDs or Binding SIDs can be used to reduce the label stack size. As an example, to steer the traffic on the same path as before, PE1 may be able to use the following label stack: <Node_P9, Node_P5, Binding_P5, Node_PE2>. In this example we consider a combination of Node SIDs and a Binding SID advertised by P5 that will stitch the traffic along the path P10->P11->P12->P13. The instruction associated with the binding SID at P5 is thus to swap Binding_P5 to Adj_P12-P13 and then push <Adj_P11-P12, Node_P11>. P5 acts as a stitching node that pushes additional labels on an existing label stack, P5's MSD needs also to be taken into account and may limit the number of labels that could be imposed.

6. LSP stitching using the binding SID

The binding SID allows binding a segment identifier to an existing LSP. As examples, the binding SID can represent an RSVP-TE tunnel, an LDP path (through the mapping server advertisement), or a SPRING path. Each LSP associated with a binding SID has its own entropy label capability.

In the figure 3, we consider that:

- P6, PE2, P10, P11, P12, P13 are pure LDP routers.
- PE1, P1, P2, P3, P4, P7, P8, P9 are pure SPRING routers.
- P5 is running SPRING and LDP.
- P5 acts as a mapping server and advertises Prefix SIDs for the LDP FECs: an index value of 20 is used for PE2.
- All SPRING routers use an SRGB of [1000, 1999].
- P6 advertises label 20 for the PE2 FEC.
- Traffic from PE1 to PE2 uses the shortest path.



In term of packet forwarding, by learning the mapping-server advertisement from P5, PE1 imposes a label 1020 to an IP packet destinated to PE2. SPRING routers along the shortest path to PE2 will switch the traffic until it reaches P5 which will perform the LSP stitching. P5 will swap the SPRING label 1020 to the LDP label 20 advertised by the nexthop P6. P6 will then forward the packet using the LDP label towards PE2.

PE1 cannot push an ELI/EL for the binding SID without knowing that the tail-end of the LSP associated with the binding (PE2) is entropy label capable.

To accomodate the mix of signalling protocols involved during the stitching, the entropy label capability SHOULD be propagated between

the signalling protocols. Each binding SID SHOULD have its own entropy label capability that MUST be inherited from the entropy label capability of the associated LSP. If the router advertising the binding SID does not know the ELC state of the target FEC, it MUST NOT set the ELC for the binding SID. An ingress node MUST NOT push an ELI/EL associated with a binding SID unless this binding SID has the entropy label capability. How the entropy label capability is advertised for a binding SID is outside the scope of this document.

In our example, if PE2 is LDP entropy label capable, it will add the entropy label capability in its LDP advertisement. When P5 receives the FEC/label binding for PE2, it learns about the ELC and can set the ELC in the mapping server advertisement. Thus PE1 learns about the ELC of PE2 and may push an ELI/EL associated with the binding SID.

The proposed solution only works if the SPRING router advertising the binding SID is also performing the dataplane LSP stitching. In our example, if the mapping server function is hosted on P8 instead of P5, P8 does not know about the ELC state of PE2's LDP FEC. As a consequence, it does not set the ELC for the associated binding SID.

7. Insertion of entropy labels for SPRING path

7.1. Overview

The solution described in this section follows the dataplane processing defined in [RFC6790]. Within a SPRING path, a node may be ingress, egress, transit (regarding the entropy label processing described in [RFC6790]), or it can be any combination of those. For example:

- The ingress node of a SPRING domain may be an ingress node from an entropy label perspective.

- Any LSR terminating a segment of the SPRING path is an egress node (because it terminates the segment) but may also be a transit node if the SPRING path is not terminated because there is a subsequent SPRING MPLS label in the stack.

- Any LSR processing a binding SID may be a transit node and an ingress node (because it may push additional labels when processing the binding SID).

As described earlier, an LSR may have a limitation, ERLD, on the depth of the label stack that it can read and process in order to do multipath load-balancing based on entropy labels.

If an EL does not occur within the ERLD of an LSR in the label stack of an MPLS packet that it receives, then it would lead to poor load-balancing at that LSR. Hence an ELI/EL pair must be within the ERLD of the LSR in order for the LSR to use the EL during load-balancing.

Adding a single ELI/EL pair for the entire SPRING path may lead also to poor load-balancing as well because the EL/ELI may not occur within the ERLD of some LSR on the path (if too deep) or may not be present in the stack when it reaches some LSRs if it is too shallow.

In order for the EL to occur within the ERLD of LSRs along the path corresponding to a SPRING label stack, multiple <ELI, EL> pairs MAY be inserted in this label stack.

The insertion of the ELI/EL SHOULD occur only with a SPRING label advertised by an LSR that advertised an ERLD (the LSR is entropy label capable) or with a SPRING label associated with a binding SID that has the ELC set.

The ELs among multiple <ELI, EL> pairs inserted in the stack MAY be the same or different. The LSR that inserts <ELI, EL> pairs MAY have limitations on the number of such pairs that it can insert and also the depth at which it can insert them. If, due to limitations, the inserted ELs are at positions such that an LSR along the path receives an MPLS packet without an EL in the label stack within that LSR's ERLD, then the load-balancing performed by that LSR would be poor. An implementation MAY consider multiple criteria when inserting <ELI, EL> pairs.

7.1.1. Example 1 where the ingress node has a sufficient MSD

Figure 4

In the figure 4, PE1 wants to forward some MPLS VPN traffic over an explicit path to PE2 resulting in the following label stack to be pushed onto the received IP header: <Adj_P1P2, Adj_set_P2P3, Adj_P3P4, Adj_P4P5, Adj_P5P6, Adj_P6PE2, VPN_label>. PE1 is limited to push a maximum of 11 labels (MSD=11). P2, P3 and P6 have an ERLD of 3 while others have an ERLD of 10.

PE1 can only add two ELI/EL pairs in the label stack due to its MSD limitation. It should insert them strategically to benefit load-balancing along the longest part of the path.

PE1 may take into account multiple parameters when inserting ELs, as examples:

- The ERLD value advertised by transit nodes.
- The requirement of load-balancing for a particular label value.
- Any service provider preference: favor beginning of the path or end of the path.

In the figure 4, a good strategy may be to use the following stack <Adj_P1P2, Adj_set_P2P3, ELI1, EL1, Adj_P3P4, Adj_P4P5, Adj_P5P6, Adj_P6PE2, VPN_label>. The original stack requests P2 to forward based on a L3 adjacency set that will require load-balancing. Therefore it is important to ensure that P2 can load-balance correctly. As P2 has a limited ERLD of 3, ELI/EL must be inserted just next to the label that P2 will use to forward. On the path to PE2, P3 has also a limited ERLD, but P3 will forward based on a basic adjacency segment that may require no load-balancing. Therefore it does not seem important to ensure that P3 can do load-balancing despite of its limited ERLD. The next nodes along the forwarding path have a high ERLD that does not cause any issue, except P6, moreover P6 is using some LAGs to PE2 and so is expected to load-balance. It becomes important to insert a new ELI/EL just next to P6 forwarding label.

In the case above, the ingress node had enough label push capacity to ensure end-to-end load-balancing taking into the path attributes. There might be some cases, where the ingress node may not have the necessary label imposition capacity.

7.1.2. Example 2 where the ingress node has not a sufficient MSD

Figure 5

In the figure 5, PE1 wants to forward MPLS VPN traffic over an explicit path to PE2 resulting in the following label stack to be pushed onto the IP header: <Adj_P1P2, Adj_set_P2P3, Adj_P3P4, Adj_P4P5, Adj_P5P6, Adj_set_P6P7, Adj_P7P8; Adj_set_P8PE2, VPN_label>. PE1 is limited to push a maximum of 11 labels, P2, P3 and P6 have an ERLD of 3 while others have an ERLD of 15.

Using a similar strategy as the previous case may lead to a dilemma, as PE1 can only push a single ELI/EL while we may need a minimum of three to load-balance the end-to-end path. An optimized stack that would enable end-to-end load-balancing may be: <Adj_P1P2, Adj_set_P2P3, ELI1, EL1, Adj_P3P4, Adj_P4P5, Adj_P5P6, Adj_set_P6P7, ELI2, EL2, Adj_P7P8; Adj_set_P8PE2, ELI3, EL3, VPN_label>.

A decision needs to be taken to favor some part of the path for load-balancing considering that load-balancing may not work on the other part. A service provider may decide to place the ELI/EL after the P6 forwarding label as it will allow P4 and P6 to load-balance. Placing the ELI/EL at bottom of the stack is also a possibility enabling load-balancing for P4 and P8.

7.2. Considerations for the placement of entropy labels

The sample cases described in the previous section showed that placing the ELI/EL when the maximum number of labels to be pushed is limited is not an easy decision and multiple criteria may be taken into account.

This section describes some considerations that could be taken into account when placing ELI/ELs. This list of criteria is not considered as exhaustive and an implementation MAY take into account additional criteria or tie-breakers that are not documented here.

An implementation SHOULD try to maximize the load-balancing where multiple ECMP paths are available and minimize the number of EL/ELIs that need to be inserted. In case of a trade-off, an implementation MAY provide flexibility to the operator to select the criteria to be considered when placing EL/ELIs or the sub-objective for which to optimize.

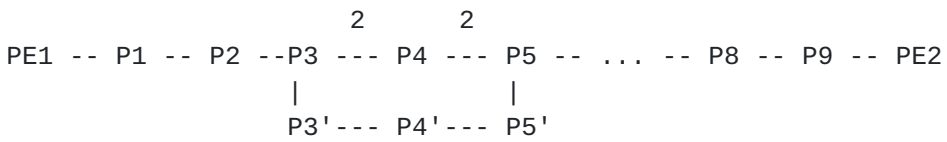


Figure 6

The figure above will be used as reference in the following subsections. All metrics are equal to 1, except P3-P4 and P4-P5 which have a metric 2.

7.2.1. ERLD value

As mentioned in Section 7.1, the ERLD value is an important parameter to consider when inserting ELI/EL. If an ELI/EL does not fall within the ERLD of a node on the path, the node will not be able to load-balance the traffic efficiently.

The ERLD value can be advertised via protocols and those extensions are described in separate documents [I-D.ietf-isis-mpls-elc] and [I-D.ietf-ospf-mpls-elc].

Let's consider a path from PE1 to PE2 using the following stack pushed by PE1: <Adj_P1P2, Node_P9, Adj_P9PE2, Service_label>.

Using the ERLD as an input parameter may help to minimize the number of required ELI/EL pairs to be inserted. An ERLD value must be retrieved for each SPRING label in the label stack.

For a label bound to an adjacency segment, the ERLD is the ERLD of the node that advertised the adjacency segment. In the example above, the ERLD associated with Adj_P1P2 would be the ERLD of router P1 as P1 will perform the forwarding based on the Adj_P1P2 label.

For a label bound to a node segment, multiple strategies MAY be implemented. An implementation may try to evaluate the minimum ERLD value along the node segment path. If an implementation cannot find the minimum ERLD along the path of the segment, it can use the ERLD of the starting node instead. In the example above, if the implementation supports computation of minimum ERLD along the path, the ERLD associated with label Node_P9 would be the minimum ERLD between nodes {P2,P3,P4 ..., P8}. If an implementation does not support the computation of minimum ERLD, it should consider the ERLD of P2 (starting node that will forward based on the Node_P9 label).

For a label bound to a binding segment, if the binding segment describes a path, an implementation may also try to evaluate the minimum ERLD along this path. If the implementation cannot find the minimum ERLD along the path of the segment, it can use the ERLD of the starting node instead.

7.2.2. Segment type

Depending of the type of segment a particular label is bound to, an implementation may deduce that this particular label will be subject to load-balancing on the path.

7.2.2.1. Node-SID

An MPLS label bound to a Node-SID represents a path that may cross multiple hops. Load-balancing may be needed on the node starting this path but also on any node along the path.

In the figure 6, let's consider a path from PE1 to PE2 using the following stack pushed by PE1: <Adj_P1P2, Node_P9, Adj_P9PE2, Service_label>.

If, for example, PE1 is limited to push 6 labels, it can add a single ELI/EL within the label stack. An operator may want to favor a placement that would allow load-balancing along the Node-SID path. In the figure above, P3 which is along the Node-SID path requires load-balancing on two equal-cost paths.

An implementation may try to evaluate if load-balancing is really required within a node segment path. This could be done by running an additional SPT computation and analysis of the node segment path to prevent a node segment that does not really require load-balancing from being preferred when placing EL/ELIs. Such inspection may be time consuming for implementations and without a 100% guarantee, as a node segment path may use LAG that could be invisible from the IP topology. A simpler approach would be to consider that a label bound to a Node-SID will be subject to load-balancing and requires an EL/ELI.

7.2.2.2. Adjacency-set SID

An adjacency-set is an adjacency SID that refers to a set of adjacencies. When an adjacency-set segment is used within a label stack, an implementation can deduce that load-balancing is expected at the node that advertised this adjacency segment. An implementation could then favor this particular label value when placing ELI/ELs.

7.2.2.3. Adjacency-SID representing a single IP link

When an adjacency segment representing a single IP link is used within a label stack, an implementation can deduce that load-balancing may not be expected at the node that advertised this adjacency segment.

The implementation could then decide to place ELI/ELs to favor other LSRs than the one advertising this adjacency segment.

Readers should note that an adjacency segment representing a single IP link may require load-balancing. This is the case when a LAG (L2

bundle) is implemented between two IP nodes and the L2 bundle SR extensions [I-D.ietf-isis-l2bundles] are not implemented. In such a case, it may be useful to insert an EL/ELI in a readable position for the LSR advertising the label associated with the adjacency segment.

7.2.2.4. Adjacency-SID representing a single link within a L2 bundle

When L2 bundle SR extensions [I-D.ietf-isis-l2bundles] are used, adjacency segments may be advertised for each member of the bundle. In this case, an implementation can deduce that load-balancing is not expected on the LSR advertising this segment and could then decide to place ELI/ELs to favor other LSRs than the one advertising this adjacency segment.

7.2.2.5. Adjacency-SID representing a L2 bundle

When L2 bundle SR extensions [I-D.ietf-isis-l2bundles] are used, an adjacency segment may be advertised to represent the bundle. In this case, an implementation can deduce that load-balancing is expected on the LSR advertising this segment and could then decide to place ELI/ELs to favor this LSR.

7.2.3. Maximizing number of LSRs that will load-balance

When placing ELI/ELs, an implementation may try to maximize the number of LSRs that both need to load-balance (i.e., have ECMP paths) and that will be able to perform load-balancing (i.e., the EL label is within their ERLD).

Let's consider a path from PE1 to PE2 using the following stack pushed by PE1: <Adj_P1P2, Node_P9, Adj_P9PE2, Service_label>. All routers have an ERLD of 10, expect P1 and P2 which have an ERLD of 4. PE1 is able to push 6 labels, so only a single ELI/EL can be added.

In the example above, adding ELI/EL next to Adj_P1P2 will only allow load-balancing at P1 while inserting it next to Adj_PE2P9, will allow load-balancing at P2,P3 ... P9 and maximizing the number of LSRs that could perform load-balancing.

7.2.4. Preference for a part of the path

An implementation may propose to favor a part of the end-to-end path when the number of EL/ELI that can be pushed is not enough to cover the entire path. As example, a service provider may want to favor load-balancing at the beginning of the path or at the end of path, so the implementation should prefer putting the ELI/ELs near the top or near of the bottom of the stack.

7.2.5. Combining criteria

An implementation can combine multiple criteria to determine the best EL/ELIs placement. However, combining too many criteria may lead to implementation complexity and high resource consumption. Each time the network topology changes, a new evaluation of the EL/ELI placement will be necessary for each impacted LSPs.

8. A simple example algorithm

A simple implementation might take into account ERLD when placing ELI/EL while trying to minimize the number of EL/ELIs inserted and trying to maximize the number of LSRs that can load-balance.

The example algorithm is based on the following considerations:

- An LSR that is limited in the number of <ELI, EL> pairs that it can insert SHOULD insert such pairs deeper in the stack.

- An LSR should try to insert <ELI, EL> pairs at positions so that for the maximum number of transit LSRs, the EL occurs within the ERLD of those LSRs.

- An LSR should try to insert the minimum number of such pairs while trying to satisfy the above criteria.

The pseudocode of the example algorithm is shown below.

```
Initialize the current EL insertion point to the
  bottommost label in the stack that is EL-capable
while (local-node can push more <ELI,EL> pairs OR
          insertion point is not above label stack) {
    insert an <ELI,EL> pair below current insertion point
    move new insertion point up from current insertion point until
        ((last inserted EL is below the ERLD) AND (ERLD > 2)
                        AND
         (new insertion point is EL-capable))
    set current insertion point to new insertion point
}
```

Figure 7: Example algorithm to insert <ELI, EL> pairs in a label stack

When this algorithm is applied to the example described in Section 3, it will result in ELs being inserted in two positions, one below the label L_N-D and another below L_N-P3. Thus the resulting label stack would be <L_N-P3, ELI, EL, L_A-L1, L_N-D, ELI, EL>

9. Deployment Considerations

As long as LSR node dataplane capabilities are limited (number of labels that can be pushed, or number of labels that can be inspected), hop-by-hop load-balancing of SPRING encapsulated flows will require trade-offs.

Entropy label is still a good and usable solution as it allows load-balancing without having to perform a deep packet inspection on each LSR: it does not seem reasonable to have an LSR inspecting UDP ports within a GRE tunnel carried over a 15 label SPRING tunnel.

Due to the limited capacity of reading a deep stack of MPLS labels, multiple EL/ELIs may be required within the stack which directly impacts the capacity of the head-end to push a deep stack: each EL/ELI inserted requires two additional labels to be pushed.

Placement strategies of EL/ELIs are required to find the best trade-off. Multiple criteria may be taken into account and some level of customization (by the user) may be required to accommodate the different deployments. Analyzing the path of each destination to determine the best EL/ELI placement may be time consuming for the control plane, we encourage implementations to find the best trade-off between simplicity, resource consumption, and load-balancing efficiency.

In future, hardware and software capacity may increase dataplane capabilities and may be remove some of these limitations, increasing load-balancing capability using entropy labels.

10. Options considered

Different options that were considered to arrive at the recommended solution are documented in this section.

These options are detailed here only for historical purposes.

10.1. Single EL at the bottom of the stack

In this option, a single EL is used for the entire label stack. The source LSR S encodes the entropy label at the bottom of the label stack. In the example described in Section 3, it will result in the label stack at LSR S to look like <L_N-P3, L_A-L1, L_N-D, ELI, EL> <remaining packet header>. Note that the notation in [RFC6790] is used to describe the label stack. An issue with this approach is that as the label stack grows due an increase in the number of SIDs, the EL goes correspondingly deeper in the label stack. Hence, transit LSRs have to access a larger number of bytes in the packet

header when making forwarding decisions. In the example described in Section 3, if we consider that the LSR P1 has an ERLD of 3, P1 would load-balance traffic poorly on the parallel links L3 and L4 since the EL is below the ERLD of P1. A load-balanced network design using this approach must ensure that all intermediate LSRs have the capability to read the maximum label stack depth as required for the application that uses source routed stacking.

This option was rejected since there exist a number of hardware implementations which have a low maximum readable label depth. Choosing this option can lead to a loss of load-balancing using EL in a significant part of the network when that is a critical requirement in a service-provider network.

10.2. An EL per segment in the stack

In this option, each segment/label in the stack can be given its own EL. When load-balancing is required to direct traffic on a segment, the source LSR pushes an <ELI, EL> before pushing the label associated to this segment . In the example described in Section 3, the source LSR S encoded label stack would be <L_N-P3, ELI, EL, L_A-L1, L_N-D, ELI, EL> where all the ELs can be the same. Accessing the EL at an intermediate LSR is independent of the depth of the label stack and hence independent of the specific application that uses source routed tunnels with label stacking. A drawback is that the depth of the label stack grows significantly, almost 3 times as the number of labels in the label stack. The network design should ensure that source LSRs have the capability to push such a deep label stack. Also, the bandwidth overhead and potential MTU issues of deep label stacks should be considered in the network design.

This option was rejected due to the existence of hardware implementations that can push a limited number of labels on the label stack. Choosing this option would result in a hardware requirement to push two additional labels per tunnel label. Hence it would restrict the number of tunnels that can be stacked in a LSP and hence constrain the types of LSPs that can be created. This was considered unacceptable.

10.3. A re-usable EL for a stack of tunnels

In this option an LSR that terminates a tunnel re-uses the EL of the terminated tunnel for the next inner tunnel. It does this by storing the EL from the outer tunnel when that tunnel is terminated and re-inserting it below the next inner tunnel label during the label swap operation. The LSR that stacks tunnels should insert an EL below the outermost tunnel. It should not insert ELs for any inner tunnels. Also, the penultimate hop LSR of a segment must not pop the ELI and

EL even though they are exposed as the top labels since the terminating LSR of that segment would re-use the EL for the next segment.

In Section 3 above, the source LSR S encoded label stack would be <L_N-P3, ELI, EL, L_A-L1, L_N-D>. At P1, the outgoing label stack would be <L_N-P3, ELI, EL, L_A-L1, L_N-D> after it has load-balanced to one of the links L3 or L4. At P3 the outgoing label stack would be <L_N-D, ELI, EL>. At P2, the outgoing label stack would be <L_N-D, ELI, EL> and it would load-balance to one of the nexthop LSRs P4 or P5. Accessing the EL at an intermediate LSR (e.g., P1) is independent of the depth of the label stack and hence independent of the specific use-case to which the label stack is applied.

This option was rejected due to the significant change in label swap operations that would be required for existing hardware.

10.4. EL at top of stack

A slight variant of the re-usable EL option is to keep the EL at the top of the stack rather than below the tunnel label. In this case, each LSR that is not terminating a segment should continue to keep the received EL at the top of the stack when forwarding the packet along the segment. An LSR that terminates a segment should use the EL from the terminated segment at the top of the stack when forwarding onto the next segment.

This option was rejected due to the significant change in label swap operations that would be required for existing hardware.

10.5. ELs at readable label stack depths

In this option the source LSR inserts ELs for tunnels in the label stack at depths such that each LSR along the path that must load balance is able to access at least one EL. Note that the source LSR may have to insert multiple ELs in the label stack at different depths for this to work since intermediate LSRs may have differing capabilities in accessing the depth of a label stack. The label stack depth access value of intermediate LSRs must be known to create such a label stack. How this value is determined is outside the scope of this document. This value can be advertised using a protocol such as an IGP.

Applying this method to the example in Section 3 above, if LSR P1 needs to have the EL within a depth of 4, then the source LSR S encoded label stack would be <L_N-P3, ELI, EL, L_A-L1, L_N-D, ELI, EL> where all the ELs would typically have the same value.

In the case where the ERLD has different values along the path and the LSR that is inserting <ELI, EL> pairs has no limit on how many pairs it can insert, and it knows the appropriate positions in the stack where they should be inserted, this option is the same as the recommended solution in Section 7.

Note that a refinement of this solution which balances the number of pushed labels against the desired entropy is the solution described in Section 7.

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13. IANA Considerations

This memo includes no request to IANA. Note to RFC Editor: Remove this section before publication.

14. Security Considerations

This document does not introduce any new security considerations beyond those already listed in [RFC6790].

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