 Procedures for Dynamically Signaled Hierarchical Label Switched Paths

Abstract

   Label Switched Paths (LSPs) set up in Multiprotocol Label Switching
   (MPLS) or Generalized MPLS (GMPLS) networks can be used to form links
   to carry traffic in those networks or in other (client) networks.

   Protocol mechanisms already exist to facilitate the establishment of
   such LSPs and to bundle traffic engineering (TE) links to reduce the
   load on routing protocols. This document defines extensions to those
   mechanisms to support identifying the use to which such LSPs are to
   be put and to enable the TE link endpoints to be assigned addresses
   or unnumbered identifiers during the signaling process.

   The mechanisms defined in this document deprecate the technique for
   the signaling of LSPs that are to be used as numbered TE links
   described in RFC 4206.

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1. Introduction and Problem Statement

   Traffic Engineering (TE) links in a Multiprotocol Label Switching
   (MPLS) or a Generalized MPLS (GMPLS) network may be constructed from
   Label Switched Paths (LSPs) [RFC4206]. Such LSPs are known as
   hierarchical LSPs (H-LSPs).

   The LSPs established in one network may be used as TE links in
   another network, and this is particularly useful when a server layer
   network (for example, an optical network) provides LSPs for use as TE
   links in a client network (for example, a packet network). This
   enables the construction of a multilayer network (MLN) [RFC5212].

   When the number of TE links (created from LSPs or otherwise) between
   a pair of nodes grows large, it is inefficient to advertise them
   individually. This may cause scaling issues in configuration and in
   the routing protocols used to carry the advertisements. The solution
   (described in [RFC4201]) is to collect the TE links together and to
   advertise them as a single TE link called a link bundle.

These various mechanisms have proved to be very powerful in building
dynamically provisioned networks, but, as set out later in this
document, several issues have been identified during deployment with
how LSPs are established and made available for use as H-LSPs or as
components of a link bundle, and with how these links are advertised
appropriately in an interior gateway protocol (IGP). These issues
relate to how the LSP's endpoints coordinate two things: the use to
which the LSP is put and the identifiers of the endpoints.

This document provides solutions to these issues by defining
mechanisms so that the ends of signaled LSPs can exchange information
about:

- Whether the LSP is an ordinary LSP or an H-LSP.
- In which IGP instances the LSP should be advertised as a link.
- How the client networks should make use of the new links.
- Whether the link should form part of a bundle (and if so, which
  bundle).
- How the link endpoints should be identified when advertised.

This document deprecates one of the mechanisms defined in [RFC4206]
for the signaling of LSPs that are to be used as numbered TE links
(see Sections 1.3.6 and 1.4.6 for more details), and provides
extensions to the other mechanisms defined in [RFC4206] so that the
use to which the new LSP is to be put may be indicated during
signaling. It also extends the mechanisms defined in [RFC3477] for
signaling unnumbered TE links.

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].

1.1. Background

1.1.1. Hierarchical LSPs

   [RFC3031] describes how MPLS labels may be stacked so that LSPs may
   be nested with one LSP running through another. This concept of
   H-LSPs is formalized in [RFC4206] with a set of protocol mechanisms
   for the establishment of an H-LSP that can carry one or more other
   LSPs.

   [RFC4206] goes on to explain that an H-LSP may carry other LSPs only
   according to their switching types. This is a function of the way
   labels are carried. In a packet switch capable (PSC) network, the
   H-LSP can carry other PSC LSPs using the MPLS label stack. In non-
   packet networks where the label is implicit, label stacks are not
   possible, and H-LSPs rely on the ability to nest switching

technologies. Thus, for example, a lambda switch capable (LSC) LSP
can carry a time-division multiplexing (TDM) LSP, but cannot carry
another LSC LSP.

Signaling mechanisms defined in [RFC4206] allow an H-LSP to be
treated as a single hop in the path of another LSP (i.e., one hop of
the LSP carried by the H-LSP). This mechanism is known as "non-
adjacent signaling".

1.1.2. LSP Stitching Segments

LSP stitching is defined in [RFC5150]. It enables LSPs of the same
switching type to be included (stitched) as hops in an end-to-end
LSP. The stitching LSP (S-LSP) is used in the control plane in the
same way as an H-LSP, but in the data plane the LSPs are stitched so
that there is no label stacking or nesting of technologies. Thus, an
S-LSP must be of the same switching technology as the end-to-end LSP
that it facilitates.

1.1.3. Private Links

An H-LSP or S-LSP can be used as a private link. Such links are
known by their endpoints, but are not more widely known and are not
advertised by routing protocols. They can be used to carry traffic
between the endpoints, but are not usually used to carry traffic that
is going beyond the egress of the LSP.

1.1.4. Routing Adjacencies

A routing adjacency is formed between two IGP speakers that are
logically adjacent. In this sense, 'logically adjacent' means that
the routers have a protocol tunnel between them through which they
can exchange routing protocol messages. The tunnel is also usually
available for carrying IP data although a distinction should be made
in GMPLS networks between data-plane traffic and control-plane
traffic.

Routing adjacencies for forwarding data traffic are only relevant in
PSC networks (i.e., IP/MPLS networks).

1.1.5. Forwarding Adjacencies

A Forwarding Adjacency (FA) is defined in [RFC4206] as a data link
created from an LSP and advertised in the same instance of the
control plane that advertises the TE links from which the LSP is
constructed. The LSP itself is called an FA-LSP.

   Thus, an H-LSP or S-LSP may form an FA such that it is advertised as
   a TE link in the same instance of the routing protocol as was used to
   advertise the TE links that the LSP traverses.

   As observed in [RFC4206], the nodes at the ends of an FA would not
   usually have a routing adjacency.

1.1.6. Client/Server Networks

   An LSP may be created in one network and used as a link (sometimes
   called a virtual link) in another network [RFC5212]. In this case,
   the networks are often referred to as server and client networks,
   respectively.

   The server network LSP is used as an H-LSP or an S-LSP as described
   above, but it does not form an FA because the client and server
   networks run separate instances of the control-plane routing
   protocols.

   The virtual link may be used in the client network as a private link
   or may be advertised in the client network IGP. Additionally, the
   link may be used in the client network to form a routing adjacency
   and/or as a TE link.

1.1.7. Link Bundles

   [RFC4201] recognizes that a pair of adjacent routers may have a large
   number of TE links that run between them. This can be a considerable
   burden to the operator who may need to configure them and to the IGP
   that must distribute information about each of them. A TE link
   bundle is defined by [RFC4201] as a TE link that is advertised as an
   aggregate of multiple TE links that could have been advertised in
   their own right. All TE links that are collected into a TE link
   bundle have the same TE properties.

   Thus, a link bundle is a shorthand that improves the scaling
   properties of the network.

   Since a TE link may, itself, be an LSP (either an FA or a virtual
   link), a link bundle may be constructed from FA-LSPs or virtual
   links.

1.2. Desired Function

   It should be possible to signal an LSP and automatically coordinate
   its use and advertisement in any of the ways described in Section 1.3
   with minimum involvement from an operator. The mechanisms used
   should be applicable to numbered and unnumbered links and should not
   require implementation complexities.

1.3. Existing Mechanisms

   This section briefly introduces existing protocol mechanisms used to
   satisfy the desired function described in Section 1.2.

1.3.1. LSP Setup

   Both unidirectional LSPs and bidirectional LSPs are signaled from the
   ingress label switching router (LSR) to the egress LSR. That is, the
   ingress LSR is the initiator, and the egress learns about the LSP
   through the signaling protocol [RFC3209] [RFC3473].

1.3.2. Routing Adjacency Establishment and Link State Advertisement

   Although hosts can discover routers (for example, through ICMP
   [RFC1256]), routing adjacencies are usually configured at both ends
   of the adjacency. This requires that each router know the identity
   of the router at the other end of the link connecting the routers,
   and know that the IGP is to be run on this link.

   Once a routing adjacency has been established, a pair of routers may
   use the IGP to share information about the links available for
   carrying IP traffic in the network.

   Suitable routing protocols are OSPF version 2 [RFC2328], OSPF version
   3 [RFC5340], and IS-IS [RFC1195].

1.3.3. TE Link Advertisement

   Extensions have been made to IGPs to advertise TE link properties
   ([RFC3630], [RFC5329], [RFC5305], [RFC5308], and [ISIS-IPV6-TE]) and
   also to advertise link properties in GMPLS networks ([RFC4202],
   [RFC4203], and [RFC5307]).

   TE link advertisement can be performed by the same instance of the
   IGP as is used for normal link state advertisement, or can use a
   separate instance. Furthermore, the ends of a TE link advertised in
   an IGP do not need to form a routing adjacency. This is particularly
   the case with FAs as described in Section 1.1.5.

1.3.4. Configuration and Management Techniques

   LSPs are usually created as the result of a management action. This
   is true even when a control plane is used: the management action is a
   request to the control plane to signal the LSP.

   If the LSP is to be used as an H-LSP or S-LSP, management commands
   can be used to install the LSP as a link. The link must be defined,
   interface identifiers allocated, and the endpoints configured to know
   about (and advertise, if necessary) the new link.

   If the LSP is to be used as part of a link bundle, the operator must
   decide which bundle it forms part of and ensure that information is
   configured at the ingress and egress, along with the necessary
   interface identifiers.

   These mechanisms are perfectly functional and quite common in MLNs,
   but require configuration coordination and additional management.
   They are open to user error and misconfiguration that might result in
   the LSP not being used (a waste of resources) or the LSP being made
   available in the wrong way with some impact on traffic engineering.

1.3.5. Signaled Unnumbered FAs

   [RFC3477] describes how to establish an LSP and to make it available
   automatically as a TE link in the same instance of the routing
   protocol as advertises the TE links it traverses, using IPv4-based
   unnumbered identifiers to identify the new TE link. That is,
   [RFC3477] describes how to create an unnumbered FA.

   The mechanism, as defined in Section 3 of [RFC3477], is briefly as
   follows:

   - The ingress of the LSP signals the LSP as normal using a Path
     message, and includes an LSP_TUNNEL_INTERFACE_ID object. The
     LSP_TUNNEL_INTERFACE_ID object identifies:
     - The sender's LSR Router ID
     - The sender's interface ID for the TE link being created

   - The egress of the LSP responds as normal to accept the LSP and set
     it up, and includes an LSP_TUNNEL_INTERFACE_ID object. The
     LSP_TUNNEL_INTERFACE_ID object identifies:
     - The egress's LSR Router ID
     - The egress's interface ID for the TE link being created.

-   Following the exchange of the Path and Resv messages, both the
    ingress and the egress know that the LSP is to be advertised as a
    TE link in the same instance of the routing protocol as was used to
    advertise the TE links that it traverses, and also know the
    unnumbered interface identifiers to use in the advertisement.

[RFC3477] does not include mechanisms to support IPv6-based
unnumbered identifiers, nor IPv4 or IPv6 numbered identifiers.

1.3.6. Establishing Numbered FAs through Signaling and Routing

[RFC4206] describes procedures to establish an LSP and to make it
available automatically as a TE link that is identified using IPv4
addresses in the same instance of the routing protocol as advertises
the TE links it traverses (that is, as a numbered FA).

The mechanism, as defined in [RFC4206], is briefly as follows:

-   The ingress of the LSP signals the LSP as normal using a Path
    message, and sets the IPv4 tunnel sender address to the IP address
    it will use to identify its interface for the TE link being
    created. This is one address from a /31 pair.

-   The egress of the LSP responds as normal to accept the LSP and set
    it up. It infers the address that it must assign to identify its
    interface for the TE link being created as the partner address of
    the /31 pair.

-   The ingress decides whether the LSP is to be advertised as a TE
    link (i.e., as an FA). If so, it advertises the link in the IGP in
    the usual way.

-   If the link is unidirectional, nothing more needs to be done. If
    the link is bidirectional, the egress must also advertise the link,
    but it does not know that advertisement is required as there is no
    indication in the signaling messages.

-   When the ingress's advertisement of the link is received by the
    egress, it must check to see whether it is the egress of the LSP
    that formed the link. Typically, this means the egress:
    -   Checks to see if the link advertisement is new.
    -   Checks to see if the Link-ID address in the received
        advertisement matches its own TE Router ID.
    -   Checks the advertising router ID from the advertisement against
        the ingress address of each LSP for which it is the egress.
    -   Deduces the LSP that has been advertised as a TE link and issues
        the corresponding advertisement for the reverse direction.

It is possible that some reduction in processing can be achieved by
mapping based on the /31 pairing, but nevertheless, there is a fair
amount of processing required, and this does not scale well in large
networks.

Note that this document deprecates this procedure as explained in
Section 1.4.6.

No explanation is provided in [RFC4206] of how to create numbered
IPv6 FAs.

1.4. Overview of Required Extensions

This section provides a brief outline of the required protocol
extensions.

1.4.1. Efficient Signaling of Numbered FAs

The mechanism described in Section 1.3.6 is inefficient. The egress
must wait until it receives an advertisement from the ingress before
it knows that the LSP is to be installed as a TE link and advertised
as an FA. Further, it must parse all received advertisements to
determine if any is the trigger for it to advertise an FA.

An efficient signaling mechanism is required so that the egress is
informed by the ingress during LSP establishment.

1.4.2. LSPs for Use as Private Links

There is currently no mechanism by which an ingress can indicate that
an LSP is set up for use as a private link. Any attempt to make it a
link would currently cause it to be advertised as an FA.

A signaling mechanism is needed to identify the use to which an LSP
is to be put.

1.4.3. Signaling an LSP for Use in Another Network

The existing signaling/routing mechanisms are designed for use in the
creation of FAs. That is, the TE link created is advertised in the
single IGP instance.

The numbered TE link mechanism (Section 1.3.6) could, in theory, be
used in an MLN with multiple IGP instances if the addressing model is
kept consistent across the networks, and if the egress searches all
advertisements in all IGP instances. However, this is complex and
does not work for unnumbered interfaces.

A signaling mechanism is required to indicate in which IGP instance
the TE link should be advertised.

1.4.4. Signaling an LSP for Use in a Link Bundle

A signaling mechanism is required to indicate that an LSP is intended
to form a component link of a link bundle, and to identify the bundle
and the IGP instance in which the bundle is advertised.

1.4.5. Support for IPv4 and IPv6

The protocol mechanisms must support IPv4 and IPv6 numbered and
unnumbered TE links.

1.4.6. Backward Compatibility

The existing protocol mechanisms for unnumbered FAs as defined in
[RFC4206] and [RFC3477] must continue to be supported, and new
mechanisms must be devised such that their introduction will not
break existing implementations or deployments.

Note that an informal survey in the CCAMP working group established
that there are no significant deployments of numbered FAs established
using the technique described in [RFC4206] and set out in Section
1.3.6. Therefore, this document deprecates this procedure.

2. Overview of Solution

This section provides an overview of the mechanisms and protocol
extensions defined in this document. Details are presented in
Section 3.

2.1. Common Approach for Numbered and Unnumbered Links

The LSP_TUNNEL_INTERFACE_ID object [RFC3477] is extended for use for
all H-LSPs and S-LSPs whether they form numbered or unnumbered IPv4
or IPv6 links. Different Class Types of the object identify the
address type for which it applies.

2.2. LSP Usage Indication

   The LSP_TUNNEL_INTERFACE_ID object is given flags in a new Actions
   field to say how the LSP is to be used. The following categories are
   supported:

   - The LSP is used as an advertised TE link.
   - The LSP is used to form a routing adjacency.
   - The LSP is used to form an advertised TE link and a routing
     adjacency.
   - The LSP forms a private link and is not advertised.
   - The LSP is used as part of a link bundle.
   - The LSP is used as a hierarchical LSP or a stitching segment.

2.3. IGP Instance Identification

   An optional TLV is added to the LSP_TUNNEL_INTERFACE_ID object to
   identify the IGP instance into which the link formed by the LSP is to
   be advertised. If the TLV is absent and the link is to be advertised
   as indicated by the Actions field, the link is advertised in the same
   instance of the IGP as was used to advertise the TE links it
   traverses.

2.4. Link Bundle Identification

   When an LSP is to be used as a component link of a link bundle, the
   LSP_TUNNEL_INTERFACE_ID object refers to the bundle indicating how
   the bundle is addressed and used, and a new TLV indicates the
   component link identifier for the link that the LSP creates.

2.5. Backward Compatibility

   Backward compatibility has three aspects.

   - Existing mechanisms for unnumbered FAs described in [RFC3477] and
     [RFC4206] must continue to work, so that ingress nodes do not have
     to be updated when egresses are updated.

   - Existing mechanisms for establishing numbered FAs described in
     [RFC4206] are safely deprecated by this document, as they are not
     significantly deployed.

   - New mechanisms must be gracefully rejected by existing egress
     implementations so that egress nodes do not have to be updated when
     ingresses are updated.

3. Mechanisms and Protocol Extensions

   This section defines protocol mechanisms and extensions to achieve
   the function described in the previous section.

3.1. LSP_TUNNEL_INTERFACE_ID Object

   The principal signaling protocol element used to achieve all of the
   required functions is the LSP_TUNNEL_INTERFACE_ID object defined in
   [RFC3477]. The existing definition and usage continues to be
   supported as described in the next section. Subsequent sections
   describe new variants of the object (denoted by new Class Types), and
   additional information carried in the object by means of extensions.

3.1.1. Existing Definition and Usage

   This document does not deprecate the mechanisms defined in [RFC3477]
   and [RFC4206]. Those procedures must continue to operate as
   described in Section 3.7.

   That means that the LSP_TUNNEL_INTERFACE_ID object with Class Type 1
   remains unchanged, and can be used to establish an LSP that will be
   advertised as an unnumbered TE link in the same instance of the IGP
   as was used to advertise the TE links that the LSP traverses (that
   is, as an FA). The procedure is unchanged and operates as summarized
   in Section 1.3.5.

   [RFC3477] does not make any suggestions about where in Path or Resv
   messages the LSP_TUNNEL_INTERFACE_ID object should be placed. See
   Section 3.5 for recommended placement of this object in new
   implementations.

3.1.2. Unnumbered Links with Action Identification

   A new C-Type variant of the LSP_TUNNEL_INTERFACE_ID object is defined
   to carry an unnumbered interface identifier and to indicate into
   which instance of the IGP the consequent TE link should be
   advertised. This does not deprecate the use of C-Type 1.

   The format of the object is as shown below.

   C-NUM = 193, C-Type = 4

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                       LSR's Router ID                         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                     Interface ID (32 bits)                    |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |    Actions    |                   Reserved                    |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   ~                            TLVs                               ~
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
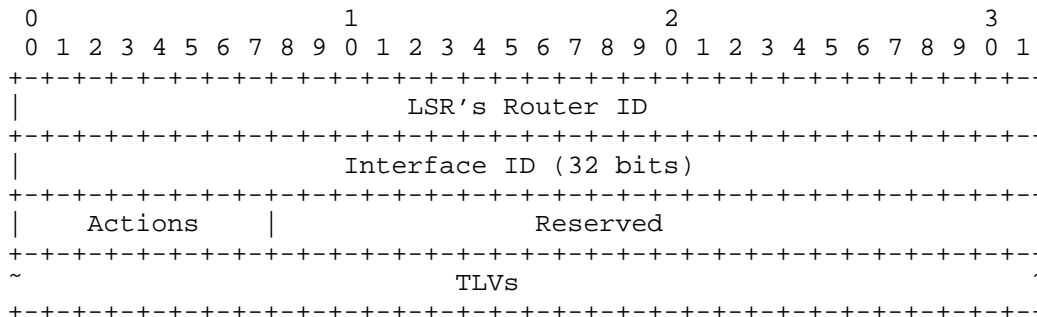
   LSR's Router ID

      Unchanged from the definition in [RFC3477].

   Interface ID

      Unchanged from the definition in [RFC3477].

   Actions

      This field specifies how the LSP that is being set up is to be
      treated.

      The field has meaning only on a Path message. On a Resv
      message, the field SHOULD be set to reflect the value received
      on the corresponding Path message, and it MUST be ignored on
      receipt.

      The field is composed of bit flags as follows:

        -+-+-+-+-+-+-+-
       | | | |H|B|R|T|P|
        -+-+-+-+-+-+-+-
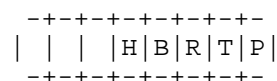
      P-flag (Private)
        0 means that the LSP is to be advertised as a link according
          to the settings of the other flags.
        1 means the LSP is to form a private link and is not to be
          advertised in the IGP, but is to be used according to the
          settings of the other flags.

      T-flag (TE link)
        0 means that the LSP is to be used as a TE link.
        1 means that the LSP is not to be used as a TE link. It may
          still be used as an IP link providing a routing adjacency
          as defined by the R-flag.

R-flag (Routing adjacency)
  0 means that the link is not to be used as a routing
    adjacency.
  1 means that the link is to be used to form a routing
    adjacency.

B-flag (Bundle)
  0 means that the LSP will not form part of a link bundle.
  1 means that the LSP will form part of a bundle. See Section
    3.3 for more details.

H-flag (Hierarchy/stitching)
  The use of an LSP as an H-LSP or as an S-LSP is usually
  implicit from the network technologies of the networks and
  the LSP, but this is not always the case (for example, in PSC
  networks).
  0 means that the LSP is to be used as a hierarchical LSP.
  1 means that the LSP is to be used as a stitching segment.

Other bits are reserved for future use. They MUST be set to
zero on transmission and SHOULD be ignored on receipt.

Note that all defined bit flags have meaning at the same time.
An LSP that is to form an FA would carry the Actions field set
to 0x00. That is:
  P=0 (advertised)
  T=0 (TE link)
  R=0 (not a routing adjacency)
  B=0 (not a bundle)
  H=0 (hierarchical LSP)

Reserved

  The Reserved bits MUST be set to zero on transmission and
  SHOULD be ignored on receipt.

TLVs

  Zero, one, or more TLVs may be present. Each TLV is encoded as
  follows:

Type (16 bits)

The identifier of the TLV. Two type values are defined in
this document:

1 IGP Instance Identifier TLV
2 Unnumbered Component Link Identifier TLV
3 IPv4 Numbered Component Link Identifier TLV
4 IPv6 Numbered Component Link Identifier TLV

Length (16 bits)

Indicates the total length of the TLV in octets, i.e., 4 +
the length of the value field in octets. A value field
whose length is not a multiple of four MUST be zero-padded
so that the TLV is four-octet aligned.

Value

The data for the TLV padded as described above.

If this object is carried in a Path message, it is known as the
"Forward Interface ID" for the LSP that is being set up. On a Resv
message, the object is known as the "Reverse Interface ID" for the
LSP.

3.1.3. IPv4 Numbered Links with Action Identification

A new C-Type variant of the LSP_TUNNEL_INTERFACE_ID object is defined
to carry an IPv4 numbered interface address.

The format of the object is as shown below.

C-NUM = 193, C-Type = 2

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|               IPv4 Interface Address                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Actions    |                 Reserved                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~                             TLVs                              ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

IPv4 Interface Address

   The address assigned to the interface that the sender applies
   to this LSP.

Actions

   See Section 3.1.2.

Reserved

   See Section 3.1.2.

TLVs

   See Section 3.1.2.

If this object is carried in a Path message, it is known as the
"Forward Interface ID" for the LSP that is being set up. On a Resv
message, the object is known as the "Reverse Interface ID" for the
LSP.

3.1.4. IPv6 Numbered Links with Action Identification

   A new C-Type variant of the LSP_TUNNEL_INTERFACE_ID object is defined
   to carry an IPv6 numbered interface address.

   The format of the object is as shown below.

   C-NUM = 193, C-Type = 3

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                 IPv6 Interface Address (128 bits)            |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                 IPv6 Interface Address (continued)           |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                 IPv6 Interface Address (continued)           |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                 IPv6 Interface Address (continued)           |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |    Actions    |                 Reserved                     |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   ~                            TLVs                              ~
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

        IPv6 Interface Address

            The address assigned to the interface the sender applies to
            this LSP.

        Actions

            See Section 3.1.2.

        Reserved

            See Section 3.1.2.

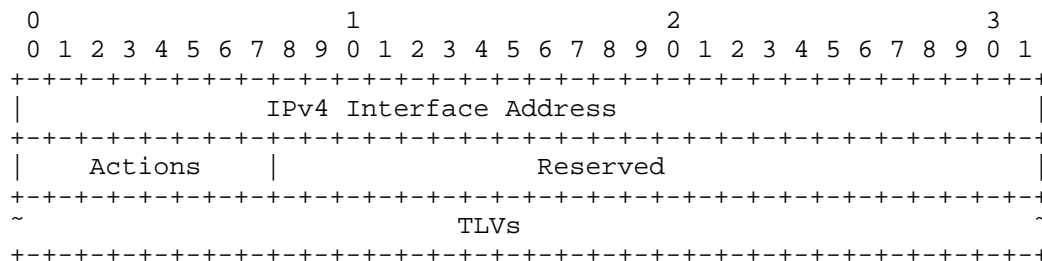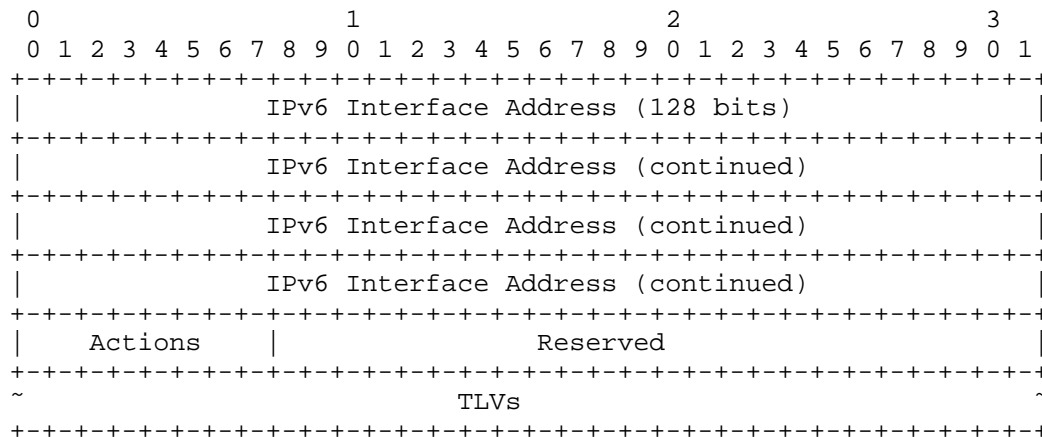   TLVs

            See Section 3.1.2.

    If this object is carried in a Path message, it is known as the
    "Forward Interface ID" for the LSP that is being set up. On a Resv
    message, the object is known as the "Reverse Interface ID" for the
    LSP.

3.2. Target IGP Identification TLV

    If the LSP being set up is to be advertised as a link, the egress
    needs to know which instance of the IGP it should use to make the
    advertisement. The default in [RFC4206] and [RFC3477] is that the
    LSP is advertised as an FA, that is, in the same instance of the IGP
    as was used to advertise the TE links that the LSP traverses.

    In order to facilitate an indication from the ingress to the egress
    of which IGP instance to use, the IGP Identification TLV is defined
    for inclusion in the new variants of the LSP_TUNNEL_INTERFACE_ID
    object defined in this document.

    The TLV has meaning only in a Path message. It SHOULD NOT be
    included in the LSP_TUNNEL_INTERFACE_ID object in a Resv message and
    MUST be ignored if found.

    If the P-flag in the Actions field of the LSP_TUNNEL_INTERFACE_ID
    object in a Path message is clear (i.e., zero), this TLV indicates
    the IGP instance to use for the advertisement. If the TLV is absent,
    the same instance of the IGP should be used as is used to advertise
    the TE links that the LSP traverses. Thus, for an FA, the TLV can be
    omitted; alternatively, the IGP Instance TLV may be present and
    identify the IGP instance or carry the reserved value 0xffffffff.

   If the P-flag in the Actions field in the LSP_TUNNEL_INTERFACE_ID
   object in a Resv message is set (i.e., one) indicating that the LSP
   is not to be advertised as a link, this TLV SHOULD NOT be present and
   MUST be ignored if encountered.

   The TLV is formatted as described in Section 3.1.2. The Type field
   has the value 1, and the Value field has the following content:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     IGP Instance Identifier                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   IGP Instance Identifier

      A 32-bit identifier assigned to each of the IGP instances within a
      network, such that ingress and egress LSRs have the same
      understanding of these numbers. This is a management
      configuration exercise outside the scope of this document.

      Note that the IGP Instance Identifier might be mapped from an
      instance identifier used in the IGP itself (such as section 2.4 of
      [RFC5340] for OSPFv3, or [OSPFv2-MI] for OSPFv2) as a matter of
      network policy. See [OSPF-TI] for further discussion of this
      topic in OSPF, and [ISIS-GENAP] for IS-IS.

      The value 0xffffffff is reserved to mean that the LSP is to be
      advertised in the same instance of the IGP as was used to
      advertise the TE links that the LSP traverses.

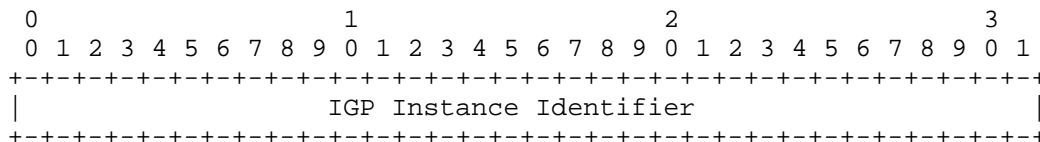3.3. Component Link Identification TLV

   If the LSP that is being set up is to be used as a component link in
   a link bundle [RFC4201], it is necessary to indicate both the
   identity of the component link and the identity of the link bundle.
   Furthermore, it is necessary to indicate how the link bundle (that
   may be automatically created by the establishment of this LSP) is to
   be used and advertised.

   If the B-flag in the Actions field of the LSP_TUNNEL_INTERFACE_ID
   object is set, the other fields of the object apply to the link
   bundle itself. That is, the interface identifiers (numbered or
   unnumbered) and the other flags in the Actions field apply to the
   link bundle and not to the component link that the LSP will form.

   Furthermore, the IGP Instance Identifier TLV (if present) also
   applies to the link bundle and not to the component link.

In order to exchange the identity of the component link, the
Component Link Identifier TLVs are introduced as set out in the next
sections. If the B-flag is set in the Actions field of the
LSP_TUNNEL_INTERFACE_ID object in the Path message, exactly one of
these TLVs MUST be present in the LSP_TUNNEL_INTERFACE_ID object in
both the Path and Resv objects.

3.3.1. Unnumbered Component Link Identification

If the component link is to be unnumbered, the Unnumbered Component
Link Identifier TLV is used. The TLV is formatted as described in
Section 3.1.2. The Type field has the value 2, and the Value field
has the following content:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Component Link Identifier                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
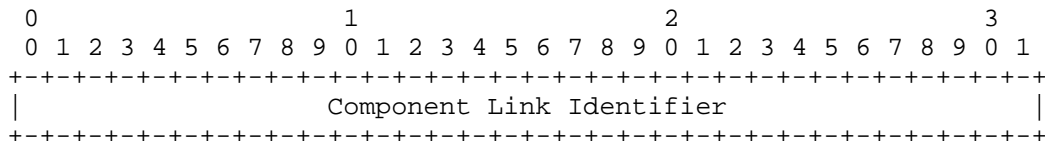
   Component Link Identifier

      Unnumbered identifier that is assigned to this component link
      within the bundle [RFC4201].

3.3.2. IPv4 Numbered Component Link Identification

If the component link is identified with an IPv4 address, the IPv4
Numbered Component Link Identifier TLV is used. The TLV is formatted
as described in Section 3.1.2. The Type field has the value 3, and
the Value field has the following content:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        IPv4 Address                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

IPv4 Address

   The IPv4 address that is assigned to this component link within
   the bundle.

3.3.3. IPv6 Numbered Component Link Identification

   If the component link is identified with an IPv6 address, the IPv6
   Numbered Component Link Identifier TLV is used. The TLV is formatted
   as described in Section 3.1.2. The Type field has the value 4, and
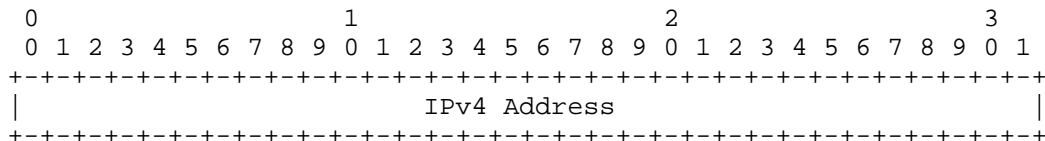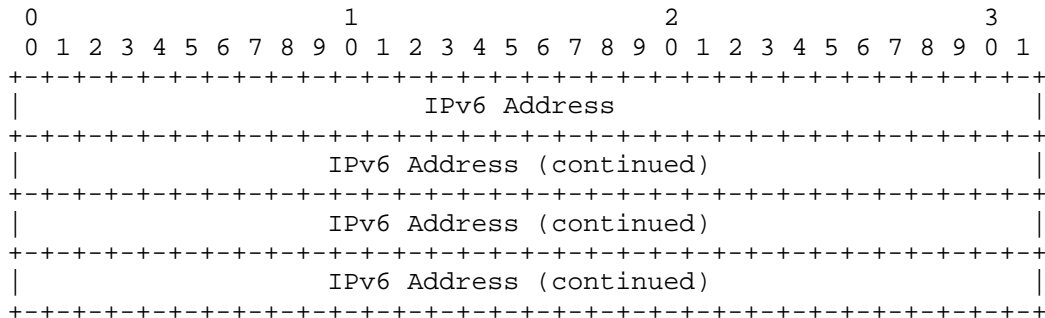   the Value field has the following content:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         IPv6 Address                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   IPv6 Address (continued)                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   IPv6 Address (continued)                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   IPv6 Address (continued)                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   IPv6 Address

      The IPv6 address that is assigned to this component link within
      the bundle.

3.4. Link State Advertisement

   The ingress and egress of an LSP that is set up using the
   LSP_TUNNEL_INTERFACE_ID object MUST advertise the LSP as agreed in
   the parameters of the object.

   Where a TE link is created from the LSP, the TE link SHOULD inherit
   the TE properties of the LSP as described in [RFC5212], but this
   process is subject to local and network-wide policy.

   It is possible that an LSP will be used to offer capacity and
   connectivity to multiple other networks. In this case, multiple
   instances of the LSP_TUNNEL_INTERFACE_ID object are permitted in the
   same Path and Resv messages. Each instance MUST have a different IGP
   Instance Identifier.

   Note, however, that a Path or Resv message MUST NOT contain more than
   one instance of the LSP_TUNNEL_INTERFACE_ID object with C-Type 1, and
   if such an object is present, all other instances of the
   LSP_TUNNEL_INTERFACE_ID object MUST include an IGP Instance
   Identifier TLV with IGP Instance Identifier set to a value that
   identifies some other IGP instance (in particular, not the value
   0xffffffff).

If the link created from an LSP is advertised in the same IGP
instance as was used to advertise the TE links that the LSP
traverses, the addresses for the new link and for the links from
which it is built MUST come from the same address space.

If the link is advertised into another IGP instance, the addresses
MAY be drawn from overlapping address spaces such that some addresses
have different meanings in each IGP instance.

In the IGP, the TE Router ID of the ingress LSR is taken from the
Tunnel Sender Address in the Sender Template object signaled in the
Path message. It is assumed that the ingress LSR knows the TE Router
ID of the egress LSR since it has chosen to establish an LSP to that
LSR and plans to use the LSP as a TE link.

The link interface addresses or link interface identifiers for the
forward and reverse direction links are taken from the
LSP_TUNNEL_INTERFACE_ID object on the Path and Resv messages,
respectively.

When an LSP is torn down through explicit action (a PathTear message
or a PathErr message with the Path_State_Removed flag set), the
ingress and egress LSRs SHOULD withdraw the advertisement of any link
that the LSP created and that was previously advertised. The link
state advertisement MAY be retained as a virtual link in another
layer network according to network-wide policy [PCE-LAYER].

3.5. Message Formats

[RFC3477] does not state where in the Path message or Resv message
the LSP_TUNNEL_INTERFACE_ID object should be placed.

It is RECOMMENDED that new implementations place the
LSP_TUNNEL_INTERFACE_ID objects in the Path message immediately after
the SENDER_TSPEC object, and in the Resv message immediately after
the FILTER_SPEC object.

All implementations SHOULD be able to handle received messages with
objects in any order, as described in [RFC3209].

3.6. Error Cases and Non-Acceptance

Error cases and non-acceptance of new object variants caused by back-
level implementations are discussed in Section 3.7.

An egress LSR that receives an LSP_TUNNEL_INTERFACE_ID object may
have cause to reject the parameters carried in the object for a
number of reasons as set out below. In all cases, the egress SHOULD

respond with a PathErr message with the error code as indicated in
the list below. In most cases, the error will arise during LSP
setup, no Resv state will exist, and the PathErr will cause Path
state to be removed. Where the error arises after the LSP has been
successfully set up, the PathErr SHOULD be sent with the
Path_State_Removed flag [RFC3473] clear so that the LSP remains
operational.

The error cases identified are as follows and are reported using the
new error code 'LSP Hierarchy Issue' (code 38) and the error values
listed below.

```
Error | Error | Error-case
code  | value |
------+-------+-------------------------------------------------------
 38        1    Link advertisement not supported
 38        2    Link advertisement not allowed by policy
 38        3    TE link creation not supported
 38        4    TE link creation not allowed by policy
 38        5    Routing adjacency creation not supported
 38        6    Routing adjacency creation not allowed by policy
 38        7    Bundle creation not supported
 38        8    Bundle creation not allowed by policy
 38        9    Hierarchical LSP not supported
 38       10    LSP stitching not supported
 38       11    Link address type or family not supported
 38       12    IGP instance unknown
 38       13    IGP instance advertisement not allowed by policy
 38       14    Component link identifier not valid
 38       15    Unsupported component link identifier address family
```

When an ingress LSR receives an LSP_TUNNEL_INTERFACE_ID object on a
Resv message, it may need to reject it because of the setting of
certain parameters in the object. Since these reasons all represent
errors rather than mismatches of negotiable parameters, the ingress
SHOULD respond with a PathTear to remove the LSP. The ingress MAY
use a ResvErr with one of the following error codes, allowing the
egress the option to correct the error in a new Resv message, or to
tear down the LSP with a PathErr with the Path_State_Removed flag
set. An ingress that uses the ResvErr MUST take precautions against
a protocol loop where the egress responds with the same
LSP_TUNNEL_INTERFACE_ID object with the same (or different) issues.

```
   Error | Error | Error-case
   code  | value |
   ------+-------+-------------------------------------------------------
    38       11    Link address type or family not supported
    38       14    Component link identifier not valid
    38       15    Unsupported component link identifier address family
    38       16    Component link identifier missing
```

3.7. Backward Compatibility

   The LSP_TUNNEL_INTERFACE_ID object defined in [RFC3477] has a class
   number of 193. According to [RFC2205], this means that a node that
   does not understand the object SHOULD ignore the object but forward
   it, unexamined and unmodified. Thus, there are no issues with
   transit LSRs supporting the pre-existing or new Class Types of this
   object.

   A back-level ingress node will behave as follows:

   - It will not issue Path messages containing LSP_TUNNEL_INTERFACE_ID
     objects with the new Class Types defined in this document.

   - It will reject Resv messages containing LSP_TUNNEL_INTERFACE_ID
     objects with the new Class Types defined in this document as
     described in [RFC2205]. In any case, such a situation would
     represent an error by the egress.

   - It will continue to use the LSP_TUNNEL_INTERFACE_ID object with
     Class Type 1 as defined in [RFC3477]. This behavior is supported
     by back-level egresses and by egresses conforming to this document.

   - According to an informal survey, there is no significant deployment
     of numbered FA establishment following the procedures defined in
     [RFC4206] and set out in Section 1.3.6 of this document. It is
     therefore safe to assume that back-level ingress LSRs will not use
     this mechanism.

   A back-level egress node will behave as follows:

   - It will continue to support the LSP_TUNNEL_INTERFACE_ID object with
     Class Type 1, as defined in [RFC3477], if issued by an ingress.

   - It will reject a Path message that carries an
     LSP_TUNNEL_INTERFACE_ID object with any of the new Class Types
     defined in this document using the procedures of [RFC2205]. This
     will inform the ingress that the egress is a back-level LSR.

      - It will not expect to use the procedures for numbered FA
        establishment defined in [RFC4206] and set out in Section 1.3.6 of
        this document.

   In summary, the new mechanisms defined in this document do not impact
   the method to exchange unnumbered FA information described in
   [RFC3477]. That mechanism can be safely used in combination with the
   new mechanisms described here and is functionally equivalent to using
   the new C-Type indicating an unnumbered link with target IGP instance
   identifier with the Target IGP Instance value set to 0xffffffff.

   The mechanisms in this document obsolete the method to exchange the
   numbered FA information described in [RFC4206] as described in
   Section 1.4.6.

4. Security Considerations

   [RFC3477] points out that one can argue that the use of the extra
   interface identifier that it provides could make an RSVP message
   harder to spoof. In that respect, the minor extensions to the
   protocol made in this document do not constitute an additional
   security risk, but could also be said to improve security.

   It should be noted that the ability of an ingress LSR to request that
   an egress LSR advertise an LSP as a TE link MUST be subject to
   appropriate policy checks at the egress LSR. That is, the egress LSR
   MUST NOT automatically accept the word of the ingress unless it is
   configured with such a policy.

   Further details of security for MPLS-TE and GMPLS can be found in
   [RFC5920].

5. IANA Considerations

5.1. New Class Types

   IANA maintains a registry of RSVP parameters called "Resource
   Reservation Protocol (RSVP) Parameters" with a sub-registry called
   "Class Names, Class Numbers, and Class Types". There is an entry in
   this registry for the LSP_TUNNEL_INTERFACE_ID object defined in
   [RFC3477] with one Class Type defined.

   IANA has allocated three new Class Types for this object as defined
   in Sections 3.1.2, 3.1.3, and 3.1.4 as follows:

```
   C-Type         Meaning                              Reference
   ----------------------------------------------------------------
     2             IPv4 interface identifier with target   [RFC6107]
     3             IPv6 interface identifier with target   [RFC6107]
     4             Unnumbered interface with target        [RFC6107]
```

5.2. Hierarchy Actions

   Section 3.1.2 defines an 8-bit flags field in the
   LSP_TUNNEL_INTERFACE_ID object. IANA has created a new sub-registry
   of the "Generalized Multi-Protocol Label Switching (GMPLS) Signaling
   Parameters" registry called the "Hierarchy Actions" sub-registry as
   follows:

   Registry Name: Hierarchy Actions
   Reference: [RFC6107]
   Registration Procedures: Standards Action

```
   Registry:
   Bit Number   Hex Value    Name                    Reference
   ----------   -----------  ----------------------  ---------
   0-2                       Unassigned
   3            0x10         Hierarchy/stitching (H)  [RFC6107]
   4            0x08         Bundle (B)               [RFC6107]
   5            0x04         Routing adjacency (R)    [RFC6107]
   6            0x02         TE link (T)              [RFC6107]
   7            0x01         Private (P)              [RFC6107]
```

5.3. New Error Codes and Error Values

   IANA maintains a registry of RSVP error codes and error values as the
   "Error Codes and Globally-Defined Error Value Sub-Codes" sub-registry
   of the "Resource Reservation Protocol (RSVP) Parameters" registry.

   IANA has defined a new error code with value 38 as below (see also
   Section 3.6).

```
   Error Code    Meaning

     38          LSP Hierarchy Issue            [RFC6107]
```

   IANA has listed the following error values for this error code (see
   also Section 3.6).

This Error Code has the following globally-defined Error
Value sub-codes:

```
 1 = Link advertisement not supported              [RFC6107]
 2 = Link advertisement not allowed by policy      [RFC6107]
 3 = TE link creation not supported                [RFC6107]
 4 = TE link creation not allowed by policy        [RFC6107]
 5 = Routing adjacency creation not supported      [RFC6107]
 6 = Routing adjacency creation not allowed by policy [RFC6107]
 7 = Bundle creation not supported                 [RFC6107]
 8 = Bundle creation not allowed by policy         [RFC6107]
 9 = Hierarchical LSP not supported                [RFC6107]
10 = LSP stitching not supported                   [RFC6107]
11 = Link address type or family not supported     [RFC6107]
12 = IGP instance unknown                          [RFC6107]
13 = IGP instance advertisement not allowed by policy [RFC6107]
14 = Component link identifier not valid           [RFC6107]
15 = Unsupported component link identifier address [RFC6107]
     family
16 = Component link identifier missing             [RFC6107]
```

6. Acknowledgements

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