                    OSPFv2 Routing Protocols Extensions for
              Automatically Switched Optical Network (ASON) Routing

Abstract

   The ITU-T has defined an architecture and requirements for operating
   an Automatically Switched Optical Network (ASON).

   The Generalized Multiprotocol Label Switching (GMPLS) protocol suite
   is designed to provide a control plane for a range of network
   technologies including optical networks such as time division
   multiplexing (TDM) networks including SONET/SDH and Optical Transport
   Networks (OTNs), and lambda switching optical networks.

   The requirements for GMPLS routing to satisfy the requirements of
   ASON routing, and an evaluation of existing GMPLS routing protocols
   are provided in other documents. This document defines extensions to
   the OSPFv2 Link State Routing Protocol to meet the requirements for
   routing in an ASON.

   Note that this work is scoped to the requirements and evaluation
   expressed in RFC 4258 and RFC 4652 and the ITU-T Recommendations
   current when those documents were written. Future extensions of
   revisions of this work may be necessary if the ITU-T Recommendations
   are revised or if new requirements are introduced into a revision of
   RFC 4258.

Status of This Memo

   This document is not an Internet Standards Track specification; it is
   published for examination, experimental implementation, and
   evaluation.

   This document defines an Experimental Protocol for the Internet
   community. This document is a product of the Internet Engineering
   Task Force (IETF). It represents the consensus of the IETF
   community. It has received public review and has been approved for
   publication by the Internet Engineering Steering Group (IESG). Not
   all documents approved by the IESG are a candidate for any level of
   Internet Standard; see Section 2 of RFC 5741.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at http://www.rfc-editor.org/info/rfc5787.

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1. Introduction

   The Generalized Multiprotocol Label Switching (GMPLS) [RFC3945]
   protocol suite is designed to provide a control plane for a range of
   network technologies including optical networks such as time division
   multiplexing (TDM) networks including SONET/SDH and Optical Transport
   Networks (OTNs), and lambda switching optical networks.

   The ITU-T defines the architecture of the Automatically Switched
   Optical Network (ASON) in [G.8080].

   [RFC4258] details the routing requirements for the GMPLS suite of
   routing protocols to support the capabilities and functionality of
   ASON control planes identified in [G.7715] and in [G.7715.1].

   [RFC4652] evaluates the IETF Link State routing protocols against the
   requirements identified in [RFC4258]. Section 7.1 of [RFC4652]
   summarizes the capabilities to be provided by OSPFv2 [RFC2328] in
   support of ASON routing. This document details the OSPFv2 specifics
   for ASON routing.

   Multi-layer transport networks are constructed from multiple networks
   of different technologies operating in a client-server relationship.
   The ASON routing model includes the definition of routing levels that
   provide scaling and confidentiality benefits. In multi-level
   routing, domains called routing areas (RAs) are arranged in a
   hierarchical relationship. Note that as described in [RFC4652] there
   is no implied relationship between multi-layer transport networks and
   multi-level routing. The multi-level routing mechanisms described in
   this document work for both single-layer and multi-layer networks.

   Implementations may support a hierarchical routing topology (multi-
   level) for multiple transport network layers and/or a hierarchical
   routing topology for a single transport network layer.

   This document details the processing of the generic (technology-
   independent) link attributes that are defined in [RFC3630],
   [RFC4202], and [RFC4203] and that are extended in this document. As
   detailed in Section 4.2, technology-specific traffic engineering
   attributes (and their processing) may be defined in other documents
   that complement this document.

   Note that this work is scoped to the requirements and evaluation
   expressed in [RFC4258] and [RFC4652] and the ITU-T Recommendations
   current when those documents were written. Future extensions of
   revisions of this work may be necessary if the ITU-T Recommendations
   are revised or if new requirements are introduced into a revision of
   [RFC4258].

This document is classified as Experimental. Significant changes to routing protocols are of concern to the stability of the Internet. The extensions described in this document are intended for cautious use in self-contained environments. The objective is to determine whether these extensions are stable and functional, whether there is a demand for implementation and deployment, and whether the extensions have any impact on existing routing protocol deployments.

1.1. Conventions Used in This Document

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 RFC 2119 [RFC2119].

The reader is assumed to be familiar with the terminology and requirements developed in [RFC4258] and the evaluation outcomes detailed in [RFC4652].

General ASON terminology is provided in Appendix A. ASON routing terminology is described in Appendix B.

2. Routing Areas, OSPF Areas, and Protocol Instances

An ASON routing area (RA) represents a partition of the data plane, and its identifier is used within the control plane as the representation of this partition.

RAs are arranged in hierarchical levels such that any one RA may contain multiple other RAs, and is wholly contained by a single RA. Thus, an RA may contain smaller RAs inter-connected by links. The limit of the subdivision results in an RA that contains just two sub-networks interconnected by a single link.

An ASON RA can be mapped to an OSPF area, but the hierarchy of ASON RA levels does not map to the hierarchy of OSPF routing areas. Instead, successive hierarchical levels of RAs MUST be represented by separate instances of the protocol. Thus, inter-level routing information exchange (as described in Section 6) involves the export and import of routing information between protocol instances.

An ASON RA may therefore be identified by the combination of its OSPF instance identifier and its OSPF area identifier. With proper and careful network-wide configuration, this can be achieved using just the OSPF area identifier, and this process is RECOMMENDED in this document. These concepts and the subsequent handling of network reconfiguration is discussed in Section 6.

3. Reachability

   In order to advertise blocks of reachable address prefixes, a
   summarization mechanism is introduced that complements the techniques
   described in [RFC5786].

   This extension takes the form of a network mask (a 32-bit number
   indicating the range of IP addresses residing on a single IP
   network/subnet). The set of local addresses is carried in an OSPFv2
   TE LSA Node Attribute TLV (a specific sub-TLV is defined per address
   family, i.e., IPv4 and IPv6, used as network-unique identifiers).

   The proposed solution is to advertise the local address prefixes of a
   router as new sub-TLVs of the (OSPFv2 TE LSA) Node Attribute top-
   level TLV. This document defines the following sub-TLVs:

      - Node IPv4 Local Prefix sub-TLV: Length: variable
      - Node IPv6 Local Prefix sub-TLV: Length: variable

3.1. Node IPv4 Local Prefix Sub-TLV

   The Type field of the Node IPv4 Local Prefix sub-TLV is assigned a
   value in the range 32768-32777 agreed to by all participants in the
   experiment. The Value field of this sub-TLV contains one or more
   local IPv4 prefixes. The Length is measured in bytes and, as defined
   in [RFC3630], reports the length in bytes of the Value part of the
   sub-TLV. It is set to 8 x n, where n is the number of local IPv4
   prefixes included in the sub-TLV.

   The Node IPv4 Local Prefix sub-TLV has the following format:

```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |            Type               |          Length (8 x n)       |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                       Network Mask 1                          |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                       IPv4 Address 1                          |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
   //                           ...                               //
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                       Network Mask n                          |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                       IPv4 Address n                          |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
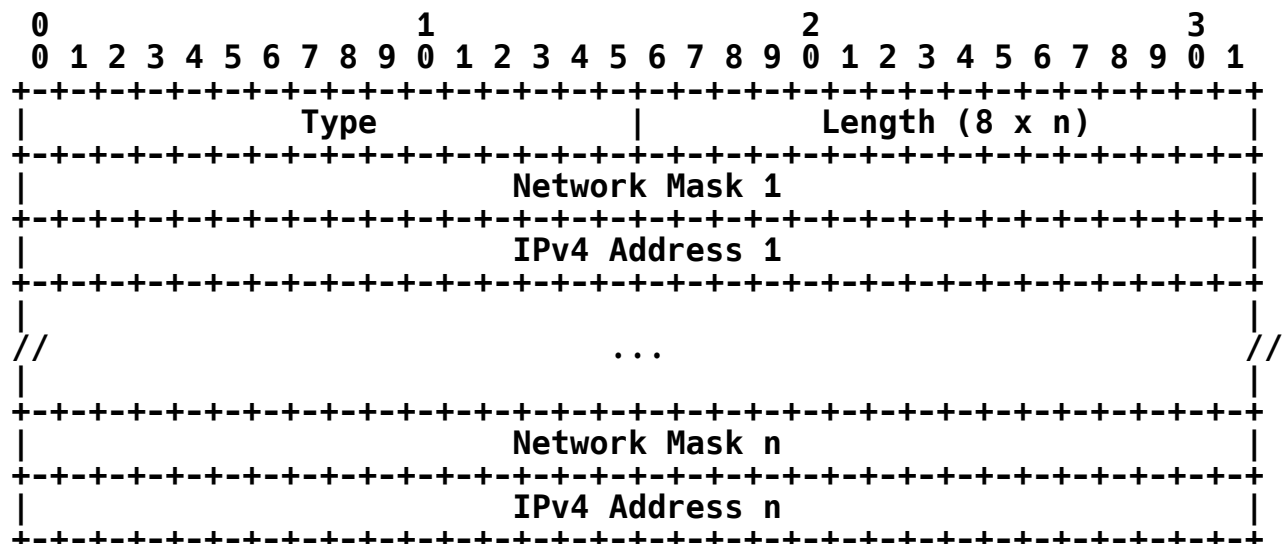
Network mask i: A 32-bit number indicating the IPv4 address mask for the ith advertised destination prefix.

Each <Network mask, IPv4 Address> pair listed as part of this sub-TLV represents a reachable destination prefix hosted by the advertising Router ID.

The local addresses that can be learned from Opaque TE LSAs (that is, the router address and TE interface addresses) SHOULD NOT be advertised in the node IPv4 Local Prefix sub-TLV.

3.2. Node IPv6 Local Prefix Sub-TLV

The Type field of the Node IPv6 Local Prefix sub-TLV is assigned a value in the range 32768-32777 agreed to by all participants in the experiment. The Value field of this sub-TLV contains one or more local IPv6 prefixes. IPv6 Prefix representation uses [RFC5340], Section A.4.1.
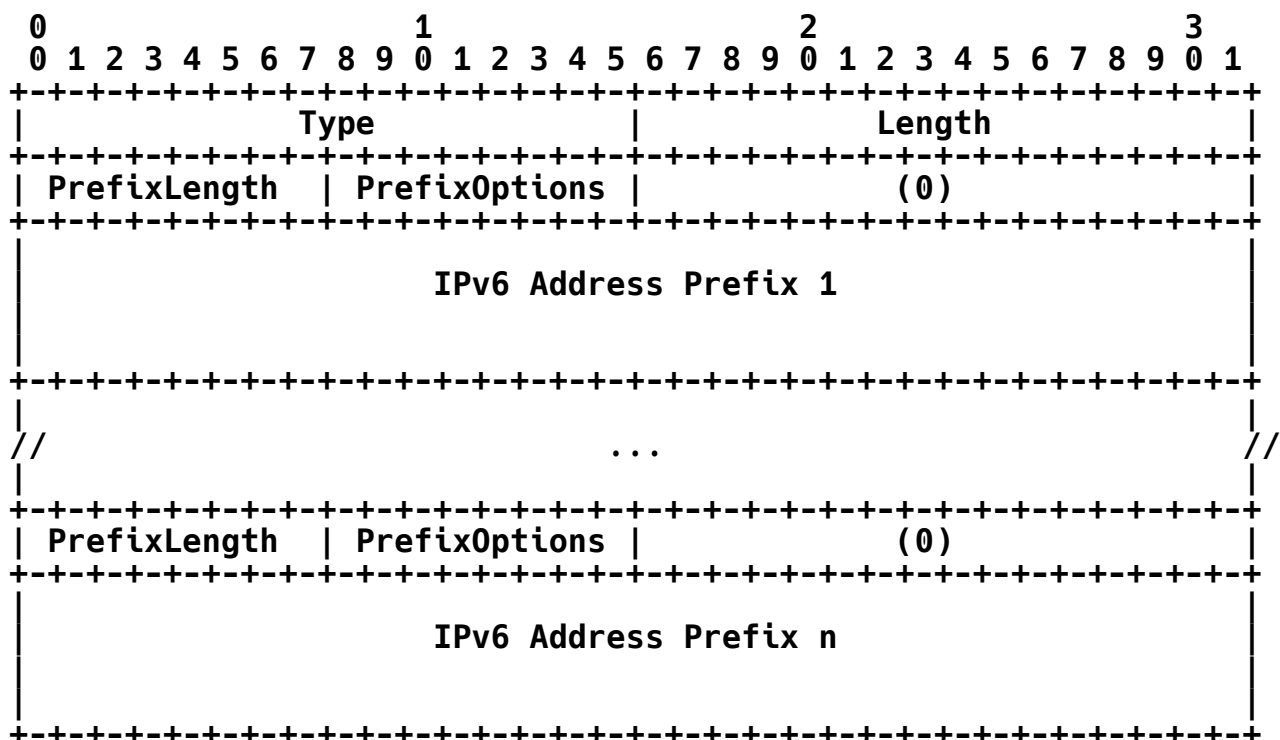
The Node IPv6 Local Prefix sub-TLV has the following format:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              Type             |             Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| PrefixLength  | PrefixOptions |              (0)              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                                                               |
|                    IPv6 Address Prefix 1                      |
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
//                            ...                              //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| PrefixLength  | PrefixOptions |              (0)              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                                                               |
|                    IPv6 Address Prefix n                      |
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Length reports the length of the Value part of the sub-TLV in bytes.
It is set to the sum over all of the local prefixes included in the
sub-TLV of (4 + (number of 32-bit words in the prefix) * 4).

The encoding of each prefix potentially using fewer than four 32-bit
words is described below.

   PrefixLength: Length in bits of the prefix.

   PrefixOptions: 8-bit field describing various capabilities
      associated with the prefix (see [RFC5340], Section A.4.2).

   IPv6 Address Prefix i: The ith IPv6 address prefix in the list.
      Each prefix is encoded in an even multiple of 32-bit words using
      the fewest pairs of 32-bit words necessary to include the entire
      prefix. Thus, each prefix is encoded in either 64 or 128 bits
      with trailing zero bit padding as necessary.

The local addresses that can be learned from TE LSAs, i.e., router
address and TE interface addresses, SHOULD NOT be advertised in the
node IPv6 Local Prefix sub-TLV.

4. Link Attribute

   [RFC4652] provides a map between link attributes and characteristics
   and their representation in sub-TLVs of the top-level Link TLV of the
   Opaque TE LSA [RFC3630] and [RFC4203], with the exception of the
   local adaptation (see below). Advertisement of this information
   SHOULD be supported on a per-layer basis, i.e., one Opaque TE LSA per
   switching capability (and per bandwidth granularity, e.g., low-order
   virtual container and high-order virtual container).

4.1. Local Adaptation

   Local adaptation is defined as a TE link attribute (i.e., sub-TLV)
   that describes the cross/inter-layer relationships.

   The Interface Switching Capability Descriptor (ISCD) TE Attribute
   [RFC4202] identifies the ability of the TE link to support cross-
   connection to another link within the same layer, and the ability to
   use a locally terminated connection that belongs to one layer as a
   data link for another layer (adaptation capability). However, the
   information associated with the ability to terminate connections
   within that layer (referred to as the termination capability) is
   embedded with the adaptation capability.

For instance, a link between two optical cross-connects will contain
at least one ISCD attribute describing the lambda switching capable
(LSC) switching capability; whereas a link between an optical cross-
connect and an IP/MPLS LSR will contain at least two ISCD attributes:
one for the description of the LSC termination capability and one for
the packet switching capable (PSC) adaptation capability.

In OSPFv2, the Interface Switching Capability Descriptor (ISCD) is a
sub-TLV (of type 15) of the top-level Link TLV (of type 2) [RFC4203].

The adaptation and termination capabilities are advertised using two
separate ISCD sub-TLVs within the same top-level Link TLV.

Per [RFC4202] and [RFC4203], an interface MAY have more than one ISCD
sub-TLV. Hence, the corresponding advertisements should not result
in any compatibility issues.

Further refinement of the ISCD sub-TLV for multi-layer networks is
outside the scope of this document.

4.2. Bandwidth Accounting

GMPLS routing defines an Interface Switching Capability Descriptor
(ISCD) that delivers, among other things, information about the
(maximum/minimum) bandwidth per priority that a Label Switched Path
(LSP) can make use of. Per [RFC4202] and [RFC4203], one or more ISCD
sub-TLVs can be associated with an interface. This information,
combined with the Unreserved Bandwidth (sub-TLV defined in [RFC3630],
Section 2.5.8), provides the basis for bandwidth accounting.

In the ASON context, additional information may be included when the
representation and information in the other advertised fields are not
sufficient for a specific technology (e.g., SDH). The definition of
technology-specific information elements is beyond the scope of this
document. Some technologies will not require additional information
beyond what is already defined in [RFC3630], [RFC4202], and
[RFC4203].

5. Routing Information Scope

5.1. Terminology and Identification

The definition of short-hand terminology introduced in [RFC4652] is
repeated here for clarity.

- Pi is a physical (bearer/data/transport plane) node.

- Li is a logical control plane entity that is associated to a single
  data plane (abstract) node. Each Li is identified by a unique TE
  Router ID. The latter is a control plane identifier, defined as
  the Router Address top-level TLV of the Type 1 TE LSA [RFC3630].

  Note: The Router Address top-level TLV definition, processing, and
  usage remain per [RFC3630]. This TLV specifies a stable IP address
  of the advertising router (Ri) that is always reachable if there is
  any IP connectivity to it (e.g., via the Data Communication
  Network). Moreover, each advertising router advertises a unique,
  reachable IP address for each Pi on behalf of which it makes
  advertisements.

- Ri is a logical control plane entity that is associated to a
  control plane "router". The latter is the source for topology
  information that it generates and shares with other control plane
  "routers". The Ri is identified by the (advertising) Router ID
  (32-bit) [RFC2328].

  The Router ID, which is represented by Ri and which corresponds to
  the RC-ID [RFC4258], does not enter into the identification of the
  logical entities representing the data plane resources such as
  links. The Routing Database (RDB) is associated to the Ri.

Note: Aside from the Li/Pi mappings, these identifiers are not
assumed to be in a particular entity relationship except that the Ri
may have multiple Lis in its scope. The relationship between Ri and
Li is simple at any moment in time: an Li may be advertised by only
one Ri at any time. However, an Ri may advertise a set of one or
more Lis. Hence, the OSPFv2 routing protocol must support a single
Ri advertising on behalf of more than one Li.

5.2. Link Advertisement (Local and Remote TE Router ID Sub-TLV)

A Router ID (Ri) advertising on behalf multiple TE Router IDs (Lis)
creates a 1:N relationship between the Router ID and the TE Router
ID. As the link local and link remote (unnumbered) ID association is
not unique per node (per Li unicity), the advertisement needs to
indicate the remote Lj value and rely on the initial discovery
process to retrieve the [Li;Lj] relationship. In brief, as
unnumbered links have their ID defined on a per-Li basis, the remote
Lj needs to be identified to scope the link remote ID to the local
Li. Therefore, the routing protocol MUST be able to disambiguate the
advertised TE links so that they can be associated with the correct
TE Router ID.

For this purpose, a new sub-TLV of the (OSPFv2 TE LSA) top-level Link
TLV is introduced that defines the Local and Remote TE Router ID.

The Type field of the Local and Remote TE Router ID sub-TLV is
assigned a value in the range 32768-32777 agreed to by all
participants in the experiment. The Length field takes the value 8.
The Value field of this sub-TLV contains 4 octets of the Local TE
Router Identifier followed by 4 octets of the Remote TE Router
Identifier. The value of the Local and Remote TE Router Identifier
SHOULD NOT be set to 0.

The format of the Local and Remote TE Router ID sub-TLV is:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             Type              |           Length (8)          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Local TE Router Identifier                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Remote TE Router Identifier                 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
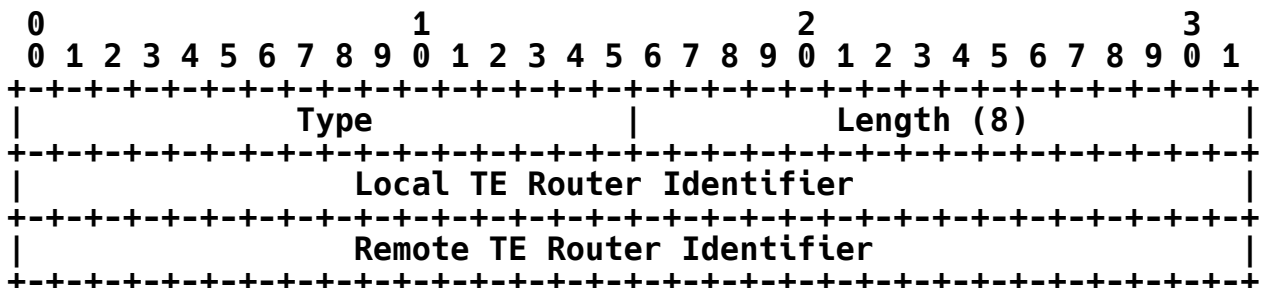
This sub-TLV is only required to be included as part of the top-level
Link TLV if the Router ID is advertising on behalf of more than one
TE Router ID. In any other case, this sub-TLV SHOULD be omitted
except if the operator plans to start off with 1 Li and progressively
add more Lis (under the same Ri) such as to maintain consistency.

Note: The Link ID sub-TLV that identifies the other end of the link
(i.e., Router ID of the neighbor for point-to-point links) MUST
appear exactly once per Link TLV. This sub-TLV MUST be processed as
defined in [RFC3630].

5.3. Reachability Advertisement (Local TE Router ID sub-TLV)
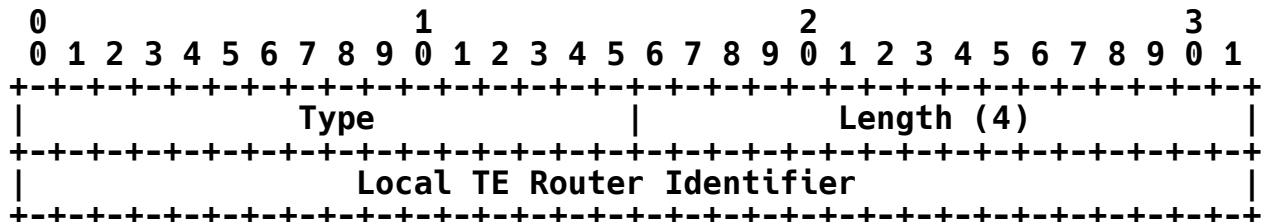
When the Router ID is advertised on behalf of multiple TE Router IDs
(Lis), the routing protocol MUST be able to associate the advertised
reachability information with the correct TE Router ID.

For this purpose, a new sub-TLV of the (OSPFv2 TE LSA) top-level Node
Attribute TLV is introduced. This TLV associates the local prefixes
(see above) to a given TE Router ID.

The Type field of the Local TE Router ID sub-TLV is assigned a value
in the range 32768-32777 agreed to by all participants in the
experiment. The Length field takes the value 4. The Value field of
this sub-TLV contains the Local TE Router Identifier [RFC3630]
encoded over 4 octets.

The format of the Local TE Router ID sub-TLV is:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            Type               |            Length (4)         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 Local TE Router Identifier                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

This sub-TLV is only required to be included as part of the Node
Attribute TLV if the Router ID is advertising on behalf of more than
one TE Router ID. In any other case, this sub-TLV SHOULD be omitted.

6. Routing Information Dissemination

An ASON routing area (RA) represents a partition of the data plane,
and its identifier is used within the control plane as the
representation of this partition. An RA may contain smaller RAs
inter-connected by links. The limit of the subdivision results is an
RA that contains two sub-networks interconnected by a single link.
ASON RA levels do not reflect routing protocol levels (such as OSPF
areas).

Successive hierarchical levels of RAs can be represented by separate
instances of the protocol.

Routing controllers (RCs) supporting RAs disseminate information
downward and upward in this hierarchy. The vertical routing
information dissemination mechanisms described in this section do not
introduce or imply a new OSPF routing area hierarchy. RCs supporting
RAs at multiple levels are structured as separate OSPF instances with
routing information exchanges between levels described by import and
export rules operating between OSPF instances.

The implication is that an RC that performs import/export of routing
information as described in this document does not implement an Area
Border Router (ABR) functionality.

6.1. Import/Export Rules

RCs supporting RAs disseminate information upward and downward in the hierarchy by importing/exporting routing information as Opaque TE LSAs (Opaque Type 1) of LS Type 10. The information that MAY be exchanged between adjacent levels includes the Router Address, Link, and Node Attribute top-level TLVs.

The Opaque TE LSA import/export rules are governed as follows:

- If the export target interface is associated with the same RA as is associated with the import interface, the Opaque LSA MUST NOT be imported.

- If a match is found between the advertising Router ID in the header of the received Opaque TE LSA and one of the Router IDs belonging to the RA of the export target interface, the Opaque LSA MUST NOT be imported.

- If these two conditions are not met, the Opaque TE LSA MAY be imported according to local policy. If imported, the LSA MAY be disseminated according to local policy. If disseminated, the normal OSPF flooding rules MUST be followed and the advertising Router ID MUST be set to the importing router's Router ID.

The imported/exported routing information content MAY be transformed, e.g., filtered or aggregated, as long as the resulting routing information is consistent. In particular, when more than one RC is bound to adjacent levels and both are allowed to import/export routing information, it is expected that these transformations are performed in a consistent manner. Definition of these policy-based mechanisms is outside the scope of this document.

In practice, and in order to avoid scalability and processing overhead, routing information imported/exported downward/upward in the hierarchy is expected to include reachability information (see Section 3) and, upon strict policy control, link topology information.

6.2 Discovery and Selection

6.2.1. Upward Discovery and Selection

In order to discover RCs that are capable of disseminating routing information up the routing hierarchy, the following capability descriptor bit is set in the OSPF Router Information Experimental Capabilities TLV (see Section 6.2.3) carried in the Router Information LSA ([RFC4970]).

- U bit: When set, this flag indicates that the RC is capable of
  disseminating routing information upward to the adjacent level.

In the case that multiple RCs are advertised from the same RA with
their U bit set, the RC with the highest Router ID, among those RCs
with the U bit set, SHOULD be selected as the RC for upward
dissemination of routing information. The other RCs MUST NOT
participate in the upward dissemination of routing information as
long as the Opaque LSA information corresponding to the highest
Router ID RC does not reach MaxAge. This mechanism prevents more
than one RC advertising routing information upward in the routing
hierarchy from the same RA.

Note that if the information to allow the selection of the RC that
will be used to disseminate routing information up the hierarchy from
a specific RA cannot be discovered automatically, it MUST be manually
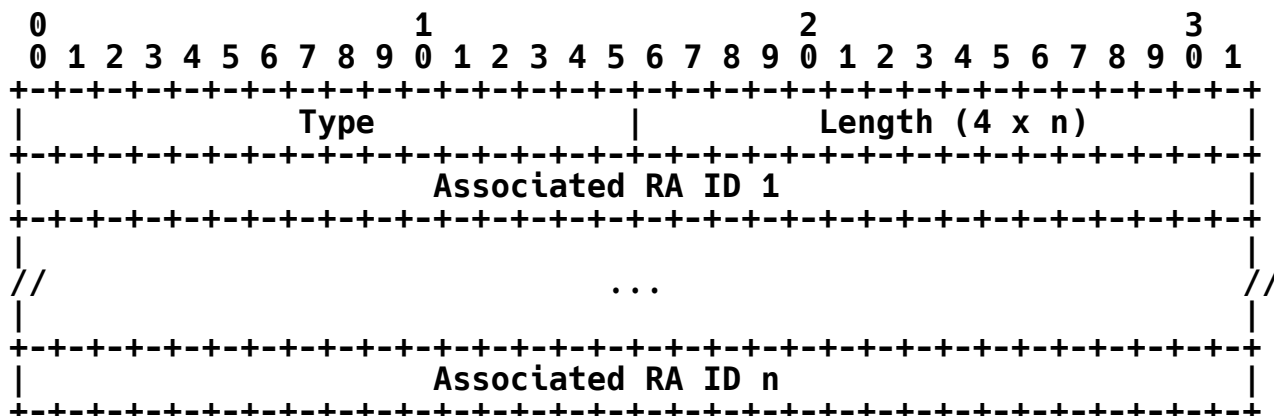configured.

Once an RC has been selected, it remains unmodified even if an RC
with a higher Router ID is introduced and advertises its capability
to disseminate routing information upward the adjacent level (i.e., U
bit set). This hysteresis mechanism prevents from disturbing the
upward routing information dissemination process in case, e.g., of
flapping.

6.2.2. Downward Discovery and Selection

The same discovery mechanism is used for selecting the RC responsible
for dissemination of routing information downward in the hierarchy.
However, an additional restriction MUST be applied such that the RC
selection process takes into account that an upper level may be
adjacent to one or more lower (RA) levels. For this purpose, a
specific TLV indexing the (lower) RA ID to which the RCs are capable
of disseminating routing information is needed.

The Downstream Associated RA ID TLV is carried in the OSPF Router
Information LSA [RFC4970]. The Type field of the Downstream
Associated RA ID TLV is assigned a value in the range 32768-32777
agreed to by all participants in the experiment. The Length of this
TLV is n x 4 octets. The Value field of this sub-TLV contains the
list of Associated RA IDs. Each Associated RA ID value is encoded
following the OSPF area ID (32 bits) encoding rules defined in
[RFC2328].

The format of the Downstream Associated RA ID TLV is:

```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |              Type             |         Length (4 x n)        |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                      Associated RA ID 1                       |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
   //                             ...                             //
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                      Associated RA ID n                       |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

To discover RCs that are capable of disseminating routing information downward through the routing hierarchy, the following capability descriptor bit is set in the OSPF Router Information Experimental Capabilities TLV (see Section 6.2.3) carried in the Router Information LSA ([RFC4970]).

Note that the Downstream Associated RA ID TLV MUST be present when the D bit is set.

- D bit: when set, this flag indicates that the RC is capable of disseminating routing information downward to the adjacent levels.

If multiple RCs are advertised for the same Associated RA ID, the RC with the highest Router ID, among the RCs with the D bit set, MUST be selected as the RC for downward dissemination of routing information. The other RCs for the same Associated RA ID MUST NOT participate in the downward dissemination of routing information as long as the Opaque LSA information corresponding to the highest Router ID RC does not reach MaxAge. This mechanism prevents more than one RC from advertising routing information downward through the routing hierarchy.

Note that if the information to allow the selection of the RC that will be used to disseminate routing information down the hierarchy to a specific RA cannot be discovered automatically, it MUST be manually configured.

The OSPF Router information Opaque LSA (Opaque type of 4, Opaque ID of 0) and its content, in particular the Router Informational Capabilities TLV [RFC4970] and TE Node Capability Descriptor TLV [RFC5073], MUST NOT be re-originated.

6.2.3. Router Information Experimental Capabilities TLV

   A new TLV is defined for inclusion in the Router Information LSA to
   carry experimental capabilities because the assignment policy for
   bits in the Router Informational Capabilities TLV is "Standards
   Action" [RFC5226] prohibiting its use from Experimental documents.

   The format of the Router Information Experimental Capabilities TLV is
   as follows:

```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |              Type             |             Length            |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                   Experimental Capabilities                  |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
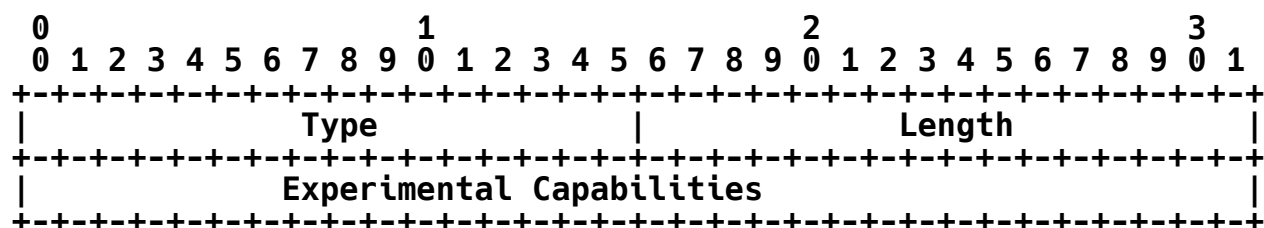
   Type   A value in the range 32768-32777 agreed to by all
              participants in the experiment.

   Length   A 16-bit field that indicates the length of the value
              portion in octets and will be a multiple of 4 octets
              dependent on the number of capabilities advertised.
              Initially, the length will be 4, denoting 4 octets of
              informational capability bits.

   Value   A variable-length sequence of capability bits rounded to
              a multiple of 4 octets padded with undefined bits.

   The following experimental capability bits are assigned:

   Bit   Capabilities

   0   The U bit (see Section 6.2.1)
   1   The D bit (see Section 6.2.2)

6.3. Loop Prevention

   When more than one RC is bound to an adjacent level of the hierarchy,
   and is configured or selected to redistribute routing information
   upward and downward, a specific mechanism is required to avoid
   looping of routing information. Looping is the re-introduction of
   routing information that has been advertised from the upper level
   back to the upper level. This specific case occurs, for example,
   when the RC advertising routing information downward in the hierarchy
   is not the same one that advertises routing upward in the hierarchy.

When these conditions are met, it is necessary to have a means by
which an RC receiving an Opaque TE LSA imported/exported downward by
an RC associated to the same RA does not import/export the content of
this LSA back upward into the (same) upper level.

Note that configuration and operational simplification can be
obtained when both functionalities are configured on a single RC (per
pair of adjacent levels) fulfilling both roles. Figure 1 provides an
example where such simplification applies.

```
        .............................................
        .                                           .
        .           RC_5 ------------ RC_6          .
        .            |                 |            .
        .            |                 |       RA_Y .
 Upper  .         ********       ********           .
 Layer  ..........* RC_1a *.........* RC_2a *...........
        .         *  |    *         *  |    *        .
 _____* RC_1b *_____* RC 2b *_____
        ...........* RC_1b *...   ...* RC 2b *...........
 Lower  .         ********   .   .  ********          .
 Layer  .            |       .   .     |              .
        .  RA_Z      |       .   .     |         RA_X .
        .            |       .   .     |              .
        .          RC_3      .   .   RC_4             .
        .                    .   .                    .
        .                    .   .                    .
        ......................   ......................
```
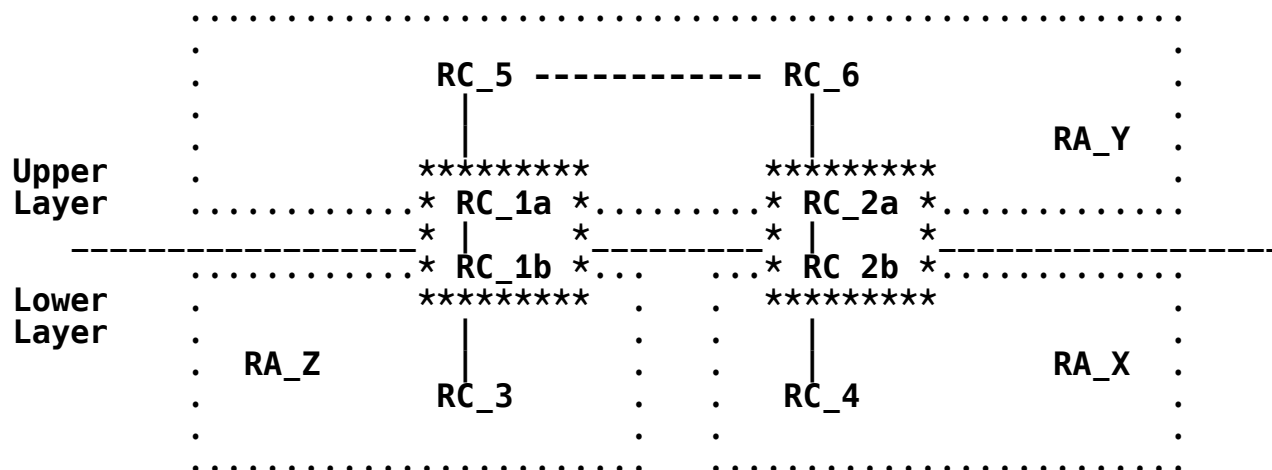
                Figure 1. Hierarchical Environment (Example)

In this case, the procedure described in this section MAY be omitted,
as long as these conditions are permanently guaranteed. In all other
cases, without exception, the procedure described in this section
MUST be applied.

6.3.1. Associated RA ID

We need some way of filtering the downward/upward re-originated
Opaque TE LSA. Per [RFC5250], the information contained in Opaque
LSAs may be used directly by OSPF. By adding the RA ID associated
with the incoming routing information, the loop prevention problem
can be solved.

This additional information, referred to as the Associated RA ID, MAY
be carried in Opaque LSAs that include any of the following top-level
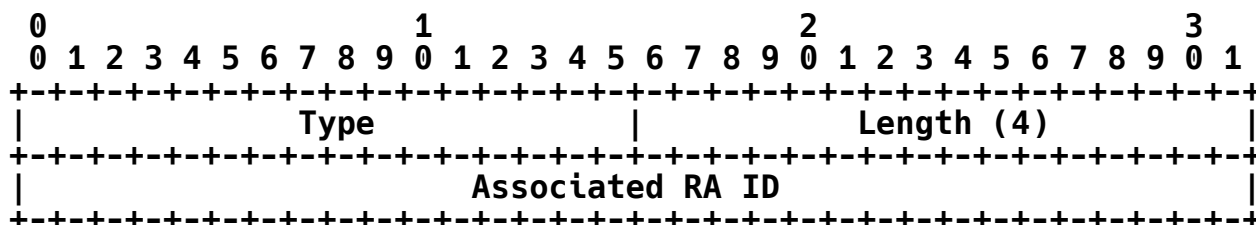TLVs:

     - Router Address top-level TLV
     - Link top-level TLV
     - Node Attribute top-level TLV

The Associated RA ID reflects the identifier of the area from which
the routing information is received. For example, for a multi-level
hierarchy, this identifier does not reflect the originating RA ID; it
will reflect the RA from which the routing information is imported.

The Type field of the Associated RA ID sub-TLV is assigned a value in
the range 32768-32777 agreed to by all participants in the
experiment. The same value MUST be used for the Type regardless of
which TLV the sub-TLV appears in.

The Length of the Associated RA ID TLV is 4 octets. The Value field
of this sub-TLV contains the Associated RA ID. The Associated RA ID
value is encoded following the OSPF area ID (32 bits) encoding rules
defined in [RFC2328].

The format of the Associated RA ID TLV is defined as follows:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              Type                 |           Length (4)      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Associated RA ID                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

6.3.2. Processing

When fulfilling the rules detailed in Section 6.1, a given Opaque LSA
is imported/exported downward or upward the routing hierarchy, and
the Associated RA ID TLV is added to the received Opaque LSA list of
TLVs such as to identify the area from which this routing information
has been received.

When the RC adjacent to the lower or upper routing level receives
this Opaque LSA, the following rule is applied (in addition to the
rule governing the import/export of Opaque LSAs as detailed in
Section 6.1).

- If a match is found between the Associated RA ID of the received
  Opaque TE LSA and the RA ID belonging to the area of the export
  target interface, the Opaque TE LSA MUST NOT be imported.

- Otherwise, this Opaque LSA MAY be imported and disseminated
  downward or upward the routing hierarchy following the OSPF
  flooding rules.

This mechanism ensures that no race condition occurs when the
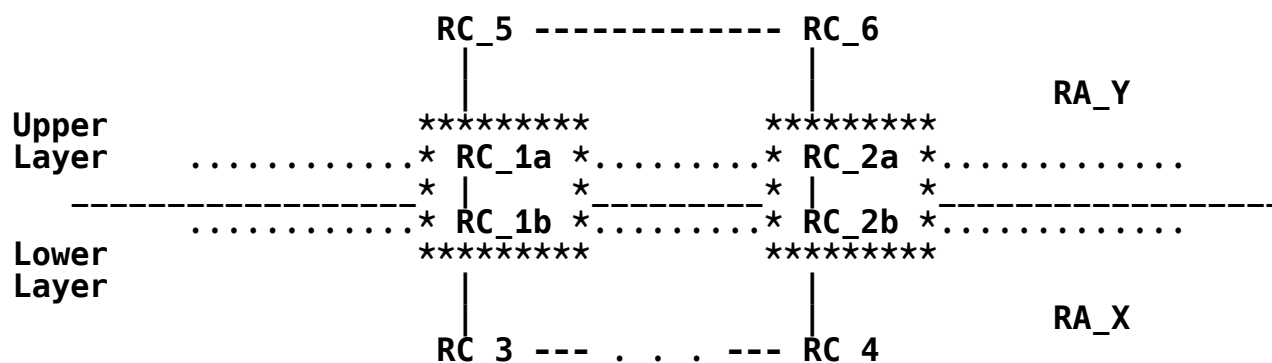conditions depicted in Figure 2 are met.

```
                    RC_5 ------------ RC_6
                     |                 |
                     |                 |                RA_Y
       Upper         *********         *********
       Layer     ............* RC_1a *.........* RC_2a *.............
       _____* | *_____* | *_____
                 ............* RC_1b *.........* RC_2b *.............
       Lower         *********         *********
       Layer           |                 |
                       |                 |                RA_X
                    RC_3 --- . . . --- RC_4
```

                Figure 2.   Race Condition Prevention (Example)

   Assume that RC_1b is configured for exporting routing information
   upward toward RA_Y (upward the routing hierarchy) and that RC_2a is
   configured for exporting routing information toward RA_X (downward
   the routing hierarchy).

   Assume that routing information advertised by RC_3 would reach RC_4
   faster across RA_Y through hierarchy.

   If RC_2b is not able to prevent from importing that information, RC_4
   may receive that information before the same advertisement would
   propagate in RA_X (from RC_3) to RC_4. For this purpose, RC_1a
   inserts the Associated RA X to the imported routing information from
   RA_X. Because RC_2b finds a match between the Associated RA ID (X)
   of the received Opaque TE LSA and the ID (X) of the RA of the export
   target interface, this LSA MUST NOT be imported.

6.4. Resiliency

   OSPF creates adjacencies between neighboring routers for the purpose
   of exchanging routing information. After a neighbor has been
   discovered, bidirectional communication is ensured, and a routing
   adjacency is formed between RCs, loss of communication may result in
   partitioned OSPF areas and so in partitioned RAs.

   Consider for instance (see Figure 2) the case where RC_1a and RC_1b
   are configured for exchanging routing information downward and upward
   RA_Y, respectively, and that RC_2a and RC_2b are not configured for
   exchanging any routing information toward RA_X. If the communication
   between RC_1a and RC_2a is broken (due, e.g., to RC_5 - RC_6
   communication failure), RA_Y could be partitioned.

   In these conditions, it is RECOMMENDED that RC_2a be re-configurable
   such as to allow for exchanging routing information downward to RA_X.
   This reconfiguration MAY be performed manually or automatically. In

the latter cases, automatic reconfiguration uses the mechanism
described in Section 6.2 (forcing MaxAge of the corresponding opaque
LSA information in case the originating RC becomes unreachable).
Manual reconfiguration MUST be supported.

6.5. Neighbor Relationship and Routing Adjacency

It is assumed that (point-to-point) IP control channels are
provisioned/configured between RCs belonging to the same routing
level. Provisioning/configuration techniques are outside the scope
of this document.

Once established, the OSPF Hello protocol is responsible for
establishing and maintaining neighbor relationships. This protocol
also ensures that communication between neighbors is bidirectional.
Routing adjacency can subsequently be formed between RCs following
mechanisms defined in [RFC2328].

6.6 Reconfiguration

This section details the RA ID reconfiguration steps.

Reconfiguration of the RA ID occurs when the RA ID is modified, e.g.,
from value Z to value X or Y (see Figure 2).

The process of reconfiguring the RA ID involves:

- Disable the import/export of routing information from the upper and
  lower levels (to prevent any LS information update).

- Change the RA ID of the local level RA from, e.g., Z to X or Y.
  Perform a Link State Database (LSDB) checksum on all routers to
  verify that LSDBs are consistent.

- Enable import of upstream and downstream routing information such
  as to re-synchronize local-level LSDBs from any LS information that
  may have occurred in an upper or a lower routing level.

- Enable export of routing information downstream such as to re-sync
  the downstream level with the newly reconfigured RA ID (as part of
  the re-advertised Opaque TE LSA).

- Enable export of routing information upstream such as to re-sync
  the upstream level with the newly reconfigured RA ID (as part of
  the re-advertised Opaque TE LSA).

Note that the re-sync operation needs to be carried out only between
the directly adjacent upper and lower routing levels.

7. OSPFv2 Scalability

     - Routing information exchange upward/downward in the hierarchy
       between adjacent RAs SHOULD by default be limited to reachability
       information. In addition, several transformations such as prefix
       aggregation are RECOMMENDED when allowing the amount of information
       imported/exported by a given RC to be decreased without impacting
       consistency.

     - Routing information exchange upward/downward in the hierarchy
       involving TE attributes MUST be under strict policy control.
       Pacing and min/max thresholds for triggered updates are strongly
       RECOMMENDED.

     - The number of routing levels MUST be maintained under strict policy
       control.

8. Security Considerations

     This document specifies the contents and processing of Opaque LSAs in
     OSPFv2 [RFC2328]. Opaque TE and RI LSAs defined in this document are
     not used for SPF computation, and so have no direct effect on IP
     routing. Additionally, ASON routing domains are delimited by the
     usual administrative domain boundaries.

     Any mechanisms used for securing the exchange of normal OSPF LSAs can
     be applied equally to all Opaque TE and RI LSAs used in the ASON
     context. Authentication of OSPFv2 LSA exchanges (such as OSPF
     cryptographic authentication [RFC2328] and [RFC5709]) can be used to
     secure against passive attacks and provide significant protection
     against active attacks. [RFC5709] defines a mechanism for
     authenticating OSPF packets by making use of the HMAC algorithm in
     conjunction with the SHA family of cryptographic hash functions.

     [RFC2154] adds 1) digital signatures to authenticate OSPF LSA data,
     2) a certification mechanism for distribution of routing information,
     and 3) a neighbor-to-neighbor authentication algorithm to protect
     local OSPFv2 protocol exchanges.

9. Experimental Code Points

     This document is classified as Experimental. It defines new TLVs and
     sub-TLVs for inclusion in OSPF LSAs. According to the assignment
     policies for the registries of code points for these TLVs and sub-
     TLVs, values must be assigned from the experimental ranges and must
     not be recorded by IANA or mentioned in this document.

     The following sections summarize the TLVs and sub-TLVs concerned.

9.1. Sub-TLVs of the Link TLV

   This document defines the following sub-TLVs of the Link TLV carried
   in the OSPF TE LSA:

   - Local and Remote TE Router ID sub-TLV
   - Associated RA ID sub-TLV

   The defining text for code point assignment for sub-TLVs of the OSPF
   TE Link TLV says ([RFC3630]):

      o Types in the range 10-32767 are to be assigned via Standards
         Action.

      o Types in the range 32768-32777 are for experimental use; these
         will not be registered with IANA, and MUST NOT be mentioned by
         RFCs.

      o Types in the range 32778-65535 are not to be assigned at this
         time.

   That means that the new sub-TLVs must be assigned type values from
   the range 32768-32777. It is a matter for experimental
   implementations to assign their own code points, and to agree with
   cooperating implementations participating in the same experiments
   what values to use.

   Note that the same value for the Associated RA ID sub-TLV MUST be
   used when it appears in the Link TLV, the Node Attribute TLV, and the
   Router Address TLV.

9.2. Sub-TLVs of the Node Attribute TLV

   This document defines the following sub-TLVs of the Node Attribute
   TLV carried in the OSPF TE LSA.

      - Node IPv4 Local Prefix sub-TLV
      - Node IPv6 Local Prefix sub-TLV
      - Local TE Router ID sub-TLV
      - Associated RA ID sub-TLV

   The defining text for code point assignment for sub-TLVs of the OSPF
   Node Attribute TLV says ([RFC5786]):

      o Types in the range 3-32767 are to be assigned via Standards
         Action.

        o Types in the range 32768-32777 are for experimental use; these
           will not be registered with IANA, and MUST NOT be mentioned by
           RFCs.

        o Types in the range 32778-65535 are not to be assigned at this
           time. Before any assignments can be made in this range, there
           MUST be a Standards Track RFC that specifies IANA
           Considerations that covers the range being assigned.

   That means that the new sub-TLVs must be assigned type values from
   the range 32768-32777. It is a matter for experimental
   implementations to assign their own code points, and to agree with
   cooperating implementations participating in the same experiments
   what values to use.

   Note that the same value for the Associated RA ID sub-TLV MUST be
   used when it appears in the Link TLV, the Node Attribute TLV, and the
   Router Address TLV.

9.3. Sub-TLVs of the Router Address TLV

   The OSPF Router Address TLV is defined in [RFC3630]. No sub-TLVs are
   defined in that document and there is no registry or allocation
   policy for sub-TLVs of the Router Address TLV.

   This document defines the following new sub-TLV for inclusion in the
   OSPF Router Address TLV:

   - Associated RA ID sub-TLV

   Note that the same value for the Associated RA ID sub-TLV MUST be
   used when it appears in the Link TLV, the Node Attribute TLV, and the
   Router Address TLV. This is consistent with potential for a future
   definition of a registry with policies that match the other existing
   registries.

9.4. TLVs of the Router Information LSA

   This document defines two new TLVs to be carried in the Router
   Information LSA.

      - Downstream Associated RA ID TLV
      - Router Information Experimental Capabilities TLV

   The defining text for code point assignment for TLVs of the OSPF
   Router Information LSA says ([RFC4970]):

      o 1-32767 Standards Action.

   o Types in the range 32768-32777 are for experimental use; these
      will not be registered with IANA and MUST NOT be mentioned by
      RFCs.

   o Types in the range 32778-65535 are reserved and are not to be
      assigned at this time. Before any assignments can be made in
      this range, there MUST be a Standards Track RFC that specifies
      IANA Considerations that covers the range being assigned.

That means that the new TLVs must be assigned type values from the
range 32768-32777. It is a matter for experimental implementations
to assign their own code points, and to agree with cooperating
implementations participating in the same experiments what values to
use.

10. References

10.1. Normative References

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10.2. Informative References

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               M., Li, T., and R. Atkinson, "OSPFv2 HMAC-SHA
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   http://www.itu.int.

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               Architecture and Requirements for Link State Protocols",
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11. Acknowledgements

Appendix A. ASON Terminology

   This document makes use of the following terms:

   Administrative domain: (See Recommendation [G.805].) For the
      purposes of [G7715.1], an administrative domain represents the
      extent of resources that belong to a single player such as a
      network operator, a service provider, or an end-user.
      Administrative domains of different players do not overlap amongst
      themselves.

   Control plane: performs the call control and connection control
      functions. Through signaling, the control plane sets up and
      releases connections, and may restore a connection in case of a
      failure.

   (Control) Domain: represents a collection of (control) entities that
      are grouped for a particular purpose. The control plane is
      subdivided into domains matching administrative domains. Within
      an administrative domain, further subdivisions of the control
      plane are recursively applied. A routing control domain is an
      abstract entity that hides the details of the RC distribution.

   External NNI (E-NNI): interfaces are located between protocol
      controllers between control domains.

   Internal NNI (I-NNI): interfaces are located between protocol
      controllers within control domains.

   Link: (See Recommendation G.805.) A "topological component" that
      describes a fixed relationship between a "subnetwork" or "access
      group" and another "subnetwork" or "access group". Links are not
      limited to being provided by a single server trail.

   Management plane: performs management functions for the transport
      plane, the control plane, and the system as a whole. It also
      provides coordination between all the planes. The following
      management functional areas are performed in the management plane:
      performance, fault, configuration, accounting, and security
      management.

   Management domain: (See Recommendation G.805.) A management domain
      defines a collection of managed objects that are grouped to meet
      organizational requirements according to geography, technology,
      policy, or other structure, and for a number of functional areas
      such as configuration, security, (FCAPS), for the purpose of
      providing control in a consistent manner. Management domains can
      be disjoint, contained, or overlapping. As such, the resources

within an administrative domain can be distributed into several
possible overlapping management domains. The same resource can
therefore belong to several management domains simultaneously, but
a management domain shall not cross the border of an
administrative domain.

Subnetwork Point (SNP): The SNP is a control plane abstraction that
represents an actual or potential transport plane resource. SNPs
(in different subnetwork partitions) may represent the same
transport resource. A one-to-one correspondence should not be
assumed.

Subnetwork Point Pool (SNPP): A set of SNPs that are grouped together
for the purposes of routing.

Termination Connection Point (TCP): A TCP represents the output of a
Trail Termination function or the input to a Trail Termination
Sink function.

Transport plane: provides bidirectional or unidirectional transfer of
user information, from one location to another. It can also
provide transfer of some control and network management
information. The transport plane is layered; it is equivalent to
the Transport Network defined in Recommendation G.805.

User Network Interface (UNI): interfaces are located between protocol
controllers between a user and a control domain. Note: There is
no routing function associated with a UNI reference point.

Appendix B. ASON Routing Terminology

This document makes use of the following terms:

Routing Area (RA): an RA represents a partition of the data plane,
and its identifier is used within the control plane as the
representation of this partition. Per [G.8080], an RA is defined
by a set of sub-networks, the links that interconnect them, and
the interfaces representing the ends of the links exiting that RA.
An RA may contain smaller RAs inter-connected by links. The limit
of subdivision results in an RA that contains two sub-networks
interconnected by a single link.

Routing Database (RDB): a repository for the local topology, network
topology, reachability, and other routing information that is
updated as part of the routing information exchange and may
additionally contain information that is configured. The RDB may
contain routing information for more than one routing area (RA).

Routing Components: ASON routing architecture functions. These
    functions can be classified as protocol independent (Link Resource
    Manager or LRM, Routing Controller or RC) or protocol specific
    (Protocol Controller or PC).

Routing Controller (RC): handles (abstract) information needed for
    routing and the routing information exchange with peering RCs by
    operating on the RDB. The RC has access to a view of the RDB.
    The RC is protocol independent.

Note: Since the RDB may contain routing information pertaining to
    multiple RAs (and possibly to multiple layer networks), the RCs
    accessing the RDB may share the routing information.

Link Resource Manager (LRM): supplies all the relevant component and
    TE link information to the RC. It informs the RC about any state
    changes of the link resources it controls.

Protocol Controller (PC): handles protocol-specific message exchanges
    according to the reference point over which the information is
    exchanged (e.g., E-NNI, I-NNI), and internal exchanges with the
    RC. The PC function is protocol dependent.

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