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BIER-TE for Broadcast Link

Abstract

This document describes extensions to "Bit Index Explicit Replication Traffic Engineering" (BIER-TE) for supporting LANs (i.e., broadcast links). For a multicast packet with an explicit point-to-multipoint (P2MP) path traversing LANs, the packet is replicated and forwarded statelessly along the path.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

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1. Introduction

[[I-D.ietf-bier-te-arch](#)] introduces Bit Index Explicit Replication (BIER) Traffic/Tree Engineering (BIER-TE). It is an architecture for per-packet stateless explicit point to multipoint (P2MP) multicast path/tree. A Bit-Forwarding Router (BFR) in a BIER-TE domain has a BIER-TE Bit Index Forwarding Table (BIFT). A BIER-TE BIFT on a BFR comprises a forwarding entry for a BitPosition (BP) assigned to each of the adjacencies of the BFR. If the BP represents a forward connected adjacency, the forwarding entry for the BP forwards the multicast packet with the BP to the directly connected BFR neighbor of the adjacency. If the BP represents a BFER (i.e., egress node) or say a local decap adjacency, the forwarding entry for the BP decapsulates the multicast packet with the BP and passes a copy of the payload of the packet to the packet's NextProto within the BFR.

In [[I-D.ietf-bier-te-arch](#)], for a LAN, the adjacency to each neighboring BFR on the LAN is given a unique BitPosition. The

adjacency of this BitPosition is a forward connected adjacency towards the BFR and this BitPosition is populated into the BIFT of all the other BFRs on that LAN. This solution for a LAN does not work in some cases.

For a packet with an explicit point-to-multipoint (P2MP) path, if the path traverses some BFRs/nodes on a LAN, each of these BFRs/nodes on the LAN may receive duplicated packets. Thus some of the egress nodes will receive duplicated packets.

This document proposes a solution for LANs to resolve this issue. For a packet with an explicit P2MP path traversing LANs (i.e., broadcast links), the packet is replicated and forwarded statelessly along the path. Each of the egress nodes of the path will not receive any duplicated packet.

1.1. Terminology

BIER: Bit Index Explicit Replication.

BIER-TE: BIER Traffic Engineering.

BFR: Bit-Forwarding Router.

BFIR: Bit-Forwarding Ingress Router.

BFER: Bit-Forwarding Egress Router.

BFR-id: BFR Identifier. It is a number in the range [1,65535].

BFR-NBR: BFR Neighbor.

BFR-prefix: An IP address (either IPv4 or IPv6) of a BFR.

BIRT: Bit Index Routing Table. It is a table that maps from the BFR-id (in a particular sub-domain) of a BFER to the BFR-prefix of that BFER, and to the BFR-NBR on the path to that BFER.

BIFT: Bit Index Forwarding Table.

IGP: Interior Gateway Protocol.

LSDB: Link State DataBase.

OSPF: Open Shortest Path First.

IS-IS: Intermediate System to Intermediate System.

2. Example Application of Current BIER-TE with LAN

This section illustrates an example application of the current BIER-TE defined in [I-D.ietf-bier-te-arch] to the BIER-TE topology with LAN in Figure 1.

2.1. Example BIER-TE Topology with LAN

An example BIER-TE topology with a LAN for a BIER-TE domain is shown in Figure 1. It has 8 nodes/BFRs A, B, C, D, E, F, G and H. Nodes/BFRs D, F, E, H and A are BFERs and have local decap adjacency BitPositions (BPs for short) 1, 2, 3, 4, and 5 respectively. For simplicity, these BPs are represented by (SI:BitString), where SI = 0 and BitString is of 8 bits. BPs 1, 2, 3, 4, and 5 are represented by 1 (0:00000001), 2 (0:00000010), 3 (0:00000100), 4 (0:00001000) and 5 (0:00010000) respectively.

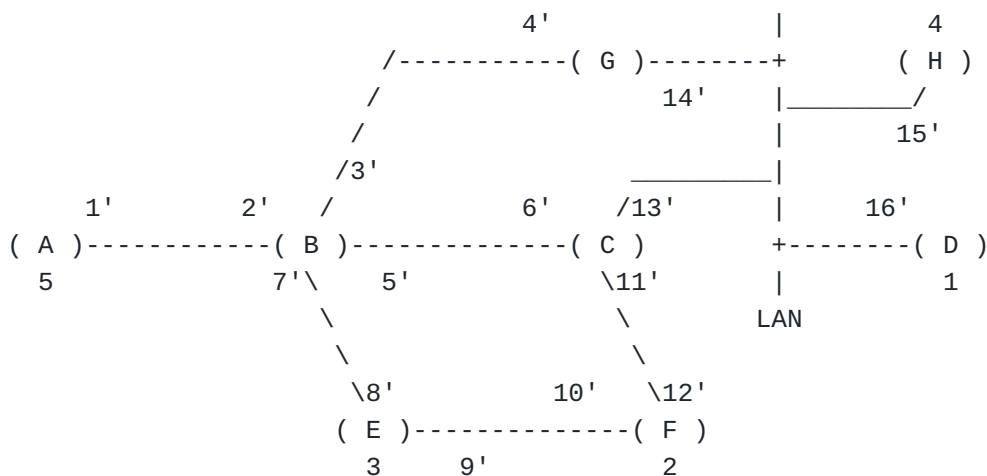


Figure 1: Example BIER-TE Topology with BP to BFR on LAN

The BitPositions for the forward connected adjacencies are represented by i' , where i is from 1 to 16. In one option, they are encoded as $(n+i)$, where n is a power of 2 such as 32768. For simplicity, these BitPositions are represented by (SI:BitString), where $SI = (6 + (i-1)/8)$ and BitString is of 8 bits. BitPositions i' (i from 1 to 16) are represented by 1'(6:00000001), 2'(6:00000010), 3'(6:00000100), 4'(6:00001000), 5'(6:00010000), 6'(6:00100000), 7'(6:01000000), 8'(6:10000000), 9'(7:00000001), 10'(7:00000010), . . . , 16'(7:10000000).

For a link between two nodes X and Y, there are two BitPositions for two forward connected adjacencies. These two forward connected adjacency BitPositions are assigned on nodes X and Y respectively. The BitPosition assigned on X is the forward connected adjacency of Y. The BitPosition assigned on Y is the forward connected adjacency of X.

For example, for the link between nodes B and C in the figure, two forward connected adjacency BitPositions 5' and 6' are assigned to two ends of the link. BitPosition 5' is assigned on node B to B's end of the link. It is the forward connected adjacency of node C. BitPosition 6' is assigned on node C to C's end of the link. It is the forward connected adjacency of node B.

For a LAN (i.e., broadcast link) connecting nodes X1, X2, ..., Xm, there are m BitPositions for m forward connected adjacencies. These m forward connected adjacency BitPositions are assigned on nodes X1, X2, ..., Xm respectively.

For the LAN connecting 4 nodes C, G, H and D in the figure, 4 forward connected adjacency BitPositions 13', 14', 15' and 16' are assigned to C, G, H and D respectively.

2.2. BIER-TE BIFT on BFR

Every BFR in a BIER-TE domain/topology has a BIER-TE BIFT. This section shows the BIER-TE BIFT on every BFR/node of the BIER-TE topology with LAN in [Figure 1](#).

For the BIER-TE topology in [Figure 1](#), each of 8 nodes/BFRs A, B, C, D, E, F, G and H has its BIER-TE BIFT for the topology. The BIFT on a BFR comprises a forwarding entry for each of the adjacencies of the BFR.

The BIER-TE BIFT on BFR A (i.e., node A) is shown in [Figure 2](#). There are two adjacencies of A. One is the forward connected adjacency from A to B (represented by BP 2'); the other is the local decap adjacency (represented by BP 5) for BFER (i.e., egress) A. The BIFT on A has two forwarding entries.

Adjacency BP (SI:BitString)	Action	BFR-NBR (Next Hop)
2'(6:00000010)	fw-connected	B
5 (0:00010000)	local-decap	

Figure 2: BIER-TE BIFT on BFR A

The 1st forwarding entry in the BIFT is for BitPosition 2', which is the forward connected adjacency from A to B. For a multicast packet with BitPosition 2', which indicates that the P2MP path in the packet traverses the adjacency from A to B, the forwarding entry forwards the packet to B along the link from A to B.

The 2nd forwarding entry in the BIFT locally decapsulates a multicast packet with BitPosition 5 and passes a copy of the payload of the packet to the packet's NextProto. It is for BitPosition 5, which is the local decap adjacency for BFER (i.e., egress) A. For a multicast packet with BitPosition 5, which indicates that the P2MP path in the packet has node A as one of its destinations (i.e., egress nodes), the forwarding entry decapsulates the packet and passes a copy of the payload of the packet to the packet's NextProto within node A.

The BIER-TE BIFT on BFR B (i.e., node B) is shown in [Figure 3](#). There are four forward connected adjacencies of B. They are the forward connected adjacencies from B to A (represented by BP 1'), B to G (represented by BP 4'), B to C (represented by BP 6') and B to E (represented by BP 8') respectively. The BIFT on B has four forwarding entries for these adjacencies.

Adjacency BP (SI:BitString)	Action	BFR-NBR (Next Hop)
1'(6:00000001)	fw-connected	A
4'(6:00001000)	fw-connected	G
6'(6:00100000)	fw-connected	C
8'(6:10000000)	fw-connected	E

Figure 3: BIER-TE BIFT on BFR B

The 1st forwarding entry in the BIFT is for BitPosition 1', which is the forward connected adjacency from B to A. For a multicast packet with BitPosition 1', which indicates that the P2MP path in the packet traverses the adjacency from B to A, the forwarding entry forwards the packet to A along the link from B to A.

The 2nd forwarding entry in the BIFT is for BitPosition 4', which is the forward connected adjacency from B to G. For a multicast packet with BitPosition 4', which indicates that the P2MP path in the packet traverses the adjacency from B to G, the forwarding entry forwards the packet to G along the link from B to G.

The 3rd forwarding entry in the BIFT is for BitPosition 6', which is the forward connected adjacency from B to C. For a multicast packet with BitPosition 6', which indicates that the P2MP path in the

packet traverses the adjacency from B to C, the forwarding entry forwards the packet to C along the link from B to C.

The 4-th forwarding entry in the BIFT is for BitPosition 8', which is the forward connected adjacency from B to E. For a multicast packet with BitPosition 8', which indicates that the P2MP path in the packet traverses the adjacency from B to E, the forwarding entry forwards the packet to E along the link from B to E.

The BIER-TE BIFT on BFR C (i.e., node C) is shown in [Figure 4](#). There are five forward connected adjacencies of C. They are the forward connected adjacencies from C to B (represented by BP 5'), C to F (represented by BP 12'), C to G (represented by BP 14'), C to H (represented by BP 15') and C to D (represented by BP 16') respectively. The BIFT on C has five forwarding entries for these adjacencies.

Adjacency BP (SI:BitString)	Action	BFR-NBR (Next Hop)
5'(6:00010000)	fw-connected	B
12'(7:00001000)	fw-connected	F
14'(7:00100000)	fw-connected	G
15'(7:01000000)	fw-connected	H
16'(7:10000000)	fw-connected	D

Figure 4: BIER-TE BIFT on BFR C

The BIER-TE BIFT on BFR D (i.e., node D) is shown in [Figure 5](#). There are four adjacencies of D. Three of them are the forward connected adjacencies from D to C (represented by BP 13'), D to G (represented by BP 14') and D to H (represented by BP 15') respectively; the other is the local decap adjacency (represented by BP 1) for BFER (i.e., egress) D. The BIFT on D has four forwarding entries for these adjacencies.

Adjacency BP (SI:BitString)	Action	BFR-NBR (Next Hop)
13'(7:00010000)	fw-connected	C
14'(7:00100000)	fw-connected	G
15'(7:01000000)	fw-connected	H
1 (0:00000001)	local-decap	

Figure 5: BIER-TE BIFT on BFR D

The BIER-TE BIFT on BFR E (i.e., node E) is shown in [Figure 6](#). There are three adjacencies of E. Two of them are the forward connected adjacencies from E to B (represented by BP 7') and E to F (represented by BP 10') respectively; the other is the local decap adjacency (represented by BP 3) for BFER (i.e., egress) E. The BIFT on E has three forwarding entries for these adjacencies.

Adjacency BP (SI:BitString)	Action	BFR-NBR (Next Hop)
7'(6:01000000)	fw-connected	B
10'(7:00000010)	fw-connected	F
3 (0:00000100)	local-decap	

Figure 6: BIER-TE BIFT on BFR E

The BIER-TE BIFT on BFR F (i.e., node F) is shown in [Figure 7](#). There are three adjacencies of F. Two of them are the forward connected adjacencies from F to E (represented by BP 9') and F to C (represented by BP 11') respectively; the other is the local decap adjacency (represented by BP 2) for BFER (i.e., egress) F. The BIFT on F has three forwarding entries for these adjacencies.

Adjacency BP (SI:BitString)	Action	BFR-NBR (Next Hop)
9'(7:00000001)	fw-connected	E
11'(7:00000100)	fw-connected	C
2 (0:00000010)	local-decap	

Figure 7: BIER-TE BIFT on BFR F

The BIER-TE BIFT on BFR G (i.e., node G) is shown in [Figure 8](#). There are four forward connected adjacencies of G. They are the adjacencies from G to B (represented by BP 3'), G to C (represented by BP 13'), G to H (represented by BP 15') and G to D (represented by BP 16') respectively. The BIFT on G has four forwarding entries for these adjacencies.

Adjacency BP (SI:BitString)	Action	BFR-NBR (Next Hop)
3'(6:00000100)	fw-connected	B
13'(7:00010000)	fw-connected	C
15'(7:01000000)	fw-connected	H
16'(7:10000000)	fw-connected	D

Figure 8: BIER-TE BIFT on BFR G

The BIER-TE BIFT on BFR H (i.e., node H) is shown in [Figure 9](#). There are four adjacencies of H. Three of them are the forward connected adjacencies from H to C (represented by BP 13'), H to G (represented by BP 14') and H to D (represented by BP 16') respectively; the other is the local decap adjacency (represented by BP 4) for BFER (i.e., egress) H. The BIFT on H has four forwarding entries for these adjacencies.

Adjacency BP (SI:BitString)	Action	BFR-NBR (Next Hop)
13'(7:00010000)	fw-connected	C
14'(7:00100000)	fw-connected	G
16'(7:10000000)	fw-connected	D
4 (0:00001000)	local-decap	

Figure 9: BIER-TE BIFT on BFR H

2.3. Example P2MP Path with LAN

This section presents the forwarding behaviors along an explicit P2MP path in [Figure 1](#) going through the LAN in the figure.

The explicit P2MP path traverses the link/adjacency from A to B (indicated by BP 2'), the link/adjacency from B to G (indicated by BP 4') and the link/adjacency from B to C (indicated by BP 6'), the link/adjacency from G to H (indicated by BP 15'), and the link/adjacency from C to F (indicated by BP 12'). This path is represented by {2', 4', 6', 12', 15', 2, 4}. The packet at A has this path.

For the packet with the P2MP path, A forwards the packet to B according to the forwarding entry for BP 2' in its BIFT.

After receiving the packet from A, B forwards the packet to G and C according to the forwarding entries for BPs 4' and 6' in B's BIFT respectively. The packet received by G has path {12', 15', 2, 4}. The packet received by C has path {12', 15', 2, 4}.

After receiving the packet from B, G sends the packet to H according to the forwarding entry for BP 15' in G's BIFT.

After receiving the packet from B, C copies and sends the packet to H and F according to the forwarding entries for BPs 15' and 12' in C's BIFT respectively.

Egress node H of the P2MP path receives the duplicated packets. One packet is from G, and the same copy is from C.

The solution proposed for LANs in this document resolve this issue. For a packet with an explicit P2MP path traversing LANs (i.e., broadcast links), the packet is replicated and forwarded statelessly

along the path. Each of the egress nodes of the path will not receive any duplicated packet.

3. Improved BIER-TE with LAN

3.1. New BP Assignments for LAN

For all the nodes/BFRs attached to a LAN (i.e., broadcast link), it is assumed that they are connected a pseudo node. In one implementation, the pseudo node is the Designated Router (DR) of the LAN in OSPF or the Designated Intermediate System (DIS) of the LAN in IS-IS.

For the connection between the pseudo node and each of the nodes/BFRs attached to a LAN, two BPs are assigned to it. One is for the adjacency from the BFR to the pseudo node, the other is for the adjacency from the pseudo node to the BFR.

The adjacency from a BFR to the pseudo node is called a LAN adjacency. The adjacency from the pseudo node to a BFR is a forward connected adjacency.

For example, suppose that the pseudo node for the LAN in [Figure 1](#) is Px. The BP assignments for the LAN (i.e., connections between Px and BFRs C, G, H and D) are illustrated in [Figure 10](#).

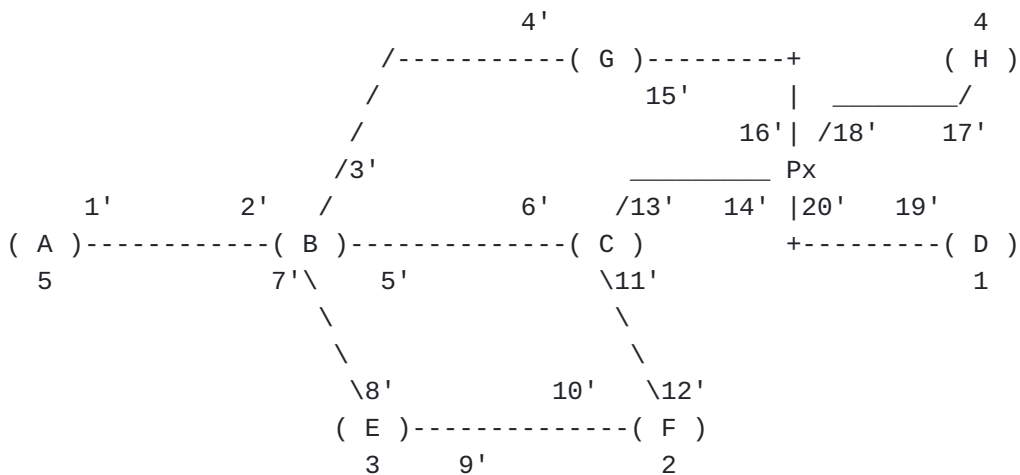


Figure 10: Example BIER-TE Topology with BPs for LAN

The connection/adjacency from Px to C is assigned BP 13', and the connection/adjacency from C to Px is assigned BP 14'.

The connection/adjacency from Px to G is assigned BP 15', and the connection/adjacency from G to Px is assigned BP 16'.

The connection/adjacency from Px to H is assigned BP 17', and the connection/adjacency from H to Px is assigned BP 18'.

The connection/adjacency from Px to D is assigned BP 19', and the connection/adjacency from D to Px is assigned BP 20'.

In an alternative, all the nodes/BFRs attached to a LAN are assumed fully connected each other (i.e., they are fully meshed). For a connection between any two BFRs on the LAN, two forward connected adjacencies are assigned to the two ends of the connection.

For example, there are four BFRs C, G, H and D attached to the LAN in [Figure 1](#). There are six connections among these four BFRs. They are connections between C and G, C and H, C and D, G and H, G and D, H and D. Twelve BPs are needed for these six connections.

In general, for n BFRs attached to a LAN, there are $n*(n-1)/2$ connections among these n BFRs and $n*(n-1)$ BPs are needed for these connections. This may not be scalable. But for this alternative, the BIER-TE BIFT on a BFR needs not to be changed except for considering the full mesh connections among the BFRs attached to a LAN.

3.2. Improved BIER-TE BIFT on BFR

Each BFR in a BIER-TE domain has a BIER-TE BIFT. For a BFR not attached to any LAN, the BIER-TE BIFT on the BFR is the same as before. For a BFR attached to a LAN, its BIER-TE BIFT is changed for considering the LAN.

For example, BFRs C, G, H and D are attached to a LAN in [Figure 1](#). The BIER-TE BIFT on each of these four BFRs is changed for the new BP assignments for the LAN in [Figure 10](#).

For a BFR attached to a LAN, suppose that the pseudo node for the LAN is Px. The improved BIER-TE BIFT on the BFR comprises a forwarding entry for the LAN adjacency from the BFR to Px and a secondary BIFT for Px. The secondary BIFT for Px on the BFR contains a forwarding entry for each of the forward connected adjacencies from Px to the BFRs attached to the LAN except for the adjacency from Px to the BFR.

For example, the improved BIER-TE BIFT on BFR C is illustrated in [Figure 11](#). It comprises the forwarding entry for the LAN adjacency from C to Px (indicated by BP 14') and the secondary BIFT for Px on BFR C. The secondary BIFT contains three forwarding entries for three forward connected adjacencies from Px to G (indicated by 15'), Px to H (indicated by 17') and Px to D (indicated by 19') respectively.

Adjacency BP (SI:BitString)	Action	BFR-NBR (Next Hop)
15'(7:01000000)	fw-connected	G
17'(8:00000001)	fw-connected	H
19'(8:00000100)	fw-connected	D

Secondary BIFT for Px on BFR C

Adjacency BP (SI:BitString)	Action	BFR-NBR (Next Hop)
5'(6:00010000)	fw-connected	B
12'(7:00001000)	fw-connected	F
14'(7:00100000)	lan-connected	Px

Figure 11: Improved BIER-TE BIFT on BFR C

The improved BIER-TE BIFT on BFR G is illustrated in [Figure 12](#). It comprises the forwarding entry for the LAN adjacency from G to Px (indicated by BP 16') and the secondary BIFT for Px on BFR G. The secondary BIFT contains three forwarding entries for three forward connected adjacencies from Px to C (indicated by 13'), Px to H (indicated by 17') and Px to D (indicated by 19') respectively.

Adjacency BP (SI:BitString)	Action	BFR-NBR (Next Hop)
13'(7:00010000)	fw-connected	C
17'(8:00000001)	fw-connected	H
19'(8:00000100)	fw-connected	D

Secondary BIFT for Px on BFR G

Adjacency BP (SI:BitString)	Action	BFR-NBR (Next Hop)
3'(6:00000100)	fw-connected	B
16'(7:00100000)	lan-connected	Px

Figure 12: Improved BIER-TE BIFT on BFR G

The improved BIER-TE BIFT on BFR H is illustrated in [Figure 13](#). It comprises the forwarding entry for the LAN adjacency from H to Px (indicated by BP 18') and the secondary BIFT for Px on BFR H. The secondary BIFT contains three forwarding entries for three forward connected adjacencies from Px to C (indicated by 13'), Px to G (indicated by 15') and Px to D (indicated by 19') respectively.

Adjacency BP (SI:BitString)	Action	BFR-NBR (Next Hop)
13'(7:00010000)	fw-connected	C
15'(7:01000000)	fw-connected	G
19'(8:00000100)	fw-connected	D

Secondary BIFT for Px on BFR H

Adjacency BP (SI:BitString)	Action	BFR-NBR (Next Hop)
4 (0:00001000)	local-decap	
18'(8:00000010)	lan-connected	Px

Figure 13: Improved BIER-TE BIFT on BFR H

The improved BIER-TE BIFT on BFR D is illustrated in [Figure 14](#). It comprises the forwarding entry for the LAN adjacency from D to Px (indicated by BP 20') and the secondary BIFT for Px on BFR D. The secondary BIFT contains three forwarding entries for three forward connected adjacencies from Px to C (indicated by 13'), Px to G (indicated by 15') and Px to H (indicated by 17') respectively.

Adjacency BP (SI:BitString)	Action	BFR-NBR (Next Hop)
13'(7:00010000)	fw-connected	C
15'(7:01000000)	fw-connected	G
17'(8:00000001)	fw-connected	H

Secondary BIFT for Px on BFR D

Adjacency BP (SI:BitString)	Action	BFR-NBR (Next Hop)
1 (0:00000001)	local-decap	
20'(8:00000001)	lan-connected	Px

Figure 14: Improved BIER-TE BIFT on BFR D

3.3. Updated Forwarding Procedure

The forwarding procedure defined in [I-D.ietf-bier-te-arch] is updated/enhanced for using an improved BIER-TE BIFT to support BIER-TE with LAN.

The updated procedure is described in Figure 15. For a multicast packet containing the BitString encoding an explicit P2MP path, if the BP in the BitString is for a LAN adjacency to pseudo node Px for the LAN, the updated forwarding procedure on a BFR sends the packet towards Px's next hop nodes on the P2MP path encoded in the packet.

The procedure on a BFR "sends" (i.e., works as sending) the packet with the BP for the LAN adjacency to Px according to the forwarding entry for the BP in the improved BIER-TE BIFT on the BFR. And then it acts on Px to "send" (i.e., works as sending) the packet to each of the Px's next hop nodes that are on the P2MP path using the secondary BIFT for Px.

It obtains the secondary BIFT for Px on the BFR, clears all the BPs for the adjacencies of the BFR including the adjacency from the BFR to Px, copies and sends the packet to each of the Px's next hop nodes on the P2MP path using the secondary BIFT for Px.

For each Px's next hop node on the P2MP path, which is represented by BP j in the packet's BitString, it gets the forwarding entry for BP j from the secondary BIFT for Px, copies the packet, updates the

copy's BitString by clearing all the BPs for Px's adjacencies, and sends the updated copy to the next hop node according to the forwarding entry.

```

Packet = the packet received by BFR;
FOR each BP k (from the rightmost in Packet's BitString) {
  IF BP k is local decap adjacency (or say BP of BFER) {
    Copies Packet, sends the copy to the multicast
    flow overlay and clears bit k in Packet's BitString
  } ELSE IF BP k is forward connected adjacency of the BFR {
    Finds the forwarding entry in the BIER-TE BIFT using BP k,
    Copies Packet, updates the copy's BitString by
    clearing all the BPs for the adjacencies of the BFR,
    and sends the updated copy to BFR-NBR
  } ELSE IF BP k is LAN adjacency to Px {
    Obtains the secondary BIFT for Px,
    Clears all the BPs for the adjacencies of the BFR,
    FOR each BP j (from the rightmost in Packet's BitString) {
      IF BP j is Px's forward connected adjacency {
        Gets the forwarding entry for BP j in the
        secondary BIFT for Px,
        Copies Packet, updates the copy's BitString by
        clearing all the BPs for Px's adjacencies,
        and sends the updated copy to BFR-NBR
      }
    }
  }
}

```

Figure 15: Updated Forwarding Procedure

4. Example Application of Improved BIER-TE

This section illustrates an example application of improved BIER-TE to [Figure 1](#). It shows the forwarding behaviors along an explicit P2MP path in [Figure 10](#) going through the LAN in the figure.

The new BP assignments for the LAN in [Figure 1](#) is shown in [Figure 10](#). The improved BIER-TE BIFT on each of the BFRs attached to the LAN is given in [Section 3.2](#).

The explicit P2MP path traverses the link/adjacency from A to B (indicated by BP 2'), the link/adjacency from B to G (indicated by BP 4') and the link/adjacency from B to C (indicated by BP 6'), the link/adjacency from G to Px (indicated by BP 16'), the link/adjacency from C to F (indicated by BP 12'), and the link/adjacency from Px to H (indicated by BP 17'). This path is represented by {2', 4', 6', 12', 16', 17', 2, 4}. The packet at A has this path.

For the packet with the P2MP path, A forwards the packet to B according to the forwarding entry for BP 2' in its BIFT.

After receiving the packet from A, B forwards the packet to G and C according to the forwarding entries for BPs 4' and 6' in B's BIFT respectively. The packet received by G has path {12', 16', 17', 2, 4}. The packet received by C has path {12', 16', 17', 2, 4}.

After receiving the packet from B, G "sends" the packet to Px according to the forwarding entry for BP 16' in G's improved BIER-TE BIFT. After receiving the packet from G, which has path {12', 17', 2, 4}, Px "sends" the packet to H according to the forwarding entry for BP 17' in the secondary BIFT for Px (a part of G's improved BIER-TE BIFT).

After receiving the packet from G, which has path {12', 2, 4}, H decapsulates the packet and passes a copy of the payload of the packet to the packet's NextProto within node H according to the forwarding entry for BP 4 in H's improved BIER-TE BIFT.

After receiving the packet from B, which has path {12', 16', 17', 2, 4}, C sends the packet to F according to the forwarding entry for BP 12' in C's improved BIER-TE BIFT.

After receiving the packet from C, which has path {16', 17', 2, 4}, F decapsulates the packet and passes a copy of the payload of the packet to the packet's NextProto within node F according to the forwarding entry for BP 2 in F's BIER-TE BIFT.

Egress node H of the P2MP path does not receive any duplicated packet.

5. Security Considerations

TBD.

6. IANA Considerations

No requirements for IANA.

7. Acknowledgements

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