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                    LFA selection for Multi-Homed Prefixes
                   draft-ietf-rtgwg-multihomed-prefix-lfa-08

Abstract

   This document shares experience gained from implementing algorithms
   to determine Loop-Free Alternates (LFAs) 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", "NOT RECOMMENDED", "MAY", and
   "OPTIONAL" in this document are to be interpreted as described in BCP
   14 RFC8174 [RFC2119] RFC8174 [RFC8174] when, and only when, they
   appear in all capitals, as shown here.

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material or to cite them other than as "work in progress."

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1. Introduction

   A framework for the development of IP fast-reroute mechanisms is
   detailed in [RFC5714]. The use of LFAs for IP Fast Reroute is
   specified in [RFC5286]. Section 6.1 of [RFC5286] describes a method
   to determine LFAs 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.

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

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

   LFA   - Loop-Free Alternate

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 $D\_opt(N,P) = Min (D\_opt(N,PO\_i) + Cost(PO\_i,P))$
over all PO_i

Link-Protection:
$D\_opt(N,PO\_i)+ Cost(PO\_i,P) < D\_opt(N,S) +$
$\qquad\qquad\qquad\qquad D\_opt(S,PO\_best) + Cost(PO\_best,P)$

Link-Protection + Downstream-paths-only:
$D\_opt(N,PO\_i)+ Cost(PO\_i,P) < D\_opt(S,PO\_best) + Cost(PO\_best,P)$

Node-Protection:
$D\_opt(N,PO\_i)+ Cost(PO\_i,P) < D\_opt(N,E) +$
$\qquad\qquad\qquad\qquad D\_opt(E,PO\_best) + Cost(PO\_best,P)$

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.
   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 presented in Figure 3. 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---------+
```
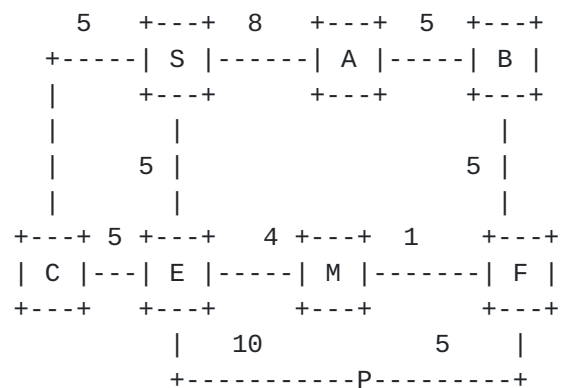
Figure 3: MHP with same ECMP Next-hop

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 example network presented in Figure 4, 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.

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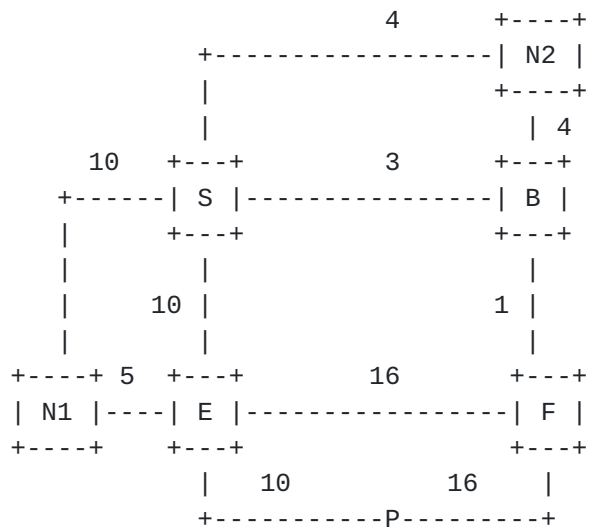
                Figure 4: MHP with different ECMP Next-hops

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 looping.

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


Link-Protection + Downstream-paths-only:
F_opt(N,PO_i)+ Cost(PO_i,P) < F_opt(S,PO_best) + Cost(PO_best,P)


Node-Protection:
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 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_opt(N,PO_i)+ Cost(PO_i,P) < D_opt(N,S) +
                                 D_opt(S,PO_best) + Cost(PO_best,P)


   Link-Protection + Downstream-paths-only:
   D_opt(N,PO_i)+ Cost(PO_i,P) < D_opt(S,PO_best) + Cost(PO_best,P)


   Node-Protection:
   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 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.

```
              +---+  10  +---+  10 +---+
              | S |------|N1 |-----|D1 |
              +---+      +---+     +---+
                |                    |
             10 |                 10 |
                |MAX_MET(N2 to S)    |
                |                    |
                |       +---+        |
                +-------|N2 |--------+
                        +---+
                     10  |
                        +---+
                        |D2 |
                        +---+
```
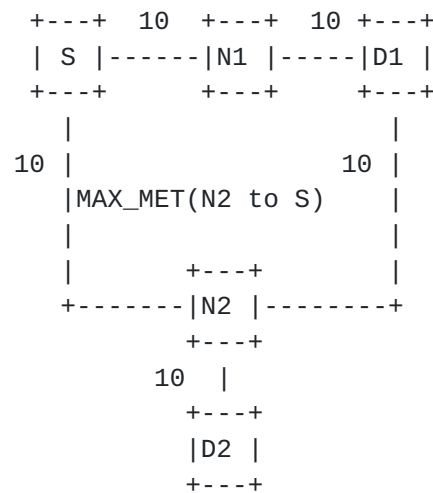
Figure 8: Link with IGP MAX_METRIC

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 (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 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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inputs. Thanks to Stewart Bryant for being document shepherd and
providing detailed review comments.

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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 change any of the discussed
protocol specifications [RFC1195] [RFC5120] [RFC2328] [RFC5838], and
the security considerations of the LFA base specification [RFC5286]
therefore continue to apply.

10. References

10.1. Normative References

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