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LFA selection for Multi-Homed Prefixes
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Abstract

This document shares experience gained from implementing algorithms to determine Loop-Free Alternates for multi-homed prefixes. In particular, this document provides explicit inequalities that can be used to evaluate neighbors as a potential alternates for multi-homed prefixes. It also provides detailed criteria for evaluating potential alternates for external prefixes advertised by OSPF ASBRs. This documents updates and expands some of the "Routing Aspects" as specified in Section 6 of RFC 5286.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC8174 [RFC8174].

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1. Introduction

A framework for the development of IP fast- reroute mechanisms is detailed in [RFC5714]. The use of Loop-Free Alternates (LFA) for IP Fast Reroute is specified in [RFC5286]. Section 6.1 of [RFC5286] describes a method to determine loop-free alternates for multi-homed prefixes (MHPs). This document describes a procedure using explicit inequalities that can be used by a computing router to evaluate a neighbor as a potential alternate for a multi-homed prefix. The results obtained are equivalent to those obtained using the method described in Section 6.1 of [RFC5286]. However, some may find this formulation useful.

Section 6.3 of [RFC5286] discusses complications associated with computing LFAs for multi-homed prefixes in OSPF. This document provides detailed criteria for evaluating potential alternates for external prefixes advertised by OSPF ASBRs, as well as explicit inequalities.

This document also provides clarifications, additional considerations to [RFC5286], to address a few coverage and operational observations. These observations are in the area of handling IS-IS attach (ATT) bit in Level-1 (L1) area, links provisioned with MAX_METRIC for traffic engineering (TE) purposes and in the area of Multi Topology (MT) IGP deployments. These are elaborated in detail in Section 3.2 and Section 5.

1.1. Acronyms

AF	-	Address Family
ATT	-	IS-IS Attach Bit
ECMP	-	Equal Cost Multi Path
IGP	-	Interior Gateway Protocol
IS-IS	-	Intermediate System to Intermediate System
LSP	-	IS-IS Link State PDU
OSPF	-	Open Shortest Path First
MHP	-	Multi-homed Prefix
MT	-	Multi Topology
SPF	-	Shortest Path First PDU

2. LFA inequalities for MHPs

This document proposes the following set of LFA inequalities for selecting the most appropriate LFAs for multi-homed prefixes (MHPs). They can be derived from the inequalities in [RFC5286] combined with the observation that $D_{opt}(N,P) = \text{Min} (D_{opt}(N,PO_i) + \text{cost}(PO_i,P))$ over all PO_i

Link-Protection:

$$D_{opt}(N,PO_i) + \text{cost}(PO_i,P) < D_{opt}(N,S) + D_{opt}(S,PO_{best}) + \text{cost}(PO_{best},P)$$

Link-Protection + Downstream-paths-only:

$$D_{opt}(N,PO_i) + \text{cost}(PO_i,P) < D_{opt}(S,PO_{best}) + \text{cost}(PO_{best},P)$$

Node-Protection:

$$D_{opt}(N,PO_i) + \text{cost}(PO_i,P) < D_{opt}(N,E) + D_{opt}(E,PO_{best}) + \text{cost}(PO_{best},P)$$

Where,

- P - The multi-homed prefix being evaluated for computing alternates
- S - The computing router
- N - The alternate router being evaluated
- E - The primary next-hop on shortest path from S to prefix P.
- PO_i - The specific prefix-originating router being evaluated.
- PO_{best} - The prefix-originating router on the shortest path from the computing router S to prefix P.
- $\text{Cost}(X,P)$ - Cost of reaching the prefix P from prefix originating node X.
- $D_{opt}(X,Y)$ - Distance on the shortest path from node X to node Y.

Figure 1: LFA inequalities for MHPs

3. LFA selection for the multi-homed prefixes

To compute a valid LFA for a given multi-homed prefix P, a computing router S MUST follow one of the appropriate procedures below, for each alternate neighbor N.

Link-Protection :

=====

1. If alternate neighbor N is also prefix-originator of P,
 - 1.a. Select N as a LFA for prefix P (irrespective of the metric advertised by N for the prefix P).
2. Else, evaluate the link-protecting LFA inequality for P with the N as the alternate neighbor.
 - 2.a. If LFA inequality condition is met, select N as a LFA for prefix P.
 - 2.b. Else, N is not a LFA for prefix P.

Link-Protection + Downstream-paths-only :

=====

1. Evaluate the link-protecting + downstream-only LFA inequality for P with the N as the alternate neighbor.
 - 1.a. If LFA inequality condition is met, select N as a LFA for prefix P.
 - 1.b. Else, N is not a LFA for prefix P.

Node-Protection :

=====

1. If alternate neighbor N is also prefix-originator of P,
 - 1.a. Select N as a LFA for prefix P (irrespective of the metric advertised by N for the prefix P).
2. Else, evaluate the appropriate node-protecting LFA inequality for P with the N as the alternate neighbor.
 - 2.a. If LFA inequality condition is met, select N as a LFA for prefix P.
 - 2.b. Else, N is not a LFA for prefix P.

Figure 2: Rules for selecting LFA for MHPs

In case an alternate neighbor N is also one of the prefix-originators of prefix P, N being a prefix-originator it is guaranteed that N will not loop back packets destined for prefix P to computing router S. So N MUST be chosen as a valid LFA for prefix P, without evaluating any of the inequalities in Figure 1 as long as downstream-paths-only LFA is not desired. To ensure such a neighbor N also provides a downstream-paths-only LFA, router S MUST also evaluate the downstream-only LFA inequality specified in Figure 1 for neighbor N and ensure router N satisfies the inequality.

However, if N is not a prefix-originator of P, the computing router SHOULD evaluate one of the corresponding LFA inequalities, as mentioned in Figure 1, once for each remote node that originated the prefix. In case the inequality is satisfied by the neighbor N router S MUST choose neighbor N, as one of the valid LFAs for the prefix P.

For more specific rules please refer to the later sections of this document.

3.1. Improved coverage with simplified approach to MHPs

LFA base specification [RFC5286] Section 6.1 recommends that a router computes the alternate next-hop for an IGP multi-homed prefix by considering alternate paths via all routers that have announced that prefix and the same has been elaborated with appropriate inequalities in the above section. However, [RFC5286] Section 6.1 also allows for the router to simplify the multi-homed prefix calculation by assuming that the MHP is solely attached to the router that was its pre-failure optimal point of attachment, at the expense of potentially lower coverage. If an implementation chooses to simplify the multi-homed prefix calculation by assuming that the MHP is solely attached to the router that was its pre-failure optimal point of attachment, the procedure described in this memo can potentially improve coverage for equal cost multi path (ECMP) MHPs without incurring extra computational cost.

This document improves the above approach to provide loop-free alternatives without any additional cost for ECMP MHPs as described through the below example network. The approach specified here MAY also be applicable for handling default routes as explained in Section 3.2.

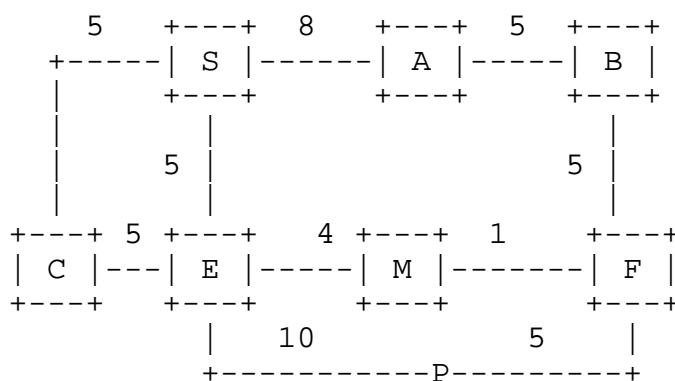


Figure 3: MHP with same ECMP Next-hop

In the above network a prefix p, is advertised from both Node E and Node F. With simplified approach taken as specified in [RFC5286] Section 6.1, prefix P will get only link protection LFA through the neighbor C while a node protection path is available through neighbor A. In this scenario, E and F both are pre-failure optimal points of attachment and share the same primary next-hop. Hence, an implementation MAY compare the kind of protection A provides to F

(link-and-node protection) with the kind of protection C provides to E (link protection) and inherit the better alternative to prefix P and here it is A.

However, in the below network prefix P has an ECMP through both node E and node F with cost 20. Though it has 2 pre-failure optimal points of attachment, the primary next-hop to each pre-failure optimal point of attachment is different. In this case, prefix P MUST inherit corresponding LFAs of each primary next-hop calculated for the router advertising the same respectively. In the below diagram that would be node E's and node F's LFA i.e., node N1 and node N2 respectively.

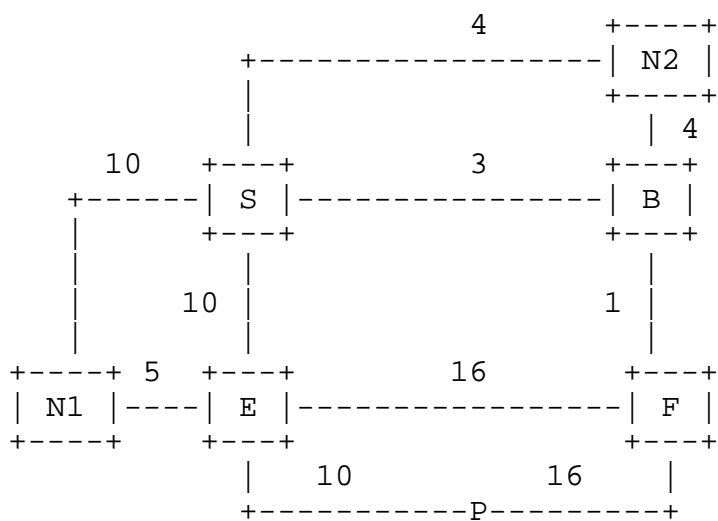


Figure 4: MHP with different ECMP Next-hops

In summary, if there are multiple pre-failure points of attachment for a MHP and primary next-hop of a MHP is same as that of the primary next-hop of the router that was pre-failure optimal point of attachment, an implementation MAY provide a better protection to MHP without incurring any additional computation cost.

3.2. IS-IS ATT Bit considerations

Per [RFC1195] a default route needs to be added in Level1 (L1) router to the closest reachable Level1/Level2 (L1/L2) router in the network advertising ATT (attach) bit in its LSP-0 fragment. All L1 routers in the area would do this during the decision process with the next-hop of the default route set to the adjacent router through which the closest L1/L2 router is reachable. The base LFA specification [RFC5286] does not specify any procedure for computing LFA for a default route in IS-IS L1 area. This document specifies, a node can

consider a default route is being advertised from the border L1/L2 router where ATT bit is set, and can do LFA computation for that default route. But, when multiple ECMP L1/L2 routers are reachable in an L1 area corresponding best LFAs SHOULD be given for each primary next-hop associated with default route. Considerations as specified in Section 3 and Section 3.1 are applicable for default routes, if the default route is considered as ECMP MHP. Note that, this document doesn't alter any ECMP handling rules or computation of LFAs for ECMP in general as laid out in [RFC5286].

4. LFA selection for the multi-homed external prefixes

Redistribution of external routes into IGP is required in case of two different networks getting merged into one or during protocol migrations. External routes could be distributed into an IGP domain via multiple nodes to avoid a single point of failure.

During LFA calculation, alternate LFA next-hops to reach the best ASBR could be used as LFA for the routes redistributed via that ASBR. When there is no LFA available to the best ASBR, it may be desirable to consider the other ASBRs (referred to as alternate ASBR hereafter) redistributing the external routes for LFA selection as defined in [RFC5286] and leverage the advantage of having multiple re-distributing nodes in the network.

4.1. IS-IS

LFA evaluation for multi-homed external prefixes in IS-IS is similar to the multi-homed internal prefixes. Inequalities described in Section 2 would also apply to multi-homed external prefixes.

4.2. OSPF

Loop Free Alternates [RFC5286] describes mechanisms to apply inequalities to find the loop free alternate neighbor. For the selection of alternate ASBR for LFA consideration, additional rules have to be applied in selecting the alternate ASBR due to the external route calculation rules imposed by [RFC2328].

This document defines inequalities specifically for the alternate loop-free ASBR evaluation, based on those in [RFC5286].

4.2.1. Rules to select alternate ASBR

The process to select an alternate ASBR is best explained using the rules below. The below process is applied when primary ASBR for the concerned prefix is chosen and there is an alternate ASBR originating same prefix.

1. If RFC1583Compatibility is disabled
 - 1a. if primary ASBR and alternate ASBR belong to intra area non-backbone go to step 2.
 - 1b. If primary ASBR and alternate ASBR belong to intra-area backbone and/or inter-area path go to step 2.
 - 1c. for other paths, skip this alternate ASBR and consider next ASBR.
2. Compare cost types (type 1/type 2) advertised by alternate ASBR and by the primary ASBR
 - 2a. If not the same type skip alternate ASBR and consider next ASBR.
 - 2b. If same proceed to step 3.
3. If cost types are type 1, compare costs advertised by alternate ASBR and by the primary ASBR
 - 3a. If costs are the same then program ECMP FRR and return.
 - 3b. else go to step 5..
4. If cost types are type 2, compare costs advertised by alternate ASBR and by the primary ASBR
 - 4a. If costs are different, skip alternate ASBR and consider next ASBR.
 - 4b. If cost are the same, proceed to step 4c to compare cost to reach ASBR/forwarding address.
 - 4c. If cost to reach ASBR/forwarding address are also same program ECMP FRR and return.
 - 4d. If cost to reach ASBR/forwarding address are different go to step 5.
5. If route type (type 5/type 7)
 - 5a. If route type is same, check route p-bit, forwarding address field for routes from both ASBRs match. If p-bit and forwarding address matches proceed to step 6.
If not, skip this alternate ASBR and consider next ASBR.
 - 5b. If route type is not same, skip this alternate ASBR and consider next alternate ASBR.
6. Apply inequality on the alternate ASBR.

Figure 5: Rules for selecting alternate ASBR in OSPF

4.2.1.1. Multiple ASBRs belonging different area

When "RFC1583compatibility" is set to disabled, OSPF [RFC2328] defines certain rules of preference to choose the ASBRs. While selecting alternate ASBR for loop evaluation for LFA, these rules

should be applied to ensure that the alternate neighbor does not cause loop.

When there are multiple ASBRs belonging to different area advertising the same prefix, pruning rules as defined in [RFC2328] section 16.4.1 are applied. The alternate ASBRs pruned using above rules are not considered for LFA evaluation.

4.2.1.2. Type 1 and Type 2 costs

If there are multiple ASBRs not pruned via rules defined in Section 4.2.1.1, the cost type advertised by the ASBRs is compared. ASBRs advertising type 1 costs are preferred and the type 2 costs are pruned. If two ASBRs advertise same type 2 cost, the alternate ASBRs are considered along with their cost to reach ASBR/forwarding address for evaluation. If the two ASBRs have same type 2 cost as well as same cost to reach ASBR, ECMP FRR is programmed. When there are multiple ASBRs advertising same type 2 cost for the prefix, primary AS external route calculation as described in [RFC2328] section 16.4.1 selects the route with lowest type 2 cost. ASBRs advertising different type 2 cost (higher cost) are not considered for LFA evaluation. Alternate ASBRs advertising type 2 cost for the prefix but are not chosen as primary due to higher cost to reach ASBR are considered for LFA evaluation. The inequalities for evaluating alternate ASBR for type 1 and type 2 costs are same, as the alternate ASBRs with different type 2 costs are pruned and the evaluation is based on equal type 2 cost ASBRs.

4.2.1.3. RFC1583compatibility is set to enabled

When RFC1583Compatibility is set to enabled, multiple ASBRs belonging to different area advertising same prefix are chosen based on cost and hence are valid alternate ASBRs for the LFA evaluation. The inequalities described in Section 4.2.2 are applicable based on forwarding address and cost type advertised in External LSA.

4.2.1.4. Type 7 routes

Type 5 routes always get preference over Type 7 and the alternate ASBRs chosen for LFA calculation should belong to same type. Among Type 7 routes, routes with p-bit and forwarding address set have higher preference than routes without these attributes. Alternate ASBRs selected for LFA comparison should have same p-bit and forwarding address attributes.

4.2.2. Inequalities to be applied for alternate ASBR selection

The alternate ASBRs selected using above mechanism described in Section 4.2.1, are evaluated for Loop free criteria using below inequalities.

4.2.2.1. Forwarding address set to non-zero value

Link-Protection:

$$F_{\text{opt}}(N, PO_i) + \text{cost}(PO_i, P) < D_{\text{opt}}(N, S) + F_{\text{opt}}(S, PO_{\text{best}}) + \text{cost}(PO_{\text{best}}, P)$$

Link-Protection + Downstream-paths-only:

$$F_{\text{opt}}(N, PO_i) + \text{cost}(PO_i, P) < F_{\text{opt}}(S, PO_{\text{best}}) + \text{cost}(PO_{\text{best}}, P)$$

Node-Protection:

$$F_{\text{opt}}(N, PO_i) + \text{cost}(PO_i, P) < D_{\text{opt}}(N, E) + F_{\text{opt}}(E, PO_{\text{best}}) + \text{cost}(PO_{\text{best}}, P)$$

Where,

- P - The multi-homed prefix being evaluated for computing alternates
- S - The computing router
- N - The alternate router being evaluated
- E - The primary next-hop on shortest path from S to prefix P.
- PO_i - The specific prefix-originating router being evaluated.
- PO_{best} - The prefix-originating router on the shortest path from the computing router S to prefix P.
- cost(X,Y) - External cost for Y as advertised by X
- F_{opt}(X,Y) - Distance on the shortest path from node X to Forwarding address specified by ASBR Y.
- D_{opt}(X,Y) - Distance on the shortest path from node X to node Y.

Figure 6: LFA inequality definition when forwarding address is non-zero

4.2.2.2. ASBRs advertising type1 and type2 cost

Link-Protection:

$$D_{\text{opt}}(N, PO_i) + \text{cost}(PO_i, P) < D_{\text{opt}}(N, S) + D_{\text{opt}}(S, PO_{\text{best}}) + \text{cost}(PO_{\text{best}}, P)$$

Link-Protection + Downstream-paths-only:

$$D_{\text{opt}}(N, PO_i) + \text{cost}(PO_i, P) < D_{\text{opt}}(S, PO_{\text{best}}) + \text{cost}(PO_{\text{best}}, P)$$

Node-Protection:

$$D_{\text{opt}}(N, PO_i) + \text{cost}(PO_i, P) < D_{\text{opt}}(N, E) + D_{\text{opt}}(E, PO_{\text{best}}) + \text{cost}(PO_{\text{best}}, P)$$

Where,

- P - The multi-homed prefix being evaluated for computing alternates
- S - The computing router
- N - The alternate router being evaluated
- E - The primary next-hop on shortest path from S to prefix P.
- PO_i - The specific prefix-originating router being evaluated.
- PO_{best} - The prefix-originating router on the shortest path from the computing router S to prefix P.
- cost(X,Y) - External cost for Y as advertised by X.
- D_{opt}(X,Y) - Distance on the shortest path from node X to node Y.

Figure 7: LFA inequality definition for type1 and type 2 cost

5. LFA Extended Procedures

This section explains the additional considerations in various aspects as listed below to the base LFA specification [RFC5286].

5.1. Links with IGP MAX_METRIC

Section 3.5 and 3.6 of [RFC5286] describe procedures for excluding nodes and links from use in alternate paths based on the maximum link metric (as defined for IS-IS in [RFC5305] or as defined in [RFC6987] for OSPF). If these procedures are strictly followed, there are situations, as described below, where the only potential alternate available which satisfies the basic loop-free condition will not be considered as alternative.

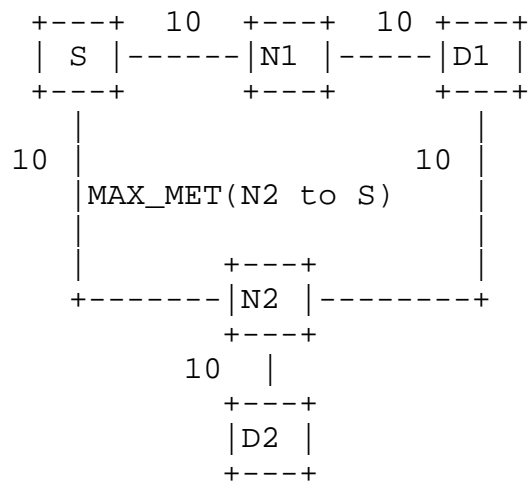


Figure 8: Link with IGP MAX_METRIC

In the simple example network, all the link costs have a cost of 10 in both directions, except for the link between S and N2. The S-N2 link has a cost of 10 in the forward direction i.e., from S to N2, and a cost of MAX_METRIC ($0xfffff / 2^{24} - 1$ for IS-IS and $0xffff$ for OSPF) in the reverse direction i.e., from N2 to S for a specific end-to-end Traffic Engineering (TE) requirement of the operator. At node S, D1 is reachable through N1 with cost 20, and D2 is reachable through N2 with cost 20. Even though neighbor N2 satisfies basic loop-free condition (inequality 1 of [RFC5286]) for D1, S's neighbor N2 could be excluded as a potential alternative because of the current exclusions as specified in section 3.5 and 3.6 procedure of [RFC5286]. But, as the primary traffic destined to D2 continues to use the link and hence irrespective of the reverse metric in this case, same link MAY be used as a potential LFA for D1.

Alternatively, reverse metric of the link MAY be configured with MAX_METRIC-1, so that the link can be used as an alternative while meeting the operator's TE requirements and without having to update the router to fix this particular issue.

5.2. Multi Topology Considerations

Section 6.2 and 6.3.2 of [RFC5286] state that multi-topology OSPF and IS-IS are out of scope for that specification. This memo clarifies and describes the applicability.

In Multi Topology (MT) IGP deployments, for each MT ID, a separate shortest path tree (SPT) is built with topology specific adjacencies, the LFA principles laid out in [RFC5286] are actually applicable for MT IS-IS [RFC5120] LFA SPF. The primary difference in this case is,

identifying the eligible-set of neighbors for each LFA computation which is done per MT ID. The eligible-set for each MT ID is determined by the presence of IGP adjacency from Source to the neighboring node on that MT-ID apart from the administrative restrictions and other checks laid out in [RFC5286]. The same is also applicable for MT-OSPF [RFC4915] or different AFs in multi instance OSPFv3 [RFC5838].

However for MT IS-IS, if a "standard topology" is used with MT-ID #0 [RFC5286] and both IPv4 [RFC5305] and IPv6 routes/AFs [RFC5308] are present, then the condition of network congruency is applicable for LFA computation as well. Network congruency here refers to, having same address families provisioned on all the links and all the nodes of the network with MT-ID #0. Here with single decision process both IPv4 and IPv6 next-hops are computed for all the prefixes in the network and similarly with one LFA computation from all eligible neighbors per [RFC5286], all potential alternatives can be computed.

6. IANA Considerations

This document has no actions for IANA.

7. Acknowledgements

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9. Security Considerations

Existing OSPF security considerations and stronger authentication and manual key management mechanisms are specified in [RFC7474] SHOULD be considered for OSPF deployments. Security concerns for IS-IS are addressed in [RFC5304] and [RFC5310]. Further security analysis for IS-IS protocol is done in [RFC7645] SHOULD be considered for IS-IS deployments. This document does not introduce any change in any of the protocol [RFC1195] [RFC5120] [RFC2328] [RFC5838] specifications discussed here and also this does not introduce any new security issues other than as noted in the LFA base specification [RFC5286].

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