

Network Working Group
Internet-Draft
Intended status: Standards Track
Expires: 19 July 2024

A. Bashandy
S. Litkowski
C. Filsfils
Cisco Systems
P. Francois
INSA Lyon
B. Decraene
Orange
D. Voyer
Bell Canada
16 January 2024

**Topology Independent Fast Reroute using Segment Routing
draft-ietf-rtgwg-segment-routing-ti-lfa-13**

Abstract

This document presents Topology Independent Loop-free Alternate Fast Re-route (TI-LFA), aimed at providing protection of node and adjacency segments within the Segment Routing (SR) framework. This Fast Re-route (FRR) behavior builds on proven IP-FRR concepts being LFAs, remote LFAs (RLFA), and remote LFAs with directed forwarding (DLFA). It extends these concepts to provide guaranteed coverage in any two connected networks using a link-state IGP. A key aspect of TI-LFA is the FRR path selection approach establishing protection over the expected post-convergence paths from the point of local repair, reducing the operational need to control the tie-breaks among various FRR options.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of [BCP 78](#) and [BCP 79](#).

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at <https://datatracker.ietf.org/drafts/current/>.

Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."

This Internet-Draft will expire on 19 July 2024.

Copyright Notice

Copyright (c) 2024 IETF Trust and the persons identified as the document authors. All rights reserved.

This document is subject to [BCP 78](#) and the IETF Trust's Legal Provisions Relating to IETF Documents (<https://trustee.ietf.org/license-info>) in effect on the date of publication of this document. Please review these documents carefully, as they describe your rights and restrictions with respect to this document. Code Components extracted from this document must include Revised BSD License text as described in Section 4.e of the [Trust Legal Provisions](#) and are provided without warranty as described in the Revised BSD License.

Table of Contents

- [1.](#) Acronyms [3](#)
- [2.](#) Introduction [4](#)
 - [2.1.](#) Conventions used in this document [6](#)
- [3.](#) Terminology [7](#)
- [4.](#) Base principle [7](#)
- [5.](#) Intersecting P-Space and Q-Space with post-convergence paths [8](#)
 - [5.1.](#) Extended P-Space property computation for a resource X, over post-convergence paths [8](#)
 - [5.2.](#) Q-Space property computation for a resource X, over post-convergence paths [8](#)
 - [5.3.](#) Scaling considerations when computing Q-Space [9](#)
- [6.](#) TI-LFA Repair path [9](#)
 - [6.1.](#) FRR path using a direct neighbor [10](#)
 - [6.2.](#) FRR path using a PQ node [10](#)
 - [6.3.](#) FRR path using a P node and Q node that are adjacent . . . [10](#)
 - [6.4.](#) Connecting distant P and Q nodes along post-convergence paths [11](#)
- [7.](#) Building TI-LFA repair lists [11](#)
 - [7.1.](#) The active segment is a node segment [11](#)
 - [7.2.](#) The active segment is an adjacency segment [11](#)
 - [7.2.1.](#) Protecting [Adjacency, Adjacency] segment lists . . . [12](#)
 - [7.2.2.](#) Protecting [Adjacency, Node] segment lists [12](#)
- [8.](#) Dataplane specific considerations [13](#)
 - [8.1.](#) MPLS dataplane considerations [13](#)
 - [8.2.](#) SRv6 dataplane considerations [13](#)
- [9.](#) TI-LFA and SR algorithms [14](#)
- [10.](#) Usage of Adjacency segments in the repair list [14](#)
- [11.](#) Advantages of using the expected post-convergence path during FRR [15](#)
- [12.](#) Analysis based on real network topologies [17](#)
- [13.](#) Security Considerations [22](#)

[14](#). IANA Considerations [22](#)
[15](#). Contributors [22](#)
[16](#). Acknowledgments [23](#)
[17](#). References [23](#)
 [17.1](#). Normative References [23](#)
 [17.2](#). Informative References [23](#)
Authors' Addresses [25](#)

[1](#). Acronyms

- * DLFA: Remote LFA with Directed forwarding.
- * FRR: Fast Re-route.
- * IGP: Interior Gateway Protocol.
- * LFA: Loop-Free Alternate.
- * LSDB: Link State DataBase.
- * PLR: Point of Local Repair.
- * RL: Repair list.
- * RLFA: Remote LFA.
- * RSPT: Reverse Shortest Path Tree.
- * SID: Segment Identifier.
- * SLA: Service Level Agreement.
- * SPF: Shortest Path First.
- * SPT: Shortest Path Tree.
- * SR: Segment Routing.
- * SRGB: Segment Routing Global Block.
- * SRLG: Shared Risk Link Group.
- * TI-LFA: Topology Independant LFA.
- * TLDP: Target Label Distribution Protocol.

2. Introduction

Segment Routing aims at supporting services with tight SLA guarantees [RFC8402]. By relying on SR this document provides a local repair mechanism for standard link-state IGP shortest path capable of restoring end-to-end connectivity in the case of a sudden directly connected failure of a network component. Non-SR mechanisms for local repair are beyond the scope of this document. Non-local failures are addressed in a separate document [I-D.bashandy-rtgwg-segment-routing-uloop].

The term topology independent (TI) refers to the ability to provide a loop free backup path irrespective of the topologies used in the network. This provides a major improvement compared to LFA [RFC5286] and remote LFA [RFC7490] which cannot provide a complete protection coverage in some topologies as described in [RFC6571].

When the network reconverges, micro-loops [RFC5715] can form due to transient inconsistencies in the forwarding tables of different routers. If it is determined that micro-loops are a significant issue in the deployment, then a suitable loop-free convergence method, such as one of those described in [RFC5715], [RFC6976], [RFC8333], or [I-D.bashandy-rtgwg-segment-routing-uloop] should be implemented.

TI-LFA is a local operation applied by the PLR when it detects failure of one of its local links. As such, it does not affect:

- * Micro-loops that appear - or do not appear - as part of the distributed IGP convergence [RFC5715] on the paths to the destination that do not pass thru TI-LFA paths:
 - As explained in [RFC5714], such micro-loops may result in the traffic not reaching the PLR and therefore not following TI-LFA paths.
- * Micro-loops that appear - or do not appear - when the failed link is repaired.

TI-LFA paths are loop-free. What's more, they follow the post-convergence paths, and, therefore, not subject to micro-loops due to difference in the IGP convergence times of the nodes thru which they pass.

TI-LFA paths are applied from the moment the PLR detects failure of a local link and until IGP convergence at the PLR is completed. Therefore, early (relative to the other nodes) IGP convergence at the PLR and the consecutive "early" release of TI-LFA paths may cause

micro-loops, especially if these paths have been computed using the methods described in Section [Section 6.2](#), [Section 6.3](#), or [Section 6.4](#) of the draft. One of the possible ways to prevent such micro-loops is local convergence delay ([\[RFC8333\]](#)).

TI-LFA procedures are complementary to application of any micro-loop avoidance procedures in the case of link or node failure:

- * Link or node failure requires some urgent action to restore the traffic that passed thru the failed resource. TI-LFA paths are pre-computed and pre-installed and therefore suitable for urgent recovery
- * The paths used in the micro-loop avoidance procedures typically cannot be pre-computed.

For each destination in the network, TI-LFA pre-installs a backup forwarding entry for each protected destination ready to be activated upon detection of the failure of a link used to reach the destination. TI-LFA provides protection in the event of any one of the following: single link failure, single node failure, or single SRLG failure. In link failure mode, the destination is protected assuming the failure of the link. In node protection mode, the destination is protected assuming that the neighbor connected to the primary link has failed. In SRLG protecting mode, the destination is protected assuming that a configured set of links sharing fate with the primary link has failed (e.g. a linecard or a set of links sharing a common transmission pipe).

Protection techniques outlined in this document are limited to protecting links, nodes, and SRLGs that are within a link-state IGP area. Protecting domain exit routers and/or links attached to another routing domains are beyond the scope of this document

By using SR, TI-LFA does not require the establishment of TLDP sessions (Targeted Label Distribution Protocol) with remote nodes in order to take advantage of the applicability of remote LFAs (RLFA) [\[RFC7490\]](#)[\[RFC7916\]](#) or remote LFAs with directed forwarding (DLFA)[\[RFC5714\]](#). All the Segment Identifiers (SIDs) are available in the link state database (LSDB) of the IGP. As a result, preferring LFAs over RLFAs or DLFAs, as well as minimizing the number of RLFA or DLFA repair nodes is not required anymore.

By using SR, there is no need to create state in the network in order to enforce an explicit FRR path. This relieves the nodes themselves from having to maintain extra state, and it relieves the operator from having to deploy an extra protocol or extra protocol sessions just to enhance the protection coverage.

Although not a Ti-LFA requirement or constraint, TI-LFA also brings the benefit of the ability to provide a backup path that follows the expected post-convergence path considering a particular failure which reduces the need of locally configured policies that drive the backup path selection ([RFC7916]). The easiest way to express the expected post-convergence path in a loop-free manner is to encode it as a list of adjacency segments. However, this may create a long SID list that some hardware may not be able to push. One of the challenges of TI-LFA is to encode the expected post-convergence path by combining adjacency segments and node segments. Each implementation will be free to have its own SID list optimization algorithm. This document details the basic concepts that could be used to build the SR backup path as well as the associated dataplane procedures.

[Section 3](#) defines the main notations used in the document. They are in line with [\[RFC5714\]](#).

[Section 4](#) defines the main principles of TI-LFA backup path computation.

[Section 5](#) suggests to compute the P-Space and Q-Space properties defined in [Section 3](#), for the specific case of nodes lying over the post-convergence paths towards the protected destinations.

Using the properties defined in [Section 5](#), [Section 6](#) describes how to compute protection lists that encode a loop-free post-convergence path towards the destination.

[Section 7](#) defines the segment operations to be applied by the PLR to ensure consistency with the forwarding state of the repair node.

[Section 11](#) highlights advantages of using the expected post-convergence path during FRR.

By applying the algorithms specified in this document to actual service providers and large enterprise networks, we provide real life measurements for the number of SIDs used by repair paths. [Section 12](#) summarizes these measurements.

[2.1](#). Conventions used in this document

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.

3. Terminology

We define the main notations used in this document as the following.

We refer to "old" and "new" topologies as the LSDB state before and after the considered failure.

$SPT_{old}(R)$ is the Shortest Path Tree rooted at node R in the initial state of the network.

$SPT_{new}(R, X)$ is the Shortest Path Tree rooted at node R in the state of the network after the resource X has failed.

PLR stands for "Point of Local Repair". It is the router that applies fast traffic restoration after detecting failure in a directly attached link, set of links, and/or node.

Similar to [[RFC7490](#)], we use the concept of P-Space and Q-Space for TI-LFA.

The P-space $P(R,X)$ of a router R with regard to a resource X (e.g. a link $S-F$, a node F , or a SRLG) is the set of routers reachable from R using the pre-convergence shortest paths without any of those paths (including equal-cost path splits) transiting through X .

Consider the set of neighbors of a router R and a resource X . Exclude from that set of neighbors that are reachable from R using X . The Extended P-Space $P'(R,X)$ of a node R with regard to a resource X is the union of the P-spaces of the neighbors in that reduced set of neighbors with regard to the resource X .

The Q-space $Q(R,X)$ of a router R with regard to a resource X is the set of routers from which R can be reached without any path (including equal-cost path splits) transiting through X .

$EP(P, Q)$ is an explicit SR-based path from a node P to a node Q .

A symmetric network is a network such that the IGP metric of each link is the same in both directions of the link.

4. Base principle

The basic algorithm to compute the repair path is to pre-compute $SPT_{new}(R,X)$ and for each destination, encode the repair path as a loop-free SID list. One way to provide a loop-free SID list is to use adjacency SIDs only. However, this approach may create very long SID lists that hardware may not be able to handle due to MSD (Maximum SID Depth) limitations.

An implementation is free to use any local optimization to provide smaller SID lists by combining Node SIDs and Adjacency SIDs. In addition, the usage of Node-SIDs allow to maximize ECMPs over the backup path. These optimizations are out of scope of this document, however the subsequent sections provide some guidance on how to leverage P-Spaces and Q-Spaces to optimize the size of the SID list.

5. Intersecting P-Space and Q-Space with post-convergence paths

One of the challenges of defining an SR path following the expected post-convergence path is to reduce the size of the segment list. In order to reduce this segment list, an implementation MAY determine the P-Space/Extended P-Space and Q-Space properties (defined in [RFC7490]) of the nodes along the expected post-convergence path from the PLR to the protected destination and compute an SR-based explicit path from P to Q when they are not adjacent. Such properties will be used in [Section 6](#) to compute the TI-LFA repair list.

5.1. Extended P-Space property computation for a resource X, over post-convergence paths

We want to determine which nodes on the post-convergence path from the PLR R to the destination D are in the extended P-space of R with regard to resource X (X can be a link or a set of links adjacent to the PLR, or a neighbor node of the PLR).

This can be found by:

- * Excluding neighbors which are not on the post-convergence path when computing $P'(R, X)$
- * Then, intersecting the set of nodes belonging to the post-convergence path from R to D, assuming the failure of X, with $P'(R, X)$.

5.2. Q-Space property computation for a resource X, over post-convergence paths

We want to determine which nodes on the post-convergence path from the PLR R to the destination D are in the Q-Space of destination D with regard to resource X (X can be a link or a set of links adjacent to the PLR, or a neighbor node of the PLR).

This can be found by intersecting the set of nodes belonging to the post-convergence path from R to D, assuming the failure of X, with $Q(D, X)$.

5.3. Scaling considerations when computing Q-Space

[RFC7490] raises scaling concerns about computing a Q-Space per destination. Similar concerns may affect TI-LFA computation if an implementation tries to compute a reverse Shortest Path Tree ([RFC7490]) for every destination in the network to determine the Q-Space. It will be up to each implementation to determine the good tradeoff between scaling and accuracy of the optimization.

6. TI-LFA Repair path

The TI-LFA repair path (RP) consists of an outgoing interface and a list of segments (repair list (RL)) to insert on the SR header in accordance with the dataplane used. The repair list encodes the explicit post-convergence path to the destination, which avoids the protected resource X and, at the same time, is guaranteed to be loop-free irrespective of the state of FIBs along the nodes belonging to the explicit path. Thus, there is no need for any co-ordination or message exchange between the PLR and any other router in the network.

The TI-LFA repair path is found by intersecting P(S,X) and Q(D,X) with the post-convergence path to D and computing the explicit SR-based path EP(P, Q) from P to Q when these nodes are not adjacent along the post convergence path. The TI-LFA repair list is expressed generally as (Node_SID(P), EP(P, Q)).

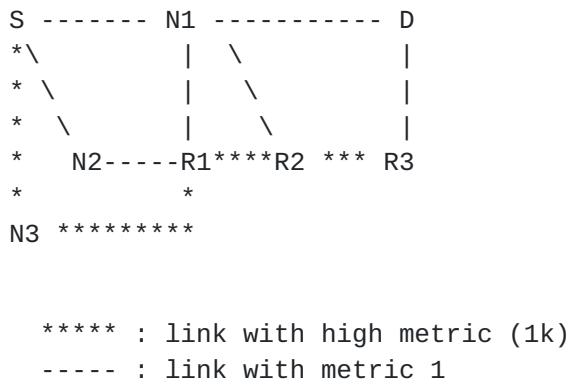


Figure 1: Sample topology with TI-LFA

As an example, in Figure 1, we are interested by the TI-LFA backup from S to D considering the failure of node N1.

- * First, P(S, N1) is computed and results in [N3, N2, R1].
- * Then, Q(D, N1) is computed and results in [R3].

- * The expected post-convergence path from S to D considering the failure of N1 is <N2 -> R1 -> R2 -> R3 -> D> (we are naming it PCPath in this example).
- * P(S, N1) intersection with PCPath is [N2, R1], R1 being the deeper downstream node in PCP, it can be assumed to be used as P node (this is an example and an implementation could use a different strategy to choose the P node).
- * Q(D, N1) intersection with PCPath is [R3], so R3 is picked as Q node. An SR explicit path is then computed from R1 (P node) to R3 (Q node) following PCPath (R1 -> R2 -> R3): <AdjSID_R1R2, AdjSID_R2R3>.

As a result, the TI-LFA repair list of S for destination D considering the failure of node N1 is: <NodeSID(R1), AdjSID_R1R2, AdjSID_R2R3>.

Most often, the TI-LFA repair list has a simpler form, as described in the following sections. [Section 12](#) provides statistics for the number of SIDs in the explicit path to protect against various failures.

[6.1.](#) FRR path using a direct neighbor

When a direct neighbor is in P(S,X) and Q(D,x) and the link to that direct neighbor is on the post-convergence path, the outgoing interface is set to that neighbor and the repair segment list SHOULD be empty.

This is comparable to a post-convergence LFA FRR repair.

[6.2.](#) FRR path using a PQ node

When a remote node R is in P(S,X) and Q(D,x) and on the post-convergence path, the repair list SHOULD be made of a single node segment to R and the outgoing interface SHOULD be set to the outgoing interface used to reach R.

This is comparable to a post-convergence RLFA repair tunnel.

[6.3.](#) FRR path using a P node and Q node that are adjacent

When a node P is in P(S,X) and a node Q is in Q(D,x) and both are on the post-convergence path and both are adjacent to each other, the repair list SHOULD be made of two segments: A node segment to P (to be processed first), followed by an adjacency segment from P to Q.

This is comparable to a post-convergence DLFA (LFA with directed forwarding) repair tunnel.

[6.4.](#) Connecting distant P and Q nodes along post-convergence paths

In some cases, there is no adjacent P and Q node along the post-convergence path. As mentioned in [Section 4](#), a list of adjacency SIDs can be used to encode the path between P and Q. However, the PLR can perform additional computations to compute a list of segments that represent a loop-free path from P to Q. How these computations are done is out of scope of this document and is left to implementation.

[7.](#) Building TI-LFA repair lists

The following sections describe how to build the repair lists using the terminology defined in [\[RFC8402\]](#). The procedures described in this section are equally applicable to both SR-MPLS and SRv6 dataplane, while the dataplane-specific considerations are described in [Section 8](#).

In this section, we explain how a protecting router S processes the active segment of a packet upon the failure of its primary outgoing interface for the packet, S-F. The failure of the primary outgoing interface may happen due to different triggers (e.g.: link failure, neighbor node failure...)

[7.1.](#) The active segment is a node segment

The active segment MUST be kept on the SR header unchanged and the repair list MUST be added. The active segment becomes the first segment of the repair list. The way the repair list is added depends on the dataplane used (see [Section 8](#)).

[7.2.](#) The active segment is an adjacency segment

We define hereafter the FRR behavior applied by S for any packet received with an active adjacency segment S-F for which protection was enabled. As protection has been enabled for the segment S-F and signaled in the IGP (for instance using protocol extensions from [\[RFC8667\]](#) and [\[RFC8665\]](#)), any SR policy using this segment knows that it may be transiently rerouted out of S-F in case of S-F failure.

The simplest approach for link protection of an adjacency segment S-F is to create a repair list that will carry the traffic to F. To do so, one or more "PUSH" operations are performed. If the repair list, while avoiding S-F, terminates on F, S only pushes segments of the repair list. Otherwise, S pushes a node segment of F, followed by the segments of the repair list. For details on the "NEXT" and "PUSH" operations, refer to [[RFC8402](#)].

This method which merges back the traffic at the remote end of the adjacency segment has the advantage of keeping as much as possible the traffic on the pre-failure path. As stated in [Section 2](#), when SR policies are involved and a strict compliance of the policy is required, an end-to-end protection should be preferred over a local repair mechanism. However, this method may not provide the expected post-convergence path to the final destination as the expected post-convergence path may not go through F. Another method requires to look to the next segment in the segment list.

We distinguish the case where this active segment is followed by another adjacency segment from the case where it is followed by a node segment.

[7.2.1](#). Protecting [Adjacency, Adjacency] segment lists

If the next segment in the list is an Adjacency segment, then the packet has to be conveyed to F.

To do so, S MUST apply a "NEXT" operation on Adj(S-F) and then one or more "PUSH" operations. If the repair list, while avoiding S-F, terminates on F, S only pushes the segments of the repair list. Otherwise, S pushes a node segment of F, followed by the segments of the repair list. For details on the "NEXT" and "PUSH" operations, refer to [[RFC8402](#)].

Upon failure of S-F, a packet reaching S with a segment list matching [adj(S-F),adj(F-M),...] will thus leave S with a segment list matching [RL(F),node(F),adj(F-M),...], where RL(F) is the repair path for destination F.

[7.2.2](#). Protecting [Adjacency, Node] segment lists

If the next segment in the stack is a node segment, say for node T, the segment list on the packet matches [adj(S-F),node(T),...].

In this case, S MUST apply a "NEXT" operation on the Adjacency segment related to S-F, followed by a "PUSH" of a repair list redirecting the traffic to a node Q, whose path to node segment T is not affected by the failure.

Upon failure of S-F, packets reaching S with a segment list matching [adj(S-F), node(T), ...], would leave S with a segment list matching [RL(Q),node(T), ...].

8. Dataplane specific considerations

8.1. MPLS dataplane considerations

MPLS dataplane for Segment Routing is described in [[RFC8660](#)].

The following dataplane behaviors apply when creating a repair list using an MPLS dataplane:

1. If the active segment is a node segment that has been signaled with penultimate hop popping and the repair list ends with an adjacency segment terminating on the tail-end of the active segment, then the active segment **MUST** be popped before pushing the repair list.
2. If the active segment is a node segment but the other conditions in 1. are not met, the active segment **MUST** be popped then pushed again with a label value computed according to the SRGB of Q, where Q is the endpoint of the repair list. Finally, the repair list **MUST** be pushed.

8.2. SRv6 dataplane considerations

SRv6 dataplane and programming instructions are described respectively in [[RFC8754](#)] and [[RFC8986](#)].

The TI-LFA path computation algorithm is the same as in the SR-MPLS dataplane. Note however that the Adjacency SIDs are typically globally routed. In such case, there is no need for a preceding Prefix SID and the resulting repair list is likely shorter.

If the traffic is protected at a Transit Node, then an SRv6 SID list is added on the packet to apply the repair list. The addition of the repair list follows the headend behaviors as specified in [section 5 of \[\[RFC8986\]\(#\)\]](#).

If the traffic is protected at an SR Segment Endpoint Node, first the Segment Endpoint packet processing is executed. Then the packet is protected as if its were a transit packet.

9. TI-LFA and SR algorithms

SR allows an operator to bind an algorithm to a prefix SID (as defined in [RFC8402]). The algorithm value dictates how the path to the prefix is computed. The SR default algorithm is known as the "Shortest Path" algorithm. The SR default algorithm allows an operator to override the IGP shortest path by using local policies. When TI-LFA uses Node-SIDs associated with the default algorithm, there is no guarantee that the path will be loop-free as a local policy may have overridden the expected IGP path. As the local policies are defined by the operator, it becomes the responsibility of this operator to ensure that the deployed policies do not affect the TI-LFA deployment. It should be noted that such situation can already happen today with existing mechanisms as remote LFA.

[RFC9350] defines a flexible algorithm (FlexAlgo) framework to be associated with Prefix SIDs. FlexAlgo allows a user to associate a constrained path to a Prefix SID rather than using the regular IGP shortest path. An implementation MAY support TI-LFA to protect Node-SIDs associated to a FlexAlgo. In such a case, rather than computing the expected post-convergence path based on the regular SPF, an implementation SHOULD use the constrained SPF algorithm bound to the FlexAlgo (using the Flex Algo Definition) instead of the regular Dijkstra in all the SPF/rSPF computations that are occurring during the TI-LFA computation. This includes the computation of the P-Space and Q-Space as well as the post-convergence path. An implementation MUST only use Node-SIDs bound to the FlexAlgo and/or Adj-SIDs that are unprotected to build the repair list.

10. Usage of Adjacency segments in the repair list

The repair list of segments computed by TI-LFA may contain one or more adjacency segments. An adjacency segment may be protected or not protected.

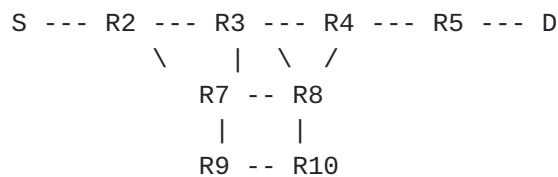


Figure 2

In Figure 2, all the metrics are equal to 1 except R2-R7,R7-R8,R8-R4,R7-R9 which have a metric of 1000. Considering R2 as a PLR to protect against the failure of node R3 for the traffic S->D, the repair list computed by R2 will be [adj(R7-R8),adj(R8-R4)]

and the outgoing interface will be to R7. If R3 fails, R2 pushes the repair list onto the incoming packet to D. During the FRR, if R7-R8 fails and if TI-LFA has picked a protected adjacency segment for adj(R7-R8), R7 will push an additional repair list onto the packet following the procedures defined in [Section 7](#).

To avoid the possibility of this double FRR activation, an implementation of TI-LFA MAY pick only non protected adjacency segments when building the repair list. However, this is important to note that FRR in general is intended to protect for a single pre-planned failure. If the failure that happens is worse than expected or multiple failures happen, FRR is not guaranteed to work. In such a case, fast IGP convergence remains important to restore traffic as quickly as possible. Implementations of TI-LFA should deal with the occurrence of multiple unrelated failures in accordance to the IP Fast Reroute Framework [[RFC5714](#)].

11. Advantages of using the expected post-convergence path during FRR

[RFC7916] raised several operational considerations when using LFA or remote LFA. [\[RFC7916\] Section 3](#) presents a case where a high bandwidth link between two core routers is protected through a PE router connected with low bandwidth links. In such a case, congestion may happen when the FRR backup path is activated. [\[RFC7916\]](#) introduces a local policy framework to let the operator tuning manually the best alternate election based on its own requirements.

From a network capacity planning point of view, it is often assumed for simplicity that if a link L fails on a particular node X, the bandwidth consumed on L will be spread over some of the remaining links of X. The remaining links to be used are determined by the IGP routing considering that the link L has failed (we assume that the traffic uses the post-convergence path starting from the node X). In Figure 3, we consider a network with all metrics equal to 1 except the metrics on links used by PE1, PE2 and PE3 which are 1000. An easy network capacity planning method is to consider that if the link L (X-B) fails, the traffic actually flowing through L will be spread over the remaining links of X (X-H, X-D, X-A). Considering the IGP metrics, only X-H and X-D can be used in reality to carry the traffic flowing through the link L. As a consequence, the bandwidth of links X-H and X-D is sized according to this rule. We should observe that this capacity planning policy works, however it is not fully accurate.

In Figure 3, considering that the source of traffic is only from PE1 and PE4, when the link L fails, depending on the convergence speed of the nodes, X may reroute its forwarding entries to the remote PEs

onto X-H or X-D; however in a similar timeframe, PE1 will also reroute a subset of its traffic (the subset destined to PE2) out of its nominal path reducing the quantity of traffic received by X. The capacity planning rule presented previously has the drawback of oversizing the network, however it allows to prevent any transient congestion (when for example X reroutes traffic before PE1 does).

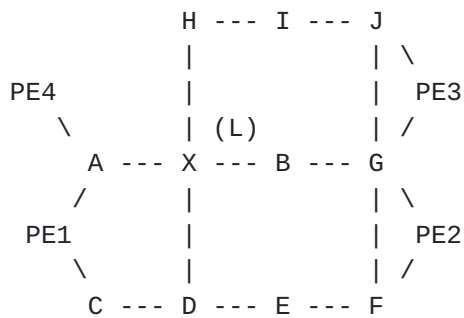


Figure 3

Based on this assumption, in order to facilitate the operation of FRR, and limit the implementation of local FRR policies, traffic can be steered by the PLR onto its expected post-convergence path during the FRR phase. In our example, when link L fails, X switches the traffic destined to PE3 and PE2 on the post-convergence paths. This is perfectly inline with the capacity planning rule that was presented before and also inline with the fact X may converge before PE1 (or any other upstream router) and may spread the X-B traffic onto the post-convergence paths rooted at X.

It should be noted, that some networks may have a different capacity planning rule, leading to an allocation of less bandwidth on X-H and X-D links. In such a case, using the post-convergence paths rooted at X during FRR may introduce some congestion on X-H and X-D links. However it is important to note, that a transient congestion may possibly happen, even without FRR activated, for instance when X converges before the upstream routers. Operators are still free to use the policy framework defined in [RFC7916] if the usage of the post-convergence paths rooted at the PLR is not suitable.

Readers should be aware that FRR protection is pre-computing a backup path to protect against a particular type of failure (link, node, SRLG). When using the post-convergence path as FRR backup path, the computed post-convergence path is the one considering the failure we are protecting against. This means that FRR is using an expected post-convergence path, and this expected post-convergence path may be actually different from the post-convergence path used if the failure that happened is different from the failure FRR was protecting

against. As an example, if the operator has implemented a protection against a node failure, the expected post-convergence path used during FRR will be the one considering that the node has failed. However, even if a single link is failing or a set of links is failing (instead of the full node), the node-protecting post-convergence path will be used. The consequence is that the path used during FRR is not optimal with respect to the failure that has actually occurred.

Another consideration to take into account is: while using the expected post-convergence path for SR traffic using node segments only (for instance, PE to PE traffic using shortest path) has some advantages, these advantages reduce when SR policies ([RFC9256]) are involved. A segment-list used in an SR policy is computed to obey a set of path constraints defined locally at the head-end or centrally in a controller. TI-LFA cannot be aware of such path constraints and there is no reason to expect the TI-LFA backup path protecting one segments in that segment list to obey those constraints. When SR policies are used and the operator wants to have a backup path which still follows the policy requirements, this backup path should be computed as part of the SR policy in the ingress node (or central controller) and the SR policy should not rely on local protection. Another option could be to use FlexAlgo ([RFC9350]) to express the set of constraints and use a single node segment associated with a FlexAlgo to reach the destination. When using a node segment associated with a FlexAlgo, TI-LFA keeps providing an optimal backup by applying the appropriate set of constraints. The relationship between TI-LFA and the SR-algorithm is detailed in [Section 9](#).

[12. Analysis based on real network topologies](#)

This section presents analysis performed on real service provider and large enterprise network topologies. The objective of the analysis is to assess the number of SIDs required in an explicit path when the mechanisms described in this document are used to protect against the failure scenarios within the scope of this document. The number of segments described in this section are applicable to instantiating segment routing over the MPLS forwarding plane.

The measurement below indicate that for link and local SRLG protection, a 1 SID repair path delivers more than 99% coverage. For node protection a 2 SIDs repair path yields 99% coverage.

Table 1 below lists the characteristics of the networks used in our measurements. The number of links refers to the number of "bidirectional" links (not directed edges of the graph). The measurements are carried out as follows:

- * For each network, the algorithms described in this document are applied to protect all prefixes against link, node, and local SRLG failure
- * For each prefix, the number of SIDs used by the repair path is recorded
- * The percentage of number of SIDs are listed in Tables 2A/B, 3A/B, and 4A/B

The measurements listed in the tables indicate that for link and local SRLG protection, 1 SID repair path is sufficient to protect more than 99% of the prefix in almost all cases. For node protection 2 SIDs repair paths yield 99% coverage.

Network	Nodes	Links	Node-to-Link Ratio	SRLG info?
T1	408	665	1.63	Yes
T2	587	1083	1.84	No
T3	93	401	4.31	Yes
T4	247	393	1.59	Yes
T5	34	96	2.82	Yes
T6	50	78	1.56	No
T7	82	293	3.57	No
T8	35	41	1.17	Yes
T9	177	1371	7.74	Yes

Table 1: Data Set Definition

The rest of this section presents the measurements done on the actual topologies. The convention that we use is as follows

- * 0 SIDs: the calculated repair path starts with a directly connected neighbor that is also a loop free alternate, in which case there is no need to explicitly route the traffic using additional SIDs. This scenario is described in [Section 6.1](#).

- * 1 SIDs: the repair node is a PQ node, in which case only 1 SID is needed to guarantee a loop-free path. This scenario is covered in [Section 6.2](#).
- * 2 or more SIDs: The repair path consists of 2 or more SIDs as described in [Section 6.3](#) and [Section 6.4](#). We do not cover the case for 2 SIDs ([Section 6.3](#)) separately because there was no granularity in the result. Also we treat the node-SID+adj-SID and node-SID + node-SID the same because they do not differ from the data plane point of view.

Table 2A and 2B below summarize the measurements on the number of SIDs needed for link protection

Network	0 SIDs	1 SID	2 SIDs	3 SIDs
T1	74.3%	25.3%	0.5%	0.0%
T2	81.1%	18.7%	0.2%	0.0%
T3	95.9%	4.1%	0.1%	0.0%
T4	62.5%	35.7%	1.8%	0.0%
T5	85.7%	14.3%	0.0%	0.0%
T6	81.2%	18.7%	0.0%	0.0%
T7	98.9%	1.1%	0.0%	0.0%
T8	94.1%	5.9%	0.0%	0.0%
T9	98.9%	1.0%	0.0%	0.0%

Table 2A: Link protection (repair size distribution)

Network	0 SIDs	1 SID	2 SIDs	3 SIDs
T1	74.2%	99.5%	99.9%	100.0%
T2	81.1%	99.8%	100.0%	100.0%
T3	95.9%	99.9%	100.0%	100.0%
T4	62.5%	98.2%	100.0%	100.0%

T5	85.7%	100.0%	100.0%	100.0%
T6	81.2%	99.9%	100.0%	100.0%
T7	98,8%	100.0%	100.0%	100.0%
T8	94,1%	100.0%	100.0%	100.0%
T9	98,9%	100.0%	100.0%	100.0%

Table 2B: Link protection repair size cumulative distribution
 Table 3A and 3B summarize the measurements on the number of SIDs needed for local SRLG protection.

Network	0 SIDs	1 SID	2 SIDs	3 SIDs
T1	74.2%	25.3%	0.5%	0.0%
T2	No SRLG Information			
T3	93.6%	6.3%	0.0%	0.0%
T4	62.5%	35.6%	1.8%	0.0%
T5	83.1%	16.8%	0.0%	0.0%
T6	No SRLG Information			
T7	No SRLG Information			
T8	85.2%	14.8%	0.0%	0.0%
T9	98,9%	1.1%	0.0%	0.0%

Table 3A: Local SRLG protection repair size distribution

Network	0 SIDs	1 SID	2 SIDs	3 SIDs
T1	74.2%	99.5%	99.9%	100.0%
T2	No SRLG Information			
T3	93.6%	99.9%	100.0%	0.0%
T4	62.5%	98.2%	100.0%	100.0%

T5	83.1%	100.0%	100.0%	100.0%
T6	No SRLG Information			
T7	No SRLG Information			
T8	85.2%	100.0%	100.0%	100.0%
T9	98.9%	100.0%	100.0%	100.0%

Table 3B: Local SRLG protection repair size Cumulative distribution
 The remaining two tables summarize the measurements on the number of SIDs needed for node protection.

Network	0 SIDs	1 SID	2 SIDs	3 SIDs	4 SIDs
T1	49.8%	47.9%	2.1%	0.1%	0.0%
T2	36.5%	59.6%	3.6%	0.2%	0.0%
T3	73.3%	25.6%	1.1%	0.0%	0.0%
T4	36.1%	57.3%	6.3%	0.2%	0.0%
T5	73.2%	26.8%	0%	0%	0%
T6	78.3%	21.3%	0.3%	0%	0%
T7	66.1%	32.8%	1.1%	0%	0%
T8	59.7%	40.2%	0%	0%	0%
T9	98.9%	1.0%	0%	0%	0%

Table 4A: Node protection (repair size distribution)

Network	0 SIDs	1 SID	2 SIDs	3 SIDs	4 SIDs
T1	49.7%	97.6%	99.8%	99.9%	100%
T2	36.5%	96.1%	99.7%	99.9%	100%
T3	73.3%	98.9%	99.9%	100.0%	100%
T4	36.1%	93.4%	99.8%	99.9%	100%

T5	73.2%	100.0%	100.0%	100.0%	100%
T6	78.4%	99.7%	100.0%	100.0%	100%
T7	66.1%	98.9%	100.0%	100.0%	100%
T8	59.7%	100.0%	100.0%	100.0%	100%
T9	98.9%	100.0%	100.0%	100.0%	100%

Table 4B: Node protection (repair size cumulative distribution)

13. Security Considerations

The techniques described in this document are internal functionalities to a router that result in the ability to guarantee an upper bound on the time taken to restore traffic flow upon the failure of a directly connected link or node. As these techniques steer traffic to the post-convergence path as quickly as possible, this serves to minimize the disruption associated with a local failure which can be seen as a modest security enhancement. The protection mechanisms does not protect external destinations, but rather provides quick restoration for destination that are internal to a routing domain.

Security considerations described in [\[RFC5286\]](#) and [\[RFC7490\]](#) apply to this document. Similarly, as the solution described in the document is based on Segment Routing technology, reader should be aware of the security considerations related to this technology ([\[RFC8402\]](#)) and its dataplane instantiations ([\[RFC8660\]](#), [\[RFC8754\]](#) and [\[RFC8986\]](#)). However, this document does not introduce additional security concern.

14. IANA Considerations

No requirements for IANA

15. Contributors

In addition to the authors listed on the front page, the following co-authors have also contributed to this document:

- * Francois Clad, Cisco Systems
- * Pablo Camarillo, Cisco Systems

16. Acknowledgments

We would like to thank Les Ginsberg, Stewart Bryant, Alexander Vainsthein, Chris Bowers, Shraddha Hedge, Wes Hardaker for their valuable comments.

17. References

17.1. Normative References

- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", [BCP 14](#), [RFC 2119](#), DOI 10.17487/RFC2119, March 1997, <<https://www.rfc-editor.org/info/rfc2119>>.
- [RFC7916] Litkowski, S., Ed., Decraene, B., Filsfils, C., Raza, K., Horneffer, M., and P. Sarkar, "Operational Management of Loop-Free Alternates", [RFC 7916](#), DOI 10.17487/RFC7916, July 2016, <<https://www.rfc-editor.org/info/rfc7916>>.
- [RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in [RFC 2119](#) Key Words", [BCP 14](#), [RFC 8174](#), DOI 10.17487/RFC8174, May 2017, <<https://www.rfc-editor.org/info/rfc8174>>.
- [RFC8402] Filsfils, C., Ed., Previdi, S., Ed., Ginsberg, L., Decraene, B., Litkowski, S., and R. Shakir, "Segment Routing Architecture", [RFC 8402](#), DOI 10.17487/RFC8402, July 2018, <<https://www.rfc-editor.org/info/rfc8402>>.
- [RFC8660] Bashandy, A., Ed., Filsfils, C., Ed., Previdi, S., Decraene, B., Litkowski, S., and R. Shakir, "Segment Routing with the MPLS Data Plane", [RFC 8660](#), DOI 10.17487/RFC8660, December 2019, <<https://www.rfc-editor.org/info/rfc8660>>.
- [RFC8754] Filsfils, C., Ed., Dukes, D., Ed., Previdi, S., Leddy, J., Matsushima, S., and D. Voyer, "IPv6 Segment Routing Header (SRH)", [RFC 8754](#), DOI 10.17487/RFC8754, March 2020, <<https://www.rfc-editor.org/info/rfc8754>>.
- [RFC8986] Filsfils, C., Ed., Camarillo, P., Ed., Leddy, J., Voyer, D., Matsushima, S., and Z. Li, "Segment Routing over IPv6 (SRv6) Network Programming", [RFC 8986](#), DOI 10.17487/RFC8986, February 2021, <<https://www.rfc-editor.org/info/rfc8986>>.

17.2. Informative References

- [I-D.bashandy-rtgwg-segment-routing-uloop]
Bashandy, A., Filsfils, C., Litkowski, S., Decraene, B., Francois, P., and P. Psenak, "Loop avoidance using Segment Routing", Work in Progress, Internet-Draft, [draft-bashandy-rtgwg-segment-routing-uloop-16](#), 17 December 2023, <<https://datatracker.ietf.org/doc/html/draft-bashandy-rtgwg-segment-routing-uloop-16>>.
- [RFC5286] Atlas, A., Ed. and A. Zinin, Ed., "Basic Specification for IP Fast Reroute: Loop-Free Alternates", [RFC 5286](#), DOI 10.17487/RFC5286, September 2008, <<https://www.rfc-editor.org/info/rfc5286>>.
- [RFC5714] Shand, M. and S. Bryant, "IP Fast Reroute Framework", [RFC 5714](#), DOI 10.17487/RFC5714, January 2010, <<https://www.rfc-editor.org/info/rfc5714>>.
- [RFC5715] Shand, M. and S. Bryant, "A Framework for Loop-Free Convergence", [RFC 5715](#), DOI 10.17487/RFC5715, January 2010, <<https://www.rfc-editor.org/info/rfc5715>>.
- [RFC6571] Filsfils, C., Ed., Francois, P., Ed., Shand, M., Decraene, B., Uttaro, J., Leymann, N., and M. Horneffer, "Loop-Free Alternate (LFA) Applicability in Service Provider (SP) Networks", [RFC 6571](#), DOI 10.17487/RFC6571, June 2012, <<https://www.rfc-editor.org/info/rfc6571>>.
- [RFC6976] Shand, M., Bryant, S., Previdi, S., Filsfils, C., Francois, P., and O. Bonaventure, "Framework for Loop-Free Convergence Using the Ordered Forwarding Information Base (oFIB) Approach", [RFC 6976](#), DOI 10.17487/RFC6976, July 2013, <<https://www.rfc-editor.org/info/rfc6976>>.
- [RFC7490] Bryant, S., Filsfils, C., Previdi, S., Shand, M., and N. So, "Remote Loop-Free Alternate (LFA) Fast Reroute (FRR)", [RFC 7490](#), DOI 10.17487/RFC7490, April 2015, <<https://www.rfc-editor.org/info/rfc7490>>.
- [RFC8333] Litkowski, S., Decraene, B., Filsfils, C., and P. Francois, "Micro-loop Prevention by Introducing a Local Convergence Delay", [RFC 8333](#), DOI 10.17487/RFC8333, March 2018, <<https://www.rfc-editor.org/info/rfc8333>>.
- [RFC8665] Psenak, P., Ed., Previdi, S., Ed., Filsfils, C., Gredler, H., Shakir, R., Henderickx, W., and J. Tantsura, "OSPF Extensions for Segment Routing", [RFC 8665](#), DOI 10.17487/RFC8665, December 2019, <<https://www.rfc-editor.org/info/rfc8665>>.

- [RFC8667] Previdi, S., Ed., Ginsberg, L., Ed., Filsfils, C., Bashandy, A., Gredler, H., and B. Decraene, "IS-IS Extensions for Segment Routing", [RFC 8667](#), DOI 10.17487/RFC8667, December 2019, <<https://www.rfc-editor.org/info/rfc8667>>.
- [RFC9256] Filsfils, C., Talaulikar, K., Ed., Voyer, D., Bogdanov, A., and P. Mattes, "Segment Routing Policy Architecture", [RFC 9256](#), DOI 10.17487/RFC9256, July 2022, <<https://www.rfc-editor.org/info/rfc9256>>.
- [RFC9350] Psenak, P., Ed., Hegde, S., Filsfils, C., Talaulikar, K., and A. Gulko, "IGP Flexible Algorithm", [RFC 9350](#), DOI 10.17487/RFC9350, February 2023, <<https://www.rfc-editor.org/info/rfc9350>>.

Authors' Addresses

Ahmed Bashandy
Cisco Systems
Email: abashandy.ietf@gmail.com

Stephane Litkowski
Cisco Systems
France
Email: slitkows@cisco.com

Clarence Filsfils
Cisco Systems
Brussels
Belgium
Email: cfilsfil@cisco.com

Pierre Francois
INSA Lyon
Email: pierre.francois@insa-lyon.fr

Bruno Decraene
Orange
Issy-les-Moulineaux
France
Email: bruno.decraene@orange.com

Daniel Voyer
Bell Canada
Canada
Email: daniel.voyer@bell.ca