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        IS-IS Extensions Supporting IEEE 802.1aq Shortest Path Bridging
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Abstract

   802.1aq Shortest Path Bridging (SPB) is being standardized by the
   IEEE as the next step in the evolution of the various spanning tree
   and registration protocols. 802.1aq allows for true shortest path
   forwarding in a mesh Ethernet network context utilizing multiple
   equal cost paths. This permits it to support much larger layer 2
   topologies, with faster convergence, and vastly improved use of the
   mesh topology. Combined with this is single point provisioning for
   logical connectivity membership, which includes point-to-point,
   point-to-multi-point and multi-point-to-multipoint variations. This
   memo documents the IS-IS changes required to support this IEEE
   protocol and provides some context and examples.

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1. Introduction

   802.1aq Shortest Path Bridging (SPB) [802.1aq] is being standardized
   by the IEEE as the next step in the evolution of the various
   spanning tree and registration protocols. 802.1aq allows for true
   shortest path forwarding in an Ethernet mesh network context
   utilizing multiple equal cost paths. This permits SPB to support
   much larger layer 2 topologies, with faster convergence, and vastly
   improved use of the mesh topology. Combined with this is single
   point provisioning for logical connectivity membership which
   includes point-to-point (E-LINE), point-to-multi-point (E-TREE) and
   multi-point-to-multipoint (E-LAN) variations.

   The control protocol for 802.1aq is IS-IS [IS-IS] augmented with a
   small number of TLVs and sub TLVs. This supports two Ethernet
   encapsulating data paths, 802.1ad (Provider Bridges) [PB] and
   802.1ah (Provider Backbone Bridges) [PBB]. This memo documents those
   TLVs while providing some overview.

   Note that 802.1aq requires no state machine or other substantive
   changes to [IS-IS]. 802.1aq simply requires a new Network Layer
   Protocol Identifier (NLPID) and set of TLVs. In the event of
   confusion between this document and [IS-IS], [IS-IS] should be taken
   as authoritative.

2. Terminology

   In addition to well understood IS-IS terms, this memo uses
   terminology from IEEE 802.1 and introduces a few new terms:

   802.1ad   Provider Bridging (PB) - Q-in-Q encapsulation
   802.1ah   Provider Backbone Bridges (PBB), MAC-IN-MAC
                  encapsulation
   802.1aq   Shortest Path Bridging (SPB)
   Base-VID   VID used to identify a VLAN in management operations
   B-DA   Backbone Destination Address 802.1ah PBB
   B-MAC   Backbone MAC Address
   B-SA   Backbone Source address in 802.1ah PBB header
   B-VID   Backbone VLAN ID in 802.1ah PBB header
   B-VLAN   Backbone Virtual LAN
   BridgeID   64 bit quantity = (Bridge Priority:16)<<48 | SYSID:48
   BridgePriority 16 bit relative priority of a node for tie breaking
   C-MAC   Customer MAC. Inner MAC in 802.1ah PBB header
   C-VID   Customer VLAN ID
   C-VLAN   Customer Virtual LAN
   DA   Destination Address

```
   ECT-ALGORITHM  32 bit unique id of an SPF tie breaking set of rules.
   ECT-MASK       64 bit mask XORed with BridgeID during tie breaking.
   E-LAN          Bidirectional Logical Connectivity between >2 UNIs.
   E-LINE         Bidirectional Logical Connectivity between two UNIs.
   E-TREE         Asymmetric Logical Connectivity between UNIs.
   FDB            Filtering Database: {DA/VID}->{next hops}
   I-SID          Logical Grouping Identifier for E-LAN/LINE/TREE UNIs.
   LAN            Local Area Network
   LSDB           Link State Database
   LSP            Link State Packet
   MAC-IN-MAC     Ethernet in Ethernet framing as per 802.1ah[PBB]
   MDT            Multicast Distribution Tree
   MMRP           Multiple Mac Registration Protocol 802.1ak[MMRP]
   MT-ISIS        Multi Topology IS-IS as used in [MT]
   MT             Multi Topology. As used in [MT]
   MT-ID          Multi Topology Identifier (12 bits). As used in [MT]
   NLPID          Network Layer Protocol Identifier: IEEE 802.1aq= 0xC1
   Q-in-Q         Additional S-VLAN after a C-VLAN (802.1ad)[PB]
   PBB            Provider Backbone Bridge - forwards using PBB
   Ingress Check  Source Forwarding Check - drops misdirected frames
   (S,G)          Source & Group - identity of a source specific tree
   (*,G)          Any Source & Group - identity of a shared tree
   SA             Source Address.
   SPB            Shortest Path Bridging - generally all of 802.1aq.
   SPB            Shortest Path Bridge - device implementing 802.1aq.
   SPB-instance   Logical SPB instance correlated by MT-ID.
   SPBM           Device implementing SPB MAC mode
   SPBV           Device implementing SPB VID mode
   SPT            Shortest Path Tree computed by one ECT-ALORITHM
   SPT Region     A set of SPBs with identical VID usage on their NNIs
   SPSourceID     20 bit identifier of the source of multicast frames.
   SPVID          SPBV: a C-VLAN or S-VLAN that identifies the source.
   UNI            User Network Interface: Customer to SPB attach point.
   VID            VLAN ID 12 bit logical identifier after MAC header.
   VLAN           Virtual LAN: A logical network in the control plane
```

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].

The lower case forms with an initial capital "Must", "Must Not",
"Shall", "Shall Not", "Should", "Should Not", "May", and "Optional"
in this document are to be interpreted in the sense defined in

[RFC2119], but are used where the normative behavior is defined in
documents published by SDOs other than the IETF.

4. 802.1aq Overview

This section provides an overview of the behavior of [802.1aq] and
is not intended to be interpreted as normative text. For the
definitive behavior the reader should consult [802.1aq]. Nonetheless
lower case forms with initial capitalization of the conventions in
RFC2119 are used in this section to give the reader an indication of
the intended normative behaviors as above.

802.1aq utilizes 802.1Q based Ethernet bridging. The filtering
database (FDB) is populated as a consequence of the topology
computed from the IS-IS database. For the reader unfamiliar with
IEEE terminology, the definition of Ethernet behavior is almost
entirely in terms of "filtering" (of broadcast traffic) rather than
"forwarding" (the explicit direction of unicast traffic). This
document uses the generic term "forwarding", and it has to be
understood that these two terms simply represent different ways of
expressing the same behaviors.

802.1aq supports multiple modes of operation depending on the type
of data plane and the desired behavior. For the initial two modes of
802.1aq (SPBV and SPBM), routes are shortest path, are forward and
reverse path symmetric with respect to any source / destination pair
within the SPB domain, and are congruent with respect to unicast and
multicast. Hence the shortest path tree (SPT) to a given node is
congruent with the multicast distribution tree (MDT) from a given
node. The MDT for a given VLAN is a pruned subset of the complete
MDT for a given node which is identical to its SPT. Symmetry and
congruency preserve packet ordering and proper fate sharing of OAM
flows by the forwarding path. Such modes are fully supported by
existing [802.1ag] and [Y.1731] OA&M mechanisms.

VLANs provide a natural delineation of service instances. 802.1aq
supports two modes, SPB VID (SPBV) and SPB MAC (SPBM). In SPBV
multiple VLANS can be used to distribute load on different shortest
path trees (each computed by a different tie breaking rule) on a
service basis. In SPBM service instances are delineated by I-SIDs
but VLANs again can be used to distribute load on different shortest
path trees.

There are two encapsulation methods supported. SPBM can be used in a PBB network implementing PBB (802.1ah [PBB]) encapsulation. SPBV can be used in PB networks implementing VLANs, PB (802.1aq [PB]) or PBB encapsulation. The two modes can co-exist simultaneously in an SPB network.

The practical design goals for SPBV and SPBM in the current 802.1aq specification are networks of size 100 nodes and 1000 nodes respectively. However since SPBV can be sparsely used in an SPB Region it can simply span a large SPB region with a small number of SPVIDs.

In SPBM and SPBV each bridge has at least one unique "known" MAC address which is advertised by IS-IS in the SYS-ID.

In the forwarding plane, SPBM uses the combination of one or more B-VIDs and "known" Backbone-MAC (B-MAC) addresses that have been advertised in IS-IS. The term Backbone simply implies an encapsulation that is often used in the backbone networks, but the encapsulation is useful in other types of networks where hiding C-MACs is useful.

The SPBM filtering database (FDB) is computed and installed for unicast and multicast MAC addresses, while the SPBV filtering database is computed and installed for unidirectional VIDs (referred to as SPVIDs), after which MAC reachability is learned (exactly as in bridged Ethernet) for unicast MACs.

Both SPBV and SPBM use source specific multicast trees. If they share the same ECT-ALGORITHM (32 bit world wide unique definition of the computation) the tree is the same SPT. For SPBV (S,G) is encoded by a source-specific VID (the SPVID) and a standard Group MAC address. For SPBM (S,G) is encoded in the destination B-MAC address as the concatenation of a 20 bit SPB wide unique nodal nickname (referred to as the SPSourceID) and the 24 bit I-SID together with the B-VID which corresponds to the ECT-ALGORITHM network wide.

802.1aq supports membership attributes which are advertised with the I-SID (SPBM) or Group Address (SPBV) that define the group. Individual members can be transmitters (T) and/or receivers (R) within the group and the multicast state is appropriately sized to these requests. Multicast group membership is possible even without transmit membership by performing head end replication to the receivers thereby eliminating transit multicast state entirely.

Some highly connected mesh networks provide for path diversity by offering multiple equal cost alternatives between nodes. Since

congruency and symmetry Must be honored, a single tree may leave
some links under utilized. By using different deterministic tie
breakers, up to sixteen shortest paths of arbitrary diversity are
possible between any pair of nodes. This distributes the traffic on
a VLAN basis. SPBV and SPBM May share a single SPT with a single
ECT-ALGORITHM or use any combination of the 16 ECT-ALGORITHMs. An
extensible framework permits additional or alternative algorithms
with other properties and parameters (e.g. ECMP, (*,G)) to also be
supported without any changes in this or the IEEE documents.

4.1. Multi Topology Support

SPB incorporates the multi topology features of [MT] thereby
allowing multiple logical SPB instances within a single IS-IS
instance.

To accomplish this, all SPB related information is either explicitly
or implicitly associated with a Multi Topology Identifier (MT-ID).
SPB information related to a given MT-ID thus forms a single logical
SPB instance.

Since SPB has its own adjacency metrics and those metrics are also
associated with an MT-ID it is not only possible to have different
adjacency metrics (or infinite metrics) for SPB adjacencies,
distinct from IP or other NLPIDs riding in this IS-IS instance, and
also distinct from those used by other SPB instances in the same IS-
IS instance.

Data plane traffic for a given MT-ID is intrinsically isolated by
the VLANs assigned to the SPB instance in question. Therefore VLANs
(represented by VIDs in TLVs and data plane) Must Not overlap
between SPB instances (regardless of how the control planes are
isolated).

The [MT] mechanism when applied to SPB allows different routing
metrics and topology subsets for different classes of services.

The use of [MT] other than the default MT-ID#0 is completely
OPTIONAL.

The use of [MT] to separate SPB from other NLPIDs is also OPTIONAL.

4.2. Data Path SPBM - Unicast

Unicast frames in SPBM are encapsulated as per 802.1ah [PBB]. A
Backbone Source Address (B-SA), Backbone Destination Address (B-DA),
Backbone VLAN ID (B-VID) and an I-Component Service Instance ID (I-

TAG) are used to encapsulate the Ethernet frame. The B-SA is a B-MAC associated with the ingress 802.1aq bridge, usually the "known" B-MAC of that entire bridge. The B-DA is one of the "known" B-MACs associated with the egress 802.1aq bridge. The B-VID and I-TAG are mapped based on the physical or logical UNI port (untagged, or tagged either by S-TAG or C-TAG) being bridged. Normal learning and broadcast to unknown C-MACs is applied as per [PBB] at the ingress/egress SPBs only.

Unlike [PBB] on a (*,G) tree, the B-DA forwarding on tandem nodes (NNI to NNI) is performed without learning. Instead the output of 802.1aq computations, based on the TLVs specified in this document, are used to populate the filtering data bases (FDB). The FDB entries map {B-DA, B-VID} to an outgoing interface and are only populated from the IS-IS database and computations.

The B-SA/B-VID is checked on tandem nodes against the ingress port. If the B-SA/B-VID (as a destination) entry in the FDB does not point to the port on which the packet arrived the packet is discarded. This is referred to as an Ingress Check and serves as a very powerful loop mitigation mechanism.

4.3. Data Path SPBM - Multicast (Head End Replication)

Head end replication is supported for instances where there is a sparse community of interest or a low likelihood of multicast traffic. Head end replication requires no Multicast state in the core. A UNI port wishing to use head end replication Must Not advertise its I-SID membership with the TX bit set but instead Must locally and dynamically construct the appropriate unicast serial replication to all the other receivers (RX) of the same I-SID.

When an unknown customer unicast or a multicast frame arrives at an SPBM User to Network Interface (UNI) port which has been configured to replicate only at the head end the packet is replicated once for each receiver, encapsulated and sent as a unicast frame. The set of receivers is determined by inspecting the IS-IS database for other SPBs that have registered interest in the same I-SID with the RX (receive) attribute set. This RX/I-SID pair is found in the SPBM Service Identifier and Unicast Address sub-TLV. The packets are encapsulated as per the SPBM Unicast forwarding above.

4.4. Data Path SPBM - Multicast (Tandem Replication)

Tandem replication uses the Shortest path Tree to replicate Frames only where the tree forks and there is at least one receiver on each branch. Tandem replication is bandwidth efficient but uses multicast

FDB entries (state) in core bridges which might be unnecessary if
there is little multicast traffic demand. The head end replication
mode is best suited for the case where there is little or no true
multicast traffic for an I-SID. Tandem replication is triggered on
transit nodes when the I-SID is advertised with the TX bit set.

Broadcast, unknown unicast or multicast frames arriving at an SPBM
UNI port are encapsulated with a B-DA multicast address which
uniquely identifies the encapsulating node (the root of the
Multicast Distribution Tree) and the I-SID scoping this multicast.

This B-DA address is a well formed multicast group address (as per
802.1Q and 802.1ah) which concatenates the SPSourceID A' with the I-
SID M (written as DA=<A',M> and uniquely identifying the (S,G)
tree). This exact format is given in Figure 1 below:

```
 M L TYP
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |1|1|0|0|SPSrcMS|  SPSrc [8:15] |  SPSrc [0:7]  |  ISID [16:23] |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |  ISID [8:15]  |   ISID [0:7]  |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                    Figure 1 SPBM Multicast Address format
                       (SPSrcMS represents SPSrc [16:19])

Note In Figure 1, the index numbering from less significant bit to
   more significant bit within a byte or field within a byte gives
   the wire order of the bits in the address consistent with the IETF
   format in the rest of this document. (The IEEE convention for
   number representation reverses the bits within an octet compared
   with IETF practice).

o M is the multicast bit- always set to 1 for a multicast DA. (It
   is the lowest bit in the most significant byte.)

o L is the local bit- always set to 1 for a SPBM constructed
   multicast DA.

o TYP is the SPSourceID type. 00 is the only type supported at this
   time.

o SPSRC (SPSourceID) is a 20 bit quantity that uniquely identifies
   a SPBM node for all B-VIDs allocated to SPBM operation. This is
   just the SPSourceID advertised in the SPB Instance sub-TLV. The
   value SPSourceID = 0 has special significance; it is advertised
   by an SPBM node which has been configured to assign its
   SPSourceID dynamically, which requires LSDB synchronization, but
   where the SPSourceID assignment has not yet completed.

o I-SID is the 24 bit I component Service ID advertised in the SPBM
   Service Identifier TLV. It occupies the lower 24 bits of the SPBM
   multicast DA. The I-SID value 0xfff is reserved for SPBM control
   traffic(refer to the default I-SID in [802.1aq]).

This multicast address format is used as the DA on frames when they
are first encapsulated at ingress to the SPBM network. The DA is
also installed into the FDBs on all SPBM nodes that are on the
corresponding SPT between the source and other nodes that have
registered receiver interest in the same I-SID.

Just as with unicast forwarding, the B-SA/B-VID May be used to
perform an ingress check, but the SPSourceID encoded in the DA and
the "drop-on-unknown" functionality of the FDB in [PBB] achieve the
same effect.

The I-Component at the egress SPBM device has completely standard
[PBB] behavior and therefore will:

1) learn the remote C-SA to B-SA relationship and
2) bridge the original customer frame to the set of local UNI ports
that are associated with the I-SID.

4.5. Data Path SPBV Broadcast

When a packet for an unknown DA arrives at a SPBV UNI port VID
translation (or VID encapsulation for un-tagged Frames) with the
corresponding SPVID for this VLAN and ingress SPB is performed.

SPVID forwarding is simply an SPT that follows normal VLAN
forwarding behavior, with the exception that the SPVID is
unidirectional. As a result shared learning (SVL) is used between
the forward and reverse path SPVIDs associated with the same Base-
VID to allow SPBV unicast forwarding to operate in the normal
reverse learning fashion.

Ingress check is done by simply verifying that the bridge to which
the SPVID has been assigned is indeed "shortest path" reachable over
the link over which the packet tagged with that SPVID arrived. This

check is computed from the IS-IS database and is implied when the
SPVID is associated with a specific incoming port.

4.6. Data Path SPBV Unicast

Conversely when a packet for a known DA arrives at a SPBV UNI port
VID translation (or VID encapsulation for un-tagged Frames) with the
corresponding SPVID for this VLAN and ingress SPB is performed.

Since the SPVID will have been configured to follow a source
specific SPT and the DA is known the packet will follow the source
specific path towards the destination C-MAC.

Ingress check is as per the previous SPBV section.

4.7. Data Path SPBV Multicast

C-DA multicast addresses May be advertised from SPBV UNI ports.
These may be configured or learned through MMRP. The MMRP protocol
is terminated at the edge of the SPBV network and IS-IS carries the
multicast addresses. Tandem SPBV devices will check to see if they
are on the SPF tree between SPBV UNI ports advertising the same C-DA
multicast address, and if so will install multicast state to follow
the SPBV SPF trees.

Ingress check is as per the previous two SPBV sections.

5. SPBM Example

Consider the following small example network shown in Figure 2.
Nodes are drawn in boxes with the last nibble of their B-MAC address
:1..:7, the rest of the B-MAC address nibbles are 4455-6677-00xx.
Links are drawn as -- and / while the interface indexes are drawn as
numbers next to the links. UNI ports are shown as <==> with the
desired I-SID show at the end of the UNI ports as i1.

```
                    +----+          +----+
                    | :4 | 2 ------1 | :5 | <==> i1
                    +----+          +----+
                  1       3       3      2
                 /         \       /        \
                1           4     3          2
            +----+         +----+          +----+
   i1 <==> | :1 | 2----1 | :2 | 2------1 | :3 | <==> i1
            +----+         +----+          +----+
             3           6     5          3
              \         /       \          /
               3       2         1        2
             +----+          +----+
             | :6 | 1-------3 | :7 | <==> i1
             +----+          +----+
```

                 Figure 2 - SPBM Example 7 node network

   Using the default ECT-ALGORITHM (00-80-C2-01), which picks the equal
   cost path with the lowest BridgeID, this ECT-ALGORITHM is assigned
   to B-VID 100. When all links have the same cost, then the 1 hop
   shortest paths are all direct and the 2 hop shortest paths (which
   are of course symmetric) are as follows:

   { 1-2-3, 1-2-5, 1-2-7, 6-2-5,
     4-2-7, 4-1-6, 5-2-7, 6-2-3, 4-2-3 }

   Node :1's Unicast forwarding table therefore routes toward B-MACs
   :7, :3 and :5 via interface/2 while its single hop paths are all
   direct as can be seen from its FDB given in Figure 3.

   Node :1 originates multicast since it is at the head of the MDT to
   nodes :3, :5 and :7 and is a transmitter of I-SID 1 which nodes :3,
   :5 and :7 all wish to receive. Node :1 therefore produces a
   multicast forwarding entry who's DA contains its SPSourceID (in the
   example the last 20 bits of the B-MAC) and the I-SID 1 and sends to
   interface 2 with B-VID=100. Node :1's full unicast(U) and
   multicast(M) table is shown in Figure 3. Note that the IN/IF
   (incoming interface) field is not specified for unicast traffic and
   for multicast traffic has to point back to the root of the tree,
   unless it is the head of the tree in which case we use the
   convention if/OO. Since Node :1 is not transit for any multicast it
   only has a single entry for the root of its tree for I-SID=1.

```
     +-------+------------------+------+----------------+
     | IN/IF | DESTINATION ADDR | BVID | OUT/IF(s)      |
     +-------+------------------+------+----------------+
    U| if/** |   4455-6677-0002 | 0100 | {if/2         }
    U| if/** |   4455-6677-0003 | 0100 | {if/2         }
    U| if/** |   4455-6677-0004 | 0100 | {if/1         }
    U| if/** |   4455-6677-0005 | 0100 | {if/2         }
    U| if/** |   4455-6677-0006 | 0100 | {if/3         }
    U| if/** |   4455-6677-0007 | 0100 | {if/2         }
    M| if/00 |   7300-0100-0001 | 0100 | {if/2         }
```

        Figure 3 - SPBM Node :1 FDB - Unicast(U) and Multicast(M)

   Node :2, being at the center of the network, has direct 1 hop paths
   to all other nodes, therefore its unicast FDB simply sends packets
   with the given B-MAC/B-VID=100 to the interface directly to the
   addressed node. This can be seen by looking at the unicast entries
   (the first 6) shown in Figure 4.

```
     +-------+------------------+------+----------------+
     | IN/IF | DESTINATION ADDR | BVID | OUT/IF(s)      |
     +-------+------------------+------+----------------+
    U| if/** |   4455-6677-0001 | 0100 | {if/1         }
    U| if/** |   4455-6677-0003 | 0100 | {if/2         }
    U| if/** |   4455-6677-0004 | 0100 | {if/4         }
    U| if/** |   4455-6677-0005 | 0100 | {if/3         }
    U| if/** |   4455-6677-0006 | 0100 | {if/6         }
    U| if/** |   4455-6677-0007 | 0100 | {if/5         }
    M| if/01 |   7300-0100-0001 | 0100 | {if/2,if/3,if/5 }
    M| if/02 |   7300-0300-0001 | 0100 | {if/1         }
    M| if/03 |   7300-0500-0001 | 0100 | {if/1,if/5    }
    M| if/05 |   7300-0700-0001 | 0100 | {if/1,if/3    }
```

        Figure 4 - SPBM Node :2 FDB Unicast(U) and Multicast(M)

   Node :2's multicast is more complicated since it is a transit node
   for the 4 members of I-SID=1, therefore it requires 4 multicast FDB
   entries depending on which member it is forwarding/replicating on
   behalf of. For example, node :2 is on the shortest path between each
   of nodes {:3,:5,:7} and :1. So it must replicate from node :1 I-SID
   1 out on interfaces 2, 3 and 5 (to reach nodes :3, :5 and :7). It
   therefore creates a multicast DA with the SPSourceID of node :1
   together with I-SID=1 which it expects to receive over interface/1
   and will replicate out interfaces/{2, 3 and 5}. This can be seen in
   the first multicast entry in Figure 4.

Note that node :2 is not on the shortest path between nodes :3 and
:5 nor between nodes :3 and :7, however it still has to forward
packets to node :1 from node :3 for this I-SID, which results in the
second multicast forwarding entry in Figure 4. Likewise for packets
originating at nodes 5 or 7, node :2 only has to replicate twice,
which results in the last two multicast forwarding entries in Figure
4.

6. SPBV Example

Using the same example network as Figure 2, we will look at the FDBs
produced for SPBV mode forwarding. Nodes :1, :5, :3 and :7 wish to
transmit and receive the same multicast MAC traffic using multicast
address 0300-0000-000f and at the same time require congruent and
symmetric unicast forwarding. In SPBV mode the only encapsulation is
the C or S-TAG and the MAC addresses SA,DA are reverse-path learned,
as in traditional bridging.

```
              +----+            +----+
              | :4 | 2 ------1 | :5 | <==> MMAC ..:f
              +----+            +----+
           1       3          3      2
          /          \        /        \
         1            4      3          2
      +----+          +----+          +----+
MMAC<==> | :1 | 2----1 | :2 | 2------1 | :3 | <==> MMAC ..:f
 ..:f    +----+          +----+          +----+
        3            6    5            3
         \          /      \          /
          3       2        1       2
        +----+            +----+
        | :6 | 1-------3 | :7 | <==> MMAC ..:f
        +----+            +----+
```
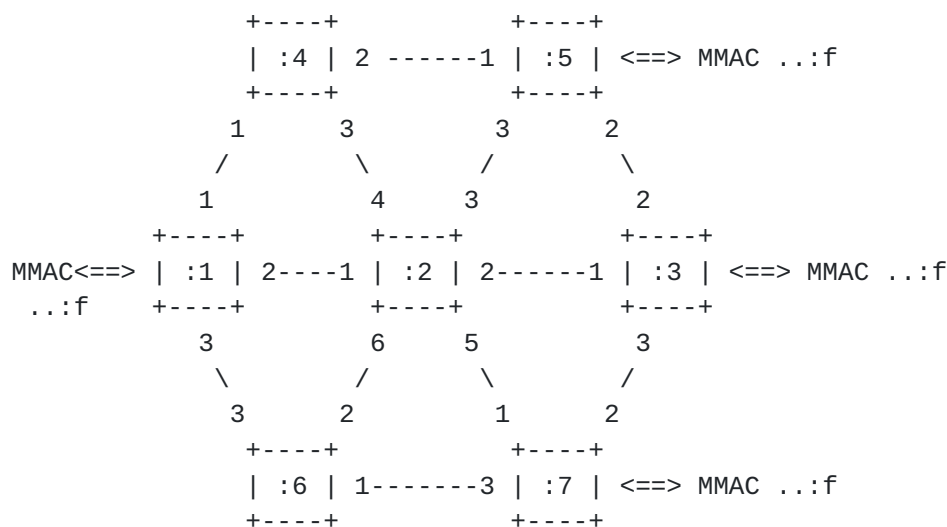
            Figure 5 - SPBV Example 7 node network

Assuming the same ECT-ALGORITHM (00-80-C2-01), which picks the equal
cost path with the lowest BridgeID, this ECT-ALGORITHM is assigned
to Base-VID 100, and for each node the SPVID = Base-VID + Node Id
(i.e. 101, 102..107). When all links have the same cost, then the 1
hop shortest paths are all direct and the 2 hop shortest paths
(which are of course symmetric) are as previously given for Figure
2.

Node :1's SPT (Shortest Path Tree) for this ECT-ALGORITHM is
therefore (described as a sequence of unidirectional paths):

```
          { 1->4, 1->6, 1->2->3, 1->2->5, 1->2->7 }
```

The FDBs therefore must have entries for the SPVID reserved for
packets originating from node :1 which in this case is VID=101.

Node :2 therefore has a FDB which looks like Figure 6. In particular
it takes packets from VID 101 on interface/01 and sends to nodes :3,
:5 and :7 via if/2, if/3 and if/5. It does not replicate anywhere
else because the other nodes :4 and :6 are reached by the SPT
directly from node :1. The rest of the FDB unicast entries follow a
similar pattern; recall that the shortest path between :4 and :6 is
via node :1, which explains replication onto only two interfaces
from if/4 and if/6. Note that the destination addresses are wild
cards and shared VLAN learning (SVL) exists between these SPVIDs,
because they are all associated with BASE VID = 100, which defines
the VLAN being bridged.

```
        +-------+------------------+------+----------------+
        | IN/IF | DESTINATION ADDR  |  VID | OUT/IF(s)      |
        +-------+------------------+------+----------------+
      U| if/01 |   **************  | 0101 | {if/2,if/3,if/5 }
      U| if/02 |   **************  | 0103 | {if/1,if/4,if/6 }
      U| if/04 |   **************  | 0104 | {if/2,if/5      }
      U| if/03 |   **************  | 0105 | {if/1,if/5,if/6 }
      U| if/06 |   **************  | 0106 | {if/2,if/3      }
      U| if/05 |   **************  | 0107 | {if/1,if/3,if/4 }
```

          Figure 6 - SPBV Node :2 FDB unicast

Now, since nodes :5, :3, :7 and :1 are advertising membership in the
same multicast group address :f, Node 2 requires additional entries
to replicate just to these specific nodes for the given multicast
group address. These additional multicast entries are given below in
Figure 7.

```
        +-------+------------------+------+----------------+
        | IN/IF | DESTINATION ADDR  |  VID | OUT/IF(s)      |
        +-------+------------------+------+----------------+
      M| if/01 |   0300-0000-000f  | 0101 | {if/2,if/3,if/5 }
      M| if/02 |   0300-0000-000f  | 0103 | {if/1           }
      M| if/03 |   0300-0000-000f  | 0105 | {if/1,if/5      }
      M| if/05 |   0300-0000-000f  | 0107 | {if/1,if/3      }
```

          Figure 7 - SPBV Node :2 FDB Multicast(M)

7. **SPB Supported Adjacency types**

   IS-IS for SPB currently only supports P2P adjacencies. Other link
   types are for future study. As a result pseudonodes and links
   to/from pseudonodes are not considered as part of the IS-IS SPF
   computations and will be avoided if present in the physical
   topology. Other NLPIDs MAY of course use them as per normal.

   IS-IS for SPB Must use the IS-IS Three-Way handshake for IS-IS
   Point-to-Point Adjacencies described in RFC 5303.

8. **SPB IS-IS adjacency addressing**

   The default behavior of 802.1aq is to use the normal IS-IS Ethernet
   multicast addresses for IS-IS.

   There are however additional Ethernet multicast addresses that have
   been assigned for 802.1aq for special use cases. These do not in
   anyway change the state machinery or packet formats of IS-IS but
   simply recommend and reserve different multicast addresses. Refer to
   [802.1aq] for additional details.

9. **IS-IS Area Address and SYSID**

   A stand-alone implementation (supporting ONLY the single NLPID=0xC1)
   of SPB Must use an IS-IS area address value of 0 and the SYSID Must
   be the well known MAC address of the SPB device.

   Non stand-alone implementations (supporting other NLPIDs) MUST use
   the normal IS-IS rules for the establishment of a level 1 domain
   (i.e. multiple area addresses are allowed but where immediate
   adjacencies share a common area address). Level 2 operations of
   course place no such restriction on adjacent area addresses.

10. **Level 1/2 Adjacency**

   SPBV and SPBM will operate either within an IS-IS level 1, or an
   ISIS level 2. As a result, the TLVs specified here MAY propagate
   either in level 1 or level 2 LSPs. IS-IS SPB implementations Must
   support level 1 and May support level 2 operations. Hierarchical SPB
   is for further study therefore these TLV's Should Not be leaked
   between level 1 and level 2.

11. **Shortest Path Default Tie Breaking**

   (ECT-ALGORITHM = 00-80-C2-01)

Two mechanisms are used to ensure symmetry and determinism in the
shortest path calculations.

The first mechanism addresses the problem when different ends
(nodes) of an adjacency advertise different values for the SPB-LINK-
METRIC. To solve this SPB shortest path calculations Must use the
maximum value of the two node's advertised SPB-LINK-METRICs when
accumulating and minimizing the (sub)path costs.

The second mechanism addresses the problem when two equal sums of
link metrics (sub)paths are found. To solve this, the (sub)path with
the fewest hops between the fork/join points Must win the tie.
However, if both (sub)paths have the same number of hops between the
fork and join points then the default tie breaking Must pick the
path traversing the intermediate node with the lower BridgeID. The
BridgeID is an 8 byte quantity whose upper 2 bytes are the node's
BridgePriority and the lower 6 bytes are the node's SYSID.

For example, consider the network in Figure 2 when a shortest path
computation is being done from node :1. Upon reaching node :7 two
competing sub-paths fork at node :1 and join at node :7. The first
via :2 and the second via :6. Assuming that all the nodes advertise
a Bridge Priority of 0, the default tie breaking rule causes the
path traversing node :2 to be selected since it has a lower BridgeID
{0...:2} than node :6 {0...:6}. Note that the operator may cause the
tie breaking logic to pick the alternate path by raising the Bridge
Priority of node :2 above that of node :6.

The above algorithm guarantees symmetric and deterministic results
in addition to having the critical property of transitivity
(shortest path is made up of sub-shortest paths).

12. Shortest Path ECT

(ECT-ALGORITHMs = 00-80-C2-01 .. 00-80-C2-10)
To create diversity in routing SPB defines 16 variations on the
above default tie breaking algorithm, these have world wide unique
designations 00-80-C2-01 through 00-80-C2-10. These designations
consist of the IEEE 802.1 OUI value 00-80-C2 concatenated with
indexes 0X01..0X10. These individual algorithms are implemented by
selecting the (sub) path with the lowest value of:

```
        XOR BYTE BY BYTE(ECT-MASK{ECT-ALGORITHM.index},BridgeID)
```

   Where:

```
        ECT-MASK{17} = { 0x00, 0x00, 0xFF, 0x88,
                         0x77, 0x44, 0x33, 0xCC,
                         0xBB, 0x22, 0x11, 0x66,
                         0x55, 0xAA, 0x99, 0xDD,
                         0xEE };

        XOR BYTE BY BYTE  - XORs BridgeID bytes with ECT-MASK
```

   ECT-MASK{1} since it xor's with all 0's is just the same as the
   default algorithm described above 00-80-C2-01, while ECT-MASK{0x02}
   since it xor's with a mask of all 1's will invert the BridgeID
   essentially picking the path traversing the largest Bridge ID. The
   other ECT-MASKs produce diverse alternatives. In all cases the
   BridgePriority, since it is the most significant part of the
   BridgeID permits overriding the SYSID as the selection criteria and
   gives the operator a degree of control on the chosen ECT paths.

   To support many other tie breaking mechanisms in the future two
   opaque ECT TLV's are defined which may be used to provide parameters
   to ECT-ALGORITHMS outside of the currently defined space.

   ECT-ALGORITHMS are mapped to VIDs and then services can be assigned
   to those VIDs. This permits a degree of traffic engineering since
   service assignment to VID is consistent end to end through the
   network.

13. Hello (IIH) protocol extensions

   IEEE 802.1aq can run in parallel with other Network Layer Protocols
   such as IPV4 and IPV6, therefore failure for two SPB nodes to
   establish an adjacency MUST NOT cause rejection of an adjacency for
   the purposes of other Network Layer Protocols.

   IEEE 802.1aq has been assigned the NLPID value 0xC1 [NLPID] which
   MUST be used by shortest path bridges (SPBs) to indicate their
   ability to run 802.1aq. This is done by including this NLPID value
   in the IS-IS IIH PDU Protocols Supported TLV (type 129). 802.1aq
   frames MUST only flow on adjacencies that advertise this NLPID in
   both directions of the IIH PDUs. 802.1aq computations MUST consider
   an adjacency that has not advertised 0xC1 NLPID in both directions
   as non-existent (infinite link metric) and MUST ignore any IIH SPB
   TLV's they receive over such adjacencies.

IEEE 802.1aq augments the normal IIH PDU with three new TLV's which like all other SPB TLVs travel within multi topology [MT] TLVs, therefore allowing multiple logical instances of SPB within a single IS-IS protocol instance.

Since SPB can use many VIDs and Must agree on which VIDs are used for which purposes, the IIH PDU's carry a digest of all the used VIDs (on the NNI's) referred to as the SPB-MCID TLV which uses a common and compact encoding taken reused from 802.1Q.

SPB neighbors May support a mechanism to verify that the contents of their topology databases are synchronized (for the purposes of loop prevention). This is done by exchanging a digest of SPB topology information (computed over all MTIDS) and taking specific actions on forwarding entries when the digests indicate a mismatch in topology. This digest is carried in the Optional SPB Digest sub-TLV.

Finally SPB needs to know which SPT sets (defined by ECT-ALGORITHMS) are being used by which VIDs, and this is carried in the Base VLAN Identifiers sub-TLV.

13.1. SPB MCID sub-TLV

This sub-TLV is added to an IIH PDU to indicate the digest for the Multiple spanning tree configuration a.k.a MCID. This TLV is a digest of local configuration of which VIDs are running which protocols. (The information is not to the level of a specific algorithm in the case of SPB). This information Must be the same on all bridges in the SPT Region controlled by an IS-IS instance. The data used to generate the MCID is populated by configuration and is a digest of the VIDs allocated to various protocols. Two MCIDs are carried to allow non disruptive transitions between configurations when the changes are non-critical.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1

+-+-+-+-+-+-+-+-+
|Type=SPB-MCID  | = 6
+-+-+-+-+-+-+-+-+
|   Length      |   (1 byte)
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+...+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          MCID (51 Bytes)                        |
|                          ..............                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+...+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Aux   MCID (51 Bytes)                       |
|                          ..............                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+...+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

o   Type: sub-TLV Type = 6 (Pending IANA).

o   Length: The size of the value defined below (102).

o   MCID (51-bytes) The complete MCID defined in IEEE 802.1Q which
    identifies an SPT Region on the basis of matching assignments of
    VIDs to control regimes (xSTP, SPBV, SPBM, etc). Briefly, the
    MCID consists of a 1 byte format selector, a 32 byte
    configuration name, a 2 byte revision level and finally a 16 byte
    signature of type HMAC-MD5 over an array of 4096 elements that
    contain identifiers of the use of the corresponding VID. Refer to
    section 13.8 of [802.1aq] for the exact format and procedure.
    Note that the use of the VID does not include specification of a
    specific SPB ECT-ALGORITHM, rather it is coarser grain.

o   Aux MCID (51-bytes) The complete MCID defined in IEEE 802.1Q
    which identifies an SPT Region. The aux MCID allows SPT Regions
    to be migrated by the allocation of new VLAN to FDB Mappings
    without interruption to existing traffic.

   The SPB MCID sub-TLV is carried within the MT-Port-Cap TLV [LAYER2]
   with the MT-ID value of 0, which in turn is carried in an IIH PDU.

13.2. SPB Digest sub-TLV

   This sub-TLV is Optionally added to an IIH PDU to indicate the
   current SPB topology digest value. It is always carried in an MT-
   Port-Cap TLV [LAYER2] with an MT-ID value of 0. This information
   should settle to be the same on all bridges in an unchanging
   topology. Matching digests indicate (with extremely high

probability) that the topology view between two SPBs is
synchronized, and is used to control the updating of forwarding
information. The SPB Agreement Digest is computed based on
contributions derived from the current topologies of all SPB MT
instances, and is designed to change when significant topology
changes occur within any SPB instance.

During the propagation of LSPs the Agreement Digest may vary between
neighbors until the key topology information in the LSPs are common.
The digest is therefore a summarized means of determining agreement
between nodes on database commonality, and hence infer agreement on
the distance to all multicast roots. When present it is used for
loop prevention as follows: For each shortest path tree where it
has been determined the distance to the root has changed, "unsafe"
multicast forwarding is blocked until the exchanged Agreement
Digests match while "safe" multicast forwarding is allowed to
continue despite the disagreement in digests and hence topology
views. [802.1aq] section 28.2 defines in detail what constitutes
"safe" vs. "unsafe".

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1

+-+-+-+-+-+-+-+-+
|Type=SPB-Digest| = 7
+-+-+-+-+-+-+-+-+
|   Length      | (1 byte)
+-----+-+---+---+
| Res |V| A | D | (1 byte)
+-+-+-+-+-+-+-+-+-+-+-+-+-+...+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|               Agreement Digest (Length - 1)               |
|                        ..............                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+...+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

o Type: sub-TLV Type = 7 (Pending IANA).

o Length: The size of the value.

o V - agreed digest valid bit. See [802.1aq] Sec 28.2.

o A (2 bits) The Agreement Number 0-3 which aligns with BPDUs
   Agreement Number concept [802.1aq]. When the Agreement Digest
   for this node changes this number is incremented. The node then
   checks for Agreement Digest match (as below). The new local
   Agreement Number and the updated local Discarded Agreement Number
   are then transmitted with the new Agreement Digest to the node's
   neighbors in the hello PDU. Once an Agreement Number has been
   sent it is considered outstanding until a matching or more recent
   Discarded Agreement Number is received from the neighbor.

o D (2 bits) The Discarded Agreement Number 0-3 which aligns with
   BPDUs Agreement Number concept. When an Agreement Digest is
   received from a neighbor, this number is set to the received
   Agreement Number, to signify that this node has received this new
   agreement and discarded any previous ones. The node then checks
   whether the local and received Agreement Digests match. If they
   do, this node then sets :

      the local Discarded Agreement Number = received Agreement
      Number + 1

      If the Agreement Digests match, AND
      received Discarded Agreement Number == local Agreement Number
      + N (N = 0 || 1)

      then the node has a topology matched to its neighbor.

   Whenever the local Discarded Agreement Number relating to a
   neighbor changes, the local Agreement Digest, Agreement Number,
   and Discarded Agreement Number are transmitted.

o Agreement Digest. This digest is used to determine when SPB is
   synchronized between neighbors for all SPB instances. The
   agreement digest is a hash computed over the set of all SPB
   adjacencies in all SPB instances. In other words, the digest
   includes all VIDs and all adjacencies for all MT instances of SPB
   (but not other network layer protocols). This reflects the fact
   that all SPB nodes in a region Must have identical VID
   allocations (see 13.1), and so all SPB instances will contain the
   same set of nodes. The size and exact procedure for computing the
   Agreement Digest is defined in section 28.2 of [802.1aq].

The SPB Digest sub-TLV is carried within the MT-Port-Cap TLV
[LAYER2] (with the MT-ID value 0) which in turn is carried in an IIH
PDU.

When supported, this sub-TLV MUST be carried on every IIH between
SPB neighbors, not just when a Digest changes.

When one peer supports this TLV and the other does not, loop
prevention by digest agreement Must Not be done by either side.

13.3. SPB Base VLAN-Identifiers sub-TLV

This sub-TLV is added to an IIH PDU to indicate the mappings between
ECT algorithms and Base-VIDs (and by implication the VID(s) used on
the forwarding path for each SPT Set for a VLAN identified by a Base
VID) that are in use. Under stable operational conditions, this
information should be the same on all bridges in the topology
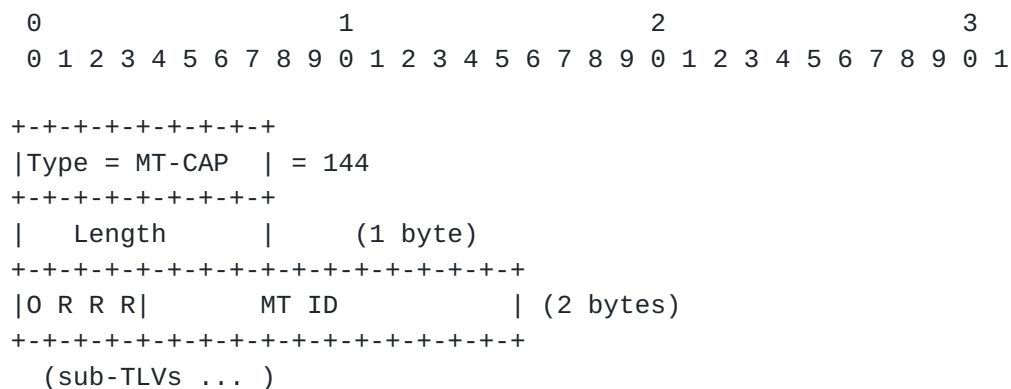identified by the MT-Port-Cap TLV [LAYER2] it is being carried
within.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1

+-+-+-+-+-+-+-+-+
|Type= SPB-B-VID| = 8
+-+-+-+-+-+-+-+-+
|   Length      |   (1 byte)
+-+-+-+-+-+-+-+-+---------------------------------------------+
|      ECT - VID Tuple (1)  (6 bytes)                         |
+-------------------------------+-----------------------------+
|      ...                      | ECT-VID Tuple(2) (6 bytes)  |
+-------------------------------+-----------------------------+
|                     .....                                   |
+-------------------------------------------------------------+
|                     .....                                   |
|                     .....                                   |
+-------------------------------------------------------------+
```

o Type: sub-TLV Type = 8 (Pending IANA).

o Length: The size of the value is ECT-VID Tuples*6 bytes. Each 6-
   byte part of the ECT-VID tuple is formatted 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

+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      ECT - Algorithm (32 bits)               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Base VID (12 bits)    |U|M|RES|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

o ECT-ALGORITHM (4 bytes) The ECT-ALGORITHM is advertised when the
   bridge supports a given ECT-ALGORITHM (by OUI/Index) on a given
   Base-VID. There are 17 predefined IEEE algorithms for SPB with
   index values 0X00..0X10 occupying the low 8 bits and the IEEE
   OUI=00-80-C2 occupying the top 24 bits of the ECT-ALGORITHM.

o Base-VID (12-bits) The Base-VID that is associated with the SPT
   Set.

o Use-Flag (1-bit) The Use-flag is set if this bridge, or any
   bridge in the LSDB is currently using this ECT-ALGORITHM and
   Base-VID. Remote usage is discovered by inspection of the U-Bit
   in the SPB Instance sub-TLV of other SPB bridges (see section
   14.1)

o M-Bit (1-bit) The M-bit indicates if this Base-VID operates in
   SPBM (M = 1) or SPBV (M = 0) mode.

The SPB Base VLAN-Identifier sub-TLV is carried within the MT-Port-
Cap TLV [LAYER2] which in turn is carried in an IIH PDU.

14. Node information extensions

All SPB nodal information extensions travel within a new multi
topology capability TLV MT-Capability (type = 144).

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1

+-+-+-+-+-+-+-+-+
|Type = MT-CAP  | = 144
+-+-+-+-+-+-+-+-+
|   Length      |    (1 byte)
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|O R R R|     MT ID        | (2 bytes)
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  (sub-TLVs ... )
```

The format of this TLV is identical in its first 2 bytes to all
current MT TLV's and carries the MT ID as defined in [MT].

The O (overload) bit carried in bit 16 has the same semantics as
specified in [MT], but in the context of SPB adjacencies only.

14.1. SPB Instance sub-TLV

The SPB Instance sub-TLV gives the SPSourceID for this node/topology
instance. This is the 20 bit value that is used in the formation of
multicast DA addresses for frames originating from this
node/instance. The SPSourceID occupies the upper 20 bits of the
multicast DA together with 4 other bits (see the SPBM 802.1ah
multicast DA address format section). This sub-TLV MUST be carried
within the MT-Capability TLV in the fragment ZERO LSP. If there is
an additional SPB instance it MUST be declared under a separate MT-
Topology and also carried in the fragment ZERO LSP.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1

+-+-+-+-+-+-+-+-+
|Type = SPB-Inst| = 1
+-+-+-+-+-+-+-+-+
|   Length      |    (1 byte)
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              CIST Root Identifier  (4 bytes)                 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              CIST Root Identifier (cont)  (4 bytes)          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          CIST External ROOT Path Cost     (4 bytes)         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Bridge Priority       |        (2 bytes)
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|R R R R R R R R R R R|V|            SPSourceID                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Num of Trees  |      (1 byte)
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|               VLAN-ID (1) Tuples    (8 bytes)                |
|               .........................                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                .........................
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|               VLAN-ID (N) Tuples    (8 bytes)                |
|               .........................                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

where VLAN-ID tuples have the format as:

```
 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
+-+-+-+-+-+-+-+-+
|U|M|A|  Res    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     ECT - Algorithm (32 bits)                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Base-VID (12 bits)   |  SPVID (12 bits)     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

o Type: sub-TLV Type 1 (Pending IANA).

o Length: Total number of bytes contained in the value field.

o CIST Root Identifier (64-bits)The CIST Root Identifier is for SPB
   interworking with RSTP and MSTP at SPT Region Boundaries. This
   is an imported value from a Spanning tree.

o CIST External Root Path Cost (32-bits) The CIST External Root
   Path Cost is the cost to root, derived from the spanning tree
   algorithm.

o Bridge Priority (16-bits) Bridge priority is the 16 bits that
   together with the 6 bytes of the System ID form the Bridge
   Identifier. This is configured exactly as specified in IEEE802
   [802.1D]. This allows SPB to build a compatible Spanning tree
   using link state by combining the Bridge Priority and the System
   ID to form the 8 byte Bridge Identifier. The 8 byte Bridge
   Identifier is also the input to the 16 pre-defined ECT tie
   breaker algorithms.

o V bit (1-Bit) The V bit (SPBM) indicates this SPSourceID is auto
   allocated(27.11). If the V bit is clear the SPSourceID has been
   configured and Must be unique. Allocation of SPSourceID is
   defined in IEEE [802.1aq]. Bridges running SPBM will allocate an
   SPSourceID if they are not configured with an explicit
   SPSourceID. The V Bit allows neighbor bridges to determine if the
   auto allocation was enabled. In the rare chance of a collision
   of SPsourceID allocation, the bridge with the highest priority
   Bridge Identifier will win conflicts and the lower priority
   Bridge will be re-allocated or if the lower priority Bridge is
   configured it will not be allowed to join the SPT Region.

o The SPSourceID is a 20 bit value used to construct multicast DA's
   as described below for multicast frames originating from the
   origin (SPB node) of the link state packet (LSP) that contains
   this TLV. More details are in IEEE [802.1aq].

o Number of Trees (8-bits) The Number of Trees is set to the number
   of [ECT-ALGORITHM, Base-VID plus flags] tuples that follow. Each
   ECT-ALGORITHM has a Base-VID, an SPVID and flags described below.
   This Must contain at least the one ECT-ALGORITMM (00-80-C2-01).

Each VID Tuple consists of:

o U-Bit (1-bit) The U-bit is set if this bridge is currently using
   this ECT-ALGORITHM for I-SIDs it sources or sinks. This is a
   strictly local indication; the semantics differ from the Use-flag
   found in the Hello, which will set the Use-Flag if it sees other
   nodal U-bits are set OR it sources or sinks itself.

o M-Bit (1-bit) The M-bit indicates if this is SPBM or SPBV mode.
   When cleared the mode is SPBV and when set the mode is SPBM.

o A bit, The A bit (SPB) when set declares this is an SPVID with
   auto allocation. The VID allocation logic details are in IEEE
   [802.1aq]. Since SPVIDs are allocated from a small pool of 12
   bit resources the chances of collision are high. To minimize
   collisions during auto allocation LSPs are initially advertised
   with the originating bridge setting the SPVID to 0. Only after
   learning the other bridges' SPVID allocations does this bridge
   re-advertise this sub-TLV with a non-zero SPVID. This will
   minimize but not eliminate the chance of a clash. In the event of
   a clash, the highest Bridge Identifier is used to select the
   winner, while the loser(s) with lower Bridge Identifier(s) Must
   withdraw their SPVID allocation(s), and select an alternative
   candidate for another trial. SPVID May also be configured. When
   the A bit is set to not specify auto allocation and the SPVID is
   set to 0 this SPBV bridge is used for transit only within the SPB
   region. If a port is configured with the BASE-VID as a neighbor
   using RSTP or MSTP the bridge will act as an ingress filter for
   that VID.

o ECT-ALGORITHM (4-bytes) ECT-ALGORITHM is advertised when the
   bridge supports a given ECT-ALGORITHM (by OUI/Index) on a given
   VID. This declaration Must match the declaration in the Hello PDU
   originating from the same bridge. The ECT-ALGORITHM and BASE-VID
   Must match what is generated in the IIHs of the same node. The
   ECT-ALGORITHM, BASE-VID tuples can come in any order however.
   There are currently 17 world wide unique 802.1aq defined ECT-
   ALGORITHMS given by values 00-80-C2-00 through 00-80-C2-10.

o Base VID (12-bits) The Base-VID that associated the SPT Set via
   the ECT-ALGORITHM.

o SPVID (12-bits) The SPVID is the Shortest Path VID assigned for
   the Base-VID to this node when using SPBV mode. It is not
   defined for SPBM Mode and Must be 0 for SPBM mode B-VIDs.

14.1.1. SPB Instance Opaque ECT-ALGORITHM sub-TLV

There are multiple ECT algorithms defined for SPB, however for the
future additional algorithms may be defined including but not
limited to ECMP / hash based behaviors and (*,G) multicast trees.
These algorithms will use this Optional TLV to define new algorithm
parametric data. For tie breaking parameters there are two broad
classes of algorithm, one which uses nodal data to break ties and
one which uses link data to break ties, this TLV is used to
associate opaque tie breaking data with a node. This sub-TLV, when
present, MUST be carried within the MT-Capability TLV (along with a
valid SPB Instance sub-TLV). Multiple copies of this sub-TLV MAY be
carried for different ECT-ALGORITHMs relating to this node.

There are of course many other uses of this opaque data which have
yet to be defined.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1

 +-+-+-+-+-+-+-+-+
 |Type=SPB-I-OALG| = 2
 +-+-+-+-+-+-+-+-+
 |   Length      |    (1 byte)
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                 Opaque ECT Algorithm    (4 bytes)            |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                 Opaque ECT Information (variable)            |
 |                   ......................                     |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

o Type: sub-TLV Type 2 (Pending IANA).

o Length: Total number of bytes contained in the value field.

o ECT-ALGORITHM: ECT-ALGORITHM is advertised when the bridge
   supports a given ECT-ALGORITHM (by OUI/Index) on a given VID.

o ECT Information: ECT-ALGORITHM Information of variable length
   which SHOULD be in sub-TLV format with an IANA numbering space
   where appropriate.

15. Adjacency information extensions

15.1. SPB Link Metric sub-TLV

The SPB Link Metric sub-TLV (type = 12) occurs within the Multi
Topology Intermediate System TLV (type 222) or within the Extended
IS Reachability TLV (type 22). If this sub TLV is not present for
an ISIS adjacency then that adjacency Must not carry SPB traffic for
the given topology instance.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1

+-+-+-+-+-+-+-+-+
|Type=SPB-Metric| = 12
+-+-+-+-+-+-+-+-+
|   Length      |     (1 byte)
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|       SPB-LINK-METRIC                         |    (3 bytes)
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Num of ports  |     (1 byte)
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Port  Identifier         |   ( 2 bytes)
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

o Type: sub-TLV Type 12 (Pending IANA).

o Length: Total number of bytes contained in the value field.

o SPB-LINK-METRIC indicates the administrative cost or weight of
   using this link as a 24 bit unsigned number. This metric applies
   to the use of this link for SPB traffic only. Smaller numbers
   indicate lower weights and are more likely to carry SPB traffic.
   Only one metric is allowed per SPB instance per link. If
   multiple metrics are required multiple SPB instances Must be
   used, either within IS-IS or within several independent IS-IS
   instances. If this metric is different at each end of a link, the
   maximum of the two values Must be used in all SPB calculations
   for the weight of this link. The maximum SPB-LINK-METRIC value
   2^24 - 1 has a special significance; this value indicates that
   although the IS-IS adjacency has formed, incompatible values have
   been detected in parameters configured within SPB itself for
   example different regions, and the link Must Not be used for
   carrying SPB traffic. Full details are found in [802.1aq].

o Num of Ports is the number of ports associated with this link.

o Port Identifier is the standard IEEE port identifier used to
   build a spanning tree associated with this link.

15.1.1. SPB Adjacency Opaque ECT-ALGORITHM sub-TLV

There are multiple ECT algorithms defined for SPB, however for the
future additional algorithms may be defined. The SPB Adjacency
Opaque ECT-ALGORITHM sub-TLV occurs within the Multi Topology
Intermediate System TLV (type 222) or the Extended IS Reachability
TLV (type 22). Multiple copies of this sub-TLV MAY be carried for
different ECT-ALGORITHMs related to this adjacency.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1

 +-+-+-+-+-+-+-+-+
 |Type=SPB-A-OALG| = 13
 +-+-+-+-+-+-+-+-+
 |   Length      |    (1 byte)
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                  Opaque ECT Algorithm    (4 bytes)           |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                  Opaque ECT Information (variable)           |
 |                  ........................                    |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

o Type: sub-TLV Type = 13 (PENDING IANA).

o Length: Total number of bytes contained in the value field.

o ECT-ALGORITHM: ECT-ALGORITHM is advertised when the bridge
   supports a given ECT-ALGORITHM (by OUI/Index) on a given VID.

o ECT Information: ECT-ALGORITHM Information of variable length in
   sub-TLV format using new IANA type values as appropriate.

16. Service information extensions

16.1. SPBM Service Identifier and Unicast Address sub-TLV

The SPBM Service Identifier and Unicast Address sub-TLV (type=3) is
used to introduce service group membership on the originating node
and/or to advertise an additional B-MAC unicast address present on,
or reachable by the 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

+-+-+-+-+-+-+-+-+
|Type = SPBM-SI | = 3
+-+-+-+-+-+-+-+-+
|   Length      |    (1 byte)
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      B-MAC ADDRESS                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    B-MAC ADDRESS  (6 bytes)   | Res. |   Base-VID (12 bits)   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|T|R| Reserved   |                ISID  #1                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|T|R| Reserved   |                ISID  #2                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                     ................
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|T|R| Reserved   |                ISID  #n                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```


o Type: sub-TLV Type = 3 (Pending IANA)

o Length: Total number of bytes contained in the value field.

o B-MAC ADDRESS is a unicast address of this node. It may be
   either the single nodal address, or may address a port or any
   other level of granularity relative to the node. In the case
   where the node only has one B-MAC address this Should be the same
   as the SYS-ID of the node. To add multiple B-MACs this TLV MUST
   be repeated per additional B-MAC.

o Base VID (12-bits) The Base-VID associated with the B-BMAC this
   allows the linkage to the ECT-Algorithm and SPT Set defined in
   the SPB Instance sub-TLV.

o ISID #1 .. #N are 24 bit service group membership identifiers.
   If two nodes have an I-SID in common, intermediate nodes on the
   unique shortest path between them will create forwarding state
   for the related B-MAC addresses and will also construct multicast
   forwarding state using the I-SID and the node's SPSourceID to
   construct a multicast DA as described in IEEE 802.1aq LSB. Each
   I-SID has a Transmit(T) and Receive(R) bit which indicates if the
   membership is as a Transmitter/Receiver or both (with both bits
   set). In the case where the Transmit(T) and Receive(R) bits are
   both zero, the I-SID instance is ignored for the purposes of
   distributed multicast computation, but the unicast B-MAC address
   Must be processed and installed at nodes providing transit to
   that address. If more I-SIDs are associated with a particular B-
   MAC than can fit in a single sub-TLV, this sub-TLV can be
   repeated with the same B-MAC but with different I-SID values.

o Note when the T bit is not set an SPB May still multicast to all
   the other receive members of this I-SID (those advertising with
   their R bits set), by configuring edge replication and serial
   unicast to each member locally.

The SPBM Service Identifier sub-TLV, when present, MUST be carried
within the MT Capability TLV and can occur multiple times in any LSP
fragment.

16.2. SPBV Mac Address sub-TLV

The SPBV MAC Address (SPBV-MAC-ADDR) sub-TLV is IS-IS sub-TLV type 4
(PENDING IANA). It Should be used for advertisement of Group MAC
Addresses in SPBV mode. Unicast MAC addresses will normally be
distributed by reverse path learning, but carrying them in this TLV
is not precluded. It has the following format :

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1

+-+-+-+-+-+-+-+-+
| Type=SPBV-ADDR|   = 4            (1 byte)
+-+-+-+-+-+-+-+-+
|   Length      |                 (1 byte)
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|R|R|S-R|      SPVID          |   (2 bytes)
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+...+-+-+-+-+-+-+-+-+-+-+-+
|T|R| Reserved  |     MAC 1 Address           |  (1+6 bytes)
+-+-+-+-+-+-+-+-+-+-+-+-+-+...+-+-+-+-+-+-+-+-+-+-+-+
                            ...
+-+-+-+-+-+-+-+-+-+-+-+-+-+...+-+-+-+-+-+-+-+-+-+-+-+
|T|R| Reserved  |     MAC N Address           |  (1+6 bytes)
+-+-+-+-+-+-+-+-+-+-+-+-+-+...+-+-+-+-+-+-+-+-+-+-+-+
```

o Type: sub-TLV Type, set to 4.

o Length: Total number of bytes contained in the value field. The
   number of MAC address associated with the SPVID is computed by
   (Length - 2)/7.

o S-R bits (2-bits) The SR bits are the service requirement
   parameter from MMRP. The service requirement parameters have the
   value 0 (Forward all Groups) and 1 (Forward All Unregistered
   Groups) defined. However this attribute May also be missing. So
   the SR bits are defined as 0 not declared, 1 Forward all Groups
   and 2 Forward All Unregistered Groups. The two 'R' reserved bits
   immediately preceding these SR bits Shall be set to zero when
   originating this sub-TLV and Shall be ignored on receipt.

o SPVID (12-bits) The SPVID and by association Base-VID and the
   ECT-ALGORITHM and SPT Set that the MAC addresses defined below
   will use. If the SPVID is not allocated the SPVID Value is 0.
   Note that if the ECT-Algorithm in use is Spanning Tree Algorithm
   this value Must be populated with the Base-VID and the MAC Must
   be populated.

o T Bit (1-bit) This is the Transmit allowed Bit for a following
   group MAC address. This is an indication that the Group MAC
   Address in the context of the SPVID of the bridge advertising
   this Group MAC Must be installed in the FDB of transit bridges,
   when the bridge computing the trees is on the corresponding ECT-
   ALGORITHM shortest path between the bridge advertising this MAC
   with the T bit set and any receiver of this Group MAC Address. A
   bridge that does not advertise this bit set for a MAC Address
   Must Not cause multicast forwarding state to be installed on
   other transit bridges in the network for traffic originating from
   that bridge.

o R Bit (1-bit) This is the Receive allowed Bit for the following
   MAC Address. This is an indication that MAC Addresses as receiver
   Must be populated and installed when the bridge computing the
   trees lies on the corresponding shortest path for this ECT-
   ALGORITHM between this receiver and any transmitter to this MAC
   Address. An entry that does not have this bit set for a Group
   MAC Address is prevented from receiving on this Group MAC Address
   because transit bridges Must Not install multicast forwarding
   state towards it in their FDBs.

o MAC Address (48-bits) The MAC address declares this bridge as
   part of the multicast interest for this destination MAC address.
   Multicast trees can be efficiently constructed for destination by
   populating FDB entries for the subset of the shortest path tree
   that connects the bridges supporting the MAC address. This
   replaces the function of MMRP for SPTs. The T and R bits above
   have meaning as specified above.

The SPBV-MAC-ADDR sub-TLV, when present, MUST be carried within the
MT-Capability TLV and can occur multiple times in any LSP fragment.

17. Security Considerations

This document adds no additional security risks to IS-IS, nor does
it provide any additional security for IS-IS when used in a
configured environment or a single operator domain such as a Data
Center.

However this protocol may be used in a zero configuration
environment. Zero configuration may apply to the automatic detection
and formation of an IS-IS adjacency (forming an NNI port). Likewise
zero configuration may apply to the automatic detection of VLAN
tagged traffic and the formation of a UNI port, with resultant ISID
advertisements.

If zero configuration methods are used to auto configure NNIs or
UNIs there are intrinsic security concerns that should be mitigated
with authentication procedures for the above cases. Such procedures
are beyond the scope of this document, and are yet to be defined.

In addition, this protocol can create significant amounts of
multicast state when an ISID is advertised with the TX bit set.
Extra care should be taken to ensure that this cannot be used in a
Denial of Service attack [RFC4732] in a zero configuration
environment.

18. IANA Considerations

Note that the NLPID value 0xC1 [NLPID] used in the IIH PDUs has
already been assigned by IANA for the purpose of 802.1aq therefore
no further action is required for this code point.

Since 802.1aq operates within the IS-IS Multi Topology framework
every sub-TLV MUST occur in the context of the proper MT TLV (with
the exception of the SPB Link Metric sub-TLV which MAY travel in TLV
22 where its MT-ID is unspecified but implied to be 0). There are
three Multi Topology TLV's in which 802.1aq requests allocation of
sub-TLV's. These are the MT-Port-Cap TLV [LAYER2] used in the IIH,
the MT-Capability TLV (new) used within the LSP and finally the MT-
Intermediate-System TLV [MT] used to contain adjacency information
within the LSP.

This document creates the following TLVs & sub-TLV's within the IIH
and LSP PDUs MT TLV's as described below. The '*' indicates IANA
action is required. Other entries are shown to provide context only.
A '?' next to a number indicates a requested but of course not
necessarily the final assigned value.

The MT-Capability TLV is the only TLV requiring a new sub-registry.
Type value 144 (TBD) is requested, with a starting sub-TLV value of
1, and managed by Expert Review.

```
   +-----+----+-----------------+--------+------+-------------+
   | PDU |TLV | SUB-TLV         | TYPE   | TYPE | #OCCURRENCE |
   +-----+----+-----------------+--------+------+-------------+
     IIH
         MT-Port-Cap              147?
 *               SPB-MCID                  6?     1
 *               SPB-Digest                7?     >=0
 *               SPB-B-VID                 8?     1

     LSP
 *       MT-Capability            144?
 *               SPB-Inst                  1?     1
 *               SPB-I-OALG                2?     >=0
 *               SPBM-SI                   3?     >=0
 *               SPBV-ADDR                 4?     >=0

         MT-Intermediate-System   222
      or Extended IS Reachability   22
 *               SPB-Metric               12?     1
 *               SPB-A-OALG               13?     >=0
```

19. References

19.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate
          Requirement Levels", BCP 14, RFC 2119, March 1997.

[IS-IS]   ISO/IEC 10589:2002, Second Edition, "Intermediate System
          to Intermediate System Intra-Domain Routing Exchange
          Protocol for use in Conjunction with the Protocol for
          Providing the Connectionless-mode Network Service (ISO
          8473)", 2002.

[MT]   M-ISIS: Multi Topology (MT) Routing in Intermediate System
          to Intermediate Systems (IS-ISs), RFC 5120, February 2008.

[802.1aq] "Standard for Local and Metropolitan Area Networks /
          Virtual Bridged Local Area Networks / Amendment: Shortest
          Path Bridging, IEEE P802.1aq Draft 3.6", 2011.

[NLPID]   www.ietf.org/id/draft-eastlake-nlpid-iana-considerations-
          04.txt

[LAYER2]   www.ietf.org/id/draft-ietf-isis-layer2-09.txt.

19.2. Informative References

[MMRP]   "Standard for Local and Metropolitan Area Networks Virtual
           Bridged Local Area Networks - Amendment 07: Multiple
           Registration Protocol", IEEE STD 802.1ak, 2007

[PB]   "Standard for Local and Metropolitan Area Networks /
           Virtual Bridged Local Area Networks / Amendment 4:
           Provider Bridges, IEEE STD 802.1ad", 2005.

[PBB]   "Standard for Local and Metropolitan Area Networks /
           Virtual Bridged Local Area Networks / Amendment 7:
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[802.1ag] "Standard for Local and Metropolitan Area Networks /
           Virtual Bridged Local Area Networks / Amendment 5:
           Connectivity Fault Management", IEEE STD 802.1ag, 2007

[Y.1731] ITU-T Y.1731 (2006), "OAM Functions and Mechanisms for
           Ethernet based networks"

[RFC4732] Handley, M., Ed, "Internet Denial-of-Service
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