                       OSPF Topology-Transparent Zone

Abstract

   This document presents a Topology-Transparent Zone (TTZ) in an OSPF
   area. A TTZ comprises a group of routers and a number of links
   connecting these routers. Any router outside of the zone is not
   aware of the zone. A TTZ hides the internal topology of the TTZ from
   the outside. It does not directly advertise any internal information
   about the TTZ to a router outside of the TTZ. The information about
   the links and routers such as a link down inside the TTZ is not
   advertised to any router outside of the TTZ.

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1. Introduction

   Networks expand as business grows and traffic increases. For
   scalability and manageability, a hierarchical network architecture is
   usually deployed in OSPF networks by regrouping routers into areas,
   which is often challenging and causes service interruptions.

   At first, reorganizing a network from one area into multiple areas or
   from a number of existing areas into even more areas is a very
   challenging and time-consuming task since it involves significant
   network architecture changes. Considering the one area case,
   originally the network has only one area, which is the backbone.
   This original backbone area will be reorganized into a new backbone
   and a number of non-backbone areas. In general, each of the
   non-backbone areas is connected to the new backbone area through the
   Area Border Routers (ABRs) between the non-backbone and the backbone
   area (refer to RFC 2328, Section 3). It demands careful redesigning
   of network topology in advance to guarantee backbone area continuity
   and non-backbone-area reachability, and it requires significant
   modifications of configurations on many routers to ensure consistent
   routing.

   Second, the services carried by the network may be interrupted while
   the network is being reorganized from one area into multiple areas or
   from a number of existing areas into even more areas since every OSPF
   interface with an area change is going down with its old area and
   then up with a new area.

   This document presents a Topology-Transparent Zone (TTZ) in an OSPF
   area and describes extensions to OSPFv2 for supporting the TTZ, which
   is scalable and resolves the issues above. A TTZ hides the internal
   topology of the TTZ from the outside. It does not directly advertise
   any internal information about the TTZ to any router outside of the
   TTZ.

2. Terminology

   TTZ link or TTZ-internal link:
      A link whose ends are within a single TTZ.

   TTZ-internal router:
      A router whose links are TTZ-internal links inside a single TTZ.

   TTZ-external router:
      A router outside of a TTZ that has no TTZ-internal links.

   TTZ-external link:
      A link not configured to be within a TTZ.

   TTZ edge router:
      A router is called a TTZ edge router if some, but not all, of its
      links are within a single TTZ.

   TTZ router:
      A TTZ-internal router or a TTZ edge router.

3. Conventions Used in This Document

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

4. Requirements

   A Topology-Transparent Zone may be deployed to resolve some critical
   issues in existing networks and future networks. The requirements
   for a TTZ are listed as follows:

   o Routers outside a TTZ MUST NOT require any changes to operate with
      the TTZ.

   o A TTZ MUST be enclosed in a single area.

   o A TTZ MUST hide the topology of the TTZ from any router outside of
      the TTZ.

5. Topology-Transparent Zone

5.1. Overview of Topology-Transparent Zone

   A Topology-Transparent Zone is identified by a TTZ identifier (ID),
   and it consists of a group of routers and a number of links
   connecting the routers. A TTZ MUST be contained within an OSPF area.

   A TTZ ID is a 32-bit number that is unique for identifying a TTZ.
   The TTZ ID SHOULD NOT be 0 in order to avoid confusion with Area 0.
   The same TTZ ID MUST be configured on the routers and/or links that
   make up a specific instance of a TTZ. All TTZ instances in an OSPF
   area MUST be unique.

   In addition to having similar functions of an OSPF area, an OSPF TTZ
   makes some improvements on an OSPF area, which include:

   o An OSPF TTZ represents a set of TTZ edge routers, connected by a
      full mesh of virtual connections between them.

   o Non-TTZ link-state information is handled as normal. TTZ routers
      receive the link-state information about the topology outside of
      the TTZ, store the information, and flood the information through
      the TTZ to the routers outside of the TTZ.

5.2. TTZ Example

   The figure below shows an area containing a TTZ: TTZ 600.

```
                    TTZ 600                        ---- TTZ-Internal Link
                       \                           ==== Normal Link
     Area X             \  ^~^~^~^~^~^~^~^~^~^~^~^~^~
                           (                       )
     ===[R15]========(==[T61]----[T81]---[T63]==)======[R29]===
         ||           (    |      \        /     |   )       ||
         ||           (    |       \      /      |   )       ||
         ||           ( [T75]       \    /       |   )       ||
         ||           (    |      ___\  /        |   )       ||
         ||           (    |     /    [T71]     [T79] )       ||
         ||           (    | [T73] /      \      |   )       ||
         ||           (    |      /        \     |   )       ||
         ||           (    |     /          \    |   )       ||
         ||           (    |    /            \   |   )       ||
     ===[R17]========(==[T65]---[T77]----[T67]==)======[R31]===
          \\           (//                    \\)       //
           ||         //v~v~v~v~v~v~v~v~v~v~v~v~\\      ||
           ||        //                         \\     ||
           ||       //                           \\    ||
            \\     //                             \\  //
        ======[R23]============================[R25]=====
             //                                     \\
            //                                       \\
```
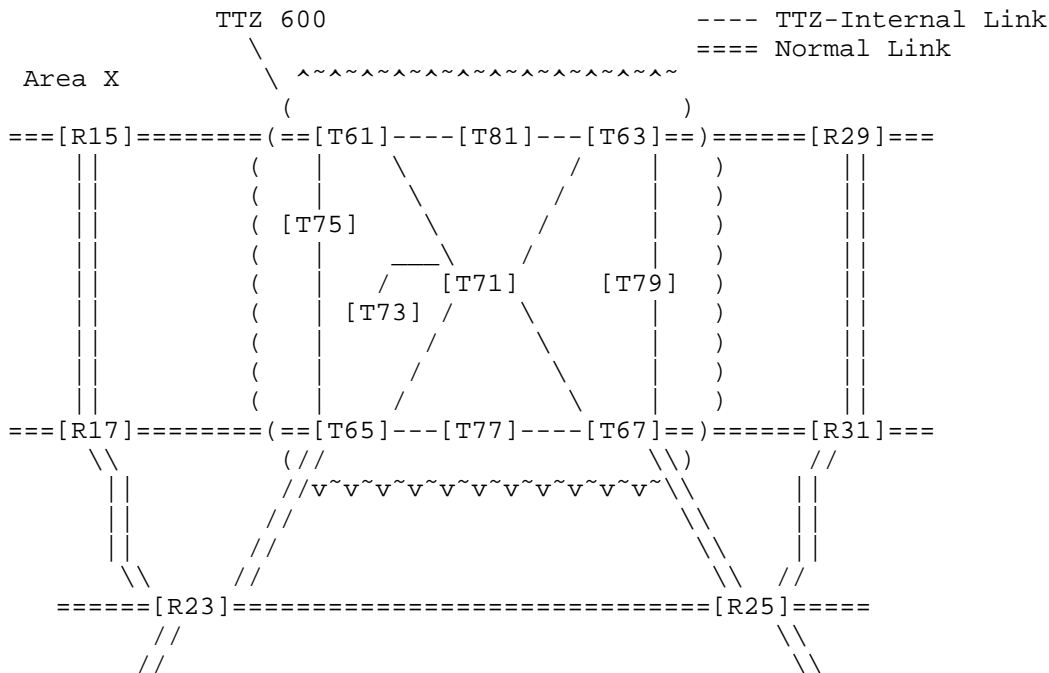
   All the routers in the figure are in area X. Routers with T (i.e.,
   T61, T63, T65, T67, T71, T73, T75, T77, T79, and T81) are also in TTZ
   600, which contains the TTZ-internal links connecting them. To
   create a TTZ, we need to configure it (refer to Section 11).

   There are two types of routers in a TTZ: TTZ-internal and TTZ edge
   routers. TTZ 600 has four TTZ edge routers: T61, T63, T65, and T67.
   Each of them has at least one adjacent router in TTZ 600 and one
   adjacent router outside of TTZ 600. For instance, router T61 is a
   TTZ edge router since it has an adjacent router, R15, outside of TTZ
   600 and three adjacent routers T71, T75, and T81 in TTZ 600.

   In addition, TTZ 600 comprises six TTZ-internal routers: T71, T73,
   T75, T77, T79, and T81. Each of them has all its adjacent routers in
   TTZ 600. For instance, router T71 is a TTZ-internal router since its

adjacent routers, T61, T63, T65, T67, and T73, are all in TTZ 600.
It should be noted that, by definition, a TTZ-internal router cannot
also be an ABR.

A TTZ hides the internal topology of the TTZ from the outside. It
does not directly advertise any internal information about the TTZ to
any router outside of the TTZ.

For instance, TTZ 600 does not send the information about TTZ-
internal router T71 to any router outside of TTZ 600; it does not
send the information about the link between TTZ routers T61 and T71
to any router outside of TTZ 600.

The figure below illustrates area X from the point of view of a
router outside of TTZ 600 after TTZ 600 is created.

```
   Area X                                       ==== Normal Link


   ===[R15]==========[T61]========[T63]========[R29]===
      ||              ||  \\       //  ||           ||
      ||              ||   \\     //   ||           ||
      ||              ||    \\   //    ||           ||
      ||              ||     \\//      ||           ||
      ||              ||     //\       ||           ||
      ||              ||    // \\      ||           ||
      ||              ||   //   \\     ||           ||
      ||              ||  //     \\    ||           ||
      ||              || //       \\   ||           ||
   ===[R17]==========[T65]========[T67]========[R31]===
       \\          //              \\          //
       ||        //                  \\       ||
       ||      //                      \\     ||
       ||    //                          \\   ||
        \\  //                             \\ //
       ======[R23]==========================[R25]=====
           //                                  \\
          //                                    \\
```

From a router outside of the TTZ, a TTZ is seen as the TTZ edge
routers connected to each other. For instance, router R15 sees that
T61, T63, T65, and T67 are connected to each other.

In addition, a router outside of the TTZ sees TTZ edge routers having
normal connections to the routers outside of the TTZ. For example,
router R15 sees that T61, T63, T65, and T67 have the normal
connections to R15; R29; R17 and R23; and R25 and R31, respectively.

6. Extensions to OSPF Protocols

   The link-state information about a TTZ includes router Link-State
   Advertisements (LSAs), which can be contained and advertised in
   opaque LSAs [RFC5250] within the TTZ. Some control information
   regarding a TTZ can also be contained and advertised in opaque LSAs
   within the TTZ. These opaque LSAs are called TTZ opaque LSAs or TTZ
   LSAs for short.

6.1. General Format of TTZ LSA

   The following is the general format of a TTZ LSA. It has a Link-
   State (LS) Type = 10/9 and TTZ LSA Type, and it contains a number of
   TLVs.

```
    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     | LS Type = 10/9|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |TTZ LSA Type(9)|                 Instance ID                    |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                      Advertising Router                       |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                      LS Sequence Number                       |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |         LS checksum           |             Length            |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
   ~                             TLVs                              ~
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
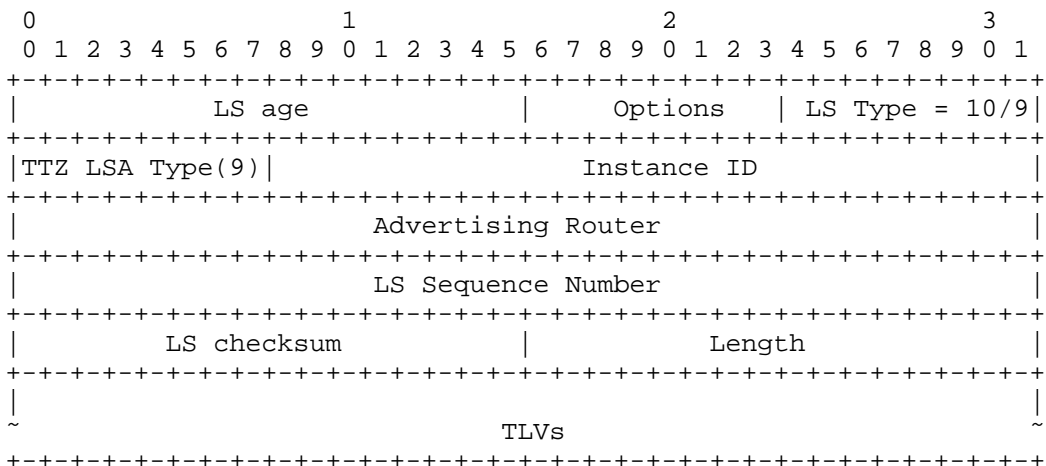
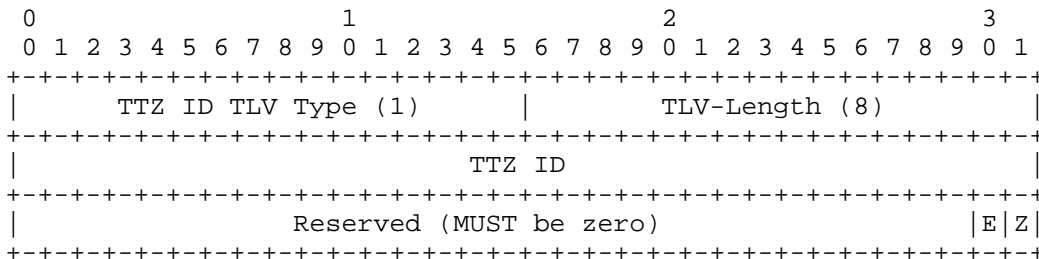   There are three TTZ LSAs of LS Type 10 defined:

   o TTZ router LSA: a TTZ LSA containing a TTZ ID TLV and a TTZ Router
      TLV.

   o TTZ control LSA: a TTZ LSA containing a TTZ ID TLV and a TTZ
      Options TLV.

   o TTZ indication LSA: a TTZ LSA containing a TTZ ID TLV with E = 0,
      which indicates that the router originating this LSA is a TTZ-
      internal router.

   There is one TTZ LSA of LS Type 9:

   o TTZ discovery LSA: a TTZ LSA containing a TTZ ID TLV and an
      optional TTZ Options TLV.

6.2. TTZ ID TLV

   A TTZ ID TLV has the following format. It contains a TTZ ID (refer
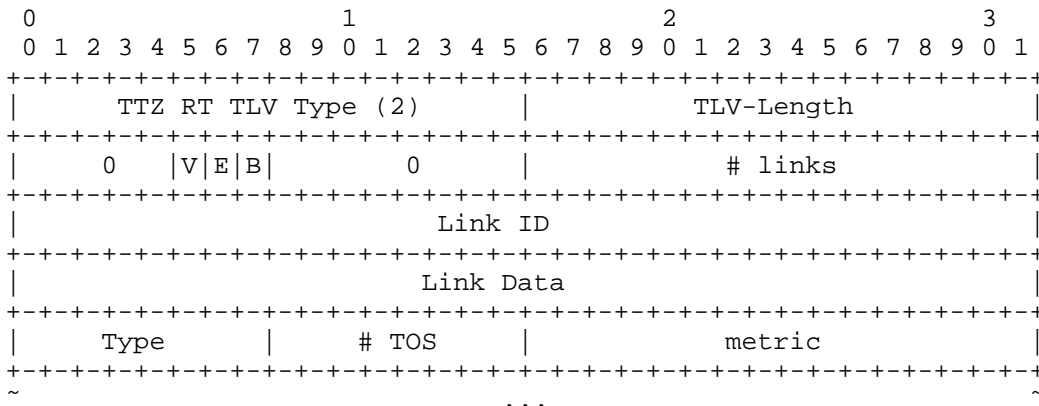   to Section 5.1) and some flags. It has the TLV-Length of 8 octets.

```
      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
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |        TTZ ID TLV Type (1)     |        TLV-Length (8)         |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                            TTZ ID                             |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |            Reserved (MUST be zero)                       |E|Z|
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

      E = 1: Indicating a router is a TTZ edge router
      Z = 1: Indicating a router has migrated to TTZ

   When a TTZ router originates a TTZ LSA containing a TTZ ID TLV, it
   MUST set flag E to 1 in the TTZ ID TLV if it is a TTZ edge router and
   to 0 if it is a TTZ-internal router. It MUST set flag Z to 1 after
   it has migrated to TTZ and to 0 before it migrates to TTZ or after it
   rolls back from TTZ (refer to Section 6.4).

6.3. TTZ Router TLV

   The format of a TTZ Router TLV is as follows. It has the same
   content as a standard OSPF router LSA (RFC 2328) with the following
   modifications.

```
      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
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |      TTZ RT TLV Type (2)       |           TLV-Length          |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |     0    |V|E|B|       0       |            # links            |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                            Link ID                            |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                           Link Data                           |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |      Type      |      # TOS     |            metric            |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     ~                              ...                              ~
```

   Note: TOS = Type of Service

For a router link, the existing 8-bit Link Type field for a router
link is split into two fields as follows:

```
   0   1   2   3   4   5   6   7
 +---+---+---+---+---+---+---+---+
 | I |          Type-1           |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
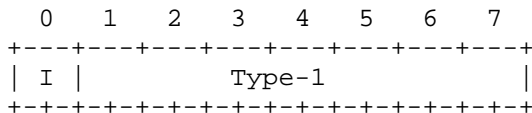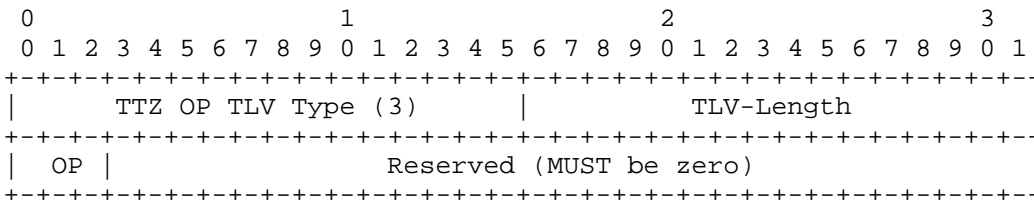
```
 I bit flag:
   1: Router link is a TTZ-internal link.
   0: Router link is a TTZ-external link.
 Type-1: The kind of the link.  The values for Type-1 are the same
         as those for Type defined in RFC 2328, Section 12.4.1.
```

The Link Type field is 8 bits and the values 128-255 of the field are
reserved (refer to [RFC4940]), which allows the reuse of the bottom 7
bits to indicate the type of TTZ-internal or external link.

6.4. TTZ Options TLV

The format of a TTZ Options TLV is as follows.

```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |      TTZ OP TLV Type (3)       |           TLV-Length          |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   | OP  |               Reserved (MUST be zero)                   |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

```
 OP Value    Meaning (Operation)
 0x001 (T):  Advertising TTZ Topology Information for Migration
 0x010 (M):  Migrating to TTZ
 0x011 (N):  Advertising Normal Topology Information for Rollback
 0x100 (R):  Rolling Back from TTZ
```

An OP field of 3 bits is defined. It may have a value of 0x001 for
T, 0x010 for M, 0x011 for N, or 0x100 for R, which indicates one of
the four operations above. When any of the other values is received,
it is ignored.

Advertising TTZ Topology Information for Migration (T):
    After a user configures a TTZ router to advertise TTZ topology
    information, advertising TTZ topology information for migration
    is triggered. The TTZ router originates a TTZ control LSA having
    a TTZ Options TLV with OP for T. It also originates its other

TTZ LSA such as a TTZ router LSA or TTZ indication LSA. When
another TTZ router receives the LSA with OP for T, it originates
its TTZ LSA as described in Section 7.

Migrating to TTZ (M):
    After a user configures a TTZ router to migrate to TTZ, migrating
    to TTZ is triggered. The TTZ router originates a TTZ control LSA
    having a TTZ Options TLV with OP for M and migrates to TTZ. When
    another TTZ router receives the LSA with OP for M, it also
    migrates to TTZ. When a router migrates to TTZ, it computes
    routes using the TTZ topology and the topology outside of the
    TTZ. For a TTZ-internal router, it also updates its TTZ
    indication LSA with Z = 1. For a TTZ edge router, it updates its
    TTZ router LSA with Z = 1 and its router LSA for virtualizing the
    TTZ. A TTZ router determines whether it is internal or edge
    based on configurations (refer to Section 11.1).

Advertising Normal Topology Information for Rollback (N):
    After a user configures a TTZ router to advertise normal topology
    information, advertising Normal topology information for rollback
    is triggered. The TTZ router originates a TTZ control LSA having
    a TTZ Options TLV with OP for N. It also advertises its normal
    LSAs such as its normal router LSA and stops advertising its
    other TTZ LSAs. When another TTZ router receives the LSA with OP
    for N, it forwards the LSA, advertises its normal LSAs, and stops
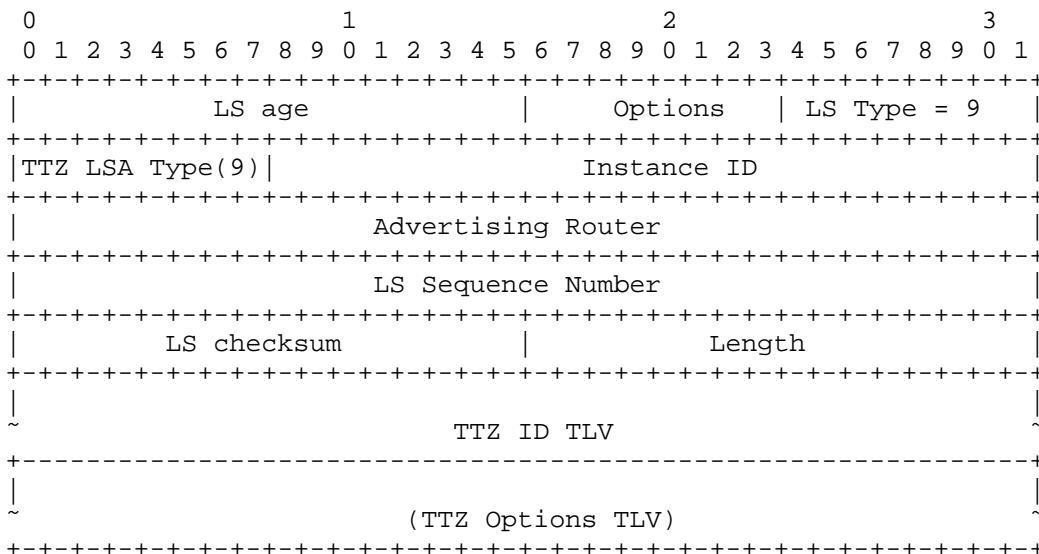   advertising its TTZ LSAs.

Rolling back from TTZ (R):
    After a user configures a TTZ router to roll back from TTZ,
    rolling back from TTZ is triggered. The TTZ router originates a
    TTZ control LSA having a TTZ Options TLV with OP for R and rolls
    back from TTZ. When another TTZ router receives the LSA with OP
    for R, it also rolls back from TTZ.

After a TTZ router originates a TTZ control LSA in response to a
configuration described above to control TTZ, it flushes the TTZ
control LSA if OP in the LSA is set for the configuration and the
configuration is removed.

6.5. Link Scope TTZ LSA

   A TTZ LSA of LS Type 9 has the following format.

```
       0                   1                   2                   3
       0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |             LS age             |     Options   | LS Type = 9   |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |TTZ LSA Type(9)|                  Instance ID                  |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                     Advertising Router                        |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                     LS Sequence Number                        |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |        LS checksum             |             Length           |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                                                               |
      ~                         TTZ ID TLV                            ~
      +---------------------------------------------------------------+
      |                                                               |
      ~                       (TTZ Options TLV)                       ~
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   It contains a mandatory TTZ ID TLV, which may be followed by an
   optional TTZ Options TLV. It is used to discover a TTZ neighbor.

7. Constructing LSAs for TTZ

   For a TTZ, its topology is represented by the LSAs generated by its
   TTZ routers for the link states in the TTZ, which include TTZ router
   LSAs by TTZ edge routers, TTZ indication LSAs by TTZ-internal
   routers, normal router LSAs, and network LSAs. The TTZ router LSAs
   and TTZ indication LSAs MUST be generated after advertising TTZ
   topology information for migration is triggered.

   A TTZ edge router generates a TTZ router LSA that has a TTZ ID TLV
   and a TTZ Router TLV. The former includes the ID of the TTZ to which
   the router belongs and flag E is set to 1, which indicates the
   originator of the LSA is a TTZ edge router. The TTZ Router TLV
   contains the TTZ-external links to the routers outside of the TTZ and
   the TTZ-internal links to the routers inside of the TTZ as described
   in Section 6. The TTZ router LSA containing this TLV is constructed
   and advertised within the TTZ.

   A TTZ-internal router generates a TTZ indication LSA that has a TTZ
   ID TLV containing the ID of the TTZ to which the router belongs and
   flag E is set to 0, which indicates the originator of the LSA is a

TTZ-internal router. For a TTZ-internal router, its regular router
LSA is still generated. If a TTZ router is a Designated Router (DR),
it originates its regular network LSA.

After receiving a trigger to migrate to TTZ such as a TTZ control LSA
with OP for M, a TTZ edge router MUST originate its normal router LSA
for virtualizing a TTZ, which comprises three groups of links in
general.

The first group is the router links connecting the TTZ-external
routers. These router links are normal router links. There is a
router link for every adjacency between this TTZ edge router and a
TTZ-external router.

The second group is the "virtual" router links connecting to the
other TTZ edge routers. For each of the other TTZ edge routers,
there is a corresponding point-to-point (P2P) router link to it from
this TTZ edge router. The cost of the link is the cost of the
shortest path from this TTZ edge router to the other TTZ edge router
within the TTZ.

In addition, the LSA may contain a third group of links, which are
the stub links for the loopback addresses inside the TTZ to be
accessed by nodes outside of the TTZ.

7.1. TTZ Migration Process

   After migration to TTZ is triggered, a TTZ router computes routes
   using its TTZ topology (refer to Section 10), and a TTZ edge router
   originates its normal router LSA for virtualizing the TTZ in two
   steps:

   Step 1: The router updates its router LSA by adding a P2P link to
      each of the other known edge routers in the TTZ and also by adding
      the stub links for the loopback addresses in the TTZ to be
      accessed outside of the TTZ according to configuration policies of
      operators.

   Step 2: After MaxLSAGenAdvTime (0.3 s) or sr-time + MaxLSAAdvTime
      (0.1 s), it removes the TTZ links from its router LSA, where
      sr-time is the time from updating its router LSA to receiving the
      ack for its router LSA and receiving the updated router LSAs
      originated by the other TTZ edge routers. In other words, it
      removes the TTZ links from its router LSA after sending its
      updated router LSA and receiving the updated router LSAs
      originated by the other TTZ edge routers for MaxLSAAdvTime or
      after sending its updated router LSA for MaxLSAGenAdvTime.
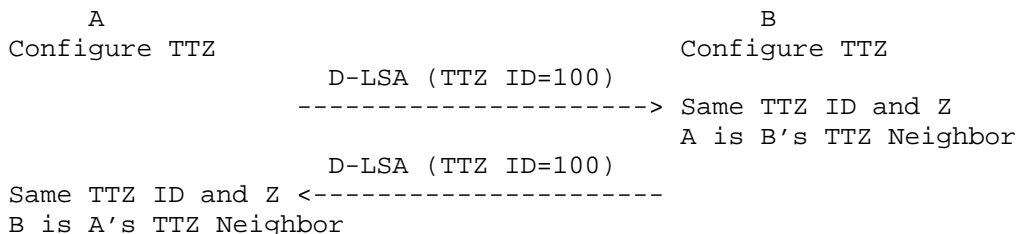   MaxLSAAdvTime and MaxLSAGenAdvTime SHOULD be set to 100 ms and 300

ms, respectively, but MAY be configurable. The former is the
maximum time for an LSA to be advertised to all the routers in an
area. The latter is the maximum time for all TTZ router LSAs to
be generated by all TTZ edge routers and advertised to all the
routers in an area after a first TTZ router LSA is generated.

This is to avoid a possible route down or change in a TTZ-external
router while the TTZ is being virtualized. If each TTZ edge router
originates its router LSA by adding its P2P links to the other TTZ
edge routers and removing its TTZ links in one step, a route taking a
path through the TTZ in the TTZ-external router may be down or
changed before all the router LSAs generated by the TTZ edge routers
reach the TTZ-external router. When the TTZ-external router computes
routes with some router LSAs originated by the TTZ edge routers,
bidirectional checks for some of the P2P links will fail. Thus, the
route taking the path through the shortest path for the P2P link
failing the bidirectional check will be down or changed.

To roll back from a TTZ smoothly after receiving a trigger to roll
back from TTZ, a TTZ edge router MUST originate its normal router LSA
in the above two steps in a reverse way.

Step 1: Initially, it updates its normal router LSA by adding the
   normal links for the links configured as TTZ links into the LSA.

Step 2: It then removes the P2P links to the other edge routers of
   the TTZ for virtualizing the TTZ and the stub links for the
   loopback addresses from its updated router LSA after sending its
   updated router LSA and receiving the updated router LSAs
   originated by the other TTZ edge routers for MaxLSAAdvTime or
   after sending its updated router LSA for MaxLSAGenAdvTime.

8. Establishing Adjacencies

   This section describes the TTZ adjacencies.

8.1. Discovery of TTZ Neighbors

   When two routers A and B are connected by a P2P link and have a
   normal adjacency, they TTZ discover each other through a TTZ LSA of
   LS Type 9 with a TTZ ID TLV. We call this LSA D-LSA for short.

   If two ends of the link have different TTZ IDs or only one end is
   configured with a TTZ ID, TTZ adjacency over the link MUST NOT be
   "formed".

If two ends of the link have the same TTZ ID and Z flag value, A and
B are TTZ neighbors. The following is a sequence of events related
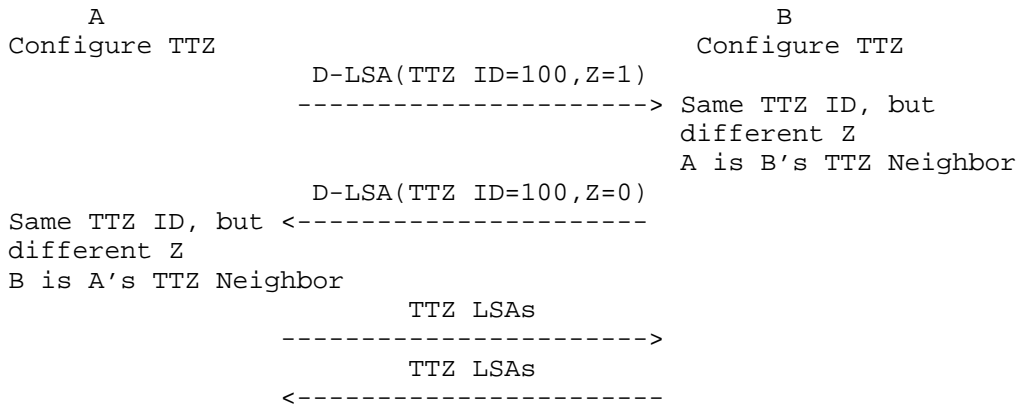to TTZ for this case.

```
          A                                              B
     Configure TTZ                                  Configure TTZ
                      D-LSA (TTZ ID=100)
                   ---------------------> Same TTZ ID and Z
                                          A is B's TTZ Neighbor
                      D-LSA (TTZ ID=100)
     Same TTZ ID and Z <---------------------
     B is A's TTZ Neighbor
```

A sends B a D-LSA with TTZ ID after the TTZ is configured on it. B
sends A a D-LSA with TTZ ID after the TTZ is configured on it.

When A receives the D-LSA from B and determines they have the same
TTZ ID and Z flag value, B is A's TTZ neighbor. A also sends B all
the TTZ LSAs it has and originates its TTZ LSA when one of the
following conditions is met.

o Z = 0 and there is a TTZ LSA with OP for T.

o Z = 1.

B is symmetric to A and acts similarly to A.

If two ends of the link have the same TTZ ID but the Z flags are
different, a TTZ adjacency over the link MUST be "formed" in the
following steps. Suppose that A has migrated to TTZ and B has not
(i.e., flag Z in A's D-LSA is 1, and flag Z in B's D-LSA is 0).

```
          A                                              B
     Configure TTZ                                  Configure TTZ
                      D-LSA(TTZ ID=100,Z=1)
                   ---------------------> Same TTZ ID, but
                                          different Z
                                          A is B's TTZ Neighbor
                      D-LSA(TTZ ID=100,Z=0)
     Same TTZ ID, but <---------------------
     different Z
     B is A's TTZ Neighbor
                             TTZ LSAs
                   ---------------------->
                             TTZ LSAs
                   <----------------------
```

When A receives the D-LSA from B and determines they have the same
TTZ ID but its Z = 1 and B's Z = 0, A sends B all the TTZ LSAs it has
and triggers B to migrate to TTZ. A updates and sends B its D-LSA by
adding a TTZ Options TLV with OP for M after sending B all the TTZ
LSAs.

```
                             D-LSA(TTZ ID=100,OP=M)
    Add TTZ Options  ----------------------> Migrate to TTZ
    TLV with OP for M
                             D-LSA(TTZ ID=100,Z=1)  Migrated to TTZ
                       <--------------------- Set Z=1

                             D-LSA(TTZ ID=100,Z=1)
    Remove               ---------------------->
    TTZ Options TLV
```
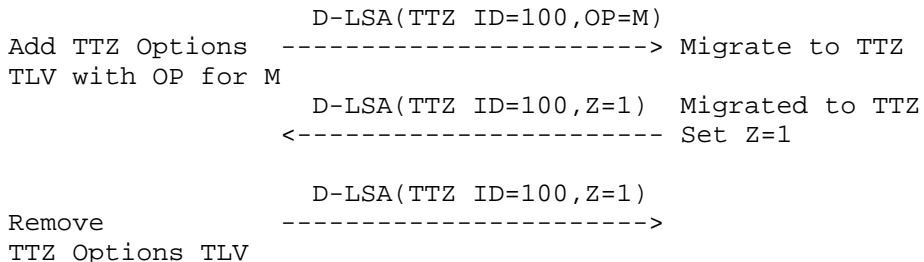
When B receives the D-LSA from A and determines they have the same
TTZ ID but its Z = 0 and A's Z = 1, B sends A all the TTZ LSAs it
has.

When B receives the D-LSA from A with OP for M, it starts to migrate
to TTZ. B updates and advertises its LSAs as needed.

After receiving B's D-LSA with Z = 1, A updates and sends B its D-LSA
by removing the TTZ Options TLV. It also updates and advertises its
LSAs as needed.

When a number of routers connected through a broadcast link have
normal adjacencies among them, they also TTZ discover each other
through D-LSAs. The Designated Router (DR) for the link MUST "form"
TTZ adjacencies with the other routers if all the routers attached to
the link have the same TTZ ID configured on the connections to the
link. Otherwise, the DR MUST NOT "form" any TTZ adjacency with any
router attached to the link.

When a number of routers connected through a broadcast link have TTZ
adjacencies among them, if a misconfigured router is introduced on
the broadcast link, the DR for the link MUST NOT "form" any TTZ
adjacency with this misconfigured router.

For routers connected via a link without any adjacency among them,
they TTZ discover each other through D-LSAs in the same way as
described above after they form a normal adjacency.

A TTZ adjacency over a link MUST be removed when one of the following
events happens.

o TTZ ID on one end of the link is changed to a different one.

   o TTZ ID on one end of the link is removed.

   o The D-LSA is not received after the D-LSA-MAX-RETRANSMIT-TIME or
      is explicitly flushed. The D-LSA-MAX-RETRANSMIT-TIME SHOULD be
      set to 60 minutes, but MAY be configurable.

   o Normal adjacency over the link is down.

   When the TTZ ID on one end of the link is removed, the corresponding
   D-LSA is flushed.

8.2. Adjacency between TTZ Edge and TTZ-External Router

   A TTZ edge router forms an adjacency with any TTZ-external router to
   which it is connected.

   When the TTZ edge router synchronizes its link-state database with
   the TTZ-external router, it sends the TTZ-external router the
   information about all the LSAs except for the LSAs belonging to the
   TTZ that are hidden from any router outside of the TTZ.

   At the end of the link-state database synchronization, the TTZ edge
   router originates its own router LSA for virtualizing the TTZ and
   sends this LSA to its adjacent routers, including the TTZ-external
   router.

9. Advertisement of LSAs

   LSAs can be divided into a couple of classes according to their
   Advertisements. The first class of LSAs is advertised within a TTZ.
   The second is advertised through a TTZ.

9.1. Advertisement of LSAs within TTZ

   Any LSA about a link state in a TTZ is advertised only within the
   TTZ. It is not advertised to any router outside of the TTZ. For
   example, a router LSA generated for a TTZ-internal router is
   advertised only within the TTZ.

   Any network LSA generated for a broadcast or Non-Broadcast Multi-
   Access (NBMA) network in a TTZ is advertised only within the TTZ. It
   is not advertised outside of the TTZ.

   Any opaque LSA generated for a TTZ-internal TE link is advertised
   only within the TTZ.

After migrating to TTZ, every edge router of a TTZ MUST NOT advertise
any LSA about a link state in the TTZ to any router outside of the
TTZ. The TTZ edge router determines whether an LSA is about a TTZ-
internal link state by checking if the advertising router of the LSA
is a TTZ-internal router (i.e., there is a TTZ indication LSA
generated by the TTZ-internal router that has the same advertising
router).

For any TTZ LSA originated by a router within the TTZ, every edge
router of the TTZ MUST NOT advertise it to any router outside of the
TTZ.

9.2. Advertisement of LSAs through TTZ

Any LSA about a link state outside of a TTZ received by an edge
router of the TTZ is advertised using the TTZ as transit. For
example, when an edge router of a TTZ receives an LSA from a router
outside of the TTZ, it floods it to its neighboring routers both
inside and outside of the TTZ. This LSA may be any LSA such as a
router LSA that is advertised within an OSPF area.

The routers in the TTZ continue to flood the LSA. When another edge
router of the TTZ receives the LSA, it floods the LSA to its
neighboring routers both inside and outside of the TTZ.

10. Computation of Routing Table

After a router migrates to TTZ, the computation of the routing table
on the router is the same as that described in RFC 2328, Section 16
with one exception. The router in a TTZ ignores the router LSAs
generated by the TTZ edge routers for virtualizing the TTZ. It
computes routes using the TTZ router LSAs and the regular LSAs,
excluding the router LSAs for virtualizing the TTZ. That is, it
computes routes using the TTZ topology and the topology outside of
the TTZ, excluding the links for virtualizing the TTZ.

11. Operations

11.1. Configuring TTZ

This section proposes some options for configuring a TTZ.

1. Configuring TTZ on Every Link in TTZ

If every link in a TTZ is configured with the same TTZ ID as a TTZ
link, the TTZ is determined. A router with some links in a TTZ and
some links not in this TTZ is a TTZ edge router. A router with all
its links in a TTZ is a TTZ-internal router.

2. Configuring TTZ on Routers in TTZ

   A same TTZ ID is configured on every TTZ-internal router in a TTZ and
   on every TTZ edge router's links connecting to the routers in the
   TTZ.

   A router configured with the TTZ ID on some of its links is a TTZ
   edge router. A router configured with the TTZ ID only is a TTZ-
   internal router. All the links on a TTZ-internal router are TTZ
   links. This option is simpler than option 1 above.

   For a TTZ edge router X with different TTZ IDs on its different
   links, router X connects two or more different TTZs. In this case,
   router X originates its router LSA for virtualizing the TTZs. This
   LSA includes the normal links connecting to routers outside of these
   TTZs and the virtual links to the other edge routers of each of these
   TTZs. Router X also originates its TTZ router LSA for each of the
   TTZs. The TTZ router LSA for TTZ N includes the links to the routers
   outside of these TTZs, the virtual links to the other edge routers of
   the other TTZs, and the TTZ links to the routers in TTZ N.

11.2. Migration to TTZ

   For a group of routers and a number of links connecting the routers
   in an area, making them transfer to work as a TTZ without any service
   interruption takes a few steps or stages.

   At first, a user configures the TTZ feature on every router in the
   TTZ. In this stage, a router does not originate or advertise its TTZ
   topology information. It will discover its TTZ neighbors.

   Second, after configuring the TTZ, a user issues a configuration on
   one router in the TTZ, which triggers every router in the TTZ to
   generate and advertise TTZ information among the routers in the TTZ.
   When the router receives the configuration, it originates a TTZ
   control LSA with OP for T (indicating TTZ information generation and
   advertisement for migration). It also originates its TTZ LSA, such
   as TTZ router LSA or TTZ indication LSA, and advertises the LSA to
   its TTZ neighbors. When another router in the TTZ receives the LSA
   with OP for T, it originates its TTZ LSA. In this stage, every
   router in the TTZ has dual roles. One is to function as a normal
   router. The other is to generate and advertise TTZ information.

   Third, a user checks whether a router in the TTZ is ready for
   migration to TTZ. A router in the TTZ is ready after it has received
   all the TTZ LSAs, including TTZ router LSAs from TTZ edge routers and
   TTZ indication LSAs from TTZ-internal routers. This information may
   be displayed on a router through a configuration.

Then, a user activates the TTZ through using a configuration such as
migrate to TTZ on one router in the TTZ. The router migrates to TTZ,
generates and advertises a TTZ control LSA with OP for M (indicating
Migrating to TTZ) after it receives the configuration. After another
router in the TTZ receives the TTZ control LSA with OP for M, it also
migrates to TTZ. Thus, activating the TTZ on one TTZ router
propagates to every router in the TTZ, which migrates to TTZ.

For an edge router of the TTZ, migrating to work as a TTZ router
comprises generating a router LSA to virtualize the TTZ and flooding
this LSA to all its neighboring routers in two steps as described in
Section 7.

In normal operations for migration to TTZ and rollback from TTZ, a
user issues a series of configurations according to certain
procedures. In an abnormal case, for example, two conflicting
configurations are issued on two TTZ routers in a TTZ at the same
time, and a TTZ router issues an error and logs the error when it
detects a conflict.

A conflicting configuration may be detected on a router on which the
configuration is issued. Thus, some abnormal cases may be prevented.
When a configuration for migration/rollback is issued on a router,
the router checks whether it is in a correct sequence of
configurations for migration/rollback through using the information
it has. For migrating a part of an area to a TTZ, the correct
sequence of configurations is in general as follows:

1) configure TTZ on every router in the part of the area to be
   migrated to TTZ;

2) configure on one router in the TTZ to trigger every router in the
   TTZ to generate and advertise TTZ information for migration; and

3) configure on one router in the TTZ to trigger every router in the
   TTZ to migrate to TTZ.

After receiving a configuration on a router to migrate to TTZ, which
is for 3), the router determines whether 2) is performed by checking
if it has received/originated TTZ LSAs. If it has not, it issues an
error to an operator (generation and advertisement of TTZ information
for migration to TTZ is not done yet) and rejects the configuration
at this time.

After a router receives a TTZ LSA with OP for M for 3) from another
router, it determines whether 2) is performed by checking if it has
received/originated TTZ LSAs. If it has not, it issues an error and
logs the error, and it does not migrate to TTZ. In this case, it

does not originate its router LSA for virtualizing the TTZ if it is a
TTZ edge router.

After receiving a configuration on a router to generate and advertise
TTZ information, which is for 2), the router determines whether 1) is
performed by checking if TTZ is configured on it. If it is not, it
issues an error to an operator (TTZ is not configured on it yet) and
rejects the configuration at this time.

For rolling back from TTZ, the correct sequence of configurations is
below.

1) configure on one router in the TTZ to trigger every router in the
   TTZ to advertise normal LSAs and stop advertising TTZ LSAs; and

2) configure on one router in the TTZ to trigger every router in the
   TTZ to roll back from TTZ.

After receiving a configuration on a router to roll back from TTZ,
which is for 2), the router determines whether 1) is performed by
checking if it has received TTZ LSA with OP for N. If it has not, it
issues an error to an operator (advertise normal LSAs and stop
advertising TTZ LSAs as rolling back from TTZ is not done yet) and
rejects the configuration at this time.

After a router receives a TTZ LSA with OP for R for 2) from another
router, it determines whether 1) is performed by checking if it has
received TTZ LSA with OP for N. If it has not, it issues an error
and logs the error, and it does not roll back from TTZ.

After receiving a configuration on a router to advertise normal LSAs
and stop advertising TTZ LSAs for rolling back from TTZ, which is for
1), the router checks whether it has any TTZ LSAs. If it does not,
it issues an error to an operator (no TTZ to be rolled back) and
rejects the configuration at this time.

11.3. Adding a Router into TTZ

When a non-TTZ router (say R1) is connected via a P2P link to a
migrated TTZ router (say T1), and there is a normal adjacency between
them over the link, a user can configure TTZ on both ends of the link
to add R1 into the TTZ to which T1 belongs. They TTZ discover each
other as described in Section 8.

When a number of non-TTZ routers are connected via a broadcast or
NBMA link to a migrated TTZ router (say T1), and there are normal
adjacencies among them, a user configures TTZ on the connection to
the link on every router to add the non-TTZ routers into the TTZ to

which T1 belongs. The DR for the link "forms" TTZ adjacencies with
the other routers connected to the link if they all have the same TTZ
ID configured for the link. This is determined through the TTZ
discovery process described in Section 8.

12. Manageability Considerations

Section 11 ("Operations") outlines the configuration process and
deployment scenarios for a TTZ. The configurable item is enabling a
TTZ on a router and/or an interface on a router. The TTZ function
may be controlled by a policy module and assigned a suitable user
privilege level to enable. A suitable model may be required to
verify the TTZ status on routers participating in the TTZ, including
their role as an internal or edge TTZ router. The mechanisms defined
in this document do not imply any new liveness detection and
monitoring requirements in addition to those indicated in [RFC2328].

13. Security Considerations

A notable beneficial security aspect of TTZ is that the TTZ is
enclosed in a single area, and TTZ could be used to mask the internal
topology. External routers that are not participating in the TTZ
will not be aware of the internal TTZ topology. It should be noted
that a malicious node could inject TTZ LSAs with the OP field set to
M or R, which could trigger the migration into/from a TTZ and may
result in the isolation of some routers in the network. Good
security practice might reuse the OSPF authentication and other
security mechanisms described in [RFC2328] and [RFC7474] to mitigate
this type of risk.

14. IANA Considerations

Under the registry name "Opaque Link-State Advertisements (LSA)
Option Types" [RFC5250], IANA has assigned a new Opaque Type registry
value for TTZ LSA as follows:

```
+====================+===============+=======================+
|   Registry Value   |  Opaque Type  |     reference         |
+====================+===============+=======================+
|        9           |    TTZ LSA    |   This document       |
+--------------------+---------------+-----------------------+
```

IANA has created and will maintain a new registry:

o OSPFv2 TTZ LSA TLVs

Initial values for the registry are given below. The future
assignments are to be made through IETF Review [RFC5226].

```
     Value          OSPFv2 TTZ LSA TLV Name   Definition
     -----          ----------------------    ----------
     0              Reserved
     1              TTZ ID TLV                see Section 6.2
     2              TTZ Router TLV            see Section 6.3
     3              TTZ Options TLV           see Section 6.4
     4-32767        Unassigned
     32768-65535    Reserved
```

15. References

15.1. Normative References

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15.2. Informative References

   [RFC5226] Narten, T. and H. Alvestrand, "Guidelines for Writing an
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Appendix A. Prototype Implementation

A.1. What Is Implemented and Tested

   1. Command-Line Interface (CLI) Commands for TTZ

   The CLIs implemented and tested include:

   o the CLIs of the simpler option for configuring TTZ, and

   o the CLIs for controlling migration to TTZ.

   2. Extensions to OSPF Protocols for TTZ

   All the extensions defined in "Extensions to OSPF Protocols"
   (Section 6) are implemented and tested except for rolling back from
   TTZ. The testing results illustrate:

   o As seen from the outside, a TTZ is virtualized as its edge routers
      connected to each other. Any router outside of the TTZ sees the
      edge routers (as normal routers) connecting to each other and to
      some other routers.

   o The link-state information about the routers and links inside the
      TTZ is contained within the TTZ. It is not advertised to any
      router outside of the TTZ.

   o TTZ is transparent. From a router inside a TTZ, it sees the
      topology (link state) outside of the TTZ. From a router outside
      of the TTZ, it sees the topology beyond the TTZ. The link-state
      information outside of the TTZ is advertised through the TTZ.

   o TTZ is backward compatible. Any router outside of a TTZ does not
      need to support or know TTZ.

   3. Smooth Migration to TTZ

   The procedures and related protocol extensions for smooth migration
   to TTZ are implemented and tested. The testing results show:

   o A part of an OSPF area is smoothly migrated to a TTZ without any
      routing disruptions. The routes on every router are stable while
      the part of the area is being migrated to the TTZ.

   o Migration to TTZ is very easy to operate.

4. Add a Router to TTZ

   Adding a router into TTZ is implemented and tested. The testing
   results illustrate:

   o A router can be easily added into a TTZ to become a TTZ router.

   o The router added into the TTZ is not seen on any router outside of
      the TTZ, but it is a part of the TTZ.

5. Leak TTZ Loopbacks Outside

   Leaking loopback addresses in a TTZ to routers outside of the TTZ is
   implemented and tested. The testing results illustrate:

   o The loopback addresses inside the TTZ are advertised to the
      routers outside of the TTZ.

   o The loopback addresses are accessible from a router outside of the
      TTZ.

A.2. Implementation Experience

   The implementation of TTZ reuses the existing OSPF code along with
   additional simple logic. A couple of engineers started to work on
   implementing the TTZ from the middle of June 2014 and finished coding
   it just before the end of July 2014. After some testing and bug
   fixes, it works as expected.

   In our implementation, the link-state information in a TTZ opaque LSA
   is stored in the same link-state database as the link-state
   information in a normal LSA. For each TTZ link in the TTZ opaque
   LSA, there is an additional flag, which is used to differentiate
   between a TTZ link and a normal link.

   Before migration to TTZ, every router in the TTZ computes its routing
   table using the normal links. After migration to TTZ, every router
   in the TTZ computes its routing table using the TTZ links and normal
   links. In the case where both the TTZ link and the normal link
   exist, the TTZ link is used.

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