          Selection of Loop-Free Alternates for Multi-Homed Prefixes

Abstract

   Deployment experience gained from implementing algorithms to
   determine Loop-Free Alternates (LFAs) for multi-homed prefixes (MHPs)
   has revealed some avenues for potential improvement. This document
   provides explicit inequalities that can be used to evaluate neighbors
   as potential alternates for MHPs. It also provides detailed criteria
   for evaluating potential alternates for external prefixes advertised
   by OSPF ASBRs. This document updates Section 6 of RFC 5286 by
   expanding some of the routing aspects.

Status of This Memo

   This is an Internet Standards Track document.

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   received public review and has been approved for publication by the
   Internet Engineering Steering Group (IESG). Further information on
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1. Introduction

   A framework for the development of IP Fast Reroute (FRR) mechanisms
   is detailed in [RFC5714]. The use of LFAs for IP FRR is specified in
   [RFC5286]. If a prefix is advertised by more than one router, that
   prefix is called a "multi-homed prefix (MHP)". MHPs generally occur
   for prefixes obtained from outside the routing domain by multiple
   routers, for subnets on links where the subnet is announced from
   multiple ends of the link, and for prefixes advertised by multiple
   routers to provide resiliency.

   Section 6.1 of [RFC5286] describes a method to determine LFAs for
   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 an MHP. The results obtained
   are equivalent to those obtained using the method described in
   Section 6.1 of [RFC5286].

   Section 6.3 of [RFC5286] discusses complications associated with
   computing LFAs for MHPs 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 and additional
   considerations to [RFC5286] to address a few coverage and operational
   observations. These observations are concerned with 1) the IS-IS ATT
   (attach) bit in the Level 1 (L1) area, 2) links provisioned with
   MAX_METRIC (see Section 5.1) for traffic engineering (TE) purposes,
   and 3) multi-topology (MT) IGP deployments. These are elaborated in
   detail in Sections 3.2 and 5.

   This specification uses the same terminology introduced in [RFC5714]
   to represent LFA and builds on the notation for inequalities used in
   [RFC5286] to compute LFAs for MHPs.

1.1. Acronyms

   AF   - Address Family

   ATT   - IS-IS Attach Bit

   ECMP   - Equal-Cost Multipath

   FRR   - Fast Reroute

   IGP   - Interior Gateway Protocol

   IS-IS   - Intermediate System to Intermediate System

   LFA   - Loop-Free Alternate

   LSP   - Link State PDU (IS-IS)

   MHP   - Multi-Homed Prefix

   MT   - Multi-Topology

   OSPF   - Open Shortest Path First

   SPF   - Shortest Path First

1.2. Requirements Language

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

2. LFA Inequalities for MHPs

   This document proposes the following set of LFA inequalities for
   selecting the most appropriate LFAs for MHPs. Distance_opt(X,Y)
   (called "D_opt(X,Y)" in this document) is defined in [RFC5714] and is
   nothing but the metric sum of the shortest path from X to Y.
   Cost(X,Y), introduced in this document, is defined as the metric
   value of prefix Y from the prefix advertising node X. These LFAs can
   be derived from the inequalities in [RFC5286] combined with the
   observation that D_opt(N,P) = Min (D_opt(N,PO_i) + Cost(PO_i,P)) over
   all PO_i.

   Link-Protecting LFAs:
      A neighbor N can provide an LFA if and only if

      D_opt(N,PO_i)+ Cost(PO_i,P) < D_opt(N,S) +
                                    D_opt(S,PO_best) + Cost(PO_best,P)

   Link-Protecting + Downstream-paths-only LFAs:
      A subset of loop-free alternates are downstream paths that must
      meet a more restrictive condition that is applicable to more
      complex failure scenarios.

      D_opt(N,PO_i)+ Cost(PO_i,P) < D_opt(S,PO_best) + Cost(PO_best,P)

   Node-Protecting LFAs:
      For an alternate next hop N to protect against node failure of a
      primary neighbor E for MHP P, N must be loop-free with respect to
      both E and MHP P. In other words, N's path to MHP P must not go
      through E (where N is the neighbor providing a loop-free
      alternate).

      D_opt(N,PO_i)+ Cost(PO_i,P) < D_opt(N,E) +
                                    D_opt(E,PO_best) + Cost(PO_best,P)

      Where:

      P   - The MHP being evaluated for computing alternates

      S   - The computing router

      N   - The alternate router being evaluated

      E   - The primary next hop on the 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,P) - The cost of reaching the prefix P from prefix
                    originating node X

      D_opt(X,Y) - The distance on the shortest path from node X to
                    node Y

3. LFA Selection for MHPs

   To compute a valid LFA for a given MHP P, a computing router S MUST,
   for each alternate neighbor N, follow one of the appropriate
   procedures below once for each remote node that originated the prefix
   P.

   Link-Protecting LFAs:

   1. If, in addition to being an alternate neighbor, N is also a
       prefix originator of P,

       A. Select N as an 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 N as
       the alternate neighbor.

       A. If the LFA inequality condition is met, select N as an LFA
           for prefix P.

       B. Else, N is not an LFA for prefix P.

   Link-Protecting + Downstream-paths-only LFAs:

   1. Evaluate the link-protecting + downstream-paths-only LFA
       inequality for P with N as the alternate neighbor.

       A. If the LFA inequality condition is met, select N as an LFA
           for prefix P.

       B. Else, N is not an LFA for prefix P.

   Node-Protecting LFAs:

   1. If, in addition to being an alternate neighbor, N is also a
       prefix originator of P,

       A. Select N as an 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 N as the alternate neighbor.

       A. If the LFA inequality condition is met, select N as an LFA
           for prefix P.

       B. Else, N is not an LFA for prefix P.

If an alternate neighbor N is also one of the prefix originators of
prefix P, it is guaranteed that N will not loop back packets destined
for prefix P to computing router S. Therefore, N MUST be chosen as a
valid LFA for prefix P without evaluating any of the inequalities in
Section 2 as long as a 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-paths-only LFA inequality
specified in Section 2 for neighbor N and ensure router N satisfies
the inequality.

However, if N is not a prefix originator of P, the computing router
MUST evaluate one of the corresponding LFA inequalities defined in
Section 2 once for each remote node that originated the prefix. If
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 Section 4.

3.1. Improved Coverage with Simplified Approach to MHPs

Section 6.1 of the LFA base specification [RFC5286] recommends that a
router computes the alternate next hop for an IGP MHP by considering
alternate paths via all routers that have announced that prefix. The
same has been elaborated with appropriate inequalities in the
previous section. However, Section 6.1 of [RFC5286] also allows for
the router to simplify the MHP 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 MHP 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 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
in the example network presented in Figure 1. The approach specified
here may also be applicable for handling default routes as explained
in Section 3.2.

```
        5   +---+  8   +---+  5  +---+
       +-----| S |------| A |-----| B |
       |     +---+      +---+     +---+
       |       |                    |
       |     5 |                  5 |
       |       |                    |
     +---+ 5 +---+   4 +---+  1     +---+
     | C |---| E |-----| M |-------| F |
     +---+   +---+     +---+       +---+
              |   10            5   |
              +-----------P---------+
```
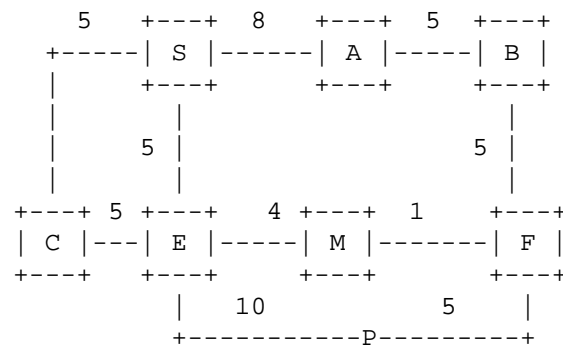
                Figure 1: MHP with Same ECMP Next Hop

   In Figure 1, a prefix P is advertised from both node E and node F.
   With a simplified approach taken as specified in Section 6.1 of
   [RFC5286], prefix P will get only a link-protecting 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.
   In this case, the better alternative is A.

   However, in the example network presented in Figure 2, prefix P has
   an ECMP through both node E and node F with cost 20. Though it has
   two 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 the corresponding LFAs of each primary
   next hop calculated for the router advertising the same. In
   Figure 2, that would be the LFA for node E and node F, i.e., node N1
   and node N2, respectively.

```
                                        4       +----+
                             +-----------------| N2 |
                             |                 +----+
                             |                   | 4
                 10     +---+          3        +---+
              +------| S |---------------| B |
              |        +---+                 +---+
              |          |                     |
              |        10 |                   1 |
              |          |                     |
          +----+ 5    +---+          16         +---+
          | N1 |----| E |----------------| F |
          +----+    +---+                 +---+
                     |     10          16     |
                     +-----------P---------+
```
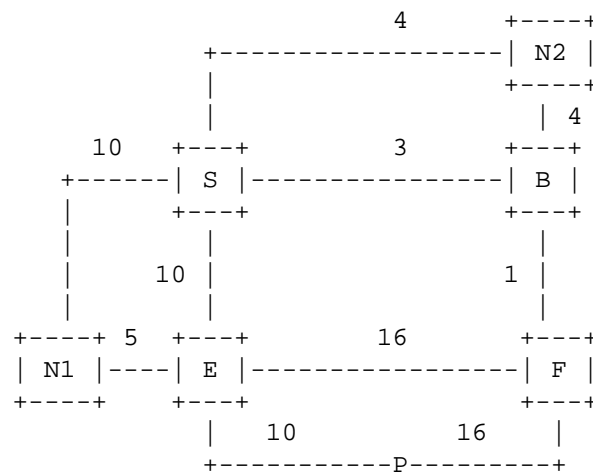
                 Figure 2: MHP with Different ECMP Next Hops

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

3.2. IS-IS ATT Bit Considerations

   Per [RFC1195], a default route needs to be added in the Level 1 (L1)
   router to the closest reachable Level 1 / Level 2 (L1/L2) router in
   the network advertising the 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 LFA base
   specification [RFC5286] does not specify any procedure for computing
   LFA for a default route in the IS-IS L1 area. This document
   specifies that a node can consider a default route is being
   advertised from the border L1/L2 router where the 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 computed for each primary next hop associated with the
   default route as this would be similar to the ECMP MHP example
   described in Section 3.1. Considerations specified in Sections 3 and
   3.1 are applicable for default routes if the default route is
   considered an 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 Multi-Homed External Prefixes

   Redistribution of external routes into IGP is required 1) when two
   different networks get merged into one or 2) during protocol
   migrations.

   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 ASBRs"
   hereafter) redistributing the external routes for LFA selection as
   defined in [RFC5286] and leverage the advantage of having multiple
   redistributing nodes in the network.

4.1. IS-IS

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

4.2. OSPF

   The LFA base specification [RFC5286] describes mechanisms to apply
   inequalities to find the loop-free alternate neighbor. Additional
   rules have to be applied in selecting the alternate ASBR for LFA
   consideration due to the external route calculation rules imposed by
   [RFC2328].

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

4.2.1. Rules to Select Alternate ASBRs

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

   1. If RFC1583Compatibility is disabled:

       A. If primary ASBR and alternate ASBR belong to intra-area
           non-backbone, go to step 2.

       B. If primary ASBR and alternate ASBR belong to intra-area
           backbone and/or inter-area path, go to step 2.

   C. For other paths, skip this alternate ASBR and consider next
       ASBR.

2. Compare cost types (type 1 / type 2) advertised by alternate ASBR
    and primary ASBR:

   A. If not the same type, skip alternate ASBR and consider next
       ASBR.

   B. If the same, proceed to step 3.

3. If cost types are type 1, compare costs advertised by alternate
    ASBR and primary ASBR:

   A. If costs are the same, then program ECMP FRR and return.

   B. Else, go to step 5.

4. If cost types are type 2, compare costs advertised by alternate
    ASBR and primary ASBR:

   A. If costs are different, skip alternate ASBR and consider next
       ASBR.

   B. If costs are the same, proceed to step 4C to compare costs to
       reach ASBR/forwarding address.

   C. If costs to reach ASBR/forwarding address are also the same,
       program ECMP FRR and return.

   D. If costs to reach ASBR/forwarding address are different, go
       to step 5.

5. Compare route types (type 5 and type 7) for alternate ASBR and
    primary ASBR:

   A. If route types are the same, check if route p-bit and
       forwarding address field for routes from both ASBRs match.
       If p-bit and forwarding address match, proceed to step 6. If
       not, skip this alternate ASBR and consider next ASBR.

   B. If route types are not the same, skip this alternate ASBR and
       consider next alternate ASBR.

6. Apply inequality on alternate ASBR.

4.2.1.1. Multiple ASBRs Belonging to Different Areas

   When RFC1583Compatibility is set to "disabled", OSPF [RFC2328]
   defines certain rules of preference to choose the ASBRs. While
   selecting an alternate ASBR for loop evaluation for LFA, these rules
   should be applied to ensure that the alternate neighbor does not
   cause looping.

   When there are multiple ASBRs belonging to different areas
   advertising the same prefix, pruning rules as defined in Section 16.4
   of [RFC2328] are applied. The alternate ASBRs pruned using these
   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 the rules described 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 the same type 2 cost, the
   alternate ASBRs are considered along with their cost to reach the
   ASBR/forwarding address for evaluation. If the two ASBRs have the
   same type 2 cost as well as the same cost to reach the ASBR, ECMP FRR
   is programmed. When there are multiple ASBRs advertising the same
   type 2 cost for the prefix, primary Autonomous System (AS) external
   route calculation, as described in Section 16.4.1 of [RFC2328],
   selects the route with the lowest type 2 cost. ASBRs advertising a
   different type 2 cost (higher cost) are not considered for LFA
   evaluation. Alternate ASBRs advertising a type 2 cost for the prefix
   but not chosen as primary due to a 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 ASBRS with equal type 2 costs.

4.2.1.3. RFC1583Compatibility is Set to "Enabled"

   When RFC1583Compatibility is set to "enabled", multiple ASBRs
   belonging to different areas advertising the 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
   the external Link State Advertisement (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 the same type.
   Among type 7 routes, routes with the p-bit and forwarding address set
   have a higher preference than routes without these attributes.
   Alternate ASBRs selected for LFA comparison should have the same
   p-bit and forwarding address attributes.

4.2.2. Inequalities to Be Applied for Alternate ASBR Selection

   The alternate ASBRs selected using the mechanism described in
   Section 4.2.1 are evaluated for loop-free criteria using the
   inequalities below.

4.2.2.1. Forwarding Address Set to Non-zero Value

   Similar to the inequalities defined in Section 2, the following
   inequalities are defined when the forwarding address is a non-zero
   value.

   Link-Protecting LFAs:

      F_opt(N,PO_i)+ Cost(PO_i,P) < D_opt(N,S) +
                                    F_opt(S,PO_best) + Cost(PO_best,P)

   Link-Protecting + Downstream-paths-only LFAs:

      F_opt(N,PO_i)+ Cost(PO_i,P) < F_opt(S,PO_best) + Cost(PO_best,P)

   Node-Protecting LFAs:

      F_opt(N,PO_i)+ Cost(PO_i,P) < D_opt(N,E) +
                                    F_opt(E,PO_best) + Cost(PO_best,P)

      Where:

      P   - The MHP being evaluated for computing alternates

      S   - The computing router

      N   - The alternate router being evaluated

      E   - The primary next hop on the 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)    -  The external cost for Y as advertised by X

    F_opt(X,Y)   -  The distance on the shortest path from node X to
                    the forwarding address specified by ASBR Y

    D_opt(X,Y)   -  The distance on the shortest path from node X to
                    node Y
```

4.2.2.2. ASBRs Advertising Type 1 and Type 2 Costs

   Similar to the inequalities defined in Section 2, the following
   inequalities are defined for type 1 and type 2 costs.

   Link-Protecting LFAs:

```
    D_opt(N,PO_i)+ Cost(PO_i,P) < D_opt(N,S) +
                                  D_opt(S,PO_best) + Cost(PO_best,P)
```

   Link-Protecting + Downstream-paths-only LFAs:

```
    D_opt(N,PO_i)+ Cost(PO_i,P) < D_opt(S,PO_best) + Cost(PO_best,P)
```

   Node-Protecting LFAs:

```
    D_opt(N,PO_i)+ Cost(PO_i,P) < D_opt(N,E) +
                                  D_opt(E,PO_best) + Cost(PO_best,P)
```

   Where:

```
    P            -  The MHP being evaluated for computing alternates

    S            -  The computing router

    N            -  The alternate router being evaluated

    E            -  The primary next hop on the 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)   - The external cost for Y as advertised by X

    D_opt(X,Y) - The distance on the shortest path from node X to
                   node Y

5. LFA Extended Procedures

   This section explains additional considerations to the LFA base
   specification [RFC5286].

5.1. Links with IGP MAX_METRIC

   Sections 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. If these procedures are strictly followed, there are
   situations, described below, where the only potential alternate
   available that satisfies the basic loop-free condition will not be
   considered as alternative. This document refers to the maximum link
   metric in IGPs as the MAX_METRIC. MAX_METRIC is called "maximum link
   metric" when defined for IS-IS in [RFC5305] and "MaxLinkMetric" when
   defined for OSPF in [RFC6987].

```
                     +---+  10  +---+  10 +---+
                     | S |------|N1 |-----|D1 |
                     +---+      +---+     +---+
                       |                    |
                    10 |                 10 |
                       |MAX_METRIC(N2 to S) |
                       |                    |
                       |        +---+       |
                     +-------|N2 |--------+
                              +---+
                           10  |
                              +---+
                              |D2 |
                              +---+
```
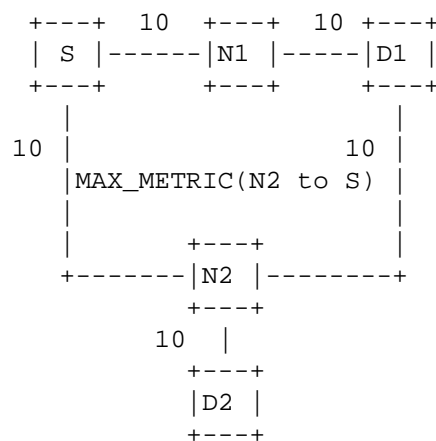
                  Figure 3: Link with IGP MAX_METRIC

   In the simple example network in Figure 3, all the links 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 (0xffffff /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 TE requirement of the operator. At node S, D1 is
   reachable through N1 with a cost of 20, and D2 is reachable through
   N2 with a cost of 20. Even though neighbor N2 satisfies the 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 specified in Sections 3.5 and 3.6 of [RFC5286].
   But, the primary traffic destined to D2 continues to use the link;
   hence, irrespective of the reverse metric in this case, the same link
   MAY be used as a potential LFA for D1.

   Alternatively, the 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. MT Considerations

   Sections 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 IGP deployments, for each MT-ID, a separate
   shortest path tree (SPT) is built with topology-specific adjacencies
   so 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; this is done per MT-ID. The eligible set for each MT-ID
   is determined by the presence of IGP adjacency from the 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 unicast topology" is used with
   MT-ID #0 [RFC5120] 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 the same address families provisioned on all the
   links and all the nodes of the network with MT-ID #0. Here, with a
   single-decision process, both IPv4 and IPv6 next hops are computed
   for all the prefixes in the network. Similarly, with one LFA
   computation from all eligible neighbors per [RFC5286], all potential
   alternatives can be computed.

6. IANA Considerations

   This document has no IANA actions.

7. Security Considerations

   The existing OSPF security considerations continue to apply, as do
   the recommended manual key management mechanisms specified in
   [RFC7474]. The existing security considerations for IS-IS also
   continue to apply, as specified in [RFC5304] and [RFC5310] and
   extended by [RFC7645] for Keying and Authentication for Routing
   Protocols (KARP). This document does not change any of the discussed
   protocol specifications (i.e., [RFC1195], [RFC5120], [RFC2328], and
   [RFC5838]); therefore, the security considerations of the LFA base
   specification [RFC5286] continue to apply.

8. References

8.1. Normative References

   [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate
              Requirement Levels", BCP 14, RFC 2119,
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