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Multicast-only Fast Reroute Based on Topology Independent Loop-free
Alternate (TI-LFA) Fast Reroute
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Abstract

This document specifies the use of Topology Independent Loop-Free
Alternate (TI-LFA) mechanisms with Multicast Only Fast ReRoute
(MoFRR) for Protocol Independent Multicast (PIM).

The TI-LFA mechanism is designed for standard link-state Interior Gateway Protocol (IGP) shortest path and Segment Routing (SR) scenarios. TI-LFA provides fast reroute protection for unicast traffic in IP networks by precomputing backup paths that avoid potential failures. By integrating TI-LFA with MoFRR, this document extends the benefits of fast reroute mechanisms to multicast traffic, enabling enhanced resilience and minimized packet loss in multicast networks. The document outlines the necessary protocol extensions and operational considerations to implement TI-LFA in conjunction with MoFRR for PIM, ensuring that multicast traffic is rapidly rerouted in the event of a failure. This document uses the a backup path computed by TI-LFA through IGP as a secondary Upstream Multicast Hop (UMH) for PIM. By using the TI-LFA backup path to send PIM secondary Join messages hop-by-hop, it achieves the generation of a fast reroute backup path for PIM multicast.

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I was also expecting to see at least rfc8102 referenced.

Also, is the approach immune against micro loops? If not a concern, can we explicit that in the doc?

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You have that exact text anyway in the intro.

a mis en forme : Surlignage

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1. Introduction

The increasing deployment of video services has heightened the importance for network operators to implement solutions that minimize service disruptions caused by faults in the IP networks

carrying delivering

these services. Multicast-only Fast Reroute (MoFRR), as defined in [RFC7431], offers a mechanism to reduce multicast packet loss in the event of node or link failures by introducing simple enhancements to multicast routing protocols, such as Protocol Independent Multicast (PIM). However, the [RFC7431] MoFRR mechanism, which selects the secondary multicast next-next-hop based solely on the loop-free alternate fast reroute defined in [RFC7431], has limitations in certain multicast deployment scenarios.

This document introduces a new mechanism for MoFRR Multicast-only Fast Reroute using Topology Independent Loop-Free Alternate (TI-LFA) [I-D.ietf-rtgwg-segment-routing-ti-lfa] fast reroute. Unlike traditional conventional methods, TI-LFA is independent of network topology,

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Starting with the sentence right after would just be fine.

Commenté [MB8]: Cite PIM RFCs

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enabling broader coverage across diverse network environments. The applicability of this mechanism extends to PIM networks, including scenarios where PIM operates over native IP, as well as public network multicast trees established by PIM. Additionally, this document addresses scenarios involving Multicast Distribution Tree (MDT) SAFI for Multicast VPN (MVPN) in [RFC6037] and [RFC6514], covering PIM-SSM Tree, PIM-SM Tree, and BIDIR-PIM Tree-tree deployments.

The TI-LFA mechanism is designed for standard link-state Interior Gateway Protocol (IGP) shortest path and Segment Routing (SR) scenarios. For each destination specified by the IGP in the a network,

TI-LFA pre-installs a backup forwarding entry for the protected destination, ready to be activated upon the detection of a link failure used to reach that destination. This document leverages the backup path computed by TI-LFA through the IGP as a secondary Upstream Multicast Hop (UMH) for PIM. By using the TI-LFA backup path to send PIM secondary join messages hop by hop, it enables the creation of a fast reroute backup path for PIM multicast.

The protection techniques described in this document are limited to protecting links and nodes within a link-state IGP area. Protecting domain exit routers and/or links attached to other routing domains is beyond the scope of this document. All the Segment Identifiers (SIDs) required are contained within the Link State Database (LSDB) of the IGP.

Note that this document introduces an optional approach for backup join paths, designed to enhance the protection scope of existing multicast systems. It is fully compatible with current protocol implementations and does not necessitate any changes to the protocols or forwarding functions on intermediate nodes. If there is a choice between vector and non-vector joins on the intermediate nodes, the non-vector option should be prioritized, which implies that protection paths will remain inactive. This document does not modify the handling of conflicts in PIM Join messages. For guidance on conflicts in join attributes, please refer to Section 3.3.3 of [RFC5384].

1.1. Terminology

This document utilizes the terminology as defined in [RFC7431] and incorporates the concepts established in [RFC7490]. The definitions of individual terms are not reiterated within this document.

2. Problem Statement

2.1. LFA for MoFRR

Section 3 of [RFC7431] specifies that the-a secondary UMH in PIM for MoFRR is a Loop-Free Alternate (LFA). However, the traditional conventional LFA mechanism requires that at least one neighbor's next-next-hop to the destination node is an-a loop-free next-next-hop. Due to existing limitations in network deployments, this mechanism only covers

Commenté [MB10]: Do you mean inter-domain? If so, some discussion on the implications/déploiement considerations are needed.

Commenté [MB11]: •Why is this cited? Why this specific flavor? What about rfc6513?
•If you maintain this mention, can we have an example to illustrate the use?

Commenté [MB12]: Consider adding refs

a mis en forme : Surlignage

Commenté [MB13]: Advertized? learned?

Commenté [MB14]: To which this refers?

Commenté [MB15]: Redundant with «protecting links ...»

Commenté [MB16]: Conflicts with «extensions» in the abstract

Commenté [MB17]: Such as?

Commenté [MB18]: Which one?

certain network topology environments. In specific network topologies, the corresponding secondary UMH cannot be computed, preventing PIM from establishing a standby multicast tree and thus from implementing MoFRR protection. Consequently, the [RFC7431] MoFRR functionality in PIM is applicable only in network topologies where LFA is feasible.

Commenté [MB19]: Corresponding to what?

The limitations of the [RFC7431] MoFRR applicability can be illustrated using the example network depicted in Figure 1. In this example, the metric of the R1-R4 link is 20, the metric of the R5-R6 link is 100, and the metrics of the other links are 10.

For multicast source S1, the primary path of the PIM Join packet is R3->R2->R1, and the secondary path is R3->R4->R1, which corresponds to the LFA path of unicast routing. In this scenario, the [RFC7431] MoFRR operates effectively.

Commenté [MB20]: The receiver should be mentioned also

For multicast source S2, the primary path of the PIM join-Join packet is R3->R2. However, an LFA does not exist. If R3 sends the packet to R4, R4 will forward it back to R3 because the IGP shortest path from R4 to R1 is R4->R3->R2. In this case, the [RFC7431] MoFRR cannot calculate a secondary UMH. Similarly, for multicast source S3, the [RFC7431] MoFRR mechanism is ineffective.

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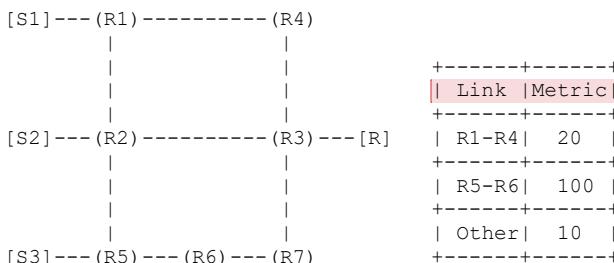


Figure 1: Example Network Topology

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2.2. RLFA for MoFRR

The Remote Loop-Free Alternate (RLFA), as defined in [RFC7490], extends the traditional LFA mechanism, allowing it to accommodate a broader range of network deployments and scenarios by utilizing a tunnel as an alternate path. The RLFA mechanism requires that there exists at least one node, denoted as node N, in the network where the fault node is neither on the path from the source node to node N nor on the path from node N to the destination node.

Commenté [MB23]: Clarify to avoid confusion with multicast source

[RFC5496] introduces the Reverse Path Forwarding (RPF) Vector attribute, which can be included in the PIM Join packet-messages to ensure that the path is selected based on the unicast reachability of the RPF Vector. By combining the RLFA mechanism with the RPF Vector, the a secondary multicast tree for MoFRR

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can be established, thereby supporting a wider range of network topologies compared to the [RFC7431] MoFRR implementation with LFA.

For instance, in the network illustrated in Figure 1, the secondary path for the PIM Join packet towards multicast source S2 cannot be computed by the [RFC7431] MoFRR, as previously described. Utilizing the RLFA-mechanism, R3 sends the packet to R4, including an RPF Vector containing the IP address of R1, which serves as the PQ node of R3 with respect to the protected R2-R3 link. Subsequently, R4 forwards the packet to R1 via the R1-R4 link, in accordance with the unicast route associated with the RPF Vector. R1 then continues to forward the packet to R2, thereby establishing the secondary path, R3->R4->R1->R2, using MoFRR with RLFA.

2.3. TI-LFA for MoFRR

While RLFA provides enhanced capabilities over LFA, it remains dependent on the network topology. In the network depicted in Figure 1, the primary path of the PIM Join packet towards multicast source S3 is R3->R2->R5. However, an RLFA path does not exist because the PQ node of R3 with respect to the protected link R2-R3 is absent. If R3 sends the packet to R7 with an RPF Vector containing the IP address of R5, R7 will forward it back to R3, as the IGP shortest path from R7 to R5 is R7->R3->R2->R5. Similarly, if R3 sends the packet to R7 with an RPF Vector containing the IP address of R6, R7 will forward it to R6, but R6 will then forward it back to R7, as the IGP shortest path from R6 to R5 is R6->R7->R3->R2->R5. In this scenario, MoFRR with RLFA is unable to compute a secondary UMH.

RLFA offers improvements over LFA but still has inherent limitations. [I-D.ietf-rtgwg-segment-routing-ti-lfa] defines a unicast FRR solution based on the TI-LFA mechanism. The TI-LFA mechanism allows the expression of a backup path using an explicit path and imposes no constraints on the network topology, thus providing a more robust FRR mechanism. Unicast traffic can be forwarded according to an explicit path list as an alternate path to protect unicast traffic, achieving full coverage across various network environments.

The alternate path provided by the TI-LFA mechanism is represented as a Segment List, which includes the NodeSID of the P-space node and the Adjacency SIDs of the links between the P-space and Q-space nodes. PIM can look up the corresponding node IP address in the unicast route base according to the NodeSID and the IP addresses of

Commenté [MB25]: Please double check

the endpoints of the corresponding link in the unicast route according to the Adjacency SIDs. However, multicast protocol packets cannot be directly forwarded along the path of the Segment List.

To establish a standby multicast tree, PIM Join messages need to be transmitted hop-by-hop. However, not all nodes and links on the unicast alternate path are included in the Segment List. If PIM protocol packets are transmitted solely in unicast mode, they effectively traverse the unicast tunnel like unicast traffic and do not pass through the intermediate nodes of the tunnel. Consequently,

the intermediate nodes on the alternate path cannot forward multicast traffic because they lack PIM state entries. PIM must create entries on each device hop-by-hop, generating an incoming interface and an outgoing interface list, to form a complete end-to-end multicast tree for forwarding multicast traffic. Therefore, simply sending PIM Join packets using the Segment List, as done with unicast traffic, is insufficient to establish a standby multicast tree.

3. A Solution

A secondary ~~Upstream Multicast Hop~~ (UMH) serves as a candidate next-hop that can be used to reach the root of ~~the-a~~ multicast tree. In this document, the secondary UMH is derived from unicast routing, utilizing the Segment List computed by TI-LFA.

~~In essence, t~~The path information from the Segment List is incorporated into the PIM packets to guide hop-by-hop ~~Reverse Path Forwarding (RPF)~~ selection. The IP address corresponding to the Node SID can be used as the segmented root node, while the IP addresses of the interfaces at both endpoints of the link associated with the Adjacency SID can be ~~directly~~ used as the local upstream interface and upstream neighbor.

~~For the PIM protocol,~~ [RFC5496] defines the PIM RPF Vector attribute, which can carry the node's IP address corresponding to the Node SID. Additionally, [RFC7891] defines the explicit RPF Vector, which can carry the peer's IP address corresponding to the Adjacency SID.

This document leverages the existing RPF Vector standards, obviating the need for PIM protocol extensions. This approach allows the establishment of a standby multicast tree based on the Segment List calculated by TI-LFA, thereby providing comprehensive MoFRR protection for multicast services across diverse network environments.

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a mis en forme : Surlignage

Consider a Segment List calculated by TI-LFA as (NodeSID(A), AdjSID(A-B)). Node A belongs to the ~~P-P~~-space, and node B belongs to the ~~Q-Q~~-space. The IP address corresponding to NodeSID(A) can be retrieved from the local link-state database of the IGP ~~protocol~~ and assumed to be IP-a. Similarly, the IP addresses of the two endpoints of the link corresponding to AdjSID(A-B) can also be retrieved from the local link-state database and assumed to be IP-La and IP-Lb.

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Within the PIM process, IP-a is treated as the standard RPF Vector Attribute and added to the PIM Join packet. IP-La is considered the local address of the incoming interface, and IP-Lb is regarded as the address of the upstream neighbor. Consequently, IP-Lb can be included in the PIM Join packet as the explicit RPF Vector Attribute.

The PIM protocol initially selects the RPF incoming interface and upstream neighbor towards IP-a and proceeds hop-by-hop to establish the PIM standby multicast tree until reaching node A. At node A, IP-Lb is treated as the PIM upstream neighbor. Node A identifies the incoming interface in the unicast routing table based on IP-Lb, and IP-Lb is used as the RPF upstream address for the PIM Join packet directed towards node B.

Upon receiving the PIM Join packet at node B, the PIM protocol,

finding no additional RPF Vector Attributes, selects the RPF incoming interface and upstream neighbor towards the multicast source directly. The protocol then continues hop-by-hop to establish the PIM standby multicast tree, extending to the router directly connected to the source.

4. Illustration

This section provides an illustration of MoFRR based on TI-LFA. The example topology is depicted in Figure 2. The metric for the R3-R4 link is 100, while the metrics for the other links are 10. All link metrics are bidirectional.

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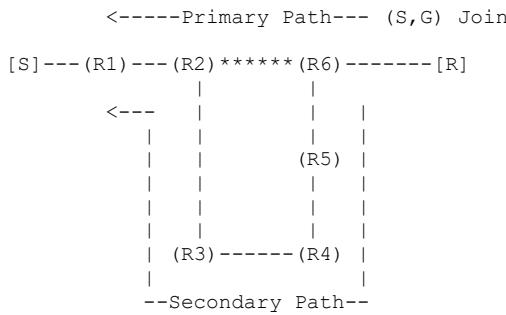


Figure 2: Example Topology

The IP addresses and SIDs involved in the MoFRR calculation are configured as follows:

IPv4 Data Plane (MPLS-SR)

Node	IP Address	Node SID
R4	IP4-R4	Label-R4
Link	IP Address	Adjacency SID
R3->R4	IP4-R3-R4	Label-R3-R4
R4->R3	IP4-R4-R3	Label-R4-R3

Commenté [MB29]: Cite authoritative RFC

IPv6 Data Plane (SRv6)

Node	IP Address	Node SID (End)
R4	IP6-R4	SID-R4
Link	IP Address	Adjacency SID (End.X)
R3->R4	IP6-R3-R4	SID-R3-R4
R4->R3	IP6-R4-R3	SID-R4-R3

Commenté [MB30]: Cite authoritative RFC

The primary path of the PIM Join packet is R6->R2->R1, and the secondary path is R6->R5->R4->R3->R2->R1. However, the traditional LFA does not function properly for the secondary path because the shortest path to R2 from R5 (or from R4) still traverses the R6-R2 link. In this scenario, R6 must calculate the secondary UMH using the proposed MoFRR method based on TI-LFA.

According to the TI-LFA algorithm, the P-space and Q-space are

illustrated in Figure 3. The TI-LFA repair path consists of the Node SID of R4 and the Adjacency SID of R4->R3. On the MPLS-SR data plane, the repair segment list is (Label-R4, Label-R4-R3). On the SRv6 data plane, the repair segment list is (SID-R4, SID-R4-R3).

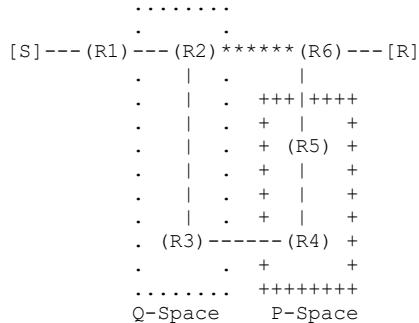


Figure 3: P-Space and Q-Space

In the PIM process, the IP addresses associated with the repair segment list are retrieved from the IGP link-state database.

On the IPv4 data plane, the Node SID Label-R4 corresponds to IP4-R4, which will be carried in the RPF Vector Attribute. The Adjacency SID Label-R4-R3 corresponds to the local address IP4-R4-R3 and the remote peer address IP4-R3-R4, with IP4-R3-R4 carried in the Explicit RPF Vector Attribute.

On the IPv6 data plane, the End SID SID-R4 corresponds to IP6-R4, which will be carried in the RPF Vector Attribute. The End.X SID SID-R4-R3 corresponds to the local address IP6-R4-R3 and the remote peer address IP6-R3-R4, with IP6-R3-R4 carried in the Explicit RPF Vector Attribute.

Subsequently, R6 installs the secondary UMH using these RPF Vectors.

```
+-----+
|Type = 0 |
|IP4-R4 |
+-----+ +-----+
|Type = 4 | |Type = 4 |
|IP4-R3-R4| |IP4-R3-R4|
+-----+ +-----+ No RPF Vector
```

R6----->R5----->R4----->R3----->R2----->R1

Figure 4: Forwarding PIM Join Packet along Secondary Path (IPv4)

On the IPv4 data plane, the forwarding of the PIM Join packet along the secondary path is shown in Figure 4.

R6 inserts two RPF Vector Attributes in the PIM Join packet: IP4-R4 of Type 0 (RPF Vector Attribute) and IP4-R3-R4 of Type 4 (Explicit RPF Vector Attribute). R6 then forwards the packet along the

secondary path.

When R5 receives the packet, it performs a unicast route lookup of the first RPF Vector IP4-R4 and sends the packet to R4.

R4, being the owner of IP4-R4, removes the first RPF Vector from the packet and forwards it according to the next RPF Vector. R4 sends the packet to R3 based on the next RPF Vector IP4-R3-R4, as its PIM neighbor R3 corresponds to IP4-R3-R4.

When R3 receives the packet, as the owner of IP4-R3-R4, it removes the RPF Vector. The packet, now devoid of RPF Vectors, is forwarded to the source through R3->R2->R1 based on unicast routes.

After the PIM Join packet reaches R1, a secondary multicast tree, R1->R2->R3->R4->R5->R6, is established hop-by-hop for (S, G) using MoFRR based on TI-LFA.

```
+-----+
|Type = 0 |
|IP6-R4  |
+-----+      +-----+
|Type = 4 |      |Type = 4 |
|IP6-R3-R4|      |IP6-R3-R4|
+-----+      +-----+  No RPF Vector
```

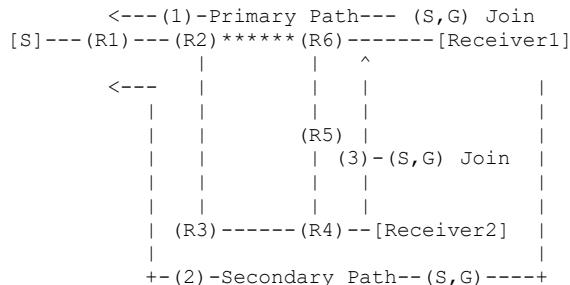
R6----->R5----->R4----->R3----->R2----->R1

Figure 5: Forwarding PIM Join Packet along Secondary Path (IPv6)

On the IPv6 data plane, the forwarding of the PIM Join packet along the secondary path is illustrated in Figure 5. The procedure is analogous to that of the IPv4 data plane.

5. Join Conflict Considerations

This section illustrates the resolution of PIM join conflicts. When intermediate nodes must choose between PIM joins with an RPF Vector attribute and those without, priority should be given to the joins without the RPF Vector attribute. Figure 6 shows the example topology. In this setup, the metric for the R3-R4 link is 100, while the metrics for all other links are 10. Additionally, all link metrics are bidirectional.



(1): Receiver1 Primary Path PIM Join (2): Receiver1

Secondary Path PIM Join with RPF Vector (3): Receiver2
Primary Path PIM Join

Figure 6: Join Conflict Scenario

Figure 6 illustrates that both R6 and R4 have receivers, with R6 utilizing MoFRR based on TI-LFA. At R6 the primary PIM Join packet path is R6->R2->R1, while the secondary path is R6->R5->R4->R3->R2->R1. At R4 the PIM Join packet path is R4->R5->R6->R2->R1.

On R5, the PIM forwarding entries are:

[R5]:

(S,G) Entry 1 from Receiver1:

 Incoming interface: R4-R5

 Outgoing interface: R5-R6 (Join with RPF Vector)

(S,G) Entry 2 from Receiver2:

 Incoming interface: R6-R5

 Outgoing interface: R5-R4 (Join without RPF Vector)

To prevent conflicts, the PIM Join without the RPF Vector should be prioritized. Thus, R5 retains only Entry 2 with R6-R5 as the incoming interface and R5-R4 as the outgoing interface. After selection, the final forwarding entry on R5 is as follows:

[R5]:

(S,G) active forwarding Entry:

 Incoming interface: R6-R5

 Outgoing interface: R5-R4

This document specifies an optional approach for backup join paths, intended to enhance the protection scope of existing multicast systems. It is fully compatible with existing protocol implementations and does not require changes to protocols or forwarding functions on intermediate nodes. In the event of PIM ~~Join~~ conflicts, ~~Join messages~~ without the RPF Vector attribute are prioritized to ensure that the original PIM forwarding functionality remains unaffected.

Commenté [MB31]: Already mentioned in the intro.

6. IANA Considerations

This document has no IANA actions.

7. Security Considerations

This document does not introduce additional security concerns. It does not change the security properties of PIM. For general PIM-SM protocol security considerations, see [RFC7761]. The security considerations of LFA, R-LFA, and MoFRR described in [RFC5286], [RFC7490], and [RFC7431] should apply to this document.

| When deploying TI-LFA, packets may be sent over nodes and links they were not transported through before, potentially raising the following security issues:

1. Spoofing and False Route Advertisements

- * Dependencies of LFA/R-LFA/TI-LFA on Routing Information
 - LFAs depend on accurate routing information to determine alternate paths. If an attacker can inject false routing information (e.g., by spoofing link-state advertisements), it could cause the network to select suboptimal or malicious paths for LFAs.
 - R-LFA and TI-LFA also depend on accurate routing information, particularly for determining the tunneling paths or explicit paths. False route advertisements could mislead the network into using insecure or compromised paths.

2. Man-in-the-Middle (MitM) On-path Attacks

- * Use of Alternate Paths
 - By rerouting traffic through alternate paths, especially those that traverse multiple hops (as in R-LFA and TI-LFA), the risk of MitM-on-path attacks increases if any of the intermediate routers on the alternate path ~~are-is~~ compromised.
 - TI-LFA, which uses explicit paths, might expose traffic to routers that were not originally part of the primary path, potentially allowing for interception or alteration of the traffic.

3. Confidentiality and Integrity

- * Traffic Encapsulation
 - R-LFA and TI-LFA involve encapsulating traffic, which may expose it to vulnerabilities if the encapsulation mechanisms are not secure. For instance, if IPsec or another secure encapsulation method is not used, an attacker might be able to intercept or alter the traffic in transit.
- * Protection of Explicit Paths
 - TI-LFA relies on explicit paths that are typically defined using segment routing. If these paths are not properly protected, an attacker could manipulate the segment list to

reroute traffic through malicious nodes.

4. Increased Attack Surface

- * Extended Topology

- By introducing LFA, R-LFA, and TI-LFA, the network increases its reliance on additional routers and links, thereby expanding the potential attack surface. Compromise of any router in these alternate paths could expose traffic to unauthorized access or disruption.

To address security issues #1 and #2 mentioned above, control plane protocols need to provide security protection. To mitigate the risks associated with false route advertisements and MitM-on-path attacks, it is recommended to use secure routing protocols (e.g., OSPFv3 with IPsec, ISIS HMAC-SHA256, or PIM with IPsec) that provide authentication and integrity protection for routing updates.

To address security issues #3 and #4 mentioned above, these mechanisms need to run within a trusted network. The security of LFA, R-LFA, and TI-LFA mechanisms heavily relies on the trustworthiness of the underlying routing infrastructure. As the solution described in the document is based on Segment Routing technology, readers should be aware of the security considerations related to this technology ([RFC8402]) and its data plane instantiations ([RFC8660], [RFC8754], and [RFC8986]).

8. References

8.1. Normative References

[I-D.ietf-rtgwg-segment-routing-ti-lfa]
Bashandy, A., Litkowski, S., Filsfils, C., Francois, P., Decraene, B., and D. Voyer, "Topology Independent Fast Reroute using Segment Routing", Work in Progress, Internet-Draft, draft-ietf-rtgwg-segment-routing-ti-lfa-19, 22 November 2024, <<https://datatracker.ietf.org/doc/html/draft-ietf-rtgwg-segment-routing-ti-lfa-19>>.

[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>>.

[RFC5384] Boers, A., Wijnands, I., and E. Rosen, "The Protocol Independent Multicast (PIM) Join Attribute Format", RFC 5384, DOI 10.17487/RFC5384, November 2008, <<https://www.rfc-editor.org/info/rfc5384>>.

[RFC5496] Wijnands, IJ., Boers, A., and E. Rosen, "The Reverse Path Forwarding (RPF) Vector TLV", RFC 5496, DOI 10.17487/RFC5496, March 2009, <<https://www.rfc-editor.org/info/rfc5496>>.

[RFC7431] Karan, A., Filsfils, C., Wijnands, IJ., Ed., and B.

Decraene, "Multicast-Only Fast Reroute", RFC 7431,
DOI 10.17487/RFC7431, August 2015,
[<https://www.rfc-editor.org/info/rfc7431>](https://www.rfc-editor.org/info/rfc7431).

- [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>](https://www.rfc-editor.org/info/rfc7490).
- [RFC7761] Fenner, B., Handley, M., Holbrook, H., Kouvelas, I., Parekh, R., Zhang, Z., and L. Zheng, "Protocol Independent Multicast - Sparse Mode (PIM-SM): Protocol Specification (Revised)", STD 83, RFC 7761, DOI 10.17487/RFC7761, March 2016, [<https://www.rfc-editor.org/info/rfc7761>](https://www.rfc-editor.org/info/rfc7761).
- [RFC7891] Asghar, J., Wijnands, IJ., Ed., Krishnasamy, S., Karan, A., and V. Arya, "Explicit Reverse Path Forwarding (RPF) Vector", RFC 7891, DOI 10.17487/RFC7891, June 2016, [<https://www.rfc-editor.org/info/rfc7891>](https://www.rfc-editor.org/info/rfc7891).

8.2. Informative References

- [RFC6037] Rosen, E., Ed., Cai, Y., Ed., and IJ. Wijnands, "Cisco Systems' Solution for Multicast in BGP/MPLS IP VPNs", RFC 6037, DOI 10.17487/RFC6037, October 2010, [<https://www.rfc-editor.org/info/rfc6037>](https://www.rfc-editor.org/info/rfc6037).
- [RFC6514] Aggarwal, R., Rosen, E., Morin, T., and Y. Rekhter, "BGP Encodings and Procedures for Multicast in MPLS/BGP IP VPNs", RFC 6514, DOI 10.17487/RFC6514, February 2012, [<https://www.rfc-editor.org/info/rfc6514>](https://www.rfc-editor.org/info/rfc6514).
- [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>](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>](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>](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>](https://www.rfc-editor.org/info/rfc8986).

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