Authors: N. Kumar   C. Pignataro
         Cisco Systems, Inc.   Cisco Systems, Inc.
         N. Akiya   L. Zheng
         Big Switch Networks   Individual Contributor
         M. Chen   G. Mirsky
         Huawei Technologies   Ericsson

BIER Ping and Trace

Abstract

Bit Index Explicit Replication (BIER) is an architecture that
provides optimal multicast forwarding through a "BIER domain"
without requiring intermediate routers to maintain any multicast
related per- flow state. BIER also does not require any explicit
tree-building protocol for its operation. A multicast data packet
enters a BIER domain at a "Bit-Forwarding Ingress Router" (BFIR),
and leaves the BIER domain at one or more "Bit-Forwarding Egress
Routers" (BFERs). The BFIR router adds a BIER header to the packet.
The BIER header contains a bit-string in which each bit represents
exactly one BFER to forward the packet to. The set of BFERs to which
the multicast packet needs to be forwarded is expressed by setting
the bits that correspond to those routers in the BIER header.

This document describes the mechanism and basic BIER OAM packet
format that can be used to perform failure detection and isolation
on the BIER data plane.

Status of This Memo

Table of Contents

1. Introduction

[RFC8279] introduces and explains BIER architecture that provides optimal multicast forwarding through a "BIER domain" without requiring intermediate routers to maintain any multicast related per- flow state. BIER also does not require any explicit tree- building protocol for its operation. A multicast data packet enters a BIER domain at a "Bit-Forwarding Ingress Router" (BFIR), and leaves the BIER domain at one or more "Bit-Forwarding Egress Routers" (BFERs). The BFIR router adds a BIER header to the packet. The BIER header contains a bit-string in which each bit represents exactly one BFER to forward the packet to. The set of BFERs to which the multicast packet needs to be forwarded is expressed by setting the bits that correspond to those routers in the BIER header.

This document describes the mechanism and basic BIER Operations, Administration, and Maintenance (OAM) packet format that can be used to perform failure detection and isolation on the BIER data plane without any dependency on other layers like the IP layer.

2. Conventions used in this document

2.1. Terminology

BFER - Bit Forwarding Egress Router

BFIR - Bit Forwarding Ingress Router

BIER - Bit Index Explicit Replication

DDMAP - Downstream Detailed Mapping TLV

ECMP - Equal Cost Multi-Path

OAM - Operation, Administration, and Maintenance

SI - Set Identifier

2.2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

3. BIER OAM

BIER OAM is defined to stay within the BIER layer by directly
following the BIER header without mandating the need for IP header.
[RFC8296] defines a 4-bit field as "Proto" to identify the payload
following the BIER header. When the payload is BIER OAM, the "Proto"
field will be set to 5 as defined in [RFC8296]

3.1. BIER OAM message format

The BIER OAM packet header format that follows BIER header is as
follows:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Ver | Message Type | Proto |            Reserved            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      OAM Message Length                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~                  Message Type Dependent Data                 ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Ver

   Set to 1.

Message Type

   This document defines the following Message Types:

             Type   Value Field
             -------- ---------------
                1   BIER Echo Request
                2   BIER Echo Reply

Proto

      This field is used to define if there is any data packet
      immediately following the OAM payload which is used for passive
      OAM functionality. This field is set to 0 if there is no data
      packet following OAM payload.

   OAM Message Length
      This field defines the length of the OAM message including the
      header and Dependent Data field.

   The Echo Request/Reply header format is as follows:

```
  0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 | Ver  | Echo Req/Rep | Proto |              Reserved          |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |  QTF |  RTF |   Reply mode  |  Return Code  |    Reserved     |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                       Sender's Handle                        |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                       Sequence Number                        |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                       TimeStamp Sent                         |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                       TimeStamp Sent                         |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                      TimeStamp Received                      |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                      TimeStamp Received                      |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 ~                           TLVs                               ~
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Proto

   Set to 0 for Echo Request/Reply header.

QTF

     Querier Timestamp Format. When set to 2, the Timestamp Sent field
     is (in seconds and microseconds, according to the Initiator's
     clock) in NTP format [RFC5905]. When set to 3, the timestamp
     format is in IEEE 1588-2008 (1588v2) Precision Time Protocol
     format. Any other value MAY be considered as sanity check failure

  RTF
     Responder Timestamp Format. When set to 2, the Timestamp Received
     field is (in seconds and microseconds, according to the
     Initiator's clock) in NTP format [RFC5905]. When set to 3, the
     timestamp format is in IEEE 1588-2008 (1588v2) Precision Time
     Protocol format. Any other value MAY be considered as sanity
     check failure.

  Reply mode
     The Reply mode is set to one of the below:

```
           Value       Meaning
           --------    ---------------
              1        Do not Reply
              2        Reply via IPv4/IPv6 UDP packet.
              3        Reply via BIER packet
```

When Reply mode is set to 1, the receiver will not send any reply.
This mode can be used for unidirectional path validation. When the
Reply mode is set to 2, the Responder BFR encapsulates the Echo
reply payload with IP header. When the Initiator intends to validate
the return BIER path, the Reply mode will be set to 3 so that the
Responder BFR will encapsulates the Echo Reply with the BIER header.

Return Code
   Set to zero if Type is "BIER Echo Request". Set to one of the
   value defined in section 3.2, if Type is "BIER Echo Reply".

Reserved
   Set to all zero value.

Sender's Handle, Sequence Number, and Timestamp
   The Sender's Handle is filled by the Initiator, and returned
   unchanged by responder BFR. This value can be used for matching
   the replies to the request.

   The Sequence Number is assigned by the Initiator and can be used
   to detect any missed replies.

   The Timestamp Sent is the time when the Echo Request is sent. The
   TimeStamp Received in Echo Reply is the time (accordingly to
   responding BFR clock) that the corresponding Echo Request was
   received. The format depends on the QTF/RTF value.

TLVs
   Carries the TLVs as defined in [Section 3.3](#).

3.2. Return Code

The responder uses the Return Code field to reply with a validity
check or other error message to Initiator. It does not carry any
meaning in Echo Request and MUST be set to zero.

The Return Code can be one of the following:

```
Value       Value Meaning
------      ---------------
  0      No return code
  1      Malformed Echo Request received
  2      One or more of the TLVs is not supported
  3      Replying BFR is the only BFER in header Bitstring
  4      Replying BFR is one of the BFER in header Bitstring
  5      Packet-Forward-Success
  6      Invalid Multipath Info Request
  8      No matching entry in the forwarding table
  9      Set-Identifier Mismatch
 10      DDMAP Mismatch
```

"No return code" will be used by Initiator in the Echo Request. This value MUST NOT be used in Echo Reply.

"Malformed Echo Request received" will be used by any BFR if the received Echo Request packet is not properly formatted.

When a receiver does not support any TLV included in the Echo Request, the Return code will be set to "One or more of the TLVs is not supported" carrying the respective TLVs.

When the received header BitString in the Echo Request packet contains only its Bit-ID, "Replying BFR is the only BFER in header BitString" is set in the reply. This value implies that the receiver is BFER and the packet is not forwarded to any more neighbors.

When the received header BitString in the Echo Request packet contains its Bit-ID in addition to other Bit-IDs, "Replying BFR is one of the BFER in header BitString" is set in the reply. This value implies that the responder is a BFER and the packet is further forwarded to one or more neighbors.

Any transit BFR will send the Echo Reply with "Packet-Forward-Success", if the TLV in the received Echo Request is understood and forwarding table has forwarding entries for the BitString. This behavior is demonstrated by a transit BFR during traceroute mode.

When the Echo Request is received with multipath info for more than one BFER, the Return Code is set to "Invalid Multipath Info Request".

If the BitString cannot be matched in the local forwarding table, the BFR will use "No matching entry in the forwarding table" in the reply.

If the BIER-MPLS label in the received Echo Request is not the one assigned for SI in Original SI-BitString TLV, "Set-Identifier Mismatch" is set in order to report the mismatch.

3.3. BIER OAM TLV

This section defines various TLVs that can be used in BIER OAM packet. The TLVs (Type-Length-Value tuples) have 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              |             Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
~                             Value                             ~
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

TLV Types are defined below; Length is the length of the Value field in octets. The Value field depends on the TLV Type.

3.3.1. Original SI-BitString TLV

The Original SI-BitString TLV carries the set of BFER and carries the same BitString that Initiator includes in the BIER header. This TLV 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 = 1              |        Length = variable      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Set ID     | Sub-domain ID |BS Len|  Reserved             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              BitString  (first 32 bits)                       ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~                                                               ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              BitString  (last 32 bits)                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Set ID field is set to the value of the Set Identifier to which the BitString belongs to. This value is derived as defined in [RFC8279]

Sub-domain ID is set to the Sub-domain value to which BFER in BitString belongs to.

BS Len is set based on the length of BitString as defined in [RFC8296]

The BitString field carries the set of BFR-IDs that Initiator will
include in the BIER header. This TLV MUST be included by Initiator
in Echo Request packet

Any Initiator MUST include this TLV in the Echo Request packet.

3.3.2. Target SI-BitString TLV

The Target SI-BitString TLV carries the set of BFER from which the
Initiator expects the reply from.This TLV 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 = 2               |        Length = variable      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Set ID     | Sub-domain ID |BS Len|  Reserved             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|               BitString  (first 32 bits)                     ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~                                                               ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|               BitString  (last 32 bits)                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Set ID field is set to the Set Identifier to which the BitString
belongs to. This value is derived as defined in [RFC8279]

Sub-domain ID is set to the Sub-domain value to which BFER in
BitString belongs to.

BS Len is set based on the length of BitString as defined in
[RFC8296]

The BitString field carries the set of BFR-IDs of BFER(s) that
Initiator expects the response from. The BitString in this TLV may
be different from the BitString in the BIER header and allows to
control the BFER responding to the Echo Request. This TLV MUST be
included by Initiator in BIER OAM packet if the Downstream Mapping
TLV (section 3.3.4) is included.

3.3.3. Incoming SI-BitString TLV

The Incoming SI-BitString TLV will be included by Responder BFR in
Reply message and copies the BitString from BIER header of incoming
Echo Request message. This TLV 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 = 3               |        Length = variable      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Set ID     | Sub-domain ID |BS Len|  Reserved             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|               BitString  (first 32 bits)                     ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~                                                              ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|               BitString  (last 32 bits)                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Set ID field is set to the Set Identifier to which the BitString
belongs to. This value is derived as defined in [RFC8279]

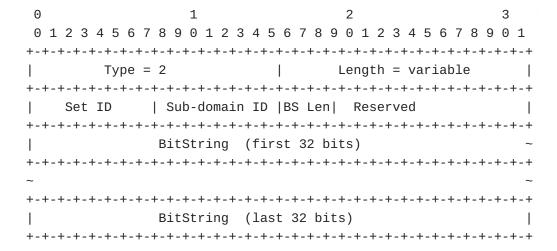Sub-domain ID is set to the Sub-domain value to which BFER in
BitString belongs to.

BS Len is set based on the length of BitString as defined in
[RFC8296]

The BitString field copies the BitString from the BIER header of the
incoming Echo Request. A Responder BFR SHOULD include this TLV in
Echo Reply if the Echo Request is received with I flag set in
Downstream Mapping TLV.

An Initiator MUST NOT include this TLV in Echo Request.

3.3.4. Downstream Mapping TLV

This TLV 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 = 4            |       Length = variable       |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |             MTU              | Address Type  |     Flags      |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |             Downstream Address (4 or 16 octets)              |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |          Downstream Interface Address (4 or 16 octets)       |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |          Sub-tlv Length          |                           |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+                           |
 .                                                              .
 .                     List of Sub-TLVs                         .
 .                                                              .
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

MTU

   Set to MTU value of outgoing interface.

Address Type

      The Address Type indicates the address type and length of IP
      address for the downstream interface. The Address type is set to
      one of the below:

            Type   Addr. Type   DA Length   DIA Length
            -------   ---------------   ----------   ----------
              1   IPv4 Numbered   4   4
              2   IPv4 Unnumbered   4   4
              3   IPv6 Numbered   16   16
              4   IPv6 Unnumbered   16   4

            DA Length - Downstream Address field Length
            DIA Length - Downstream Interface Address field Length

   Flags
      The Flags field has the following format:

```
 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|    Rsvd    |I|
+-+-+-+-+-+-+-+-+
```

   When I flag is set, the Responding BFR MUST include the Incoming SI-
   BitString TLV in Echo Reply message.

   Downstream Address and Downstream Interface Address

If the Address Type is 1, the Downstream Address MUST be set to
IPV4 BFR-Prefix of downstream BFR and Downstream Interface
Address is set to the downstream interface address.

If the Address Type is 2, the Downstream Address MUST be set to
IPV4 BFR-Prefix of downstream BFR and Downstream Interface
Address is set to the index assigned by upstream BFR to the
interface.

If the Address Type is 3, the Downstream Address MUST be set to
IPV6 BFR-Prefix of downstream BFR and Downstream Interface
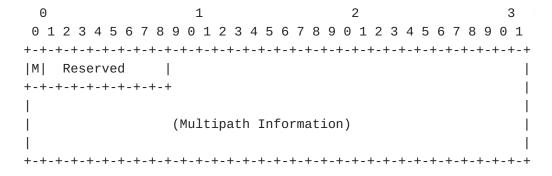Address is set to the downstream interface address.

If the Address Type is 4, the Downstream Address MUST be set to
IPv6 BFR-Prefix of downstream BFR and Downstream Interface
Address is set to the index assigned by upstream BFR to the
interface.

3.3.4.1. Downstream Detailed Mapping Sub-TLVs

This section defines the optional Sub-TLVs that can be included in
Downstream Mapping TLV.

```
        Sub-TLV Type      Value
        ------------   -------------
            1          Multipath Entropy Data
            2          Egress BitString
```

3.3.4.1.1. Multipath Entropy Data

```
  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
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |M|  Reserved     |                                             |
 +-+-+-+-+-+-+-+-+-+                                             |
 |                                                               |
 |                 (Multipath Information)                       |
 |                                                               |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
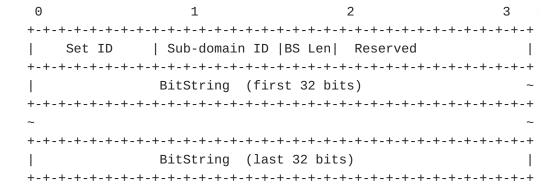
M Flag

This flag is set to 0 if all packets will be forwarded out
through the interface defined in the Downstream Mapping TLV. When
set to 1, Multipath Information will be defined by the Bit masked
Entropy data.

Multipath Information
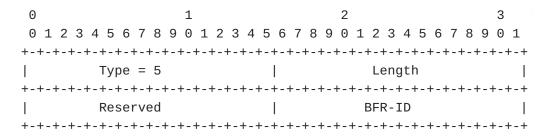Entropy Data encoded as defined in section 3.4

3.3.4.1.2. Egress BitString

   Responder BFR MAY include this Sub-TLV with the rewritten BitString
   in the outgoing interface as defined in section 6.1 of [RFC8279]

```
 0                   1                   2                   3
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |    Set ID     | Sub-domain ID |BS Len|  Reserved            |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |              BitString  (first 32 bits)                      ~
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 ~                                                              ~
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |              BitString  (last 32 bits)                       |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

3.3.5. Responder BFER TLV

   The BFER replying to the request MAY include the Responder BFER TLV.
   This TLV identifies the originator of BIER Echo Reply. This TLV 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 = 5             |             Length           |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |          Reserved             |            BFR-ID            |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

BFR-ID

     The BFR-ID field carries the BFR-ID of replying BFER. This TLV
     MAY be included by Responding BFER in BIER Echo Reply packet.

3.3.6. Responder BFR TLV

   Any transit BFR replying to the request MAY include the Responder
   BFR TLV. This is used to identify the replying BFR without BFR-ID.
   This TLV 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     TLV Type = 6              |        Length = variable      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Reserved            |          Address Type         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
~                  BFR-Prefix (4 or 16 bytes)                   ~
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Length

   The Length field varies depending on the Address Type.

Address Type

   Set to 1 for IPv4 or 2 for IPv6.

BFR-Prefix

      This field carries the local BFR-Prefix of the replying BFR. This
      TLV MAY be included by Responding BFR in BIER Echo Reply packet.

3.3.7. Upstream Interface TLV

   The BFR replying to the request MUST include the Upstream Interface
   TLV. This TLV identifies the incoming interface and the BIER-MPLS
   label in the incoming Echo Request. This TLV 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     TLV Type = 7              |        Length = variable      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Reserved            |          Address Type         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
~              Upstream Address (4 or 16 bytes)                 ~
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Length

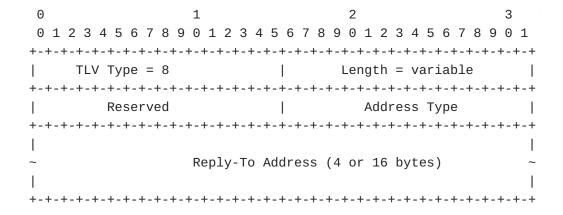   The Length field varies depending on the Address Type.

Address Type

Set to 1 for IPv4 numbered, 2 for IPv4 Unnumbered 3 for IPv6
numbered or 4 for IPv6 Unnumbered.

Upstream Address
As defined in [Section 3.3.4](#)

3.3.8. Reply-To TLV

The Initiator BFR MAY include Reply-To TLV in the Echo Request. This
TLV is used by transit BFR or BFER when the reply mode is 2. The IP
address will be used to generate the Echo Reply. This TLV 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|       TLV Type = 8            |         Length = variable     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Reserved             |         Address Type           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
~                 Reply-To Address (4 or 16 bytes)              ~
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Length

   The Length field varies depending on the Address Type.

Address Type

   Set to 1 for IPv4 or 2 for IPv6.

Reply-To Address

      Set to any locally configured address to which the Echo reply
      should be sent.

3.4. Multipath Entropy Data Encoding

The size of the Entropy field in the BIER header is 20 bits as
defined in section 2 of [[RFC8296](#)]. This encoding is similar to the
Multipath Type 9 encoding defined in Section 3.4.1.1.1 of [[RFC8029](#)].

4. Procedures

This section describes aspects of Ping and traceroute operations.

4.1. BIER OAM Processing

A BIER OAM packet MUST be sent to the BIER control plane for OAM
processing if one of the following conditions is true:

   *The receiving BFR is a BFER.

   *TTL of BIER-MPLS Label expired.

   *Router Alert label is present in the label stack.

4.2. Per BFER ECMP Discovery

As defined in [RFC8279], BIER follows the unicast forwarding path
and allows load balancing over ECMP paths between BFIR and BFER.
BIER OAM MUST support ECMP path discovery between a BFIR and a given
BFER and MUST support path validation and failure detection of any
particular ECMP path between BFIR and BFER.

[RFC8296] proposes the BIER header with the Entropy field that can
be leveraged to exercise all ECMP paths. The Initiator/BFIR will use
traceroute message to query each hop about the Entropy information
for each of the downstream paths. To avoid complexity, it is
suggested that the ECMP query is performed per BFER by carrying
required information in BIER OAM message.

The Initiator MUST include Multipath Entropy Data Sub-TLV in
Downstream Mapping TLV. It MUST also include the BFER in BitString
TLV to which the Multipath query is performed.

Any transit BFR will reply with Bit-masked Entropy for each
downstream path as defined in [RFC8029]

4.3. Sending BIER Echo Request

The Initiator MUST set the Message Type as 1 and Return Code as 0.
The Proto field in OAM packet MUST be set to 0. The choice of the
Sender's Handle and Sequence Number is a local matter to the
Initiator and SHOULD increment the Sequence Number by 1 for every
subsequent Echo Request. The QTF field is set to Initiator's local
timestamp format and TimeStamp Sent field is set to the time that
the Echo Request is sent.

The Initiator MUST include Original SI-BitString TLV. The Initiator
MUST NOT include more than one Original SI-BitString TLV. The
Initiator infers the Set Identifier value and Sub-domain ID value
from the respective BitString that will be included in the BIER
header of the packet and includes the values in "SI" and Sub-Domain
ID fields respectively.

In Ping mode, the Initiator MAY include Target SI-BitString TLV to control the responding BFER(s) by listing all the BFERs from which the Initiator expects a response. In the trace route mode, the Initiator MAY include Target SI-Bitstring TLV to control the path trace towards any specific BFER or set of BFERs. The Initiator on receiving a reply with Return code as "Replying BFR is the only BFER in header Bitstring" or "Replying router is one of the BFER in header Bitstring", SHOULD unset the respective BFR-id from Target SI- BitString for any subsequent Echo Request.

When the Reply mode is set to 2, the Initiator MUST include Reply-To TLV (section 3.3.8) in the Echo Request. The Initiator MUST also listen to the UDP port defined in this TLV and process any segment received with destination port as the value defined in the TLV and sent to control plane for BIER OAM payload processing.

The Initiator MAY include Downstream Mapping TLV (section 3.3.4) in the Echo Request to query additional information from transit BFRs and BFERs. In case of ECMP discovery, the Initiator MUST include the Multipath Entropy Data Sub-TLV and SHOULD set the Target SI- BitString TLV carrying a specific BFER ID.

The Initiator MUST encapsulate the OAM packet with BIER header and MUST set the Proto as 5 and further encapsulates with BIER-MPLS label. In ping mode, the BIER-MPLS Label TTL MUST be set to 255. In traceroute mode, the BIER-MPLS Label TTL is set successively starting from 1 and MUST stop sending the Echo Request if it receives a reply with Return code as "Replying router is the only BFER in BIER header Bitstring" from all BFER listed in Target SI- BitString TLV.

4.4. Receiving BIER Echo Request

Sending a BIER OAM Echo Request to control plane for payload processing is triggered as mentioned in section 4.1.

Any BFR on receiving Echo Request MUST perform the basic sanity check. If the BFR cannot parse the OAM Dependent data payload completely because the value in the OAM Message Length field is incorrect, BFR MUST send Echo Reply with Return Code set to "Malformed Echo Request received" if the OAM Message Length is incorrect. If the packet sanity check is fine, it SHOULD initiate the below set of variables:

Reply-Flag

   This flag is initially set to 1.

Interface-I

   The incoming interface on which the Echo Request was received.
   This MAY be used to validate the Downstream Detailed Mapping TLV
   (DDMAP) info and to populate the Upstream Interface TLV.

BIER-Label-L

   The BIER-MPLS Label received as the top label of the received
   Echo Request. This MAY be used to validate if the packet is
   traversing the desired Set Identifier and sub-domain path.

Header-H

   The BIER header of the received Echo Request. It can be used to
   validate the DDMAP info and to populate the Incoming SI-BitString
   TLV. Also, it can be used to perform Entropy calculation
   considering a different field in the header and reply via
   Multipath Entropy Data Sub-TLV.

BFR MUST initialize the Best-return-code variable to the null value.

BFR will populate the Interface-I with the identifier of the
interface over which the Echo Request is received, the top label in
the MPLS stack of the received Echo Request to BIER-Label-L, and the
BIER header to BIER-Header. If the received Echo Request carries
Target SI-BitString TLV, a BFR SHOULD run boolean AND operation
between BitString in Header-H and BitString in Target SI-BitString
TLV. If the resulting BitString is all-zero, reset Reply-Flag=0 and
go to section 4.5. Else:

  *If the BIER-Label-L does not correspond to the local label
   assigned for {sub-domain, BitStringLen, SI} in Original SI-
   BitString TLV, Set the Best-return-code to "Set-Identifier
   Mismatch" and Go to section 4.5.

* /* This step allows the detection of a synchronization problem in
the upstream BFR between BIER-Label and {sub-domain, BitStringLen,
SI} that might cause an unintended packet leak between sub-domains.
*/

  *Set the Best-return-code to "One or more of the TLVsis not
   supported" if any of the TLVs in the Echo Request message is not
   supported. Go to section 4.5.

  *If the BitString in Header-H does not match the BitString in
   Egress BitString Sub-TLV of DDMAP TLV, set the Best-return-code
   to "DDMAP Mismatch" and go to section 4.5. When there are more
   than one DDMAP TLV in the received Request packet, the Downstream
   Address and Downstream Interface Address should be matched with

Interface-I to identify the right DDMAP TLV and then perform the
BitString match.

* /* This step allows the detection of a deviation between the BIER
control plane and the BIER forwarding plane in the upstream node
that may result in a forwarding loop or packet duplication. */

  *Set the Best-return-code to "Invalid Multipath Info Request",
   when the DDMAP TLV carries Multipath Entropy Data Sub-TLV, and if
   the Target SI-BitString TLV in the received Echo Request carries
   more than 1 BFER id. Go to section 4.5. Else, list the ECMP
   downstream neighbors to reach BFR-id in Target SI-BitString TLV,
   calculate the Entropy considering the BitString in Header-H and
   Multipath Entropy Data Sub-TLV from received Echo Request. Store
   the Data for each Downstream interface in a temporary variable.
   Set the Best-return-code to 5 (Packet-Forward-Success) and goto
   Section 4.5

* /* This step instructs the node to calculate the Entropy Data for
each downstream interface to reach the BFER in Target SI-BitString
TLV by considering the incoming BitString and Entropy Data.*/

  *Set the Best-return-code to "Replying router is the only BFER in
   BIER header Bitstring", and go to section 4.5 if the responder is
   BFER and there are no more bits in BIER header Bitstring left for
   forwarding.

  *Set the Best-return-code to "Replying router is one of the BFER
   in BIER header Bitstring", and include Downstream Mapping TLV, if
   the responder is BFER and there are more bits in BitString left
   for forwarding. Also, include the Multipath information as
   defined in Section 4.2 if the received Echo Request carries
   Multipath Entropy Data Sub-TLV. Go to section 4.5.

  *Set the Best-return-code to "No matching entry in the forwarding
   table", if the forwarding lookup defined in section 6.5 of
   [RFC8279] does not match any entry for the received BitString in
   BIER header.

* /* This step allows the detection of the missing BFR-id in the
node's BIER forwarding table. It is difficult to detect the absence
of the BFR-id if the Request includes more than one BFR-ids in the
BitString and so may need to include the BFER-id that is not
responding to detect such failure. */

  *Set the Best-return-code to "Packet-Forward-Success", and include
   Downstream Mapping TLV. Go to section 4.5

4.5. Sending Echo Reply

If Reply-Flag=0, BFR MUST release the variables and MUST not send
any response to the Initiator. If Reply-Flag=1, proceed as below:

The Responder BFR SHOULD include the BitString from Header-H to
Incoming SI-BitString TLV and include the Set ID, Sub-domain ID and
BS Len that corresponds to BIER-Label-L. Responder BFR SHOULD
include the Upstream Interface TLV and populate the address from
Interface-I.

When the Best-return-code is "Replying BFR is one of the BFER in
header Bitstring", it MUST include Responder BFER TLV.

   If the received Echo Request had DDMAP with Multipath Entropy
   Data Sub-TLV, Responder BFR MUST include DDMAP as defined in
   Section 3.3.4 for each outgoing interface over which the packet
   will be replicated and include the respective Multipath Entropy
   Data Sub-TLV. For each outgoing interface, respective Egress
   BitString MUST be included in DDMAP TLV.

   If the received Echo Request had DDMAP without Multipath Entropy
   Data Sub-TLV, Responder BFR MUST include DDMAP as defined in
   Section 3.3.4 for each outgoing interface over which the packet
   will be replicated. For each outgoing interface, respective
   Egress BitString MUST be included in DDMAP TLV.

When the Best-return-code is "Replying BFR is the only BFER in
header Bitstring", it MUST include Responder BFER TLV.

The Responder MUST set the Message Type as 2 and Return Code as
Best- return-code. The Proto field MUST be set to 0.

The Echo Reply can be sent either as BIER-encapsulated or IP/UDP
encapsulated depending on the Reply mode in received Echo Request.
When the Reply mode in received Echo Request is set to 3, Responder
appends BIER header listing the BitString with BFIR ID (from Header-
H), set the Proto to 5 and set the BFIR as 0. When the Reply mode in
received Echo Request is set to 2, Responder encapsulates with IP/
UDP header. The UDP destination port MUST be set to TBD1, and the
source port MAY be set to TBD1 or other random local value. The
source IP is any local address of the responder and destination IP
is derived from Reply-To TLV.

4.6. Receiving Echo Reply

The Initiator upon receiving the Echo Reply will use the Sender's
Handle to match with Echo Request sent. If no match is found, the
Initiator MUST ignore the Echo Reply.

If receiving Echo Reply have Downstream Mapping, the Initiator
SHOULD copy the same to subsequent Echo Request(s).

If one of the Echo Reply is received with Return Code as "Replying
BFR is one of the BFER in header Bitstring", it SHOULD reset the
BFR- id of the responder from Target SI-BisString TLV in subsequent
Echo Request.

/* This step helps avoid any BFR that is both BFER and transit BFR
to respond with Echo Reply continuously. */

5. IANA Considerations

This document requests a UDP port TBD1 to be allocated by IANA for
BIER Echo.

This document requests the IANA to create and manage the below
registries and sub-registries:

5.1. BIER OAM Registry

IANA is requested to create and maintain "BIER OAM Parameters"
registry.

5.2. Message Types, Reply Modes, Return Codes

IANA is requested to create a "Message Type" sub-registry under
"BIER OAM Parameters" registry and assign the Message Types defined
in section 3.1

IANA is requested to create a "Echo Reply Mode" sub-registry under
"BIER OAM Parameters" registry and assign the Echo Reply Modes
defined in section 3.1

IANA is requested to create a "Echo Return Codes" sub-registry under
"BIER OAM Parameters" registry and assign the Return Codes defined
in section 3.2

5.3. TLVs

The TLVs and Sub-TLVs defined in this document is not limited to
Echo Request or Reply message types and is applicable for other
message types. The TLVs and Sub-TLVs requested by this document for
IANA consideration are the following:

```
    Type          Sub-Type          Value Field
   -------       --------          -----------
     1                             Original SI-BitString
     2                             Target SI-BitString
     3                             Incoming SI-BitString
     4                             Downstream Mapping
     4             1               Multipath Entropy Data
     4             2               Egress BitString
     5                             Responder BFER
     6                             Responder BFR
     7                             Upstream Interface
```

6. Security Considerations

The security consideration for BIER Ping is similar to ICMP
[RFC0792] or LSP Ping [RFC8029], [RFC6425]. As with ICMP or LSP
Ping, BFR can be exposed to Denial- of-Service (DoS) attacks, and it
is RECOMMENDED to regulate the BIER Ping packet flow to the control
plane. A rate limiter SHOULD be applied to avoid any attack.

As with ICMP or LSP Ping, a traceroute can be used to obtain network
information. It is RECOMMENDED that the implementation checks the
integrity of BFIR of the Echo messages against any local secured
list before processing the message further

7. Acknowledgement

The authors would like to thank Antoni Przygienda, Eric Rosen,
Faisal Iqbal, Jeffrey (Zhaohui) Zhang,DIA Length - Downstream
Interface Address field Length and Shell Nakash for their review and
comments.

The authors would like to thank Mankamana Mishra for his thorough
review and comments.

8. References

8.1. Normative References

[RFC2119]   Bradner, S., "Key words for use in RFCs to Indicate
            Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/
            RFC2119, March 1997, <https://www.rfc-editor.org/info/
            rfc2119>.

[RFC8174]   Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC
            2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174,
            May 2017, <https://www.rfc-editor.org/info/rfc8174>.

[RFC5905]   Mills, D., Martin, J., Ed., Burbank, J., and W. Kasch,
            "Network Time Protocol Version 4: Protocol and Algorithms

Specification", RFC 5905, DOI 10.17487/RFC5905, June
2010, <https://www.rfc-editor.org/info/rfc5905>.

[RFC8029] Kompella, K., Swallow, G., Pignataro, C., Ed., Kumar, N.,
Aldrin, S., and M. Chen, "Detecting Multiprotocol Label
Switched (MPLS) Data-Plane Failures", RFC 8029, DOI
10.17487/RFC8029, March 2017, <https://www.rfc-
editor.org/info/rfc8029>.

[RFC8279] Wijnands, IJ., Ed., Rosen, E., Ed., Dolganow, A.,
Przygienda, T., and S. Aldrin, "Multicast Using Bit Index
Explicit Replication (BIER)", RFC 8279, DOI 10.17487/
RFC8279, November 2017, <https://www.rfc-editor.org/info/
rfc8279>.

[RFC8296] Wijnands, IJ., Ed., Rosen, E., Ed., Dolganow, A.,
Tantsura, J., Aldrin, S., and I. Meilik, "Encapsulation
for Bit Index Explicit Replication (BIER) in MPLS and
Non-MPLS Networks", RFC 8296, DOI 10.17487/RFC8296,
January 2018, <https://www.rfc-editor.org/info/rfc8296>.

[RFC6425] Saxena, S., Ed., Swallow, G., Ali, Z., Farrel, A.,
Yasukawa, S., and T. Nadeau, "Detecting Data-Plane
Failures in Point-to-Multipoint MPLS - Extensions to LSP
Ping", RFC 6425, DOI 10.17487/RFC6425, November 2011,
<https://www.rfc-editor.org/info/rfc6425>.

8.2. Informative References

[RFC0792] Postel, J., "Internet Control Message Protocol", STD 5,
RFC 792, DOI 10.17487/RFC0792, September 1981, <https://
www.rfc-editor.org/info/rfc792>.

Authors' Addresses

Nagendra Kumar
Cisco Systems, Inc.
7200 Kit Creek Road
Research Triangle Park, NC 27709
US

Email: naikumar@cisco.com

Carlos Pignataro
Cisco Systems, Inc.
7200 Kit Creek Road
Research Triangle Park, NC 27709-4987
US

Email: cpignata@cisco.com

Nobo Akiya
Big Switch Networks
Japan

Email: nobo.akiya.dev@gmail.com

Lianshu Zheng
Individual Contributor
China

Email: veronique_cheng@hotmail.com

Mach Chen
Huawei Technologies

Email: mach.chen@huawei.com

Greg Mirsky
Ericsson

Email: gregimirsky@gmail.com