     OSPF-xTE: Experimental Extension to OSPF for Traffic Engineering

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Abstract

   This document defines OSPF-xTE, an experimental traffic engineering
   (TE) extension to the link-state routing protocol OSPF. OSPF-xTE
   defines new TE Link State Advertisements (LSAs) to disseminate TE
   metrics within an autonomous System (AS), which may consist of
   multiple areas. When an AS consists of TE and non-TE nodes, OSPF-xTE
   ensures that non-TE nodes in the AS are unaffected by the TE LSAs.
   OSPF-xTE generates a stand-alone TE Link State Database (TE-LSDB),
   distinct from the native OSPF LSDB, for computation of TE circuit
   paths. OSPF-xTE is versatile and extendible to non-packet networks
   such as Synchronous Optical Network (SONET) / Time Division
   Multiplexing (TDM) and optical networks.

IESG Note

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   therefore it may resemble a current IETF work in progress or a
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   discretion. Readers of this RFC should exercise caution in
   evaluating its value for implementation and deployment. See RFC 3932
   for more information.

See RFC 3630 for the IETF consensus protocol for OSPF Traffic
Engineering. The OSPF WG position at the time of publication is that
although this proposal has some useful properties, the protocol in
RFC 3630 is sufficient for the traffic engineering needs that have
been identified so far, and the cost of migrating to this proposal
exceeds its benefits.

Table of Contents

1. Introduction

   This document defines OSPF-xTE, an experimental traffic engineering
   (TE) extension to the link-state routing protocol OSPF. The
   objective of OSPF-xTE is to discover TE network topology and
   disseminate TE metrics within an autonomous system (AS). A stand-
   alone TE Link State Database (TE-LSDB), different from the native
   OSPF LSDB, is created to facilitate computation of TE circuit paths.
   Devising algorithms to compute TE circuit paths is not an objective
   of this document.

   OSPF-xTE is different from the Opaque-LSA-based approach outlined in
   [OPQLSA-TE]. Section 4 describes the motivations behind the design
   of OSPF-xTE. Section 6 outlines a transition path for those
   currently using [OPQLSA-TE] for intra-area and wish to extend this
   using OSPF-xTE across the AS.

   Readers interested in TE extensions for packet networks alone may
   skip section 9.0.

2. Principles of Traffic Engineering

   The objective of traffic engineering (TE) is to set up circuit
   path(s) between a pair of nodes or links and to forward traffic of a
   certain forwarding equivalency class (FEC) through the circuit path.
   Only unicast circuit paths are considered in this section; multicast
   variations are outside the scope.

   A traffic engineered circuit path is unidirectional and may be
   identified by the tuple: (FEC, TE circuit parameters, origin
   node/link, destination node/link).

A forwarding equivalency class (FEC) is a grouping of traffic that is
forwarded in the same manner by a node. An FEC may be classified
based on a number of criteria, as follows:

    a) traffic arriving on a specific interface,
    b) traffic arriving at a certain time of day,
    c) traffic meeting a certain packet based classification
       criteria (ex: based on a match of the fields in the IP and
       transport headers within a packet),
    d) traffic in a certain priority class,
    e) traffic arriving on a specific set of TDM (Synchronous
       Transport Signal (STS)) circuits on an interface, or
    f) traffic arriving on a certain wavelength of an interface.

Discerning traffic based on the FEC criteria is mandatory for Label
Edge Routers (LERs). The intermediate Label-Switched Routers (LSRs)
are transparent to the traffic content. LSRs are only responsible
for maintaining the circuit for its lifetime. This document will not
address definition of FEC criteria, the mapping of an FEC to circuit,
or the associated signaling to set up circuits. [MPLS-TE] and
[GMPLS-TE] address the FEC criteria. [RSVP-TE] and [CR-LDP] address
signaling protocols to set up circuits.

This document is concerned with the collection of TE metrics for all
the TE enforceable nodes and links within an autonomous system. TE
metrics for a node may include the following.

    a) Ability to perform traffic prioritization,
    b) Ability to provision bandwidth on interfaces,
    c) Support for Constrained Shortest Path First (CSPF)
       algorithms,
    d) Support for certain TE-Circuit switch type, and
    e) Support for a certain type of automatic protection switching.

TE metrics for a link may include the following.

    a) available bandwidth,
    b) reliability of the link,
    c) color assigned to the link,
    d) cost of bandwidth usage on the link, and
    e) membership in a Shared Risk Link Group (SRLG).

A number of CSPF (Constraint-based Shortest Path First) algorithms
may be used to dynamically set up TE circuit paths in a TE network.

OSPF-xTE mandates that the originating and the terminating entities
of a TE circuit path be identifiable by IP addresses.

3. Terminology

   Definitions of the majority of the terms used in the context of the
   OSPF protocol may be found in [OSPF-V2]. MPLS and traffic
   engineering terms may be found in [MPLS-ARCH]. RSVP-TE and CR-LDP
   signaling-specific terms may be found in [RSVP-TE] and [CR-LDP],
   respectively.

   The following subsections describe the native OSPF terms and the
   OSPF-xTE terms used within this document.

3.1. Native OSPF Terms

   o Native node (Non-TE node)

      A native or non-TE node is an OSPF router that is capable of IP
      packet forwarding but does not take part in a TE network. A
      native OSPF node forwards IP traffic using the shortest-path
      forwarding algorithm and does not run the OSPF-xTE extensions.

   o Native link (Non-TE link)

      A native (or non-TE) link is a network attachment to a TE or
      non-TE node used for IP packet traversal.

   o Native OSPF network (Non-TE network)

      A native OSPF network refers to an OSPF network that does not
      support TE. "Non-TE network", "native-OSPF network", and "non-TE
      topology" are used synonymously throughout the document.

   o LSP

      LSP stands for "Label-Switched Path". An LSP is a TE circuit
      path in a packet network. The terms "LSP" and "TE circuit path"
      are used synonymously in the context of packet networks.

   o LSA

      LSA stands for OSPF "Link State Advertisement".

   o LSDB

      LSDB stands for "Link State Database". An LSDB contains a
      representation of the topology of a network. A native LSDB,
      constituted of native OSPF LSAs, represents the topology of a
      native IP network. The TE-LSDB, on the other hand, is
      constituted of TE LSAs and is a representation of the TE network
      topology.

3.2. OSPF-xTE Terms

   o TE node

      A TE node is a node in the traffic engineering (TE) network. A
      TE node has a minimum of one TE link attached to it. Associated
      with each TE node is a set of supported TE metrics. A TE node
      may also participate in a native IP network.

      In a SONET/TDM or photonic cross-connect network, a TE node is
      not required to be an OSPF-xTE node. An external OSPF-xTE node
      may act as proxy for the TE nodes that cannot be routers
      themselves.

   o TE link

      A TE link is a network attachment point to a TE node and is
      intended for traffic engineering use. Associated with each TE
      link is a set of supported TE metrics. A TE link may also
      optionally carry native IP traffic.

      Of the various links attached to a TE node, only the links that
      take part in a traffic-engineered network are called TE links.

   o TE circuit path

      A TE circuit path is a unidirectional data path that is defined
      by a list of TE nodes connected to each other through TE links.
      A TE circuit path is also often referred simply as a circuit path
      or a circuit.

      For the purposes of OSPF-xTE, the originating and terminating
      entities of a TE circuit path must be identifiable by their IP
      addresses. As a general rule, all nodes and links party to a
      traffic-engineered network should be uniquely identifiable by an
      IP address.

   o OSPF-xTE node (OSPF-xTE router)

      An OSPF-xTE node is a TE node that runs the OSPF routing protocol
      and the OSPF-xTE extensions described in this document. An
      autonomous system (AS) may consist of a combination of native and
      OSPF-xTE nodes.

   o TE Control network

      The IP network used by the OSPF-xTE nodes for OSPF-xTE
      communication is referred as the TE control network or simply the
      control network. The control network can be independent of the
      TE data network.

   o TE network (TE topology)

      A TE network is a network of connected TE nodes and TE links, for
      the purpose of setting up one or more TE circuit paths. The
      terms "TE network", "TE data network", and "TE topology" are used
      synonymously throughout the document.

   o Packet-TE network (Packet network)

      A packet-TE network is a TE network in which the nodes switch
      MPLS packets. An MPLS packet is defined in [MPLS-TE] as a packet
      with an MPLS header, followed by data octets. The intermediary
      node(s) of a circuit path in a packet-TE network perform MPLS
      label swapping to emulate the circuit.

      Unless specified otherwise, the term "packet network" is used
      throughout the document to refer to a packet-TE network.

   o Non-packet-TE network (Non-packet network)

      A non-packet-TE network is a TE network in which the nodes switch
      non-packet entities such as STS time slots, Lambda wavelengths,
      or simply interfaces.

      SONET/TDM and fiber cross-connect networks are examples of non-
      packet-TE networks. Circuit emulation in these networks is
      accomplished by the switch fabric in the intermediary nodes
      (based on TDM time slot, fiber interface, or Lambda).

      Unless specified otherwise, the term non-packet network is used
      throughout the document to refer a non-packet-TE network.

o Mixed network

   A mixed network is a network that is constituted of both packet-
   TE and non-TE networks. Traffic in the network is strictly
   datagram oriented, i.e., IP datagrams or MPLS packets. Routers
   in a mixed network may be TE or native nodes.

   OSPF-xTE is usable within a packet network or a mixed network.

o Peer network

   A peer network is a network that is constituted of packet-TE and
   non-packet-TE networks combined. In a peer network, a TE node
   could potentially support TE links for the packet as well as
   non-packet data.

   OSPF-xTE is usable within a packet network or a non-packet
   network or a peer network, which is a combination of the two.

o CSPF

   CSPF stands for "Constrained Shortest Path First". Given a TE
   LSDB and a set of constraints that must be satisfied to form a
   circuit path, there may be several CSPF algorithms to obtain a TE
   circuit path that meets the criteria.

o TLV

   A TLV stands for a data object in the form: Tag-Length-Value.
   All TLVs are assumed to be of the following format, unless
   specified otherwise. The Tag and Length are 16 bits wide each.
   The Length includes the 4 octets required for Tag and Length
   specification. All TLVs described in this document are padded to
   32-bit alignment. Any padding required for alignment will not be
   a part of the length field, however. TLVs are used to describe
   traffic engineering characteristics of the TE nodes, TE links,
   and TE circuit paths.

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             Tag               |     Length (4 or more)        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Value ....                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          ....                                 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
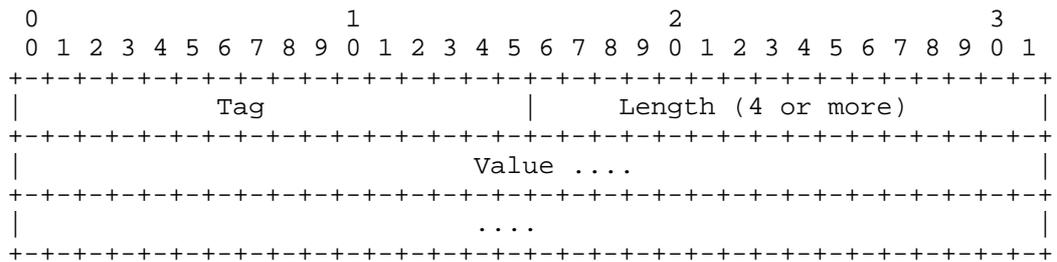
     o Router-TE TLVs (Router TLVs)

        TLVs used to describe the TE capabilities of a TE node.

     o Link-TE TLVs (Link TLVs)

        TLVs used to describe the TE capabilities of a TE link.

4. Motivations behind the Design of OSPF-xTE

   There are several motivations that led to the design of OSPF-xTE.
   OSPF-xTE is scalable, efficient, and usable across a variety of
   network topologies. These motivations are explained in detail in the
   following subsections. The last subsection lists real-world network
   scenarios that benefit from the OSPF-xTE.

4.1. Scalable Design

   In OSPF-xTE, an area-level abstraction provides the scaling required
   for the TE topology in a large autonomous system (AS). An OSPF-xTE
   area border router will advertise summary LSAs for TE and non-TE
   topologies independent of each other. Readers may refer to section
   10 for a topological view of the AS from the perspective of a OSPF-
   xTE node in an area.

   [OPQLSA-TE], on the other hand, is designed for intra-area and is not
   scalable to AS-wide scope.

4.2. Operable in Mixed and Peer Networks

   OSPF-xTE assumes that an AS may be constituted of coexisting TE and
   non-TE networks. OSPF-xTE dynamically discovers TE topology and the
   associated TE metrics of the nodes and links that form the TE
   network. As such, OSPF-xTE generates a stand-alone TE-LSDB that is
   fully representative of the TE network. Stand-alone TE-LSDB allows
   for speedy TE computations.

   [OPQLSA-TE] is designed for packet networks and is not suitable for
   mixes and peer networks. TE-LSDB in [OPQLSA-TE] is derived from the
   combination of Opaque LSAs and native LSDB. Further, the TE-LSDB
   thus derived has no knowledge of the TE capabilities of the routers
   in the network.

4.3. Efficient in Flooding Reach

   OSPF-xTE is able to identify the TE topology in a mixed network and
   to limit the flooding of TE LSAs to only the TE nodes. Non-TE nodes
   are not bombarded with TE LSAs.

In a TE network, a subset of the TE metrics may be prone to rapid
change, while others remain largely unchanged. Changes in TE metrics
must be communicated at the earliest throughout the network to ensure
that the TE-LSDB is up-to-date within the network. As a general
rule, a TE network is likely to generate significantly more control
traffic than a native network. The excess traffic is almost directly
proportional to the rate at which TE circuits are set up and torn
down within the TE network. The TE database synchronization should
occur much quicker compared to the aggregate circuit set up and
tear-down rates. OSPF-xTE defines TE-Incremental-Link-update LSA
(section 8.2) to advertise only a subset of the metrics that are
prone to rapid changes.

The more frequent and wider the flooding, the larger the number of
retransmissions and acknowledgements. The same information (needed
or not) may reach a router through multiple links. Even if the
router did not forward the information past the node, it would still
have to send acknowledgements across all the various links on which
the LSAs tried to converge. It is undesirable to flood non-TE nodes
with TE information.

4.4. Ability to Reserve TE-Exclusive Links

OSPF-xTE draws a clear distinction between TE and non-TE links. A TE
link may be configured to permit TE traffic alone, and not permit
best-effort IP traffic on the link. This permits TE enforceability
on the TE links.

When links of a TE topology do not overlap the links of a native IP
network, OSPF-xTE allows for virtual isolation of the two networks.
Best-effort IP network and TE network often have different service
requirements. Keeping the two networks physically isolated can be
expensive. Combining the two networks into a single physically
connected network will bring economies of scale, while service
enforceability can be maintained individually for each of the TE and
non-TE sections of the network.

[OPQLSA-TE] does not support the ability to isolate best-effort IP
traffic from TE traffic on a link. All links are subject to best-
effort IP traffic. An OSPF router could potentially select a TE link
to be its least cost link and inundate the link with best-effort IP
traffic, thereby rendering the link unusable for TE purposes.

4.5. Extensible Design

   The OSPF-xTE design is based on the tried-and-tested OSPF paradigm,
   and it inherits all the benefits of OSPF, present and future. TE
   LSAs are extensible, just as the native OSPF on which OSPF-xTE is
   founded are extensible.

4.6. Unified for Packet and Non-Packet Networks

   OSPF-xTE is usable within a packet network or a non-packet network or
   a combination peer network.

   Signaling protocols such as RSVP and LDP work the same across packet
   and non-packet networks. Signaling protocols merely need the TE
   characteristics of nodes and links so they can signal the nodes to
   formulate TE circuit paths. In a peer network, the underlying
   control protocol must be capable of providing a unified LSDB for all
   TE nodes (nodes with packet-TE links as well as non-packet-TE links)
   in the network. OSPF-xTE meets this requirement.

4.7. Networks Benefiting from the OSPF-xTE Design

   Below are examples of some real-world network scenarios that benefit
   from OSPF-xTE.

   o IP providers transitioning to provide TE services

      Providers needing to support MPLS-based TE in their IP network
      may choose to transition gradually. They may add new TE links or
      convert existing links into TE links within an area first and
      progressively advance to offering MPLS in the entire AS.

      Not all routers will support TE extensions at the same time
      during the migration process. Use of TE-specific LSAs and their
      flooding to OSPF-xTE only nodes will allow the vendor to
      introduce MPLS TE without destabilizing the existing network.
      The native OSPF-LSDB will remain undisturbed while newer TE links
      are added to the network.

   o Providers offering best-effort-IP & TE services

      Providers choosing to offer both best-effort-IP and TE based
      packet services simultaneously on the same physically connected
      network will benefit from the OSPF-xTE design. By maintaining
      independent LSDBs for each type of service, TE links are not
      cannibalized in a mixed network.

   o Large TE networks

      The OSPF-xTE design is advantageous in large TE networks that
      require the AS to be sub-divided into multiple areas. OSPF-xTE
      permits inter-area exchange of TE information, which ensures that
      all nodes in the AS have up-to-date, AS-wide, TE reachability
      knowledge. This in turn will make TE circuit setup predictable
      and computationally bounded.

   o Non-Packet Networks and Peer Networks

      Vendors may also use OSPF-xTE for their non-packet TE networks.
      OSPF-xTE defines the following functions in support of non-packet
      TE networks.
       (a) "Positional-Ring" type network LSAs.
       (b) Router proxying -- allowing a router to advertise on behalf
             of other nodes (that are not packet/OSPF-capable).

5. OSPF-xTE Solution Overview

5.1. OSPF-xTE Solution

   Locally-scoped Opaque LSA (type 9) is used to discovery the TE
   topology within a network. Section 7.1 describes in detail the use
   of type 9 Opaque LSA for TE topology discovery. TE LSAs are designed
   for use by the OSPF-xTE nodes. Section 8.0 describes the TE LSAs in
   detail. Changes required of the OSPF data structures to support
   OSPF-xTE are described in section 11.0. A new TE-neighbors data
   structure will be used to advertise TE LSAs along TE topology.

   An OSPF-xTE node will have a native LSDB and a TE-LSDB, while a
   native OSPF node will have just a native LSDB. Consider the OSPF
   area, constituted of OSPF-xTE and native OSPF routers, shown in
   Figure 1. Nodes RT1, RT2, RT3, and RT6 are OSPF-xTE routers with TE
   and non-TE link attachments. Nodes RT4 and RT5 are native OSPF
   routers with no TE links. When the LSA database is synchronized, all
   nodes will share the same native LSDB. OSPF-xTE nodes alone will
   have the additional TE-LSDB.

```
          +---+
          |   |--------------------------------+
          |RT6|\\                               |
          +---+  \\                             |
           ||     \\                            |
           ||      \\                           |
           ||       \\                          |
           ||        \\                         |
           ||       +---+                       |
           ||       |   |--------------+        |
           ||       |RT1|\\            |        |
           ||       +---+  \\          |        |
           ||      //|      \\         |        |
           ||    //  |       \\        |        |
           ||   //   |        \\       |        |
           ||  //    |         \\      |        |
          +---+ //   |          \\   +---+      |
          |RT2|//    |           \\ |RT3|------+
          |   |---------|---------------|   |
          +---+         |              +---+
                        |               |
                        |               |
                        |               |
                        |               |
                      +---+           +---+
                      |RT5|-------------|RT4|
                      +---+           +---+
```
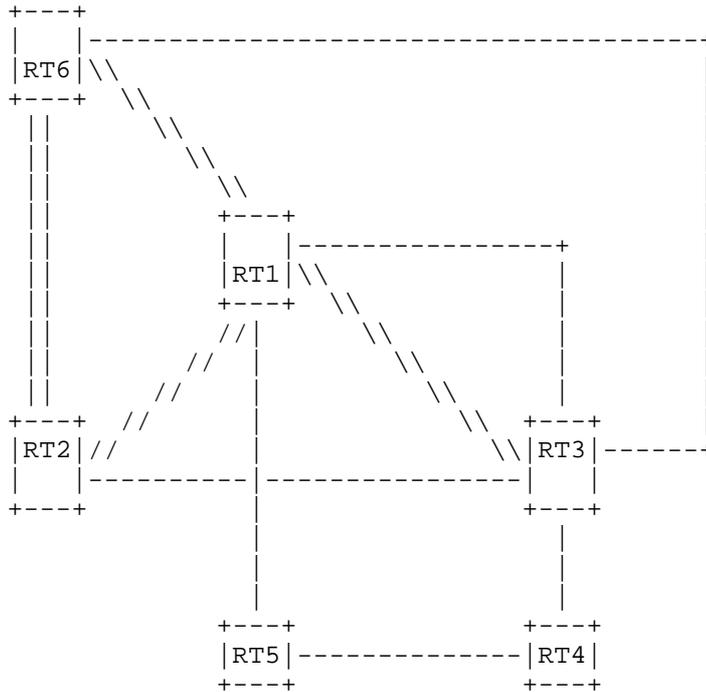
        Legend:
             --   Native (non-TE) network link
             | Native (non-TE) network link
             \\   TE network link
             || TE network link

             Figure 1. A (TE + native) OSPF Network Topology

5.2. Assumptions

   OSPF-xTE is an extension to the native OSPF protocol and does not
   mandate changes to the existing OSPF. OSPF-xTE design makes the
   following assumptions.

   (1) An OSPF-xTE node will need to establish router adjacency with at
        least one other OSPF-xTE node in the area in order for the
        router's TE database to be synchronized within the area.
        Failing this, the OSPF router will not be in the TE calculations
        of other TE routers in the area.

        It is the responsibility of the network administrator(s) to
        ensure connectedness of the TE network. Otherwise, there can be
        disjoint TE topologies within a network.

   (2) OSPF-xTE nodes must advertise the link state of its TE links.
        TE links are not obligated to support native IP traffic. Hence,
        an OSPF-xTE node cannot be required to synchronize its link-
        state database with neighbors on all its links. The only
        requirement is to have the TE LSDB synchronized across all
        OSPF-xTE nodes in the area.

   (3) A link in a packet network may be designated as a TE link or a
        native-IP link or both. For example, a link may be used for
        both TE and non-TE traffic, as long as the link is under
        subscribed in bandwidth for TE traffic (for example, 50% of the
        link capacity is set aside for TE traffic).

   (4) Non-packet TE sub-topologies must have a minimum of one node
        running OSPF-xTE protocol. For example, a SONET/SDH TDM ring
        must have a minimum of one Gateway Network Element (GNE) running
        OSPF-xTE. The OSPF-xTE node will advertise on behalf of all the
        TE nodes in the ring.

6. Strategy for Transition of Opaque LSAs to OSPF-xTE

   Below is a strategy to transition implementations currently using
   Opaque LSAs ([OPQLSA-TE]) within an area to adapt OSPF-xTE in a
   gradual fashion across the AS.

   (1) Use [OPQLSA-TE] within an area. Derive TE topology within the
        area from the combination of Opaque LSAs and native LSDB.

   (2) Use TE-Summary LSAs and TE-AS-external LSAs for inter-area
        communication. Use the TE topology within an area to summarize
        the TE networks in the area and advertise the same to all TE
        nodes in the backbone. The TE-ABRs (TE area border routers) on
        the backbone area will in turn advertise these summaries within
        their connected areas.

7. OSPF-xTE Router Adjacency -- TE Topology Discovery

   OSPF creates adjacencies between neighboring routers for the purpose
   of exchanging routing information. The following subsections
   describe the use of locally-scoped Opaque LSAs to discover OSPF-xTE
   neighboring routers. The capability is used as the basis to build a
   TE topology.

7.1. The OSPF-xTE Router Adjacency

   OSPF uses the options field in the Hello packet to advertise optional
   router capabilities [OSPF-V2]. However, all the bits in this field
   have been allocated and there is no way to advertise OSPF-xTE

capability using the options field at this time. This document
proposes using local-scope Opaque LSA (OPAQUE-9 LSA) to advertise
support for OSPF-xTE and establish OSPF-xTE adjacency. In order to
exchange Opaque LSAs, the neighboring routers must have the O-bit
(Opaque option bit) set in the options field.

[OSPF-CAP] proposes a format for exchanging router capabilities via
OPAQUE-9 LSA. Routers supporting OSPF-xTE will be required to set
the "OSPF Experimental TE" bit within the "router capabilities"
field. Two routers will not become TE neighbors unless they share a
common network link on which both routers advertise support for
OSPF-xTE. Routers that do not support OSPF-xTE may simply ignore the
advertisement.

7.2. The Hello Protocol

The Hello protocol is primarily responsible for dynamically
establishing and maintaining neighbor adjacencies. In a TE network,
it is not required for all links and neighbors to establish adjacency
using this protocol. OSPF-xTE router adjacency between two routers
is established using the method described in the previous section.

For non-broadcast multi-access (NBMA) and broadcast networks, the
HELLO protocol is responsible for electing the Designated Router and
the Backup Designated Router. Routers supporting the TE option shall
be given a higher precedence for becoming a designated router over
those that do not support TE.

7.3. The Designated Router

When a router's non-TE link first becomes functional, it checks to
see whether there is currently a Designated Router for the network.
If there is one, it accepts that Designated Router, regardless of its
router priority, so long as the current designated router is TE
compliant. Otherwise, the router itself becomes Designated Router if
it has the highest Router Priority on the network and is TE
compliant.

OSPF-xTE must be implemented on the most robust routers, as they
become likely candidates to take on the role as Designated Router.

7.4. The Backup Designated Router

The Backup Designated Router is also elected by the Hello Protocol.
Each Hello Packet has a field that specifies the Backup Designated
Router for the network. Once again, TE-compliance must be weighed in
conjunction with router priority in electing the Backup Designated
Router.

7.5. Flooding and the Synchronization of Databases

   In OSPF, adjacent routers within an area are required to synchronize
   their databases. However, a more concise requirement is that all
   routers in an area must converge on the same LSDB. As stated in item
   2 of section 5.2, a basic assertion of OSPF-xTE is that the links
   used by the OSPF-xTE control network for flooding must not be
   required to match the links used by the data network for real-time
   data forwarding. For instance, it should not be required to send
   OSPF-xTE messages over a TE link that is configured to reject non-TE
   traffic. However, the control network must be set up such that a
   minimum of one path exists between any two OSPF or OSPF-xTE routers
   within the network, for flooding purposes. This revised control
   network connectivity requirement does not jeopardize convergence of
   LSDB within an area.

   In a mixed network, where some of the neighbors are TE compliant and
   others are not, the designated OSPF-xTE router will exchange
   different sets of LSAs with its neighbors. TE LSAs are exchanged
   only with the TE neighbors. Native LSAs are exchanged with all
   neighbors (TE and non-TE alike). Restricting the scope of TE LSA
   flooding to just the OSPF-xTE nodes will not affect the native nodes
   that coexist with the OSPF-xTE nodes.

   The control traffic for a TE network (i.e., TE LSA advertisement) is
   likely to be higher than that of a native OSPF network. This is
   because the TE metrics may vary with each TE circuit setup and the
   corresponding state change must be advertised at the earliest, not
   exceeding the MinLSInterval of 5 seconds. To minimize advertising
   repetitive content, OSPF-xTE defines a new TE-incremental-Link-update
   LSA (section 8.2) that would advertise just the TLVs that changed for
   a link.

   The OSPFIGP-TE well-known multicast address 224.0.0.24 has been
   assigned by IANA for the exchange of TE-compliant database
   descriptors during database synchronization.

7.6. The Graph of Adjacencies

   If two routers have multiple networks in common, they may have
   multiple adjacencies between them. The adjacency may be one of two
   types - native OSPF adjacency and TE adjacency. OSPF-xTE routers
   will form both types of adjacency.

   Two types of adjacency graphs are possible, depending on whether a
   Designated Router is elected for the network. On physical point-to-
   point networks, point-to-multipoint networks, and virtual links,
   neighboring routers become adjacent whenever they can communicate

directly. The adjacency can be either (a) TE-compliant or (b)
native. In contrast, on broadcast and NBMA networks the designated
router and the backup designated router may maintain two sets of
adjacency. The remaining routers will form either TE-compliant or
native adjacency.

In the broadcast network in Figure 2, routers RT7 and RT3 are chosen
as the Designated and Backup Designated Routers, respectively.
Routers RT3, RT4 and RT7 are TE-compliant, but RT5 and RT6 are not.
So RT4 will have TE-compliant adjacency with the designated and
backup routers, while RT5 and RT6 will only have native adjacency
with the Designated and Backup Designated Routers.
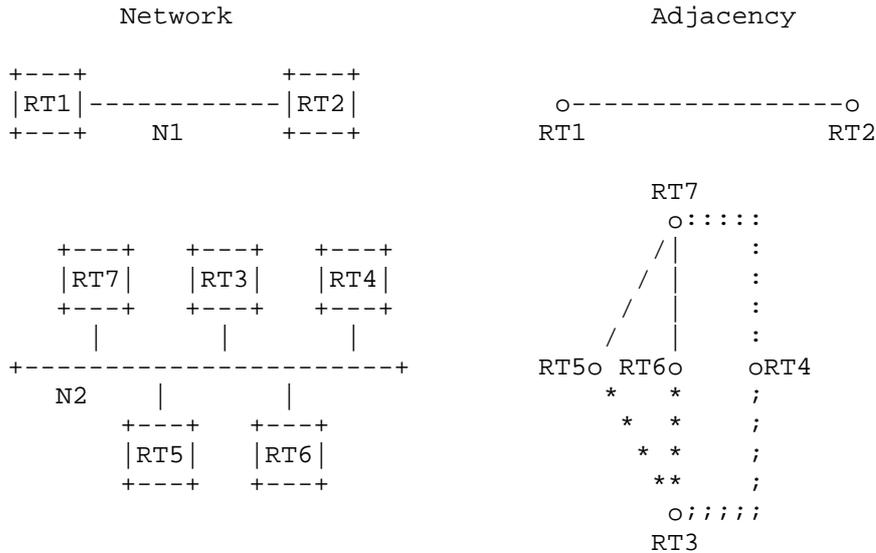
```
               Network                         Adjacency

     +---+               +---+
     |RT1|------------|RT2|           o-----------------o
     +---+     N1       +---+         RT1                      RT2

                                                RT7
                                                 o::::::
        +---+   +---+   +---+                    /|    :
        |RT7|   |RT3|   |RT4|                   / |    :
        +---+   +---+   +---+                  /  |    :
         |       |       |                    /   |    :
     +----------------------+         RT5o RT6o      oRT4
       N2      |       |                     *    *     ;
            +---+   +---+                    *    *     ;
            |RT5|   |RT6|                     *  *      ;
            +---+   +---+                      **       ;
                                              o;;;;;;
                                              RT3


             Adjacency Legend:

                 ----- Native adjacency (primary)
                 ***** Native adjacency (backup)
                 ::::: TE-compliant adjacency (primary)
                 ;;;;; TE-compliant adjacency (backup)
```

         Figure 2. Two Adjacency Graphs with TE-Compliant Routers

8. TE LSAs for Packet Network

   The OSPFv2 protocol currently has a total of 11 LSA types. LSA types
   1 through 5 are defined in [OSPF-V2]. LSA types 6, 7, and 8 are
   defined in [MOSPF], [NSSA], and [BGP-OSPF], respectively. LSA types
   9 through 11 are defined in [OPAQUE].

   Each LSA type has a unique flooding scope. Opaque LSA types 9
   through 11 are general purpose LSAs, with flooding scope set to
   link-local, area-local, and AS-wide (except stub areas) respectively.

   In the following subsections, we define new LSAs for traffic
   engineering (TE) use. The values for the new TE LSA types are
   assigned with the high bit of the LSA-type octet set to 1. The new
   TE LSAs are largely modeled after the existing LSAs for content
   format and have a unique flooding scope.

   TE-router LSA is defined to advertise TE characteristics of an OSPF-
   xTE router and all the TE links attached to the router. TE-
   incremental-Link-Update LSA is defined to advertise incremental
   updates to the metrics of a TE link. Flooding scope for both these
   LSAs is restricted to an area.

   TE-Summary network and router LSAs are defined to advertise the
   reachability of area-specific TE networks and area border routers
   (along with router TE characteristics) to external areas. Flooding
   scope of the TE-Summary LSAs is the TE topology in the entire AS less
   the non-backbone area for which the advertising router is an ABR.
   Just as with native OSPF summary LSAs, the TE-Summary LSAs do not
   reveal the topological details of an area to external areas.

   TE-AS-external LSA and TE-Circuit-Path LSA are defined to advertise
   AS external network reachability and pre-engineered TE circuits,
   respectively. While flooding scope for both these LSAs can be the
   entire AS, flooding scope for the pre-engineered TE circuit LSA may
   optionally be restricted to just the TE topology within an area.

8.1. TE-Router LSA (0x81)

   The TE-router LSA (0x81) is modeled after the router LSA and has the
   same flooding scope as the router LSA. However, the scope is
   restricted to only the OSPF-xTE nodes within the area. The TE router
   LSA describes the TE metrics of the router as well as the TE links
   attached to the router. Below is the format of the TE-router LSA.
   Unless specified explicitly otherwise, the fields carry the same
   meaning as they do in a router LSA. Only the differences are
   explained below. Router-TE flags, Router-TE TLVs, Link-TE options,
   and Link-TE TLVs are each described in the following sub-sections.

```
     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
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |            LS age              |    Options    |     0x81      |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                        Link State ID                          |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                      Advertising Router                       |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                      LS sequence number                       |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |        LS checksum            |            length             |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |    0     |V|E|B|     0        |         Router-TE flags        |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |   Router-TE flags (contd.)    |         Router-TE TLVs         |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                          ....                                 |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                  ....         |          # of TE links         |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                           Link ID                             |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                          Link Data                            |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |     Type      |       0       |         Link-TE flags          |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |    Link-TE flags (contd.)     |    Zero or more Link-TE TLVs    |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                           Link ID                             |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                          Link Data                            |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                            ...                                |
```
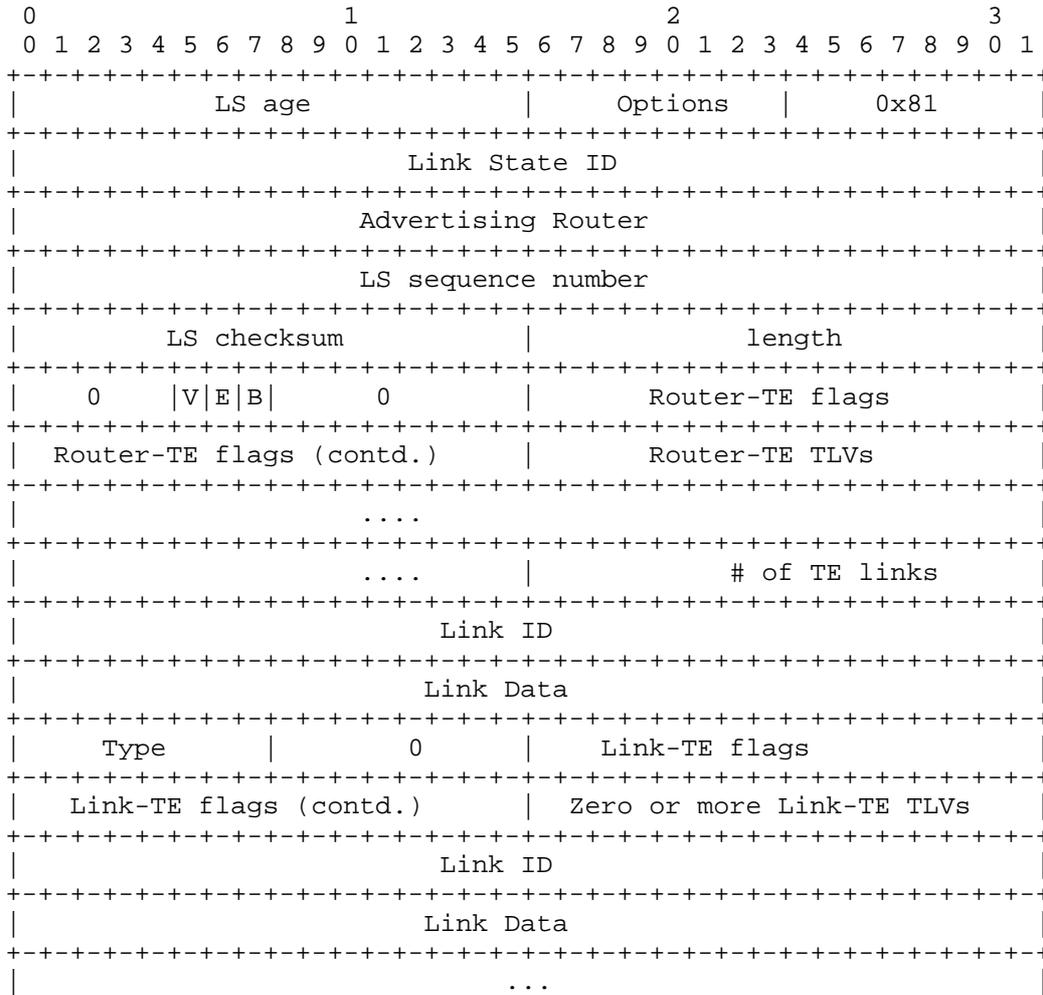
8.1.1. Router-TE Flags: TE Capabilities of the Router

   The following flags are used to describe the TE capabilities of an
   OSPF-xTE router. The remaining bits of the 32-bit word are reserved
   for future use.

```
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |L|L|P| | | |                                           |L|S|C|
    |S|E|S| | | |                                           |S|I|S|
    |R|R|C| | | |                                           |P|G|P|
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |<---- Boolean TE flags ------->|<- TE flags pointing to TLVs ->|
```
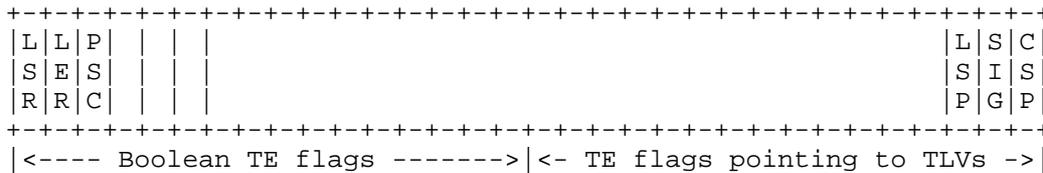
      Bit LSR - When set, the router is considered to have LSR (Label-
                Switched Router) capability.

      Bit LER - When set, the router is considered to have LER
                capability. All MPLS border routers will be required
                to have LER capability. Setting both the LER and E
                bits indicates an AS Boundary router with LER
                capability. Setting both the LER and B bits indicates
                an area border router with LER capability.

      Bit PSC - Indicates the node is packet-switch capable.

      Bit LSP - An MPLS Label switch TLV TE-NODE-TLV-MPLS-SWITCHING
                follows. This is applicable only when the PSC flag is
                set.

      Bit SIG - An MPLS Signaling-protocol-support TLV TE-NODE-TLV-
                MPLS-SIG-PROTOCOLS follows.

      BIT CSPF - A CSPF algorithm support TLV TE-NODE-TLV-CSPF-ALG
                follows.

8.1.2. Router-TE TLVs

   The following Router-TE TLVs are defined.

8.1.2.1. TE-NODE-TLV-MPLS-SWITCHING

   MPLS switching TLV is applicable only for packet switched nodes. The
   TLV specifies the MPLS packet switching capabilities of the TE node.

```
     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
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |            Tag = 0x8001        |          Length = 6           |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    | Label Depth   |   QOS         |                               |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
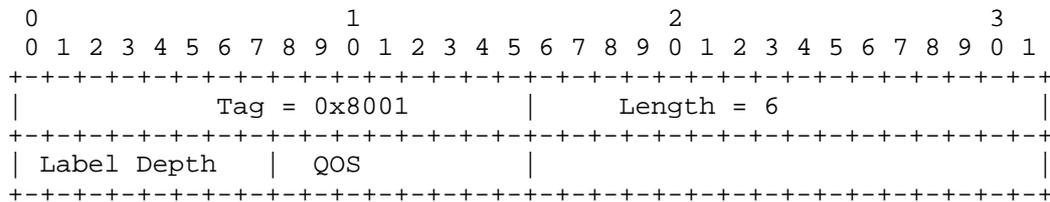
   Label Depth is the depth of label stack the node is capable of
   processing on its ingress interfaces. An octet is used to represent
   label depth. A default value of 1 is assumed when the TLV is not
   listed. Label depth is relevant when an LER has to pop multiple
   labels off the MPLS stack.

   QOS is a single-octet field that may be assigned '1' or '0'. Nodes
   supporting QOS are able to interpret the EXP bits in the MPLS header
   to prioritize multiple classes of traffic through the same LSP.

8.1.2.2.   TE-NODE-TLV-MPLS-SIG-PROTOCOLS

   MPLS signaling protocols TLV lists all the signaling protocol
   supported by the node. An octet is used to list each signaling
   protocol supported.

```
       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
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |            Tag = 0x8002        |    Length = 5, 6 or 7        |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |  Protocol-1 |    ...          |        ....                   |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
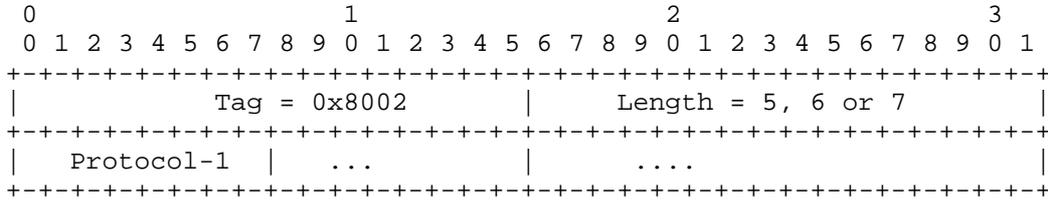
   RSVP-TE protocol is represented as 1, CR-LDP as 2, and LDP as 3.
   These are the only permitted signaling protocols at this time.

8.1.2.3.   TE-NODE-TLV-CSPF-ALGORITHMS

   The CSPF algorithms TLV lists all the CSPF algorithm codes supported.
   Support for CSPF algorithms makes the node eligible to compute
   complete or partial circuit paths. Support for CSPF algorithms can
   also be beneficial in knowing whether or not a node is capable of
   expanding loose routes (in an MPLS signaling request) into a detailed
   circuit path.

   Two octets are used to list each CSPF algorithm code. The algorithm
   codes may be vendor defined and unique within an Autonomous System.
   If the node supports 'n' CSPF algorithms, the Length would be (4 + 4
   * ((n+1)/2)) octets.

```
       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
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |            Tag = 0x8003        |    Length = 4(1 + (n+1)/2)   |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                CSPF-1          |      ....                    |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                CSPF-n          |                              |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
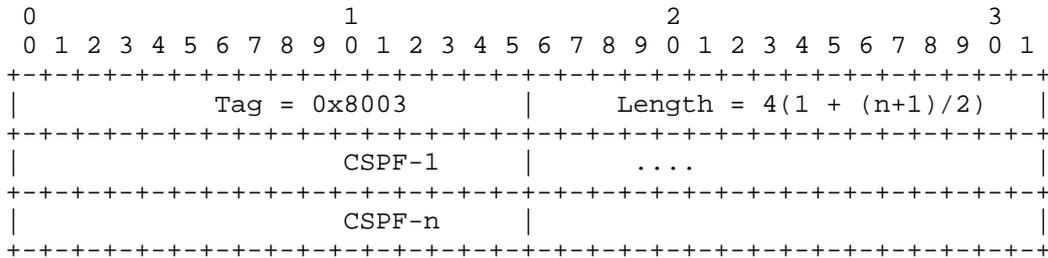
8.1.2.4. TE-NODE-TLV-NULL

   When a TE-Router or a TE link has multiple TLVs to describe the
   metrics, the NULL TLV is used to terminate the TLV list.

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |             Tag = 0x8888       |      Length = 4               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
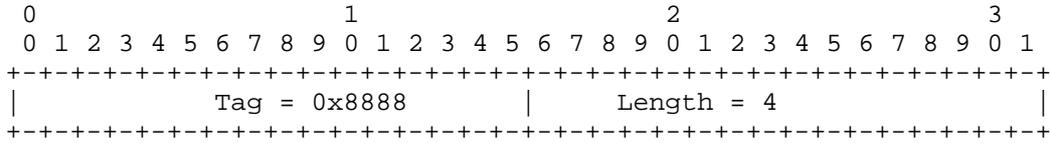
8.1.3. Link-TE Flags: TE Capabilities of a Link

   The following flags are used to describe the TE capabilities of a
   link. The remaining bits of the 32-bit word are reserved for future
   use.

```
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |T|N|P| | | |D|                                       |S|L|B|C|
   |E|T|K| | | |B|                                       |R|U|W|O|
   | |E|T| | | |S|                                       |L|G| |L|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |<---- Boolean TE flags ------->|<- TE flags pointing to TLVs ->|
```
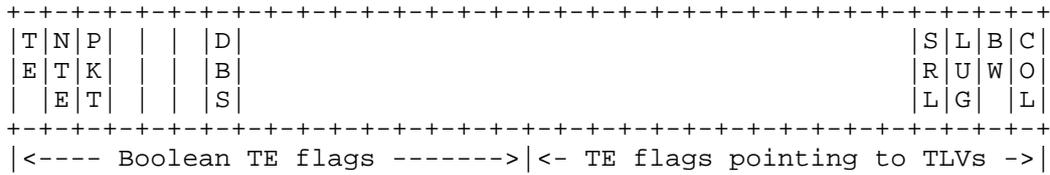
      Bit TE   - Indicates whether TE is permitted on the link. A link
                  can be denied for TE use by setting the flag to 0.

      Bit NTE   - Indicates whether non-TE traffic is permitted on the
                  TE link. This flag is relevant only when the TE flag
                  is set.

      Bit PKT   - Indicates whether or not the link is capable of IP
                  packet processing.

      Bit DBS   - Indicates whether or not database synchronization is
                  permitted on this link.

      Bit SRLG - Shared Risk Link Group TLV TE-LINK-TLV-SRLG follows.

      Bit LUG   - Link Usage Cost Metric TLV TE-LINK-TLV-LUG follows.

      Bit BW   - One or more Link Bandwidth TLVs follow.

      Bit COL   - Link Color TLV TE-LINK-TLV-COLOR follows.

8.1.4. Link-TE TLVs

8.1.4.1. TE-LINK-TLV-SRLG

   The SRLG describes the list of Shared Risk Link Groups (SRLG) the
   link belongs to. Two octets are used to list each SRLG. If the link
   belongs to 'n' SRLGs, the Length would be (4 + 4 * ((n+1)/2)) octets.

```
     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
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |          Tag = 0x0001          |    Length = 4(1 + (n+1)/2)    |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |            SRLG-1              |      ....                     |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |            SRLG-n              |                               |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
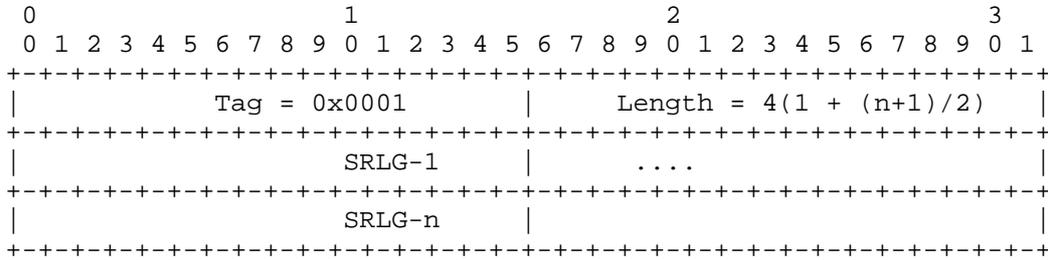
8.1.4.2 TE-LINK-TLV-BANDWIDTH-MAX

   The Bandwidth TLV specifies the maximum bandwidth of the link, as
   follows.
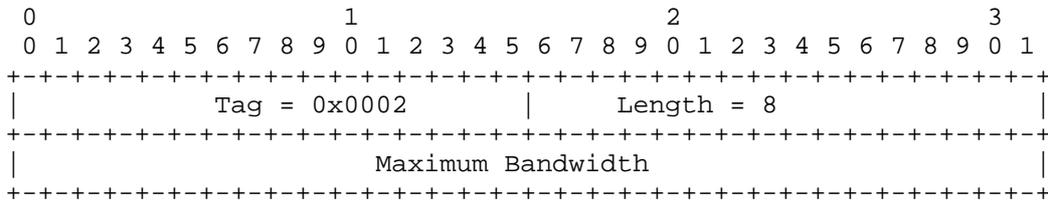
```
     0                   1                   2                   3
     0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |          Tag = 0x0002          |          Length = 8           |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                     Maximum Bandwidth                          |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   Bandwidth is expressed in units of 32 bytes/sec (256 bits/sec). A
   32-bit field for bandwidth would permit specification not exceeding 1
   terabit/sec.

   Maximum Bandwidth is the maximum link capacity expressed in bandwidth
   units. Portions or all of this bandwidth may be used for TE use.

8.1.4.3. TE-LINK-TLV-BANDWIDTH-MAX-FOR-TE

   The Bandwidth TLV specifies the maximum bandwidth available for TE
   use, as follows.
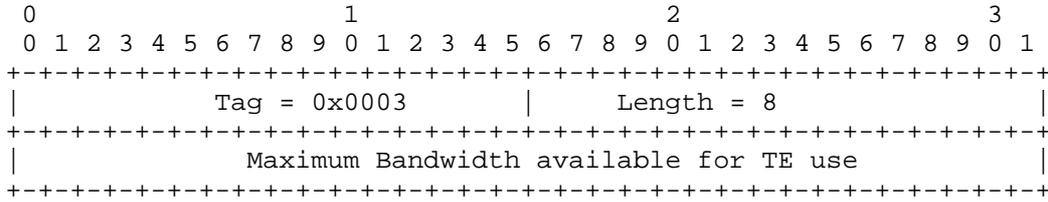
```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |           Tag = 0x0003        |           Length = 8          |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |           Maximum Bandwidth available for TE use              |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   Bandwidth is expressed in units of 32 bytes/sec (256 bits/sec). A
   32-bit field for bandwidth would permit specification not exceeding 1
   terabit/sec.

   "Maximum Bandwidth available for TE use" is the total reservable
   bandwidth on the link for use by all the TE circuit paths traversing
   the link. The link is oversubscribed when this field is more than
   the Maximum Bandwidth. When the field is less than the Maximum
   Bandwidth, the remaining bandwidth on the link may be used for non-TE
   traffic in a mixed network.

8.1.4.4. TE-LINK-TLV-BANDWIDTH-TE

   The Bandwidth TLV specifies the bandwidth reserved for TE as follows.
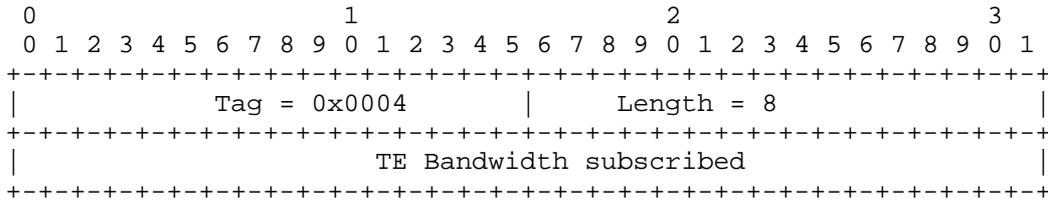
```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |           Tag = 0x0004        |           Length = 8          |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                   TE Bandwidth subscribed                     |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   Bandwidth is expressed in units of 32 bytes/sec (256 bits/sec). A
   32-bit field for bandwidth would permit specification not exceeding 1
   terabit/sec.

   "TE Bandwidth subscribed" is the bandwidth that is currently
   subscribed from of the link. "TE Bandwidth subscribed" must be less
   than the "Maximum bandwidth available for TE use". New TE circuit
   paths are able to claim no more than the difference between the two
   bandwidths for reservation.

8.1.4.5. TE-LINK-TLV-LUG

   The link usage cost TLV specifies bandwidth unit usage cost, TE
   circuit set-up cost, and any time constraints for setup and teardown
   of TE circuits on the link.

```
     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
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |           Tag = 0x0005        |           Length = 28         |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                     Bandwidth unit usage cost                 |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                      TE circuit set-up cost                   |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                  TE circuit set-up time constraint            |
    |                                                               |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                 TE circuit tear-down time constraint          |
    |                                                               |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
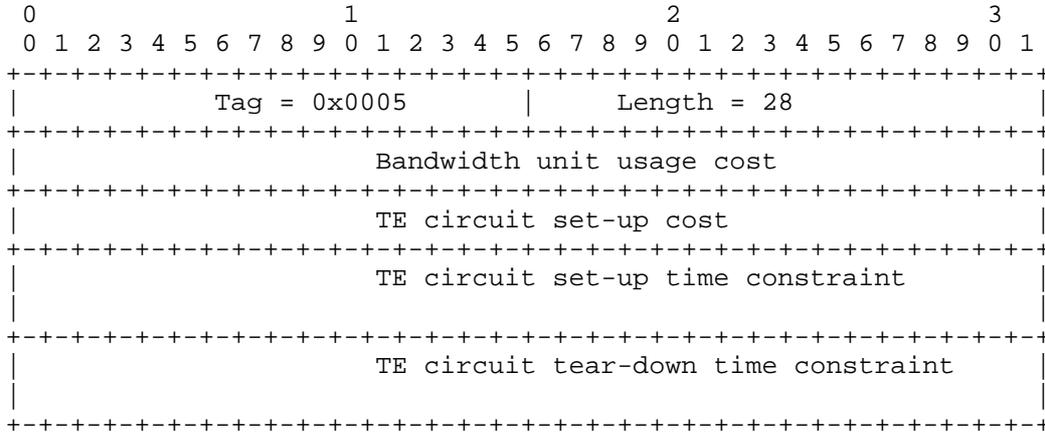
   Circuit Setup time constraint

      This 64-bit number specifies the time at or after which a TE-
      circuit path may be set up on the link. The set-up time
      constraint is specified as the number of seconds from the start
      of January 1, 1970 UTC. A reserved value of 0 implies no circuit
      setup time constraint.

   Circuit Teardown time constraint

      This 64-bit number specifies the time at or before which all TE-
      circuit paths using the link must be torn down. The teardown
      time constraint is specified as the number of seconds from the
      start of January 1 1970 UTC. A reserved value of 0 implies no
      circuit teardown time constraint.

8.1.4.6. TE-LINK-TLV-COLOR

   The color TLV is similar to the SRLG TLV, in that an Autonomous
   System may choose to issue colors to a TE link meeting certain
   criteria. The color TLV can be used to specify one or more colors
   assigned to the link as follows. Two octets are used to list each
   color. If the link belongs to 'n' number of colors, the Length would
   be (4 + 4 * ((n+1)/2)) octets.

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |            Tag = 0x0006        |    Length = 4(1 + (n+1)/2)   |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                   Color-1     |    ....                      |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                   Color-n     |                              |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
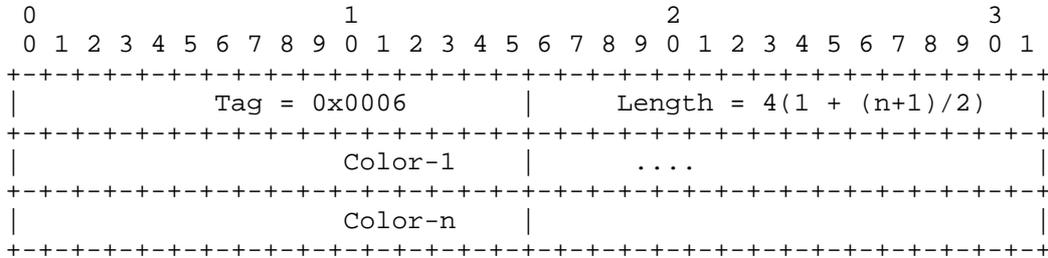
8.1.4.7. TE-LINK-TLV-NULL

   When a TE link has multiple TLVs to describe its metrics, the NULL
   TLV is used to terminate the TLV list. The TE-LINK-TLV-NULL is same
   as the TE-NODE-TLV-NULL described in section 8.1.2.4

8.2. TE-Incremental-Link-Update LSA (0x8d)

   A significant difference between a native OSPF network and a TE
   network is that the latter may be subject to frequent real-time
   circuit pinning and is likely to undergo TE-state updates. Some
   links might undergo changes more frequently than others. Flooding
   the network with TE-router LSAs at the aggregated speed of all link
   metric changes is simply not desirable. A smaller in size TE-
   incremental-link-update LSA is designed to advertise only the
   incremental link updates.

   A TE-incremental-link-update LSA will be advertised as frequently as
   the link state is changed (not exceeding once every MinLSInterval
   seconds). The TE link sequence is largely the advertisement of a
   sub-portion of router LSA. The sequence number on this will be
   incremented with the TE-router LSA's sequence as the basis. When an
   updated TE-router LSA is advertised within 30 minutes of the previous
   advertisement, the updated TE-router LSA will assume a sequence
   number that is larger than the most frequently updated of its links.

Below is the format of the TE-incremental-link-update LSA.

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |            LS age              |    Options    |     0x8d      |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                Link State ID (same as Link ID)                |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                      Advertising Router                       |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                      LS sequence number                       |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |         LS checksum           |             length            |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                          Link Data                            |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |     Type      |       0       |      Link-TE options          |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |     Link-TE options           | Zero or more Link-TE TLVs     |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |     # TOS     |                   metric                      |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                            ...                                |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |     TOS       |       0       |           TOS  metric         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
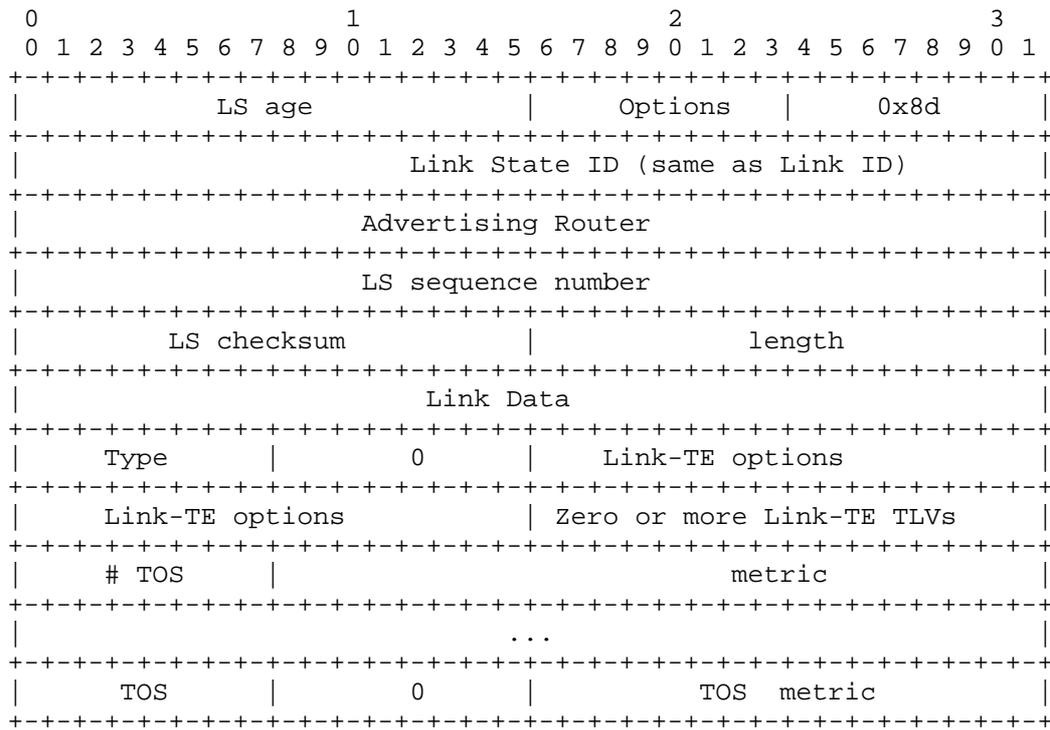
Link State ID

   This would be exactly the same as would have been specified for
   Link ID, for a link within the router LSA.

Link Data

   This specifies the router ID the link belongs to. In majority of
   cases, this would be same as the advertising router. This choice
   for Link Data is primarily to facilitate proxy advertisement for
   incremental link updates.

   Suppose that a proxy router LSA was used to advertise the TE-
   router LSA of a SONET/TDM node, and that the proxy router is now
   required to advertise incremental-link-update for the same
   SONET/TDM node. Specifying the actual router-ID to which the
   link in the incremental-link-update LSA belongs helps receiving
   nodes in finding the exact match for the LSA in their database.

The tuple of (LS Type, LSA ID, Advertising router) uniquely
identifies the LSA and replaces LSAs of the same tuple with an
older sequence number. However, there is an exception to this
rule in the context of TE-link-update LSA. TE-Link-update LSA
will initially assume the sequence number of the TE-router LSA it
belongs to. Further, when a new TE-router LSA update with a
larger sequence number is advertised, the newer sequence number
is assumed by all the link LSAs.

8.3. TE-Circuit-Path LSA (0x8C)

   TE-Circuit-path LSA (next page) may be used to advertise the
   availability of pre-engineered TE circuit path(s) originating from
   any router in the network. The flooding scope may be area-wide or
   AS-wide. Fields are as follows.

   Link State ID

   The ID of the far-end router or the far-end link-ID to which the TE
   circuit path(s) is being advertised.

   TE-circuit-path(s) flags

        Bit G - When set, the flooding scope is set to be AS-wide.
                Otherwise, the flooding scope is set to be area-wide.

        Bit E - When set, the advertised Link-State ID is an AS boundary
                router (E is for external). The advertising router and
                the Link State ID belong to the same area.

        Bit B - When set, the advertised Link State ID is an area border
                router (B is for Border)

        Bit D - When set, this indicates that the duration of circuit
                path validity follows.

        Bit S - When set, this indicates that setup time of the circuit
                path follows.

        Bit T - When set, this indicates that teardown time of the
                circuit path follows.

        CktType - This 4-bit field specifies the circuit type of the
                Forward Equivalency Class (FEC).

```
             0x01 - Origin is Router, Destination is Router.
             0x02 - Origin is Link,   Destination is Link.
             0x04 - Origin is Router, Destination is Link.
             0x08 - Origin is Link,   Destination is Router.


       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
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |            LS age              |    Options    |      0x84     |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                        Link State ID                          |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                      Advertising Router                       |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                      LS sequence number                       |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |        LS checksum            |             Length             |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |      0     |G|E|B|D|S|T|CktType| Circuit Duration (Optional)   |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                   Circuit Duration cont...                    |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      | Circuit Duration cont..       |  Circuit Setup time (Optional)|
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                  Circuit Setup time cont...                   |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      | Circuit Setup time cont..     |Circuit Teardown time(Optional)|
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                  Circuit Teardown time cont...                |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      | Circuit Teardown time cont..  |   No. of TE Circuit Paths     |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                        Circuit-TE ID                          |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                        Circuit-TE Data                        |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |      Type      |       0       |      Circuit-TE flags         |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |    Circuit-TE flags (contd.)   | Zero or more Circuit-TE TLVs |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                        Circuit-TE ID                          |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                        Circuit-TE Data                        |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                             ...                               |
```

Circuit Duration (Optional)

>   This 64-bit number specifies the seconds from the time of the LSA
>   advertisement for which the pre-engineered circuit path will be
>   valid. This field is specified only when the D-bit is set in the
>   TE-circuit-path flags.

Circuit Setup time (Optional)

>   This 64-bit number specifies the time at which the TE circuit
>   path may be set up. This field is specified only when the S-bit
>   is set in the TE-circuit-path flags. The set-up time is
>   specified as the number of seconds from the start of January 1,
>   1970 UTC.

Circuit Teardown time (Optional)

>   This 64-bit number specifies the time at which the TE circuit
>   path may be torn down. This field is specified only when the
>   T-bit is set in the TE-circuit-path flags. The teardown time is
>   specified as the number of seconds from the start of January 1
>   1970 UTC.

No. of TE Circuit Paths

>   This specifies the number of pre-engineered TE circuit paths
>   between the advertising router and the router specified in the
>   Link State ID.

Circuit-TE ID

>   This is the ID of the far-end router for a given TE circuit path
>   segment.

Circuit-TE Data

>   This is the virtual link identifier on the near-end router for a
>   given TE circuit path segment. This can be a private interface
>   or handle the near-end router uses to identify the virtual link.
>
>   The sequence of (Circuit-TE ID, Circuit-TE Data) pairs lists the
>   end-point nodes and links in the LSA as a series.

Circuit-TE flags

>   This lists the zero or more TE-link TLVs that all member elements
>   of the LSP meet.

8.4. TE-Summary LSAs

   TE-Summary LSAs are Type 0x83 and 0x84 LSAs. These LSAs are
   originated by area border routers. A TE-Summary-network LSA (0x83)
   describes the reachability of TE networks in a non-backbone area,
   advertised by the area border router. A Type 0x84 summary LSA
   describes the reachability of area border routers and AS border
   routers and their TE capabilities.

   One of the benefits of having multiple areas within an AS is that
   frequent TE advertisements within the area do not impact outside the
   area. Only the TE abstractions befitting the external areas are
   advertised.

8.4.1. TE-Summary Network LSA (0x83)

   A TE-Summary network LSA may be used to advertise reachability of
   TE-networks accessible to areas external to the originating area.
   The content and the flooding scope of a TE-Summary LSA is different
   from that of a native Summary LSA.

   The scope of flooding for a TE-Summary network LSA is AS-wide, with
   the exception of the originating area and the stub areas. The area
   border router for each non-backbone area is responsible for
   advertising the reachability of backbone networks into the area.

   Unlike a native-summary network LSA, a TE-Summary network LSA does
   not advertise summary costs to reach networks within an area. This
   is because TE parameters are not necessarily additive or comparable.
   The parameters can be varied in their expression. For example, a
   TE-Summary network LSA will not summarize a network whose links do
   not fall under an SRLG (Shared-Risk Link Group). This way, the TE-
   Summary LSA merely advertises the reachability of TE networks within
   an area. The specific circuit paths can be computed by the ABR.
   Pre-engineered circuit paths are advertised using TE-Circuit-path
   LSAs(refer to Section 8.3).

```
        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
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |            LS age              |    Options    |     0x83      |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |             Link State ID  (IP Network Number)                |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |             Advertising Router (Area Border Router)           |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                    LS sequence number                         |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |        LS checksum            |             Length            |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                       Network Mask                            |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                        Area-ID                                |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
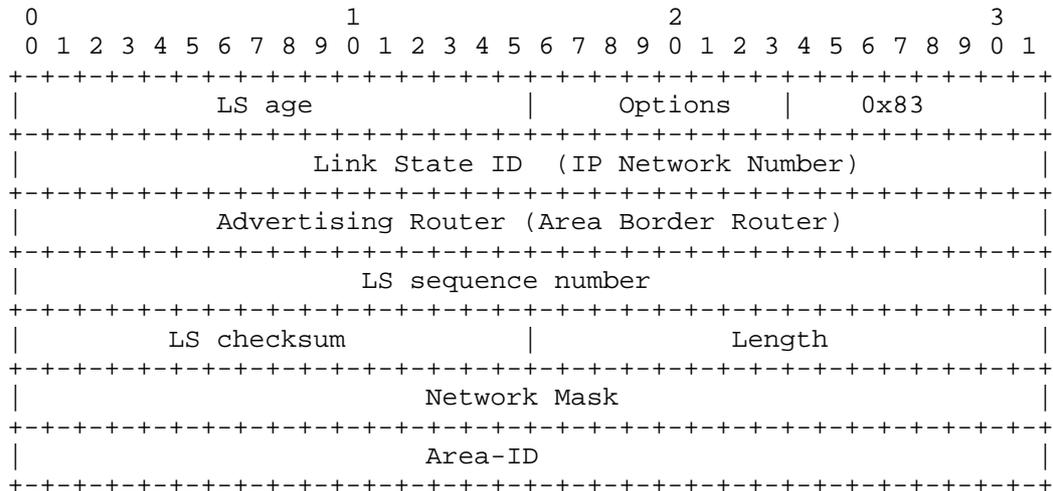
8.4.2. TE-Summary Router LSA (0x84)

   A TE-Summary router LSA may be used to advertise the availability of
   area border routers (ABRs) and AS border routers (ASBRs) that are
   TE-capable. The TE-Summary router LSAs are originated by the Area
   Border Routers. The scope of flooding for the TE-Summary router LSA
   is the non-backbone area the advertising ABR belongs to.

```
        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
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |            LS age              |    Options    |      0x84     |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                         Link State ID                         |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                    Advertising Router (ABR)                   |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                       LS sequence number                      |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |         LS checksum           |             Length            |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |     0     |E|B|      0         |          No. of Areas         |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                           Area-ID                             |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                             ...                               |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                        Router-TE flags                        |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                        Router-TE TLVs                         |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                            ....                               |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
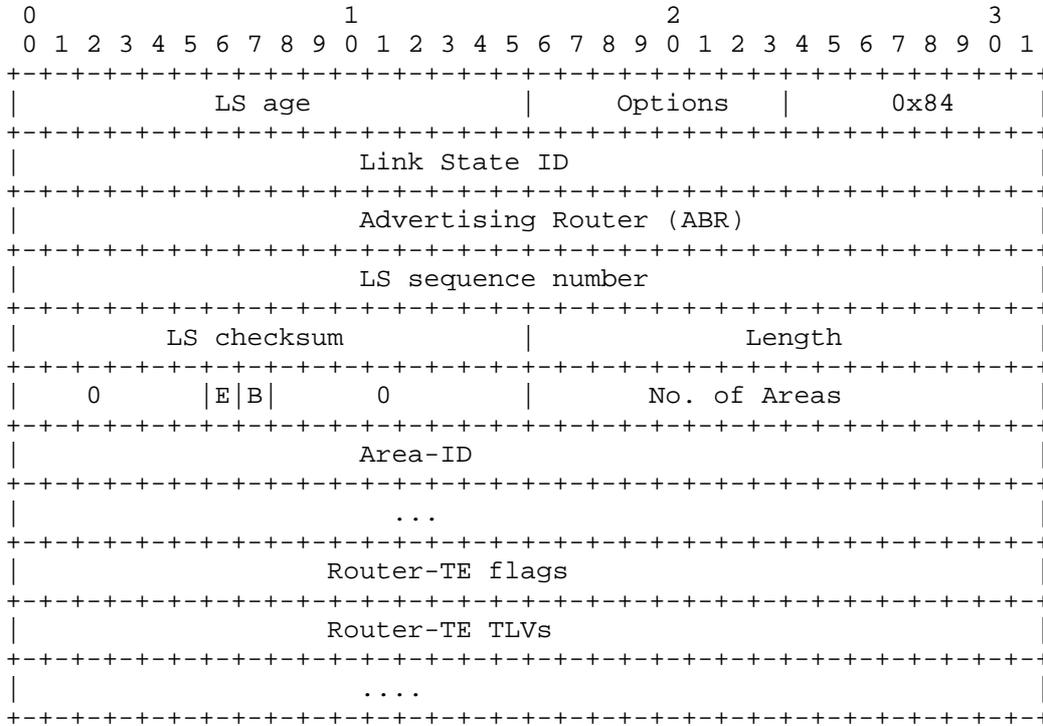
   Link State ID

      The ID of the area border router or the AS border router whose TE
      capability is being advertised.

   Advertising Router

      The ABR that advertises its TE capabilities (and the OSPF areas
      it belongs to) or the TE capabilities of an ASBR within one of
      the areas for which the ABR is a border router.

No. of Areas

>   Specifies the number of OSPF areas the link state ID belongs to.

Area-ID

>   Specifies the OSPF area(s) the link state ID belongs to. When
>   the link state ID is same as the advertising router ID, the
>   Area-ID lists all the areas the ABR belongs to. In the case the
>   link state ID is an ASBR, the Area-ID simply lists the area the
>   ASBR belongs to. The advertising router is assumed to be the ABR
>   from the same area the ASBR is located in.

Summary-router-TE flags

>   Bit E - When set, the advertised Link-State ID is an AS boundary
>   router (E is for external). The advertising router and
>   the Link State ID belong to the same area.

>   Bit B - When set, the advertised Link state ID is an Area border
>   router (B is for Border)

Router-TE flags, Router-TE TLVs

>   TE capabilities of the link-state-ID router.

>   TE Flags and TE TLVs are as applicable to the ABR/ASBR specified
>   in the link state ID. The semantics is same as specified in the
>   Router-TE LSA.

8.5. TE-AS-external LSAs (0x85)

TE-AS-external LSAs are the Type 0x85 LSAs. This is modeled after
AS-external LSA format and flooding scope. TE-AS-external LSAs are
originated by AS boundary routers with TE extensions, and describe
the TE networks and pre-engineered circuit paths external to the AS.
As with AS-external LSA, the flooding scope of the TE-AS-external LSA
is AS-wide, with the exception of stub areas.

```
      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
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |            LS age              |    Options    |     0x85      |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                        Link State ID                          |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                      Advertising Router                       |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                      LS sequence number                       |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |         LS checksum           |             length            |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                        Network Mask                           |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                      Forwarding address                       |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                      External Route Tag                       |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |  #  of Virtual TE links       |               0               |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                        Link-TE flags                          |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                        Link-TE TLVs                           |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                           ...                                 |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                    TE-Forwarding address                      |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                    External Route TE Tag                      |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                           ...                                 |
```
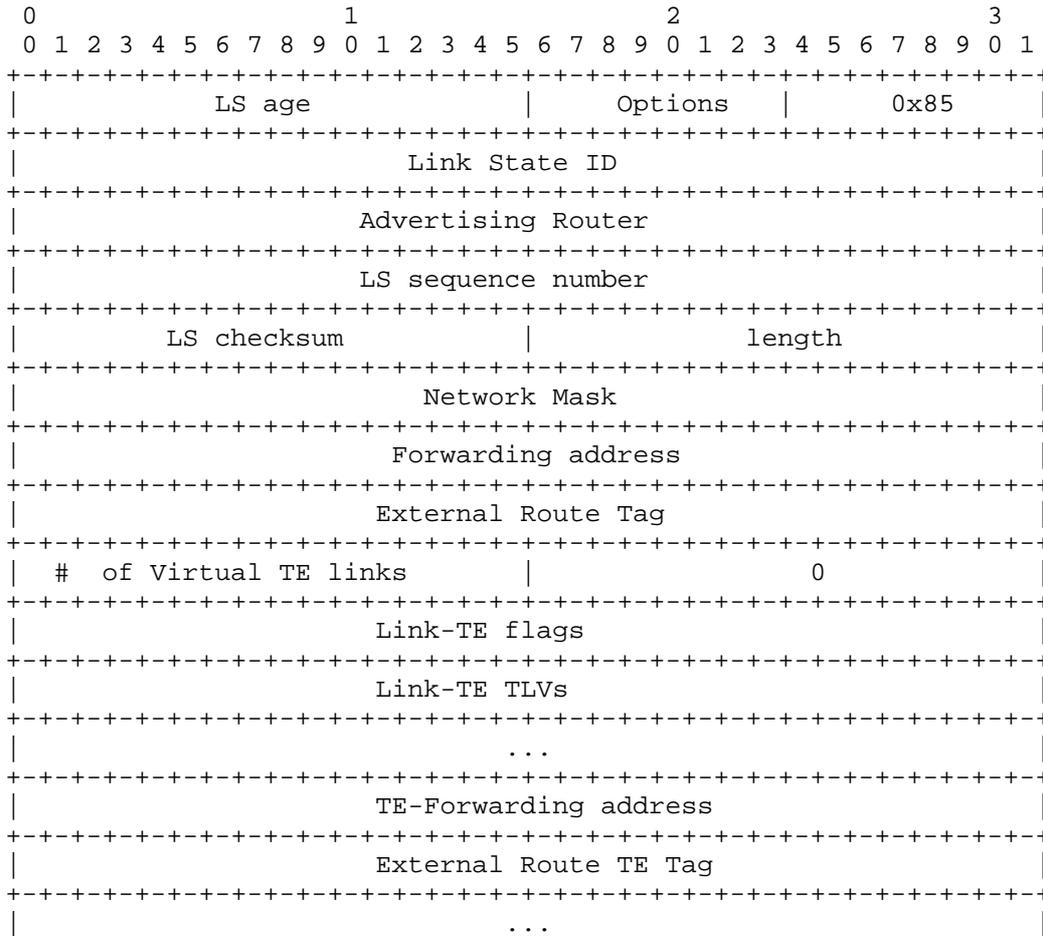
Network Mask

     The IP address mask for the advertised TE destination. For
     example, this can be used to specify access to a specific TE
     node or TE link with an mask of 0xffffffff. This can also be
     used to specify access to an aggregated set of destinations
     using a different mask. ex: 0xff000000.

Link-TE flags, Link-TE TLVs

     The TE attributes of this route. These fields are optional and
     are provided only when one or more pre-engineered circuits can
     be specified with the advertisement. Without these fields, the
     LSA will simply state TE reachability info.

   Forwarding address

       Data traffic for the advertised destination will be forwarded to
       this address. If the Forwarding address is set to 0.0.0.0, data
       traffic will be forwarded instead to the LSA's originator (i.e.,
       the responsible AS boundary router).

   External Route Tag

       A 32-bit field attached to each external route. This is not
       used by the OSPF protocol itself. It may be used to communicate
       information between AS boundary routers; the precise nature of
       such information is outside the scope of this specification.

9. TE LSAs for Non-Packet Network

   A non-packet network would use the TE LSAs described in the previous
   section for a packet network with some variations. These variations
   are described in the following subsections.

   Two new LSAs, TE-Positional-ring-network LSA and TE-Router-Proxy LSA
   are defined for use in non-packet TE networks.

   Readers may refer to [SONET-SDH] for a detailed description of the
   terms used in the context of SONET/SDH TDM networks,

9.1. TE-Router LSA (0x81)

   The following fields are used to describe each router link (i.e.,
   interface). Each router link is typed (see the below Type field).
   The Type field indicates the kind of link being described.

   Type

       A new link type "Positional-Ring Type" (value 5) is defined.
       This is essentially a connection to a TDM-Ring. TDM ring
       network is different from LAN/NBMA transit network in that nodes
       on the TDM ring do not necessarily have a terminating path
       between themselves. Second, the order of links is important in
       determining the circuit path. Third, the protection switching
       and the number of fibers from a node going into a ring are
       determined by the ring characteristics, for example, 2-fiber vs.
       4-fiber ring and Unidirectional Path Switched Ring (UPSR) vs.
       Bidirectional Line Switched Ring (BLSR).

```
          Type    Description
          _____
          1       Point-to-point connection to another router
          2       Connection to a transit network
          3       Connection to a stub network
          4       Virtual link
          5       Positional-Ring type.
```

   Link ID

      Identifies the object that this router link connects to. Value
      depends on the link's Type. For a positional-ring type, the
      Link ID shall be IP Network/Subnet number just as the case with
      a broadcast transit network. The following table summarizes the
      updated Link ID values.

```
          Type    Link ID
          _____
          1       Neighboring router's Router ID
          2       IP address of Designated Router
          3       IP network/subnet number
          4       Neighboring router's Router ID
          5       IP network/subnet number
```

   Link Data

      This depends on the link's Type field. For type-5 links, this
      specifies the router interface's IP address.

9.1.1 Router-TE flags - TE Capabilities of a Router

   Flags specific to non-packet TE nodes are described below.

```
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |L|L|P|T|L|F|                                       |S|S|S|C|
       |S|E|S|D|S|S|                                       |T|E|I|S|
       |R|R|C|M|C|C|                                       |A|L|G|P|
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |<---- Boolean TE flags ------->|<- TE flags pointing to TLVs ->|
```
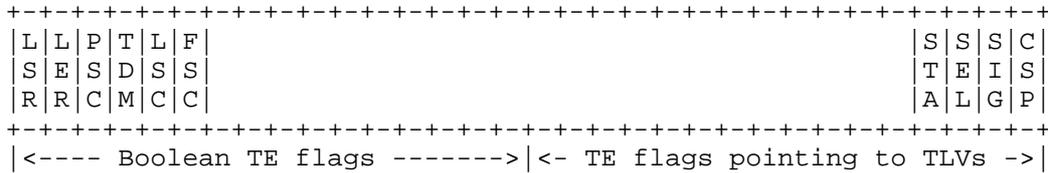
      Bit TDM - Indicates the node is TDM circuit switch capable.

      Bit LSC - Indicates the node is capable of Lambda switching.

      Bit FSC - Indicates the node is capable of fiber-switching (can
         also be a non-fiber link type).

9.1.2 Link-TE Options: TE Capabilities of a TE Link

```
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |T|N|P|T|L|F|D|                                       |S|L|B|C|
       |E|T|K|D|S|S|B|                                       |R|U|W|O|
       | |E|T|M|C|C|S|                                       |L|G|A|L|
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |<---- Boolean TE flags ------->|<- TE flags pointing to TLVs ->|
```
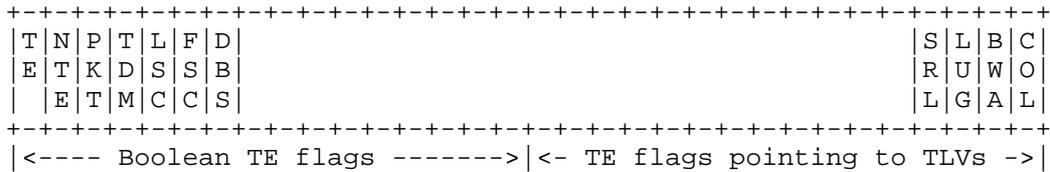
       TDM, LSC, FSC bits - Same as defined for router TE options.

9.2. TE-positional-ring-network LSA (0x82)

   Network LSA is adequate for packet TE networks. A new TE-
   positional-ring-network LSA is defined to represent type-5 link
   networks, found in non-packet networks such as SONET/SDH TDM rings.
   A type-5 ring is a collection of network elements (NEs) forming a
   closed loop. Each NE is connected to two adjacent NEs via a duplex
   connection to provide redundancy in the ring. The sequence in which
   the NEs are placed on the Ring is pertinent. The NE that provides
   the OSPF-xTE functionality is termed the Gateway Network Element
   (GNE). The GNE selection criteria is outside the scope of this
   document. The GNE is also termed the Designated Router for the ring.

   The TE-positional-ring-network LSA (0x82) is modeled after the
   network LSA and has the same flooding scope as the network LSA
   amongst the OSPF-xTE nodes within the area. Below is the format of
   the TE-Positional-Ring-network LSA. Unless specified explicitly
   otherwise, the fields carry the same meaning as they do in a network
   LSA. Only the differences are explained below.

   A TE-positional-ring-network LSA is originated for each Positional-
   Ring type network in the area. The tuple of (Link State ID, Network
   Mask) below uniquely represents a ring. The TE option must be set in
   the Options flag while propagating the LSA.

```
     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
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |              LS age            |    Options    |     0x82      |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                        Link State ID                          |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                     Advertising Router                        |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                     LS sequence number                        |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |        LS checksum             |             length           |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                       Network Mask                            |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |  Ring Type    | Capacity Unit |          Reserved             |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                       Ring capacity                           |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                  Network Element Node Id                      |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                            ...                                |
```
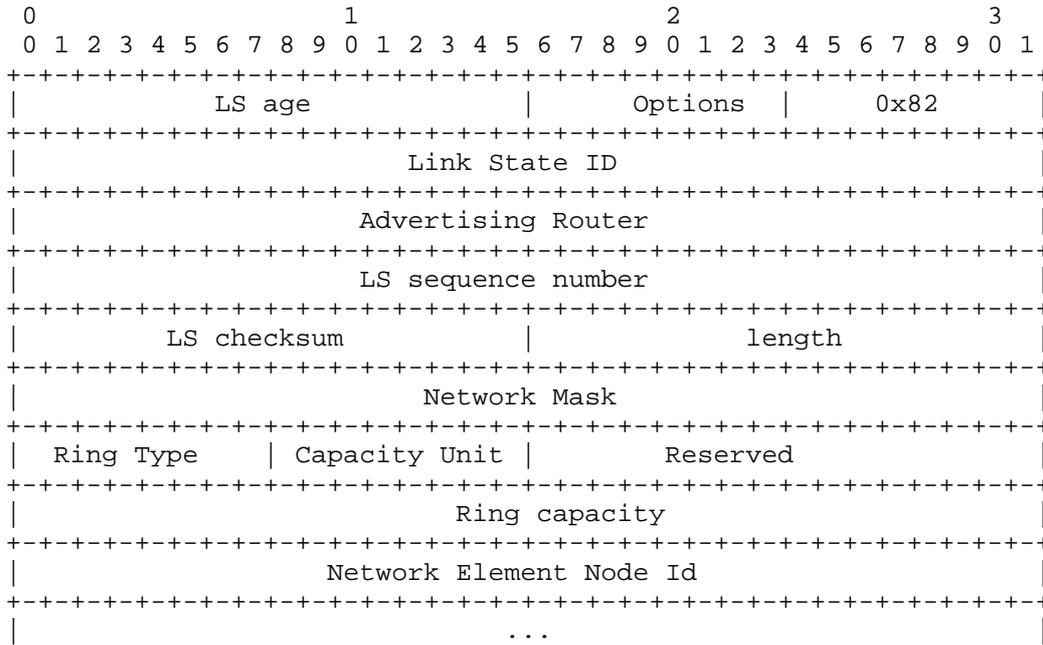
Link State ID

     This is the IP interface address of the network's Gateway
     Network Element, which is also the designated router.

Advertising Router

     Router ID of the network's Designated Router.

Ring type

     There are 8 types of SONET/SDH rings defined as follows.

     1 - A Unidirectional Line Switched 2-fiber ring (2-fiber ULSR)
     2 - A Bidirectional Line switched 2-fiber ring (2-fiber BLSR)
     3 - A Unidirectional Path Switched 2-fiber ring (2-fiber UPSR)
     4 - A Bidirectional Path switched 2-fiber ring (2-fiber BPSR)
     5 - A Unidirectional Line Switched 4-fiber ring (4-fiber ULSR)
     6 - A Bidirectional Line switched 4-fiber ring (4-fiber BLSR)
     7 - A Unidirectional Path Switched 4-fiber ring (4-fiber UPSR)
     8 - A Bidirectional Path switched 4-fiber ring (4-fiber BPSR)

Capacity Unit

     Two units are currently defined, as follows.

     1 - Synchronous Transport Signal (STS), which is the basic
         signal rate for SONET signals. The rate of an STS signal is
         51.84 Mbps

     2 - Synchronous Transport Multiplexer (STM), which is the basic
         signal rate for SDH signals. The rate of an STM signal is
         155.52 Mbps

Ring capacity

     Ring capacity expressed in number of Capacity Units.

Network Element Node Id

     The Router ID of each of the routers in the positional-ring
     network. The list must start with the designated router as the
     first element. The Network Elements (NEs) must be listed in
     strict clockwise order as they appear on the ring, starting with
     the Gateway Network Element (GNE). The number of NEs in the
     ring can be deduced from the LSA header's length field.

9.3. TE-Router-Proxy LSA (0x8e)

   This is a variation to the TE-router LSA in that the TE-router LSA is
   not advertised by the network element, but rather by a trusted TE-
   router Proxy. This is typically the scenario in a non-packet TE
   network, where some of the nodes do not have OSPF functionality and
   count on a helper node to do the advertisement for them. One such
   example would be the SONET/SDH Add-Drop Multiplexer (ADM) nodes in a
   TDM ring. The nodes may principally depend upon the GNE (Gateway
   Network Element) to do the advertisement for them. TE-router-Proxy
   LSA shall not be used to advertise area border routers and/or AS
   border routers.

```
     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
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |             LS age             |    Options     |    0x8e     |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |     Link State ID  (Router ID of the TE Network Element)     |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                      Advertising Router                      |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                     LS sequence number                      |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |        LS checksum            |            length            |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |              0                |        Router-TE flags        |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |   Router-TE flags (contd.)    |        Router-TE TLVs         |
    +-------------------------------------------------------------+
    |                          ....                               |
    +-------------------------------------------------------------+
    |                    ....       |       # of TE links          |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                          Link ID                            |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                         Link Data                           |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |    Type       |       0       |       Link-TE options        |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |   Link-TE flags               |   Zero or more Link-TE TLVs  |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                          Link ID                            |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                         Link Data                           |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                          ...                                |
```
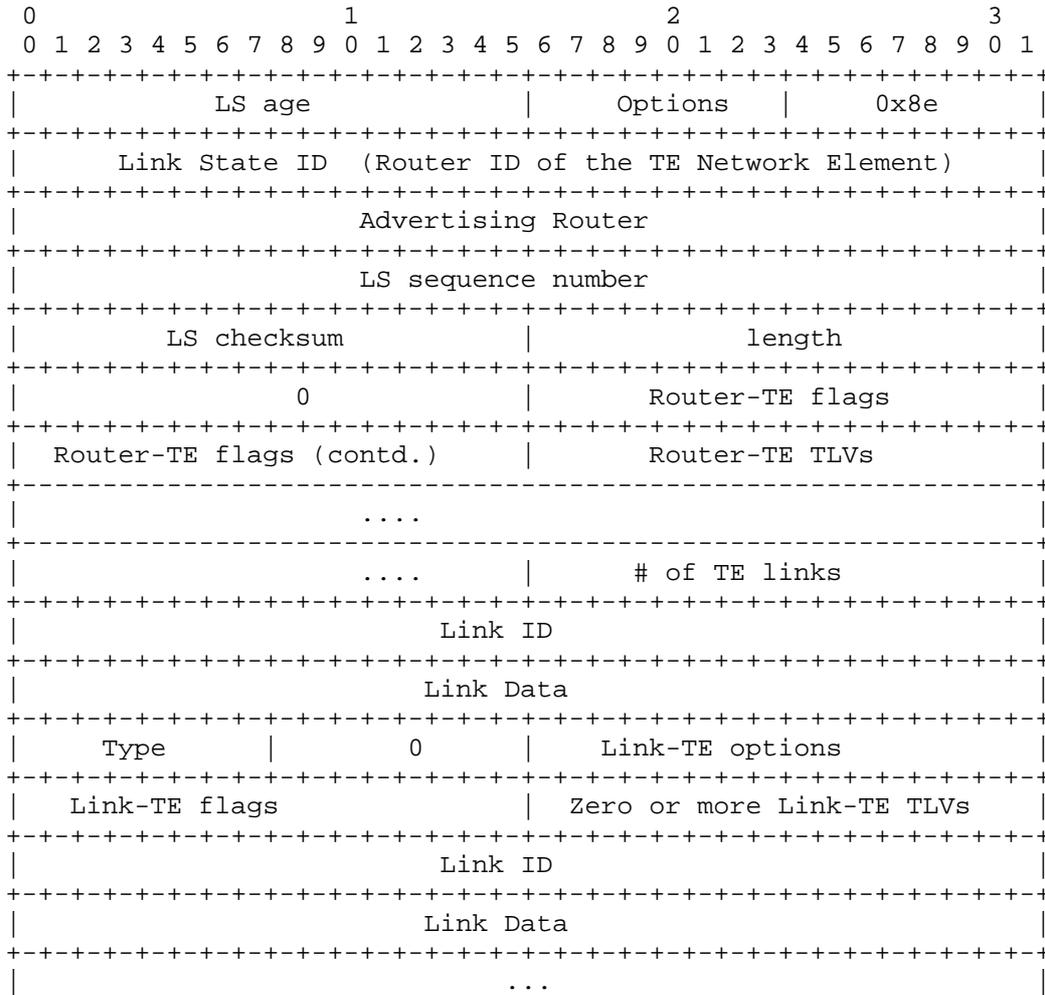
10. Abstract Topology Representation with TE Support

   Below, we consider a TE network composed of three OSPF areas, Area-1,
   Area-2 and Area-3, attached together through the backbone area.
   Area-1 an has a single area border router, ABR-A1 and no ASBRs.
   Area-2 has an area border router ABR-A2 and an AS border router
   ASBR-S1. Area-3 has two area border routers ABR-A2 and ABR-A3 and an
   AS border router ASBR-S2. The following network also assumes a pre-
   engineered TE circuit path between ABR-A1 and ABR-A2; between ABR-A1
   and ABR-A3; between ABR-A2 and ASBR-S1; and between ABR-A3 and ASBR-
   S2.

   The following figure is an inter-area topology abstraction from the
   perspective of routers in Area-1. The abstraction illustrates
   reachability of TE networks and nodes within area to the external
   areas in the same AS and to the external ASes. The abstraction also
   illustrates pre-engineered TE circuit paths advertised by ABRs and
   ASBRs.

```
                          +-------+
                          |Area-1 |
                          +-------+
+-------------+               |
|Reachable TE |          +--------+
|networks in  |-------|  ABR-A1 |
|backbone area|          +--------+
+-------------+            | | |
          +-------------+  | +----------------+
          |             |  |                  |
+----------------+      |        +----------------+
|Pre-engineered TE|     +----------+  |Pre-engineered TE|
|circuit path(s) |     | Backbone |  |circuit path(s) |
|to ABR-A2       |     | Area     |  |to ABR-A3       |
+----------------+     +----------+  +----------------+
      |         +---------+   | |  +-------------+   |
+-----------+   |        |   |  +--------------+ |
|Reachable  |   +--------+   |        | |  +-----------+
|TE networks|------|  ABR-A2 |        | ABR-A3 |--|TE networks|
|in Area A2 |   +--------+        +--------+  |in Area A3 |
+-----------+     | | | |                | |  +-----------+
    +------------+ | | +----------------+ | +----------+
    |            |   | +-----------+     | |          |
+-----------+ +--------------+     |     | |  +--------------+
|Reachable  | |Pre-engineered|     |     | |  |Pre-engineered|
|TE networks| |TE Ckt path(s)| +------+  +------+ |TE Ckt path(s)|
|in Area A3 | |to ASBR-S1    | |Area-2|  |Area-3| |to ASBR-S2    |
+-----------+ +--------------+ +------+  +------+ +--------------+
                  |           |          |          |
                  | +--------+           |  +-----------+
+-------------+   | |        |           |  |
|AS external  |   +---------+        +---------+
|TE-network   |----|  ASBR-S1 |        | ASBR-S2 |
|reachability |   +---------+        +---------+
|from ASBR-S1 |     |                   | |
+-------------+   +---+             +-------+  +-----------+
    |             |                   |          |
+----------------+   +------------+  +----------------+
|Pre-engineered TE|  |AS External  |  |Pre-engineered TE|
|circuit path(s) |  |TE-Network   |  |circuit path(s) |
|reachable from  |  |reachability |  |reachable from  |
|ASBR-S1         |  |from ASBR-S2 |  |ASBR-S2         |
+----------------+   +------------+  +----------------+
```

          Figure 3: Inter-Area Abstraction as viewed by Area-1 TE-routers

11. Changes to Data Structures in OSPF-xTE Nodes

11.1. Changes to Router Data Structure

   An OSPF-xTE router must be able to include the router-TE capabilities
   (as specified in section 8.1) in the router data structure. OSPF-xTE
   routers providing proxy service to other TE routers must also track
   the router and associated interface data structures for all the TE
   client nodes for which the proxy service is being provided.
   Presumably, the interaction between the Proxy server and the proxy
   clients is out-of-band.

11.2. Two Sets of Neighbors

   Two sets of neighbor data structures are required. TE-neighbors set
   is used to advertise TE LSAs. Only the TE nodes will be members of
   the TE-neighbor set. Native neighbors set will be used to advertise
   native LSAs. All neighboring nodes supporting non-TE links are part
   of the Native neighbors set.

11.3. Changes to Interface Data Structure

   The following new fields are introduced to the interface data
   structure.

   TePermitted

      If the value of the flag is TRUE, the interface may be advertised
      as a TE-enabled interface.

   NonTePermitted

      If the value of the flag is TRUE, the interface permits non-TE
      traffic on the interface. Specifically, this is applicable to
      packet networks, where data links may permit both TE and IP
      packets. For FSC and LSC TE networks, this flag is set to FALSE.

   FloodingPermitted

      If the value of the flag is TRUE, the interface may be used for
      OSPF and OSPF-xTE packet exchange to synchronize the LSDB across
      all adjacent neighbors. This is TRUE by default to all
      NonTePermitted interfaces that are enabled for OSPF. However, it
      is possible to set this to FALSE for some of the interfaces.

TE-TLVs

>   Each interface may define any number of TLVS that describe the
>   link characteristics.

The following existing fields in Interface data structure will take
on additional values to support TE extensions.

Type

>   The OSPF interface type can also be of type "Positional-Ring".
>   The Positional-Ring type is different from other types (such as
>   broadcast and NBMA) in that the exact location of the nodes on
>   the ring is relevant, even though they are all on the same ring.
>   SONET ADM ring is a good example of this. Complete ring
>   positional-ring description may be provided by the GNE on a ring
>   as a TE-network LSA for the ring.

List of Neighbors

>   The list may be statically defined for an interface without
>   requiring the use of Hello protocol.

12. IANA Considerations

The IANA has assigned multicast address 224.0.0.24 to OSPFIGP-TE for
the exchange of TE database descriptors.

TE LSA types and TE TLVs will be maintained by the IANA, using the
following criteria.

12.1. TE LSA Type Values

LSA type is an 8-bit field required by each LSA. TE LSA types will
have the high bit set to 1. TE LSAs can range from 0x80 through
0xFF. The following values are defined in sections 8.0 and 9.0. The
remaining values are available for assignment by the IANA with IETF
Consensus [RFC2434].

```
            TE LSA Type                       Value

            _____
            TE-Router LSA                     0x81
            TE-Positional-ring-network LSA    0x82
            TE-Summary Network LSA            0x83
            TE-Summary router LSA             0x84
            TE-AS-external LSAs               0x85
            TE-Circuit-paths LSA              0x8C
            TE-incremental-link-Update LSA    0x8d
            TE-Router-Proxy LSA               0x8e
```

12.2. TE TLV Tag Values

   TLV type is a 16-bit field required by each TE TLV. TLV type shall
   be unique across the router and link TLVs. A TLV type can range from
   0x0001 through 0xFFFF. TLV type 0 is reserved and unassigned. The
   following TLV types are defined in sections 8.0 and 9.0. The
   remaining values are available for assignment by the IANA with IETF
   Consensus [RFC2434].

```
    TE TLV Tag                         Reference      Value
                                       Section

    _____

    TE-LINK-TLV-SRLG                   Section 8.1.4.1  0x0001
    TE-LINK-TLV-BANDWIDTH-MAX          Section 8.1.4.2  0x0002
    TE-LINK-TLV-BANDWIDTH-MAX-FOR-TE   Section 8.1.4.3  0x0003
    TE-LINK-TLV-BANDWIDTH-TE           Section 8.1.4.4  0x0004
    TE-LINK-TLV-LUG                    Section 8.1.4.5  0x0005
    TE-LINK-TLV-COLOR                  Section 8.1.4.6  0x0006
    TE-LINK-TLV-NULL                   Section 8.1.4.7  0x8888
    TE-NODE-TLV-MPLS-SWITCHING         Section 8.1.2.1  0x8001
    TE-NODE-TLV-MPLS-SIG-PROTOCOLS     Section 8.1.2.2  0x8002
    TE-NODE-TLV-CSPF-ALG               Section 8.1.2.3  0x8003
    TE-NODE-TLV-NULL                   Section 8.1.2.4  0x8888
```

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   document (now defunct) titled "Flooding optimizations in link state
   routing protocols". The document provided inspiration to the authors
   to be sensitive to the high flooding rate, likely in TE networks.

14. Security Considerations

   Security considerations for the base OSPF protocol are covered in
   [OSPF-V2] and [SEC-OSPF]. This memo does not create any new security
   issues for the OSPF protocol. Security measures applied to the
   native OSPF (refer [SEC-OSPF]) are directly applicable to the TE LSAs
   described in the document. Discussed below are the security
   considerations in processing TE LSAs.

   Secure communication between OSPF-xTE nodes has a number of
   components. Authorization, authentication, integrity and
   confidentiality. Authorization refers to whether a particular OSPF-
   xTE node is authorized to receive or propagate the TE LSAs to its
   neighbors. Failing the authorization process might indicate a
   resource theft attempt or unauthorized resource advertisement. In
   either case, the OSPF-xTE nodes should take proper measures to
   audit/log such attempts so as to alert the administrator to take
   necessary action. OSPF-xTE nodes may refuse to communicate with the
   neighboring nodes that fail to prompt the required credentials.

   Authentication refers to confirming the identity of an originator for
   the datagrams received from the originator. Lack of strong
   credentials for authentication of OSPF-xTE LSAs can seriously
   jeopardize the TE service rendered by the network. A consequence of
   not authenticating a neighbor would be that an attacker could spoof
   the identity of a "legitimate" OSPF-xTE node and manipulate the
   state, and the TE database including the topology and metrics
   collected. This could potentially cause denial-of-service on the TE
   network. Another consequence of not authenticating is that an
   attacker could pose as OSPF-xTE neighbor and respond in a manner that
   would divert TE data to the attacker.

   Integrity is required to ensure that an OSPF-xTE message has not been
   accidentally or maliciously altered or destroyed. The result of a
   lack of data integrity enforcement in an untrusted environment could
   be that an imposter will alter the messages sent by a legitimate
   adjacent neighbor and bring the OSPF-xTE on a node and the whole
   network to a halt or cause a denial of service for the TE circuit
   paths effected by the alteration.

   Confidentiality of OSPF-xTE messages ensures that the TE LSAs are
   accessible only to the authorized entities. When OSPF-xTE is
   deployed in an untrusted environment, lack of confidentiality will
   allow an intruder to perform traffic flow analysis and snoop the TE
   control network to monitor the traffic metrics and the rate at which
   circuit paths are being setup and torn-down. The intruder could
   cannibalize a lesser secure OSPF-xTE node and destroy or compromise
   the state and TE-LSDB on the node. Needless to say, the least secure

   OSPF-xTE will become the Achilles heel and make the TE network
   vulnerable to security attacks.

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