Standard Representation Of Domain-Sequence
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Abstract

   The ability to compute shortest constrained Traffic Engineering Label
   Switched Paths (TE LSPs) in Multiprotocol Label Switching (MPLS) and
   Generalized MPLS (GMPLS) networks across multiple domains has been
   identified as a key requirement for P2P and P2MP scenarios. In this
   context, a domain is a collection of network elements within a common
   sphere of address management or path computational responsibility
   such as an IGP area or an Autonomous Systems. This document
   specifies a standard representation and encoding of a Domain-
   Sequence, which is defined as an ordered sequence of domains
   traversed to reach the destination domain. This document also
   defines new subobjects to be used to encode domain identifiers.

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1. Introduction

A PCE may be used to compute end-to-end paths across multi-domain
environments using a per-domain path computation technique [RFC5152].
The so called backward recursive path computation (BRPC) mechanism
[RFC5441] defines a PCE-based path computation procedure to compute
inter-domain constrained (G)MPLS TE LSPs. However, both per-domain
and BRPC techniques assume that the sequence of domains to be crossed
from source to destination is known, either fixed by the network
operator or obtained by other means. For inter-domain point-to-
multi-point (P2MP) tree, [PCE-P2MP-PROCEDURES] assumes the domain-
tree is known.

The list of domains (domain-sequence) in a point-to-point (P2P) path
or a point-to-multi-point (P2MP) tree is usually a constraint in the
path computation request. The PCE determines the next PCE to forward
the request based on the domain-sequence.

In a multi-domain path computation, a PCC MAY indicate the sequence
of domains to be traversed using the Include Route Object (IRO)
defined in [RFC5440].

When the sequence of domains is not known in advance, the
Hierarchical PCE [RFC6805] architecture and mechanisms can be used to
determine the end-to-end Domain-Sequence.

This document defines a standard way to represent and encode a
Domain-Sequence in various deployment scenarios including P2P, P2MP
and Hierarchical PCE (H-PCE) [RFC6805].

The Domain-Sequence (the set of domains traversed to reach the
destination domain) is either administratively predetermined or
discovered by some means (H-PCE) that is outside of the scope of this
document.

[RFC5440] defines the Include Route Object (IRO) and the Explicit
Route Object (ERO); [RFC5521] defines the Exclude Route Object (XRO)
and the Explicit Exclusion Route Subobject (EXRS); The use of
Autonomous Number (AS) (2-Byte) as an abstract node representing
domain is defined in [RFC3209], This document specifies new
subobjects to include or exclude domains such as an IGP area or an
Autonomous Systems (4-Byte).

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",
"SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this
document are to be interpreted as described in [RFC2119].

2. Terminology

The following terminology is used in this document.

ABR: OSPF Area Border Router. Routers used to connect two IGP
   areas.

AS: Autonomous System.

ASBR: Autonomous System Boundary Router.

BN: Boundary Node, Can be an ABR or ASBR.

BRPC: Backward Recursive Path Computation

Domain: As per [RFC4655], any collection of network elements within
   a common sphere of address management or path computational
   responsibility. Examples of domains include Interior Gateway
   Protocol (IGP) areas and Autonomous Systems (ASs).

Domain-Sequence: An ordered sequence of domains traversed to reach
   the destination domain.

ERO: Explicit Route Object

H-PCE: Hierarchical PCE

IGP: Interior Gateway Protocol. Either of the two routing
   protocols, Open Shortest Path First (OSPF) or Intermediate System
   to Intermediate System (IS-IS).

IRO: Include Route Object

IS-IS: Intermediate System to Intermediate System.

OSPF: Open Shortest Path First.

PCC: Path Computation Client: any client application requesting a
   path computation to be performed by a Path Computation Element.

PCE: Path Computation Element. An entity (component, application,
   or network node) that is capable of computing a network path or
   route based on a network graph and applying computational
   constraints.

P2MP: Point-to-Multipoint

P2P: Point-to-Point

RSVP: Resource Reservation Protocol

TE LSP: Traffic Engineering Label Switched Path.

3. Detail Description

3.1. Domains

[RFC4726] and [RFC4655] define domain as a separate administrative or
geographic environment within the network. A domain may be further
defined as a zone of routing or computational ability. Under these
definitions a domain might be categorized as an Autonomous System
(AS) or an Interior Gateway Protocol (IGP) area. Each AS can be made
of several IGP areas. In order to encode a Domain-Sequence, it is
required to uniquely identify a domain in the Domain-Sequence. A
domain can be uniquely identified by area-id or AS or both.

3.2. Domain-Sequence

A domain-sequence is an ordered sequence of domains traversed to
reach the destination domain.

A domain-sequence can be applied as a constraint and carried in path
computation request to PCE(s). A domain-sequence can also be the
result of a path computation. For example, in the case of H-PCE
[RFC6805] Parent PCE MAY send the Domain-Sequence as a result in a
path computation reply.

In this context, the ordered nature of a domain-sequence is
important. In a P2P path, the domains listed appear in the order
that they are crossed. In a P2MP path, the domain tree is
represented as list of domain sequences.

A domain-sequence enables a PCE to select the next PCE to forward the
path computation request based on the domain information.

A PCC or PCE MAY add an additional constraints covering which
Boundary Nodes (ABR or ASBR) or Border links (Inter-AS-link) MUST be
traversed while defining a Domain-Sequence.

Thus a Domain-Sequence MAY be made up of one or more of -

o AS Number

o Area ID

o Boundary Node ID

o Inter-AS-Link Address

Consequently, a Domain-Sequence can be used:

1. by a PCE in order to discover or select the next PCE in a
    collaborative path computation, such as in BRPC [RFC5441];

2. by the Parent PCE to return the Domain-Sequence when unknown,
    this can further be an input to BRPC procedure [RFC6805];

3. by a PCC (or PCE) to constraint the domains used in a H-PCE path
    computation, explicitly specifying which domains to be expanded;

4. by a PCE in per-domain path computation model [RFC5152] to
    identify the next domain(s);

3.3. Standard Representation

Domain-Sequence MAY appear in PCEP Messages, notably in -

o Include Route Object (IRO): As per [RFC5440], used to specify set
   of network elements that MUST be traversed. These subobjects are
   used to specify the domain-sequence that MUST be traversed to
   reach the destination.

o Exclude Route Object (XRO): As per [RFC5521], used to specify
   certain abstract nodes that MUST be excluded from whole path.
   These subobjects are used to specify certain domains that MUST be
   avoided to reach the destination.

o Explicit Exclusion Route Subobject (EXRS): As per [RFC5521], used
   to specify exclusion of certain abstract nodes between a specific
   pair of nodes. EXRS are a subobject inside the IRO. These
   subobjects are used to specify the domains that must be excluded
   between two abstract nodes.

o Explicit Route Object (ERO): As per [RFC5440],used to specify a
   computed path in the network.

3.4. Include Route Object (IRO)

   As per [RFC5440], IRO (Include Route Object) can be used to specify
   that the computed path MUST traverse a set of specified network
   elements or abstract nodes.

3.4.1. Subobjects

   Some subobjects are defined in [RFC3209], [RFC3473], [RFC3477] and
   [RFC4874], but new subobjects related to Domain-Sequence are needed.

   The following subobject types are used in IRO.

   The following subobject types are used.
               Type   Subobject
                1   IPv4 prefix
                2   IPv6 prefix
                4   Unnumbered Interface ID
                32   Autonomous system number (2 Byte)
                33   Explicit Exclusion (EXRS)

   This document extends the above list to support 4-Byte AS numbers and
   IGP Areas.

   The following subobject types are used.
               Type   Subobject
                TBD   Autonomous system number (4 Byte)
                TBD   OSPF Area id
                TBD   ISIS Area id

   - Autonomous system

   [RFC3209] already defines 2 byte AS number.

   To support 4 byte AS number as per [RFC4893] following subobject is
   defined:

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |L|   Type    |    Length     |            Reserved            |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                        AS Id (4 bytes)                        |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   L: The L bit is an attribute of the subobject as define in [RFC3209].

   Type: (TBA by IANA) indicating 4 byte AS Number.

   Length: 8 (Total length of the subobject in bytes).

   Reserved: Zero at transmission, Ignored at receipt.

   AS-ID: The 4 byte AS Number. Note that if 16-bit AS numbers are in
   use, the low order bits (16 through 31) should be used and the high
   order bits (0 through 15) should be set to zero.

   - IGP Area

   Since the length and format of Area-id is different for OSPF and
   ISIS, following two subobjects are defined:

   For OSPF, the area-id is a 32 bit number. The Subobject looks
       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
      +-+
      |L| Type | Length | Reserved |
      +-+
      | OSPF Area Id (4 bytes) |
      +-+

   L: The L bit is an attribute of the subobject as define in [RFC3209].

   Type: (TBA by IANA) indicating 4 byte OSPF Area ID.

   Length: 8 (Total length of the subobject in bytes).

   Reserved: Zero at transmission, Ignored at receipt.

   OSPF Area Id: The 4 byte OSPF Area ID.

   For IS-IS, the area-id is of variable length and thus the length of
   the Subobject is variable. The Area-id is as described in IS-IS by
   ISO standard [ISO 10589].

       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
      +-+
      |L| Type | Length | Area-Len | Reserved |
      +-+
      | |
      //   IS-IS Area ID   //
      | |
      +-+

L: The L bit is an attribute of the subobject as define in [RFC3209].

Type: (TBA by IANA) indicating IS-IS Area ID.

Length: Variable (Total length of the subobject in bytes including
padding). The Length MUST be at least 4, and MUST be a multiple of
4.

Area-Len: Variable (Length of the actual (non-padded) IS-IS Area
Identifier in octets; Valid values are from 2 to 11 inclusive).

Reserved: Zero at transmission, Ignored at receipt.

IS-IS Area Id: The variable-length IS-IS area identifier. Padded
with trailing zeroes to a four-byte boundary.

3.4.2. Option (A): New IRO Object Type

[RFC5440] in its description of IRO does not require the subobjects
to be in a given particular order. When considering a Domain-
Sequence, the domain relative ordering is a basic criterion and, as
such, this option suggest a new IRO object type.

```
   IRO Object-Class is 10.
   IRO Object-Type is TBD. (2 suggested value to IANA)


    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
   //                        (Subobjects)                        //
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Subobjects: The IRO is made of subobjects identical to the ones
defined in [RFC3209], [RFC3473], and [RFC3477], where the IRO
subobject type is identical to the subobject type defined in the
related documents. Some new subobjects related to Domain-Sequence
are also added in this document as mentioned in Section 3.4.

[RFC3209] defines subobjects for IPv4, IPv6 and unnumbered Interface
ID, which in the context of domain-sequence is used to specify
Boundary Node (ABR/ASBR) and Inter-AS-Links. The subobjects for AS
Number (2 or 4 Byte) and IGP Area is used to specify the domains in
the domain-sequence.

The new IRO Object-Type used to define the domain-sequence would

handle the L bit (Loose / Strict) in the subobjects similar to
[RFC3209].

Further we have following options:

* Option (A.1): New IRO Object Type for Domain-Sequence object only

A new IRO Object Type is used to specify the ordered sequence of
domains (Domain-Sequence) only. The PCReq message is modified to
allow encoding of both types of IRO; one with IRO Type 1 [RFC5440]
used to specify the intra-domain abstract nodes and resources and the
second IRO Type with the new subobjects as described in this section
to specify the domain-sequence.

All other rules of PCEP objects and message processing (ex. P bit
handling of Common Object Header) is as per [RFC5440].

* Option (A.2): New IRO Object Type for both intra and inter-domain
(domain-sequence)

A new IRO Object Type is used to include both intra nodes and inter-
domains nodes but the sequence of domain is strict. The intra-domain
nodes can still be ordered.

In case of inter-domain path computation, only the new IRO type is
used which contains the specific intra domain network nodes as well
as inter-domain abstract nodes or domains. The inter-domain abstract
nodes are encoded in the sequence they must be traversed but the
intra-domain elements MAY be an unordered set.

3.4.2.1. Handling of the Domain-Sequence IRO object

An IRO object containing Domain-Sequence subobjects constraints or
defines the domains involved in a multi-domain path computation,
typically involving two or more collaborative PCEs.

A Domain-Sequence can have varying degrees of granularity; it is
possible to have a Domain-Sequence composed of, uniquely, AS
identifiers. It is also possible to list the involved areas for a
given AS.

In any case, the mapping between domains and responsible PCEs is not
defined in this document. It is assumed that a PCE that needs to
obtain a "next PCE" from a Domain-Sequence is able to do so (e.g. via
administrative configuration, or discovery).

A PCC builds a Domain-Sequence IRO to encode the Domain-Sequence,
that is all domains that it wishes the cooperating PCEs to traverse

in order to compute the end to end path.

For each inclusion, the PCC clears the L-bit to indicate that the PCE
is required to include the domain, or sets the L-bit to indicate that
the PCC simply desires that the domain be included in the domain-
sequence.

When a PCE receives a PCEP Request message with an IRO, it looks for
a Domain-Sequence IRO (new type) to see if a domain-sequence is
specified. If the message contains more than one Domain-Sequence IRO
(new type), it MUST use the first one in the message and MUST ignore
subsequent instances.

If a PCE does not recognize the Domain-Sequence IRO (new type), it
MUST return a PCErr message with Error-Type "Unknown Object" and
Error-value "Unrecognized object Type" as described in [RFC5440].

If a PCE is unwilling or unable to process the Domain-Sequence IRO
(new type), it MUST return a PCErr message with the Error-Type "Not
supported object" and follow the relevant procedures described in
[RFC5440].

If a PCE that supports the Domain-Sequence IRO (new type) and
encounters a subobject that it does not support or recognize, it MUST
act according to the setting of the L-bit in the subobject. If the
L-bit is clear, the PCE MUST respond with a PCErr with Error-Type
"Unrecognized subobject" and set the Error-Value to the subobject
type code. If the L-bit is set, the PCE MAY respond with a PCErr as
already stated or MAY ignore the subobject: this choice is a local
policy decision.

If a PCE parses a Domain-Sequence IRO (new type), it MUST act
according to the requirements expressed in the subobject. That is,
if the L-bit is clear, the PCE(s) MUST produce a path that follows
domain-sequence nodes in order identified by the subobjects in the
path. If the L-bit is set, the PCE(s) SHOULD produce a path along
the Domain-Sequence unless it is not possible to construct a path
complying with the other constraints expressed in the request.

A successful path computation reported in a PCEP response message
MUST include an ERO to specify the path that has been computed as
specified in [RFC5440] following the sequence of domains.

In a PCEP response message, PCE MAY also supply a Domain-Sequence IRO
(new type) with the NO-PATH object indicating that the set of
elements of the request's Domain-Sequence IRO prevented the PCE from
finding a path.

   Subobject types for AS and IGP Area affect the next domain selection
   as well as finding the PCE serving that domain.

   Note that a particular domain in the domain-sequence can be
   identified by :-

   o A single IGP Area: Only the IGP (OSPF or ISIS) Area subobject is
      used to identify the next domain. (Refer Figure 1)

   o A single AS: Only the AS subobject is used to identify the next
      domain. (Refer Figure 2)

   o Both an AS and an IGP Area: Combination of both AS and Area are
      used to identify the next domain. In this case the order is AS
      Subobject followed by Area. (Refer Figure 3)

   Subobject of other types representing Boundary Node or Inter-AS-Link
   do not pay any role in the selection of next domain, but they MUST be
   applied during the final path computation procedure as before.

3.4.3. Option B: Existing IRO Object Type

   The IRO (Include Route Object) [RFC5440] is an optional object used
   to specify a set of network elements that the computed path MUST
   traverse.

   The new subobjects denoting the domain-sequence are carried in the
   same IRO Type 1, and all the rules of processing as specified in
   [RFC5440] are applied.

   Note the following differences :-

   o Order: Since there is no inherent order specified in the encoding
      of the subobjects in IRO Type 1 [RFC5440], it is the job of the
      PCE to figure out the optimal order of the domains to be crossed
      to reach the destination domain. Note that in case of doubt, or
      when applicable, the PCE can still apply the ordering as specified
      in the request message. Further PCE may have to crankback and try
      multiple permutations before figuring out the correct sequence.

   o Loose / Strict (L-Bit): [RFC5440] state that the L bit of the
      subobjects within an IRO Type 1 [RFC5440] has no meaning. This
      will be applicable for subobjects denoting domain-sequence as
      well.

   o Scope: Coexistence of intra-domain nodes, boundary nodes and
      domain nodes in the same IRO List. It is the job of PCE to figure
      out the scope and apply the processing rules accordingly. The

      nodes in the IRO which are recognized by the PCE are handled
      locally and others are forwarded to next PCE hoping they would
      handle them, the aggregating PCE (Ingress PCE or Parent) would
      make sure that all nodes in IRO are handled correctly.

3.5. Exclude Route Object (XRO)

   The Exclude Route Object (XRO) [RFC5521] is an optional object used
   to specify exclusion of certain abstract nodes or resources from the
   whole path.

3.5.1. Subobjects

   The following subobject types are defined to be used in XRO as
   defined in [RFC3209], [RFC3477], [RFC4874], and [RFC5521].

```
          Type    Subobject
           1      IPv4 prefix
           2      IPv6 prefix
           4      Unnumbered Interface ID
           32     Autonomous system number (2 Byte)
           34     SRLG
           64     IPv4 Path Key
           65     IPv6 Path Key
```

   This document extends the above list to support 4-Byte AS numbers and
   IGP Areas.

```
          Type    Subobject
           TBD    Autonomous system number (4 Byte)
           TBD    OSPF Area id
           TBD    ISIS Area id
```

3.5.1.1. Autonomous system

   The new subobjects to support 4 byte AS and IGP (OSPF / ISIS) Area
   MAY also be used in the XRO to specify exclusion of certain domains
   in the path computation procedure.

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|X|   Type      |    Length    |              Reserved          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         AS Id (4 bytes)                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The X-bit indicates whether the exclusion is mandatory or desired.

0 indicates that the AS specified MUST be excluded from the path
computed by the PCE(s).

1 indicates that the AS specified SHOULD be avoided from the inter-
domain path computed by the PCE(s), but MAY be included subject to
PCE policy and the absence of a viable path that meets the other
constraints.

All other fields are consistent with the definition in Section 3.4.

3.5.1.2. IGP Area

Since the length and format of Area-id is different for OSPF and
ISIS, following two subobjects are defined:

For OSPF, the area-id is a 32 bit number. The subobject is encoded
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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|X|   Type      |    Length    |              Reserved          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      OSPF Area Id (4 bytes)                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The X-bit indicates whether the exclusion is mandatory or desired.

0 indicates that the OSFF Area specified MUST be excluded from the
path computed by the PCE(s).

1 indicates that the OSFF Area specified SHOULD be avoided from the
inter-domain path computed by the PCE(s), but MAY be included subject
to PCE policy and the absence of a viable path that meets the other
constraints.

All other fields are consistent with the definition in Section 3.4.

For IS-IS, the area-id is of variable length and thus the length of
the subobject is variable. The Area-id is as described in IS-IS by
ISO standard [ISO 10589]. The subobject is encoded 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|X|   Type      |    Length     |  Area-Len   |    Reserved     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
//                       IS-IS Area ID                         //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The X-bit indicates whether the exclusion is mandatory or desired.

0 indicates that the ISIS Area specified MUST be excluded from the
path computed by the PCE(s).

1 indicates that the ISIS Area specified SHOULD be avoided from the
inter-domain path computed by the PCE(s), but MAY be included subject
to PCE policy and the absence of a viable path that meets the other
constraints.

All other fields are consistent with the definition in Section 3.4.

If a PCE that supports XRO and encounters a subobject that it does
not support or recognize, it MUST act according to the setting of the
X-bit in the subobject. If the X-bit is clear, the PCE MUST respond
with a PCErr with Error-Type "Unrecognized subobject" and set the
Error-Value to the subobject type code. If the X-bit is set, the PCE
MAY respond with a PCErr as already stated or MAY ignore the
subobject: this choice is a local policy decision.

All the other processing rules are as per [RFC5521].

3.6. Explicit Exclusion Route Subobject (EXRS)

Explicit Exclusion Route Subobject (EXRS) [RFC5521] is used to
specify exclusion of certain abstract nodes between a specific pair
of nodes.

The EXRS subobject may carry any of the subobjects defined for
inclusion in the XRO, thus the new subobjects to support 4 byte AS
and IGP (OSPF / ISIS) Area MAY also be used in the EXRS. The
meanings of the fields of the new XRO subobjects are unchanged when

the subobjects are included in an EXRS, except that scope of the
exclusion is limited to the single hop between the previous and
subsequent elements in the IRO.

All the processing rules are as per [RFC5521].

3.7. Explicit Route Object (ERO)

The Explicit Route Object (ERO) [RFC5440] is used to specify a
computed path in the network. PCEP ERO subobject types correspond to
RSVP-TE ERO subobject types as defined in [RFC3209], [RFC3473],
[RFC3477], [RFC4873], [RFC4874], and [RFC5520].

```
            Type    Subobject
             1      IPv4 prefix
             2      IPv6 prefix
             3      Label
             4      Unnumbered Interface ID
             32     Autonomous system number (2 Byte)
             33     Explicit Exclusion (EXRS)
             37     Protection
             64     IPv4 Path Key
             65     IPv6 Path Key
```

This document extends the above list to support 4-Byte AS numbers and
IGP Areas.

```
            Type    Subobject
             TBD    Autonomous system number (4 Byte)
             TBD    OSPF Area id
             TBD    ISIS Area id
```

The new subobjects to support 4 byte AS and IGP (OSPF / ISIS) Area
MAY also be used in the ERO to specify an abstract node (a group of
nodes whose internal topology is opaque to the ingress node of the
LSP). Using this concept of abstraction, an explicitly routed LSP
can be specified as a sequence of domains.

In case of Hierarchical PCE [RFC6805], a Parent PCE MAY be requested
to find the domain-sequence. Refer example in Section 4.6.

The format of the new ERO subobjects is similar to new IRO
subobjects, refer Section 3.4.

4. Other Considerations

4.1. Inter-Area Path Computation

In an inter-area path computation where the ingress and the egress
nodes belong to different IGP areas within the same AS, the Domain-
Sequence MAY be represented using a ordered list of Area subobjects.
The AS number MAY be skipped, as area information is enough to select
the next PCE.

```
+------------------+                    +------------------+
|                  |                    |                  |
|           +--+   |                    |       +--+       |
|   +--+    |  |   |                    |       |  |       |
|   |  |    +--+   |                    |       +--+   +--+ |
|   +--*           +                    +              |  | |
|                  |                    |              +--+ |
|         *--+     +                    +                   |
|         |  |     |                    |       +--+        |
|         +--+     |                    |       |  |        |
|                  |+------------------------+| +--+        |
|                  ++++                    +-++             |
|                  ||||        +--+        | ||             |
|  Area 2          ++++        |  |        +-++  Area 4     |
+------------------+|          +--+        |+------------------+
                   |                       |
                   |            +--+       |
                   |    +--+    |  |       |
                   |    |  |    +--+       |
                   |    +--+               |
                   |                       |
                   |                       |
                   |                       |
                   |                       |
                   |            +--+       |
                   |            |  |       |
                   |            +--+       |
+------------------+|                      |+------------------+
|                  ++-+                  +-++                  |
|                  || |                  | ||                  |
|                  ++-+      Area 0      +-++                  |
|                  |+------------------------+|   +--+         |
|         +--+     |                       |    |  |         |
|         |  |     |                       |    +--+         |
|  +--+   +--+     |                       |                 |
|  |  |            +                       +        +--+     |
|  +--+            |                       |        |  |     |
|                  +                       +        +--+     |
|         +--+     |                       |                 |
|         |  |     |                       |    +--+         |
|         +--+     |                       |    |  |         |
|                  |                       |    +--+         |
|                  |                       |                 |
|  Area 1          |                       |  Area 5         |
+------------------+                       +------------------+
```
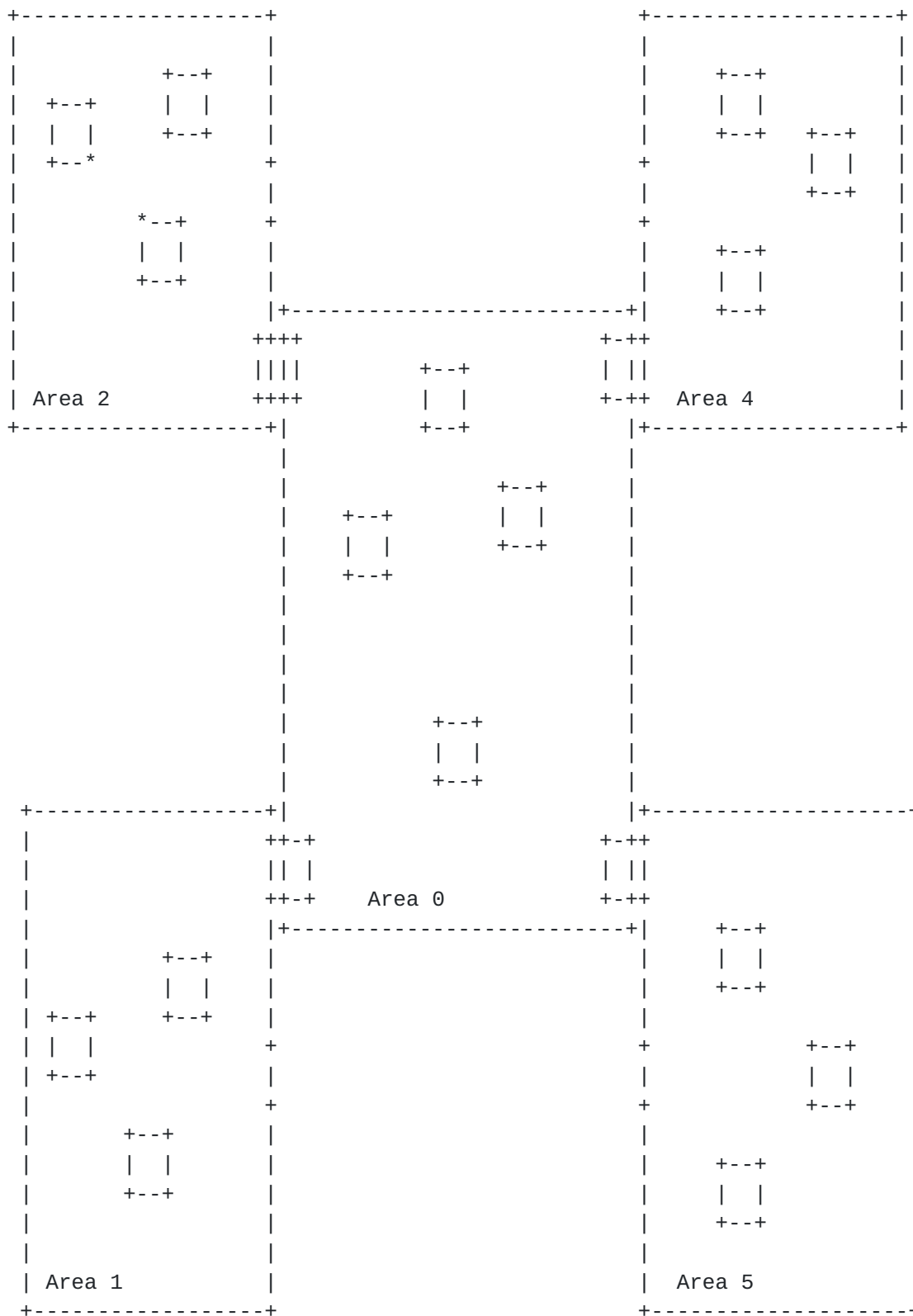
AS Number is 100.

Figure 1: Inter-Area Path Computation

   This could be represented in the <IRO> as:

```
   +---------+ +---------+ +---------+ +---------+
   |IRO      | |Sub      | |Sub      | |Sub      |
   |Object   | |Object   | |Object   | |Object   |
   |Header   | |Area 2   | |Area 0   | |Area 4   |
   |         | | |        | | |        | | |       |
   |         | | |        | | |        | | |       |
   +---------+ +---------+ +---------+ +---------+


   +---------+ +---------+ +---------+ +---------+ +---------+
   |IRO      | |Sub      | |Sub      | |Sub      | |Sub      |
   |Object   | |Object AS| |Object   | |Object   | |Object   |
   |Header   | |100      | |Area 2   | |Area 0   | |Area 4   |
   |         | | |        | | |        | | |        | | |      |
   |         | | |        | | |        | | |        | | |      |
   +---------+ +---------+ +---------+ +---------+ +---------+
```

   AS is optional and it MAY be skipped. PCE should be able to
   understand both notations.

4.2. Inter-AS Path Computation

   In inter-AS path computation, where ingress and egress belong to
   different AS, the Domain-Sequence is represented using an ordered
   list of AS subobjects. The Domain-Sequence MAY further include
   decomposed area information in Area subobjects.

4.2.1. Example 1

   As shown in Figure 2, where AS to be made of a single area, the area
   subobject MAY be skipped in the Domain-Sequence as AS is enough to
   uniquely identify the next domain and PCE.

```
                                +--------------------------------+
                                |AS 200                          |
                                |               +------+         |
                                |               |      |         |
      +------------------------+ |              |      |  +------+ |
      | AS 100                 | |              +------+  |      | |
      |              +------+ |  | +------+               |      | |
      |              |      +-+------+-+     |            +------+ |
      |              |      | |   | |     | |     |                |
      |              +------+ |  | +------+               |
      | +------+              | |              +------+         |
      | |      |              | |              |      |         |
      | |      |              | |              |      |         |
      | +------+              | |              +------+         |
      |                       | |                              |
      |              +------+ |  | +------+                    |
      |              |      +-+------+-+     |       +------+ |
      |              |      | |   | |     | |       |      | |
      |              +------+ |  | +------+         |      | |
      |                       | |                   +------+ |
      |                       | |                              |
      |                       | |                              |
      |              +------+ |  |              +------+         |
      |              |      | |  |              |      |         |
      |              |PCE   | |  |              |PCE   |         |
      |              +------+ |  |              +------+         |
      |                       | |                              |
      +------------------------+ |                              |
                                |                              |
                                +--------------------------------+
```
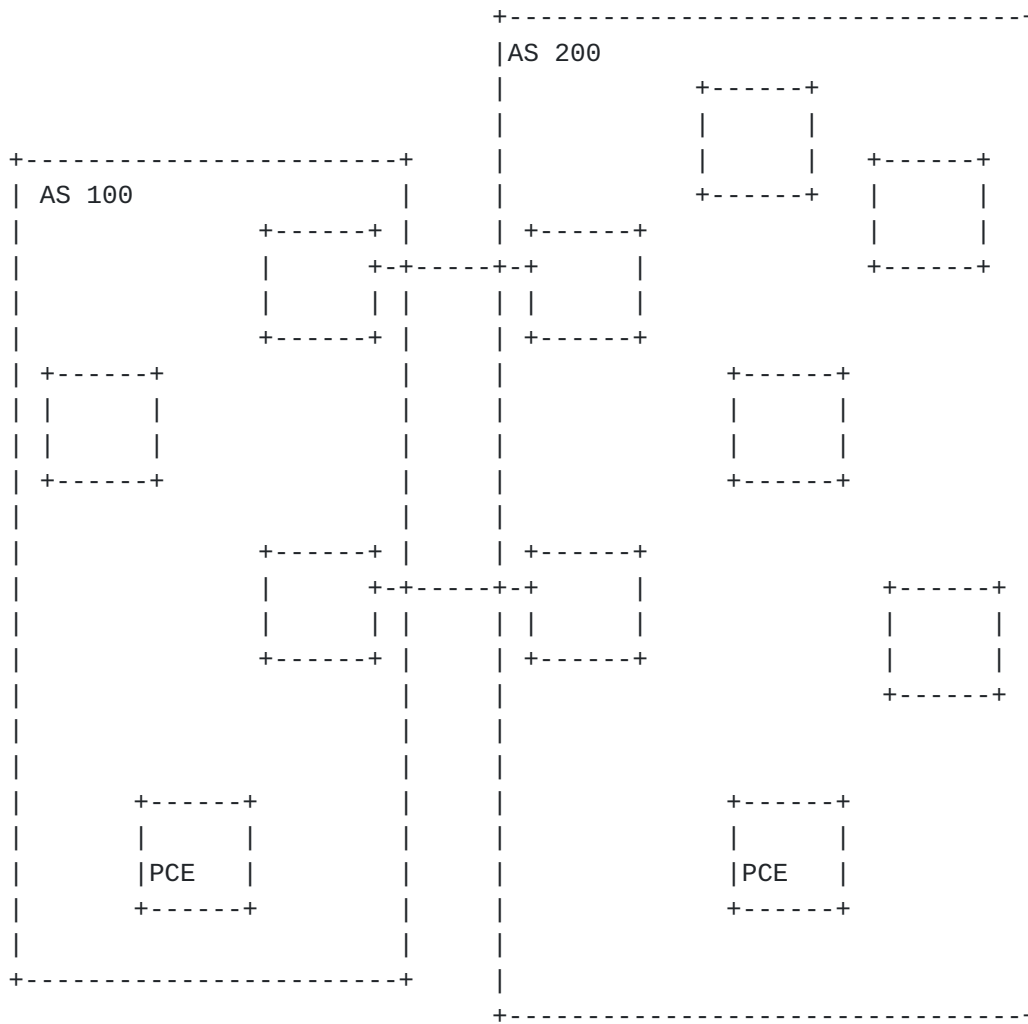
Both AS are made of Area 0.

Figure 2: Inter-AS Path Computation

This could be represented in the <IRO> as:

```
+---------+  +---------+  +---------+
|IRO      |  |Sub      |  |Sub      |
|Object   |  |Object AS|  |Object AS|
|Header   |  |100      |  |200      |
|         |  |         |  |         |
|         |  |         |  |         |
+---------+  +---------+  +---------+
```

```
+---------+  +---------+  +---------+  +---------+  +---------+
|IRO      |  |Sub      |  |Sub      |  |Sub      |  |Sub      |
|Object   |  |Object AS|  |Object   |  |Object AS|  |Object   |
|Header   |  |100      |  |Area 0   |  |200      |  |Area 0   |
|         |  |         |  |         |  |         |  |         |
|         |  |         |  |         |  |         |  |         |
+---------+  +---------+  +---------+  +---------+  +---------+
```
Area subobject is optional and it MAY be skipped. PCE should be
able to understand both notations.

4.2.2. Example 2

As shown in Figure 3, where AS 200 is made up of multiple areas and
multiple domain-sequence exist, PCE MAY include both AS and Area
subobject to uniquely identify the next domain and PCE.

```
                    |
                    |   +-------------+            +---------------+
                    |   |Area 2       |            |Area 4         |
                    |   |      +--+|            |          +--+   |
                    |   |      |  ||            |          |  |   |
                    |   |  +--+  +--+|            |   +--+   +--+   |
                    |   |  |  |    |            |   |  |          |
                    |   |  *--+    |            |   +--+          |
                    |   | /   +--+ |            |          +--+   |
                    |   |/    |  | |            |          |  |   |
                    |   /     +--+ |            |   +--+   +--+   |
                    | /|  +--+    |+-------------+|   |  |          |
                    |/ |  |  |    ++-+        +-++   +--+          |
       +-------------+/  |  +--+    || |        | ||          |
       |           /|  |        ++-+        +-++          |
       |         +--*||  +-------------+|          |+---------------+
       |         |  |||              |   +--+    |
       |         +--+||              |   |  |    |
       |   +--+    ||              |   +--+    |
       |   |  |    ||              |          |
       |   +--+    ||              |          |
       |         ||              |   +--+    |
       |+--+    ||              |   |  |    |
       || |    ||              |   +--+    |
       |+--+    ||              |          |
       |         ||              |   +--+    |
       |   +--+    ||  +------------+ |   |  |    |+---------------+
       |   |  |    ||  |Area 3       +-++    +--+   +-++ Area 5         |
       |   +--+    ||  |        | ||    | ||          |
       |         ||  |        +-++    +-++          |
       |   +--+||  |    +--+ | |  Area 0    ||   +--+    |
       |   |  |||  |    |  | | | +-------------+|   |  |    |
       |   +--*||  |    +--+ |          |   +--+    |
       |         \|  |        |          |          +--+   |
       |Area 1      |\  |    +--+    |          |   +--+   |  |   |
       +-------------+|\ |    |  |    |          |   |  |   +--+   |
                    | \|    +--+  +--+          |   +--+          |
                    | \        | |          |                |
                    | |\        +--+          |          +--+   |
                    | | \ +--+    |          |          |  |   |
                    | | \|  |    |          |          +--+   |
                    | |   *--+    |          |                |
                    | |        |          |                |
                    | +------------+          +---------------+
                    |
                    |
          AS 100     |  AS 200
                    |
```
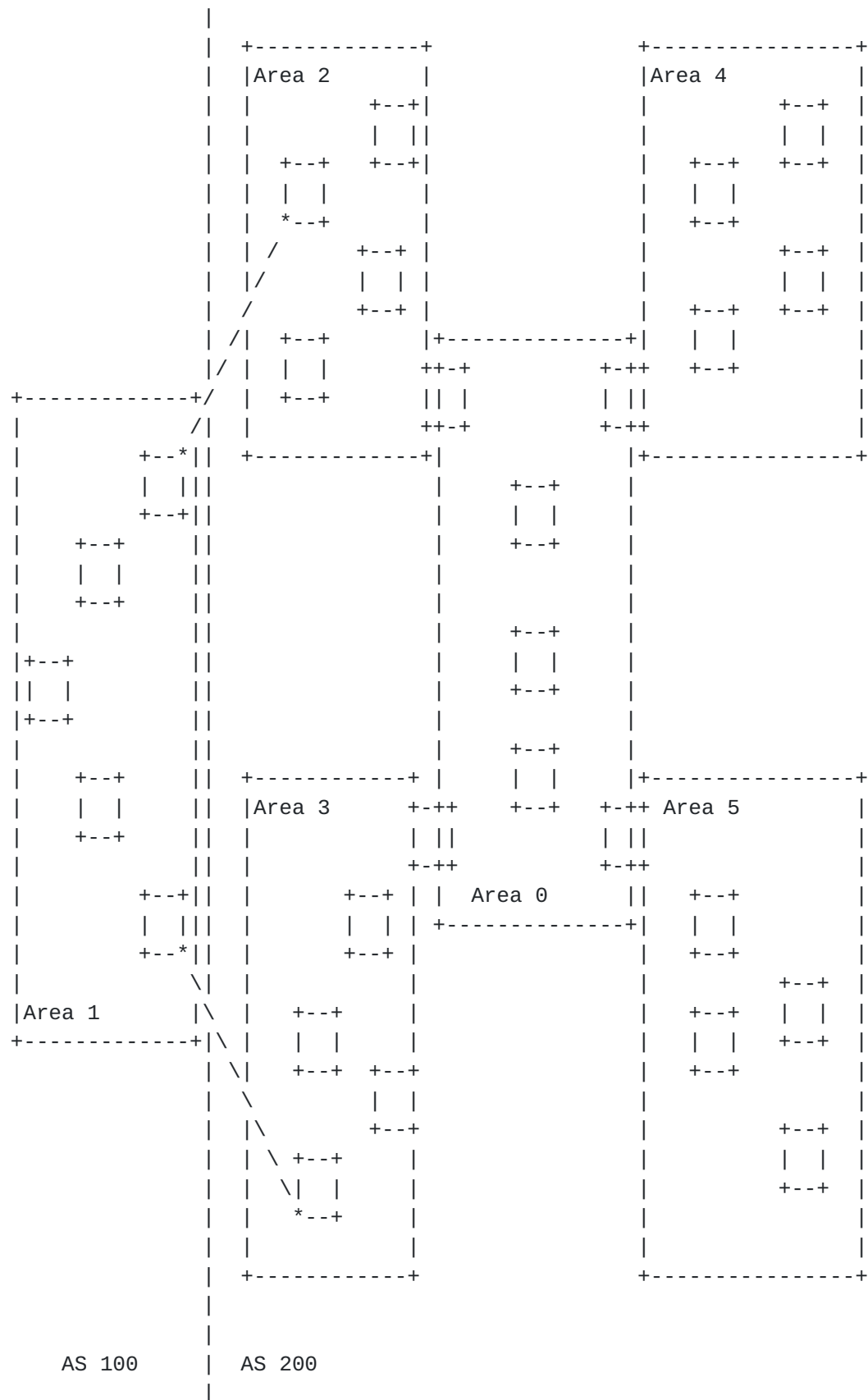
Figure 3: Inter-AS Path Computation

The Domain-Sequence can be carried in the IRO as shown below:

```
+-------+ +-------+ +-------+ +-------+ +-------+ +-------+ +-------+
|IRO    | |Sub    | |Sub    | |Sub    | |Sub    | |Sub    | |Sub    |
|Object | |Object | |Object | |Object | |Object | |Object | |Object |
|Header | |AS 100 | |Area 1 | |AS 200 | |Area 3 | |Area 0 | |Area 4 |
|       | | |     | | |     | | |     | | |     | | |     | | |     |
+-------+ +-------+ +-------+ +-------+ +-------+ +-------+ +-------+
```

The combination of both an AS and an Area uniquely identify a domain
in the Domain-Sequence.

Note that an Area domain identifier always belongs to the previous AS
that appears before it or, if no AS subobjects are present, it is
assumed to be the current AS.

If the area information cannot be provided, PCE MAY forward the path
computation request to the next PCE based on AS alone. If multiple
PCEs are responsible, PCE MAY apply local policy to select the next
PCE.

4.3. Boundary Node and Inter-AS-Link

A PCC or PCE MAY add additional constraints covering which Boundary
Nodes (ABR or ASBR) or Border links (Inter-AS-link) MUST be traversed
while defining a Domain-Sequence. In which case the Boundary Node or
Link MAY be encoded as a part of the domain-sequence using the
existing subobjects.

Boundary Nodes (ABR / ASBR) can be encoded using the IPv4 or IPv6
prefix subobjects usually the loopback address of 32 and 128 prefix
length respectively. An Inter-AS link can be encoded using the IPv4
or IPv6 prefix subobjects or unnumbered interface subobjects.

For Figure 1, an ABR to be traversed can be specified as:

```
+---------+ +---------+ +---------++---------+ +---------+
|IRO      | |Sub      | |Sub      ||Sub      | |Sub      |
|Object   | |Object   | |Object   ||Object   | |Object   |
|Header   | |Area 2   | |IPv4     ||Area 0   | |Area 4   |
|         | | |       | |x.x.x.x  || |       | | |       |
|         | | |       | | |       || |       | | |       |
+---------+ +---------+ +---------++---------+ +---------+
```

For Figure 2, an inter-AS-link to be traversed can be specified as:

```
+---------+  +---------+ +---------+ +---------+ +---------+
|IRO      |  |Sub      | |Sub      | |Sub      | |Sub      |
|Object   |  |Object AS| |Object   | |Object   | |Object AS|
|Header   |  |100      | |IPv4     | |IPv4     | |200      |
|         |  |         | |x.x.x.x  | |x.x.x.x  | |         |
|         |  |         | |         | |         | |         |
+---------+  +---------+ +---------+ +---------+ +---------+
```

4.4. PCE serving multiple domains

A single PCE MAY be responsible for multiple domains; for example PCE
function deployed on an ABR. A PCE which can support 2 adjacent
domains can internally handle this situation without any impact on
the neighboring domains.

4.5. P2MP

In case of inter-domain P2MP path computation, (Refer
[PCE-P2MP-PROCEDURES]) the path domain tree is nothing but a series
of Domain Sequences, as shown in the below figure:

```
   D1-D3-D6, D1-D3-D5 and D1-D2-D4.
            D1
           /  \
         D2   D3
        /   /  \
      D4  D5   D6
```
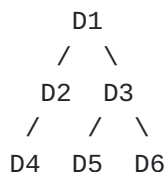
All rules of processing as applied to P2P can be applied to P2MP as
well.

In case of P2MP, different destinations MAY have different Domain-
Sequence within the domain tree, it requires domain-sequence to be
attached per destination. (Refer [PCE-P2MP-PER-DEST])

4.6. Hierarchical PCE

As per [RFC6805], consider a case as shown in Figure 4 consisting of
multiple child PCEs and a parent PCE.

```
                        +--------+
                        | Parent |
                        | PCE    |
                        +--------+

+-------------------+                      +-------------------+
|            +--+   |                      |      +--+         |
|   +--+     |  |   |                      |      |  |         |
|   |  |     +--+   |                      |      +--+    +--+  |
|   +--*            +                      +              |  |  |
|                   |                      |              +--+  |
|         *--+      +                      +                    |
|         |  |      |                      |      +--+          |
|         +--+      |                      |      |  |          |
|                  |+------------------------+|   +--+          |
|                   ++++                +-++                    |
|                   ||||       +--+     | ||                    |
| Area 2            ++++       |  |     +-++  Area 4            |
+-------------------+|         +--+          |+-----------------+
                    |               +--+     |
                    |     +--+      |  |     |
                    |     |  |      +--+     |
                    |     +--+               |
                    |                        |
                    |          +--+          |
                    |          |  |          |
                    |          +--+          |
                   +-----------------+|          |+-------------------+
|                   ++-+               +-++                     |
|                   || |               | ||                     |
|                   ++-+     Area 0    +-++                     |
|                  |+------------------------+|   +--+          |
|          +--+     |                      |   |  |          |
|          |  |     |                      |   +--+          |
| +--+     +--+     |                      |                 |
| |  |             +                      +         +--+     |
| +--+             |                      |         |  |     |
|                  +                      +         +--+     |
|       +--+       |                      |                 |
|       |  |       |                      |      +--+        |
|       +--+       |                      |      |  |        |
|                  |                      |      +--+        |
| Area 1           |                      | Area 5           |
+------------------+                      +------------------+
```
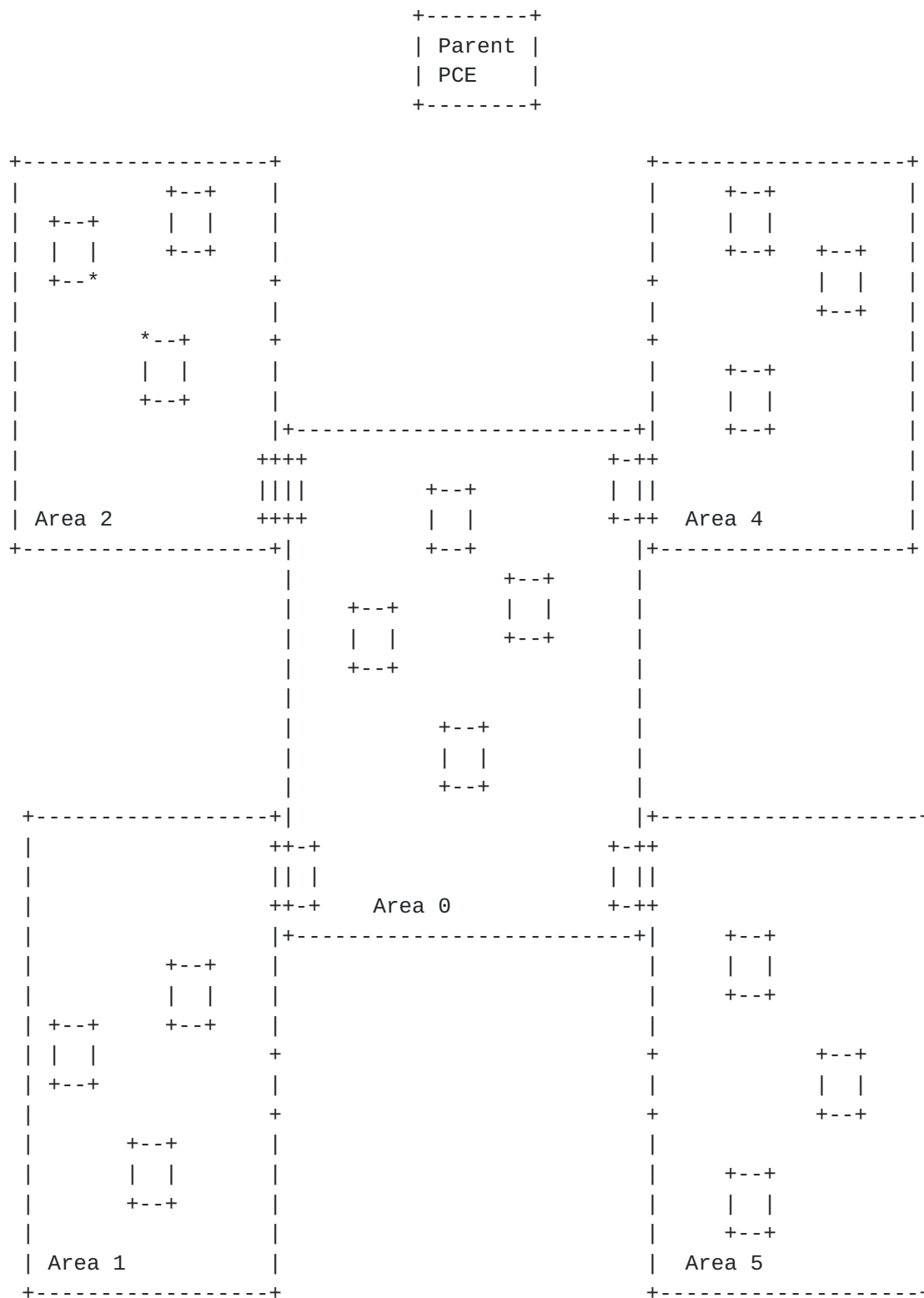
                   Figure 4: Hierarchical PCE

      In H-PCE, the Ingress PCE PCE(1) can request the parent PCE to

determine the Domain-Sequence and return it in the PCEP response,
using the ERO Object. The ERO can contain an ordered sequence of
subobjects such as AS and Area (OSPF/ISIS) subobjects. In this case,
the Domain-Sequence appear as:


```
   +---------+ +---------+ +---------+ +---------+
   |ERO      | |Sub      | |Sub      | |Sub      |
   |Object   | |Object   | |Object   | |Object   |
   |Header   | |Area 2   | |Area 0   | |Area 4   |
   |         | | |       | | |       | | |       |
   |         | | |       | | |       | | |       |
   +---------+ +---------+ +---------+ +---------+


   +---------+ +---------+ +---------+ +---------+ +---------+
   |ERO      | |Sub      | |Sub      | |Sub      | |Sub      |
   |Object   | |Object AS| |Object   | |Object   | |Object   |
   |Header   | |100      | |Area 2   | |Area 0   | |Area 4   |
   |         | | |       | | |       | | |       | | |       |
   |         | | |       | | |       | | |       | | |       |
   +---------+ +---------+ +---------+ +---------+ +---------+
```

Note that, in the case of ERO objects, no new PCEP object type is
required since the ordering constraint is assumed.

4.7. Relationship to PCE Sequence

Instead of a domain-sequence, a sequence of PCEs MAY be enforced by
policy on the PCC, and this constraint can be carried in the PCEP
path computation request (as defined in [RFC5886]).

Note that PCE-Sequence can be used along with domain-sequence in
which case PCE-Sequence SHOULD have higher precedence in selecting
the next PCE in the inter-domain path computation procedures. Note
that Domain-Sequence IRO constraints should still be checked as per
the rules of processing IRO.

4.8. Relationship to RSVP-TE

[RFC3209] already describes the notion of abstract nodes, where an
abstract node is a group of nodes whose internal topology is opaque
to the ingress node of the LSP. It further defines a subobject for
Autonomous Systems (AS) (2-Byte).

[DOMAIN-SUBOBJ] extends the notion of abstract nodes by adding new
subobjects for IGP Areas and 4-byte AS numbers. These subobjects MAY

be included in Explicit Route Object (ERO), Exclude Route object
(XRO) or Explicit Exclusion Route Subobject (EXRS).

In any case subobject type defined in RSVP-TE are identical to the
subobject type defined in the related documents in PCEP.

5. IANA Considerations

5.1. PCEP Objects

The "PCEP Parameters" registry contains a subregistry "PCEP Objects".
IANA is requested to make the following allocations from this
registry.

Object Class	Name	Reference
10	IRO	[RFC5440]
	Object-Type	
	(TBA): Domain-Sequence	[This I.D.]

5.2. New Subobjects

The "PCEP Parameters" registry contains a subregistry "PCEP Objects"
with an entry for the Include Route Object (IRO), Exclude Route
Object (XRO) and Explicit Route Object (ERO). IANA is requested to
add further subobjects as follows:

```
7  ERO
10 IRO
17 XRO
```

Subobject	Type	Reference
TBA	4 byte AS number	[This I.D.]
TBA	OSPF Area ID	[This I.D.]
TBA	IS-IS Area ID	[This I.D.]

5.3. Error Object Field Values

The "PCEP Parameters" registry contains a subregistry "Error Types
and Values". IANA is requested to make the following allocations
from this subregistry

ERROR Type	Meaning	Reference
TBA	"Unrecognized subobject"	[This I.D.]

               Error-Value: type code

[6](#). **Security Considerations**

   This document specifies a standard representation of Domain-Sequence
   and new subobjects, which MAY be used in inter-domain PCE scenarios
   as explained in other RFC and drafts. The new subobjects and Domain-
   Sequence mechanisms defined in this document allow finer and more
   specific control of the path computed by a cooperating PCE(s). Such
   control increases the risk if a PCEP message is intercepted,
   modified, or spoofed because it allows the attacker to exert control
   over the path that the PCE will compute or to make the path
   computation impossible. Therefore, the security techniques described
   in [[RFC5440](#)] are considered more important.

   Note, however, that the Domain-Sequence mechanisms also provide the
   operator with the ability to route around vulnerable parts of the
   network and may be used to increase overall network security.

[7](#). **Manageability Considerations**

[7.1](#). **Control of Function and Policy**

   Several local policy decisions should be made at the PCE. Firstly,
   the exact behavior with regard to desired inclusion and exclusion of
   domains must be available for examination by an operator and may be
   configurable. Second, the behavior on receipt of an unrecognized
   subobjects with the L or X-bit set should be configurable and must be
   available for inspection. The inspection and control of these local
   policy choices may be part of the PCEP MIB module.

[7.2](#). **Information and Data Models**

   A MIB module for management of the PCEP is being specified in a
   separate document [[PCEP-MIB](#)]. That MIB module allows examination of
   individual PCEP messages, in particular requests, responses and
   errors. The MIB module MUST be extended to include the ability to
   view the domain-sequence extensions defined in this document.

[7.3](#). **Liveness Detection and Monitoring**

   Mechanisms defined in this document do not imply any new liveness
   detection and monitoring requirements in addition to those already
   listed in [[RFC5440](#)].

7.4. Verify Correct Operations

   Mechanisms defined in this document do not imply any new operation
   verification requirements in addition to those already listed in
   [RFC5440].

7.5. Requirements On Other Protocols

   The Subobjects defined in this document SHOULD be supported by RSVP
   especially for per-domain path computation [RFC5152] where the
   domains need to encoded in the RSVP messages. [DOMAIN-SUBOBJ]
   extends the notion of abstract nodes by adding new subobjects for IGP
   Areas and 4-byte AS numbers.

   Apart from this, mechanisms defined in this document do not imply any
   requirements on other protocols in addition to those already listed
   in [RFC5440].

7.6. Impact On Network Operations

   Mechanisms defined in this document do not have any impact on network
   operations in addition to those already listed in [RFC5440].

8. Acknowledgments

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