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# Bit Index Explicit Replication (BIER) Ping and Trace
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## Abstract

Bit Index Explicit Replication (BIER) is a multicast forwarding architecture designed to simplify and optimize multicast delivery.

This document specifies the mechanism and basic BIER 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.

## Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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## 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 specified by setting the bits that correspond to those routers in the BIER header. Similarly, the Initiator of the BIER OAM packet controls the set of BFRs to which the BIER OAM packet is addressed by setting bits in the BitString field of the BIER header that correspond to the BFR-ID values of those BFRs.

Operations, Administration, and Maintenance (OAM) mechanisms are expected to support the detection of network failures. After the detection, operators localize and characterize the network defect. A query-based tool, e.g., ICMP [RFC0792] and LSP Ping [RFC8029], [RFC6425], is broadly used to detect and localize a network defect. Additionally, this mechanism can be used to check the consistency between the data and control planes. 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 without any dependency on other layers, like the IP layer. The specification conforms to R-1 through R-3, R-5, and R-11 requirements listed in [I-D.ietf-bier-oam-requirements]. To conform to R-11, BIER Echo Request message is encapsulated in the BIER header [RFC8296] that uses the same values of BIFT-id, BSL, Entropy, and DSCP fields as in the BIER header of the monitored BIER flow. Note that the BIER Echo Request/Reply protocol doesn't modify the content of the OAM field in the BIER header (Section 2 of [RFC8296]).

## 2. Conventions used in this document

### 2.1. Terminology and Acronyms

In this specification:

The term "Initiator" is used interchangeably with the "Sender of a BIER Echo Request".

An incoming interface, also referred to as ingress interface, is a BFR’s interface on which it receives a BIER Echo Request packet.

A downstream interface, also referred to as egress interface, is a BFR’s interface over which the BIER Echo Request packet may be transmitted to reach the destination.

BFER - Bit-Forwarding Egress Router

BFIR - Bit-Forwarding Ingress Router

BFR - Bit-Forwarding Router

BIFT - Bit Index Forwarding Table

BIER - Bit Index Explicit Replication

DDMAP - Downstream Detailed Mapping TLV

ECMP - Equal Cost Multi-Path

OAM - Operation, Administration, and Maintenance

SI - Set Identifier

QTF - Querier Timestamp Format

RTF - Responder Timestamp Format

NTP - Network Time Protocol

MTU - Maximum Transmission Unit

DA - Downstream Address

DIA - Downstream Interface Address

DoS - Denial-of-Service

PTP - Precision Time Protocol

## 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 an IP header. To produce information that is useful to an operator, information that statistically reflects conditions experienced by the monitored data flow, the operator must be able to ensure that active OAM packets, e.g., BIER Echo Request, traverse the set of links and nodes and receive the same forwarding treatment as the monitored flow. Hence, all fields in the BIER header that affect packet forwarding (e.g., BFIR-id, BitString) must be set to the values applied to the monitored data flow. [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 header format that follows the BIER header is displayed in Figure 1.

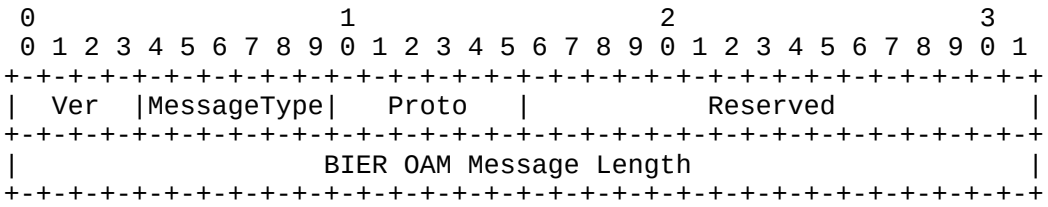


Figure 1: BIER OAM Header

Ver - a four-bit field that indicates the version of the BIER OAM header. The value defined in this document is 1. The version number is to be incremented whenever a change is made that affects the ability of an implementation to parse or process the BIER OAM header correctly. For example, if syntactic or semantic changes are made to any of the fixed fields.

Message Type - a six-bit field that identifies OAM protocol. Values defined in this document are as in Table 1.

Proto - a six-bit field. This field is used to define whether there is any data packet immediately following the OAM payload. For example, the In-situ OAM Direct Export Option header [RFC9326] can be appended to the BIER OAM message, enabling the collection of the operational state and performance metrics. This field MUST be set to 0 if no data packet follows the OAM payload. Otherwise, the value is one from the IANA registry "BIER Next Protocol Identifiers" [IANA-Next-Protocol-Identifiers].

Reserved - a two-octet field. The value MUST be zeroed on transmission and ignored on receipt.

BIER OAM Message Length - a four-octet field that reflects the length of the OAM message in octets, including the header and the Messsage Type Dependent Data.

## 3.2. BIER Echo Request/Reply Message Format

The format of the BIER Echo Request/Reply message, preceded by the BIER OAM header (Figure 1), is displayed in Figure 2.

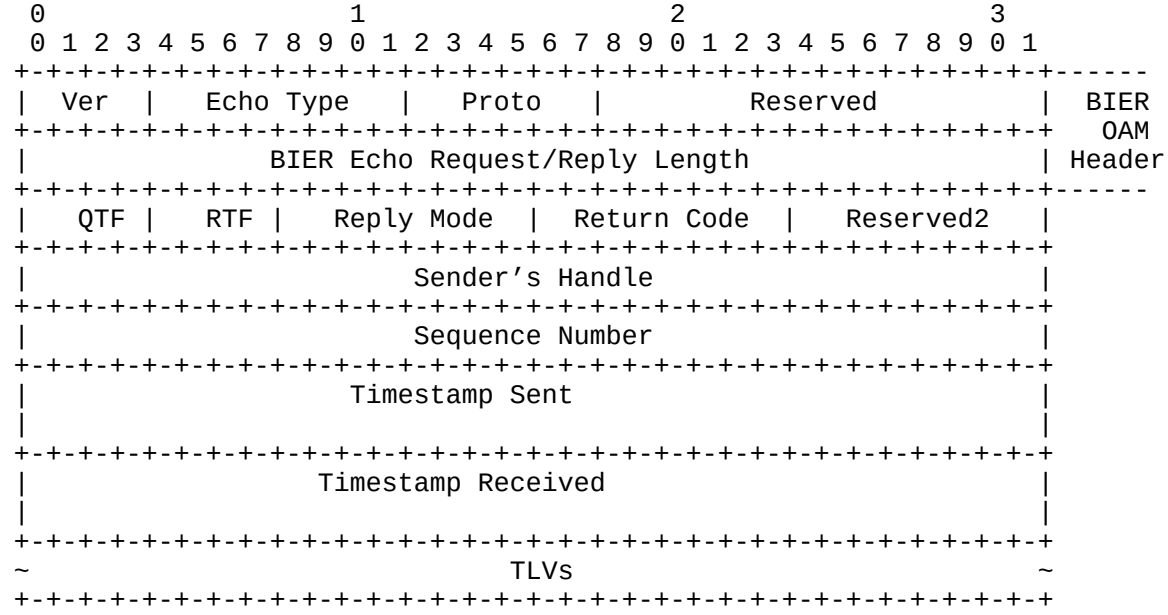


Figure 2: BIER Echo Request/Reply Format

Echo Type - a one-octet field. Valid values are listed in Table 1.

Proto field MUST be set to 0 for Echo Request/Reply header.

Reserved - a fourteen-bit field. The Reserved field MUST be zeroed on transmit and MUST be ignored on receipt.

BIER Echo Request/Reply Length a four-octet field that reflects the length of the BIER Echo Request/Reply message in octets, including the BIER OAM header Section 3.

QTF (Querier Timestamp Format) - a four-bit field. When the field is set to 2, the Timestamp Sent field is (in seconds and picoseconds, according to the Initiator's clock) in the 64-bit long NTP format [RFC5905]. When the value of the QTF field is 3, the Timestamp Sent field is in the IEEE 1588-2008 (1588v2) Precision Time Protocol (PTP) [IEEE.1588.2008] 64-bit truncated version (48-bit sec + 16-bit nsec) format.

RTF (Responder Timestamp Format) - a four-bit field. When the field is set to 2, the Timestamp Received field is (in seconds and picoseconds, according to the Initiator's clock) in 64-bit long NTP format [RFC5905]. When field's value is 3, the format of the Timestamp Received is as defined in IEEE 1588-2008 (1588v2) Precision Time Protocol [IEEE.1588.2008] for 64-bit truncated version (48-bit sec + 16-bit nsec). The Initiator MUST zero RTF in the Echo Request, and the Responder MUST ignore the value on receipt.

| Value | Description |
|---|---|
| 1 | BIER Echo Request |
| 2 | BIER Echo Reply |

Table 1: BIER Echo Type

The sender of the BIER Echo Request might receive the BIER Echo Reply with RTF different from the Sender's QTF. Thus, to calculate one-way delay, the Sender MUST be able to interpret both timestamp formats, i.e., NTP [RFC5905] and PTP [IEEE.1588.2008]. Although the use of different timestamp formats is permitted, it may cause ambiguity or even precision loss resulting from format conversion. Thus, the use of homogeneous formats is RECOMMENDED.

The Reply Mode - a one-octet field. The value MUST be set to one of the values from Table 2.

| Value | Description |
|---|---|
| 1 | Do not Reply |
| 2 | Reply via an IPv4/IPv6 UDP packet |
| 3 | Reply via a BIER packett |

Table 2: BIER Reply Mode

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 Bit-Forwarding Router (BFR) encapsulates the Echo reply payload with the IP/UDP header. The Responder BFR uses the BFIR-id field in the BIER header to determine which IP address family to use in the IP/UDP encaspulation. If the BFIR-id is associated with IPv4 and IPv6 addresses, the Responder uses its local policy to select the address family. When the Initiator intends to validate the return BIER path, the Reply Mode will be set to 3 so that the Responder BFR will encapsulate the Echo Reply with the BIER header. Also, the Reply Mode "Reply via a BIER packet" can be used if the IP network is deemed less reliable compared to the BIER layer.

Return Code - a one-octet field. The value MUST be set to zero if the Type is "BIER Echo Request". The Return Code MUST be set to zero by the Initiator of a BIER Echo Request, and ignored on its receipt. The value of the Return Code field MUST be set to one of the values defined in Section 3.3, if the Type is "BIER Echo Reply".

Reserved2 - a one-octet field. The Reserved2 field MUST be zeroed on transmit and MUST be ignored on receipt.

Sender’s Handle - a four-octet field. 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 (see Section 4.3).

Sequence Number - a four-octet field. The value of the field is assigned by the Initiator and can be used to detect any missed replies.

Timestamp - each field (Sent and Received) is an eight-octet field. 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. The Initiator MUST zero Timestamp Received in the Echo Request, and the Responder MUST ignore the value on receipt.

TLVs - Carries the TLVs as defined in Section 3.4.

## 3.3. 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 values in Table 3.

| Value | Description |
|---|---|
| 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 BFERs 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 |

Table 3: BIER Echo Return Code

"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 BFR-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 BFR-ID in addition to other BFR-IDs, "Replying BFR is one of the BFERs 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 the 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 (Section 3.4.4.1) 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 value of the BIFT-id field, representing a particular Bit Index Forwarding Table (see Section 6.4. of [RFC8279]), a.k.a. 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.

If the BitString in Header-H does not match the BitString in Egress BitString Sub-TLV of Downstream Detailed Mapping (DDMAP) TLV, a responding BFR will use "DDMAP Mismatch" to report the problem.

## 3.4. BIER OAM TLVs

This section defines various TLVs that can be used in BIER OAM packet. The TLVs (Type-Length-Value tuples) have the following format:

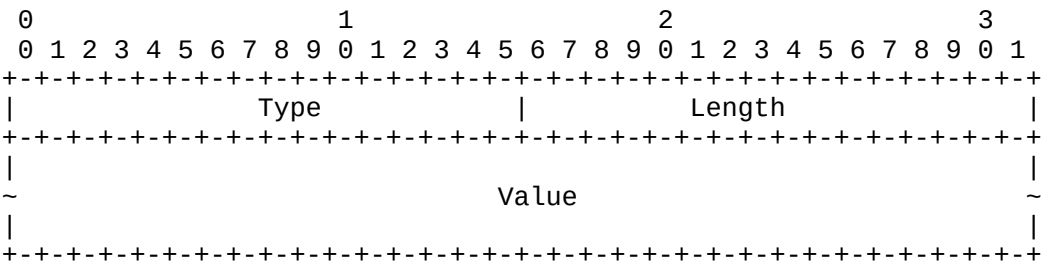


Figure 3: Type-Length-Value Format Used in BIER Echo Request/Reply

TLV Types are defined below. A system that receives an Echo Request with unknown TLV Type with the value in the range 0 - 32767 MUST transmit an Echo Reply with the Return Code "One or more of the TLVs is not supported" (2). Also, the Erroneous Echo Request TLV (Section 3.4.8) MUST be included in the BIER Echo Reply. A system that receives an Echo Request with the value in the range 32768 - 65535 MAY silently drop the packet. Length is the length of the Value field in octets. The Value field depends on the TLV Type.

### 3.4.1. Original SI-BitString TLV

The Original SI-BitString TLV carries the set of BFERs and carries the same BitString that the Initiator includes in the BIER header. This TLV has the following format:

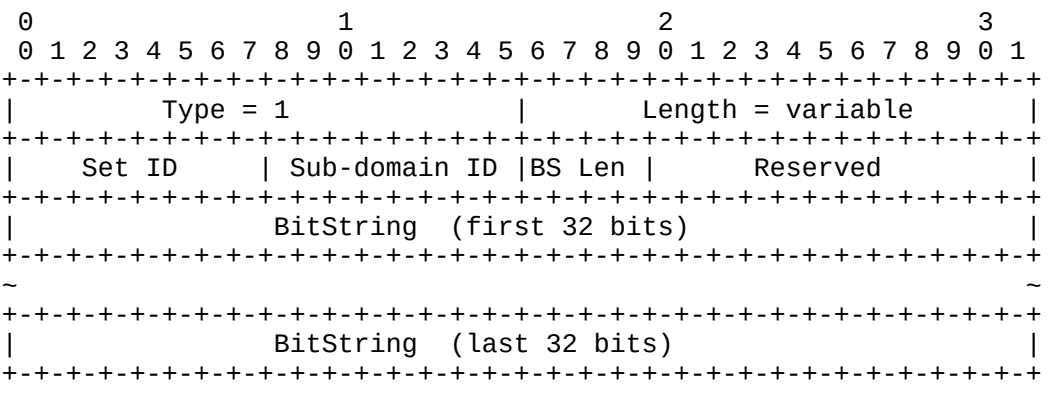


Figure 4: The Format of the Original SI-BitString TLV

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

Sub-domain ID - a one-octet field that is set to the Sub-domain value to which BFER in BitString belongs.

BS Len - a four-bit field that is set based on the length of BitString as defined in [RFC8296] reflected in four-octet words.

Reserved - a twelve-bit field. Its value MUST be zeroed on transmission and ignored on receipt.

BitString - a variable length field. The BitString field carries the set of BFR-IDs that Initiator will include in the BIER header.

Any Initiator MUST include this TLV in the Echo Request packet. A Responder MUST NOT include this TLV in the Echo Reply packet.

### 3.4.2. Target SI-BitString TLV

The Target SI-BitString TLV carries the set of BFERs from which the Initiator expects the reply. This TLV has the following format:

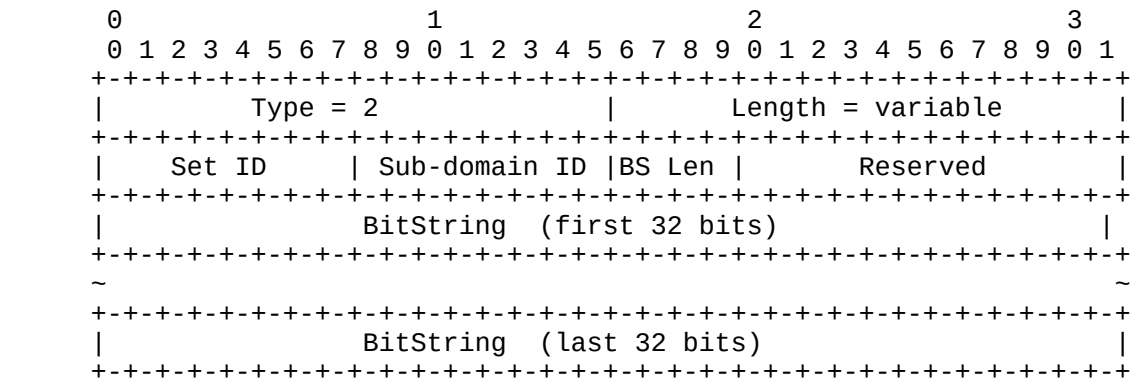


Figure 5: The Format of the Target SI-BitString TLV

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

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

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

Reserved - the value MUST be zeroed on transmission and ignored on receipt.

The BitString field carries the set of BFR-IDs of BFER(s) that Initiator expects a response. The BitString in this TLV may be different from the BitString in the BIER header and allows control of the BFER responding to the Echo Request. If the DDMAP TLV (Section 3.4.4) is included in the BIER OAM Echo Request packet, one and only one Target BitString TLV MUST also be included in the packet.

### 3.4.3. Incoming SI-BitString TLV

The Incoming SI-BitString TLV will be included by Responder BFR in Reply message and copies the BitString from the BIER header of incoming Echo Request message. This TLV has the following format:

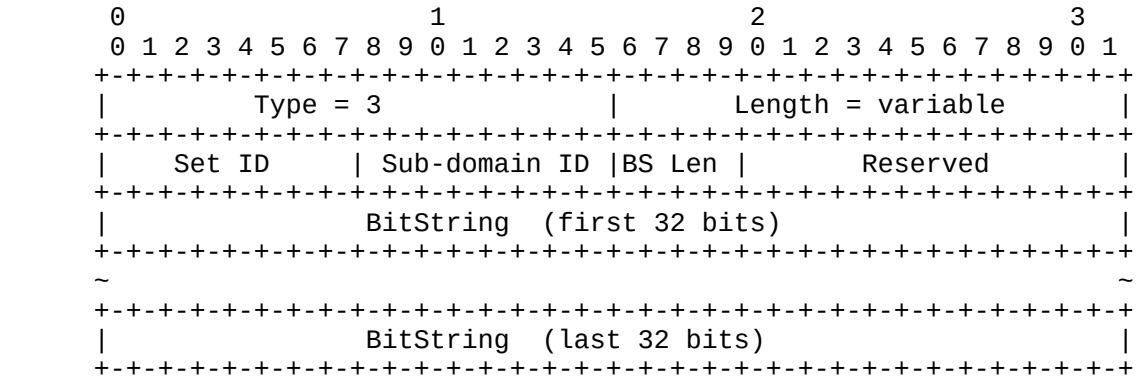


Figure 6: The Format of the Incoming SI-BitString TLV

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

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

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

Reserved - the value MUST be zeroed on transmission and ignored on receipt.

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 the I flag set in DDMAP TLV.

An Initiator MUST NOT include this TLV in Echo Request. A Responder BFR MUST include the Incoming SI-BitString TLV setting field values as specified in Section 4.5.

### 3.4.4. Downstream Detailed Mapping TLV

The Downstream Detailed Mapping object is an optional TLV that an Initiator MAY include in a BIER Echo Request message. Only one DDMAP TLV MAY appear in an BIER Echo Request. The presence of a DDMAP TLV is a request that the Responder MUST include in its BIER Echo Reply message DDMAP TLV for each interface over which this BIER OAM Echo Request could be forwarded. The BFER received the BIER Echo Request MUST NOT include DDMAP TLV in its BIER Echo Reply.

The format of the Downstream Detailed Mapping TLV shown in Figure 7.

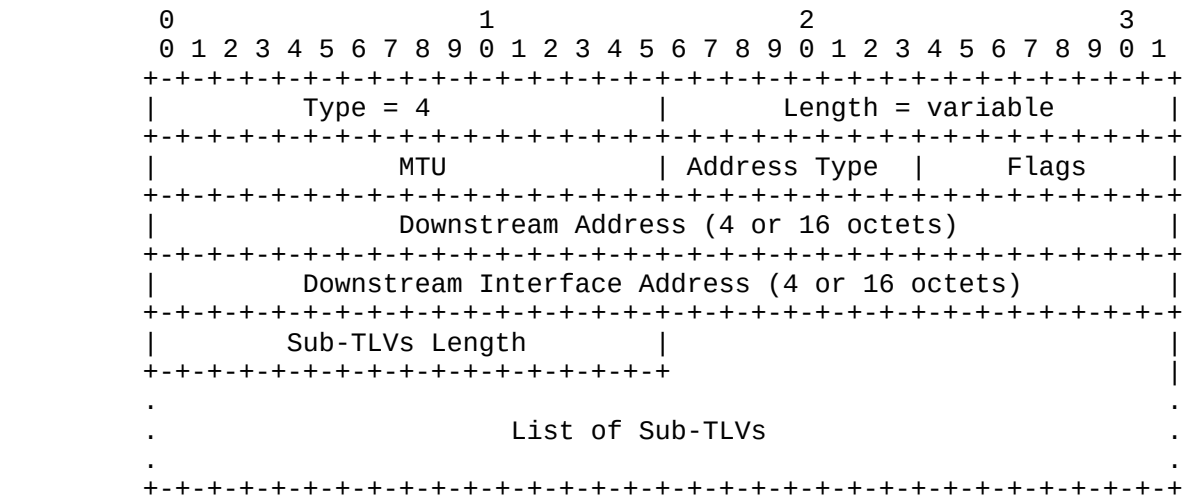


Figure 7: The Format of the Downstream Detailed Mapping TLV

Maximum Transmission Unit (MTU) A two-octet field. The MTU is the size in octets of the largest BIER packet (including the BIER header) that fits on the interface to the downstream BFR. The Initiator MUST zero the field, and the Responder ignores its value in the received BIER Echo Request. The Responder sets the value in the BIER Echo Reply.

Address Type A one-octet field. The Address Type indicates the address type and length of the IP address for the downstream interface. The value of the Address Type field is set to one of the values listed in Table 4. Any other value MUST be processed as invalid TLV. The Initiator MUST set the Address Type to IPv4

Unnumbered in its BIER Echo Request. The Responder MUST set the value in its BIER Echo reply according to the type and length of its downstream interface.

| Value | Address Type |
|---|---|
| 1 | IPv4 Numbered |
| 2 | IPv4 Unnumbered |
| 3 | IPv6 Global Unicast Address (including Unique Local Address) |
| 4 | IPv6 Link-Local Address Only |

Table 4: The Address Types

Flags The Flags field has the following format:


Figure 8: The Flags Field Format

Reserved A seven-bit field. Its value MUST be zeroed on transmission and ignored on receipt.

I A one-bit field. 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
each field is either four-octet or sixteen-octet, depending on the value of Address Type field.

Note that values of the Address Type field are mapped to combinations of lengths of Downstream Address (DA) and Downstream Address Interface (DIA) fields as shown im Table 5.

| Value | DA Length | DIA Length |
|---|---|---|
| 1 | 4 | 4 |
| 2 | 4 | 4 |
| 3 | 16 | 16 |
| 4 | 16 | 4 |

Table 5: The Address Type Lengths

where:

DA Length
: Downstream Address field Length

DIA Length
: Downstream Interface Address field Length

If the Address Type is "IPv4 Numbered" (1), the Downstream Address field 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 "IPv4 Unnumbered" (2), the Downstream Address field MUST be set to IPv4 BFR-Prefix of downstream BFR and Downstream Interface Address is set to the index assigned by the responding BFR to the interface.

If the Address Type is "IPv6 Global Unicast Address (including Unique Local Address)" (3), the Downstream Address MUST be set to IPv6 BFR-Prefix of downstream BFR and Downstream Interface Address is set to the downstream interface IPv6 Global Unicast Address (including Unique Local Address).

If the Address Type is "IPv6 Link-Local Address Only" (4), the Downstream Address MUST be set to the IPv6 BFR-Prefix of the downstream BFR, and the Downstream Interface Address is set to the index assigned by the responding BFR to the interface.

The Initiator MUST set the Downstream Address to 224.0.0.2, and the Downstream Interface Address MUST be set to 0 in the BIER Echo Request. The Responder MUST ignore these values in the received BIER Echo Request.

#### 3.4.4.1. Downstream Detailed Mapping Sub-TLVs

This section defines the optional Sub-TLVs that can be included in DDMAP TLV in Table 6.

| Value | Description |
|---|---|
| 1 | Multipath Entropy Data |
| 2 | Egress BitString |

Table 6: Sub-TLV for the Downstream Detailed Mapping TLV

Any value other than listed in Table 6 MUST be considered as invalid, the Return Code set to Malformed Echo Request received (1). Also, the Erroneous Echo Request TLV (Section 3.4.8) MUST be included in the BIER Echo Reply.

##### 3.4.4.1.1. MPLS Multipath Entropy Data Sub-TLV

MPLS Multipath Entropy Data sub-TLV is applicable for BIER Echo Request packets encapsulated in MPLS. Encoding of multipath information for other data planes, e.g., IPv6, is for further study. If the MPLS Multipath Entropy Data sub-TLV is present in the BIER Echo Request packet encapsulated in a non-MPLS data plane, it MUST be ignored by the responding BFR.

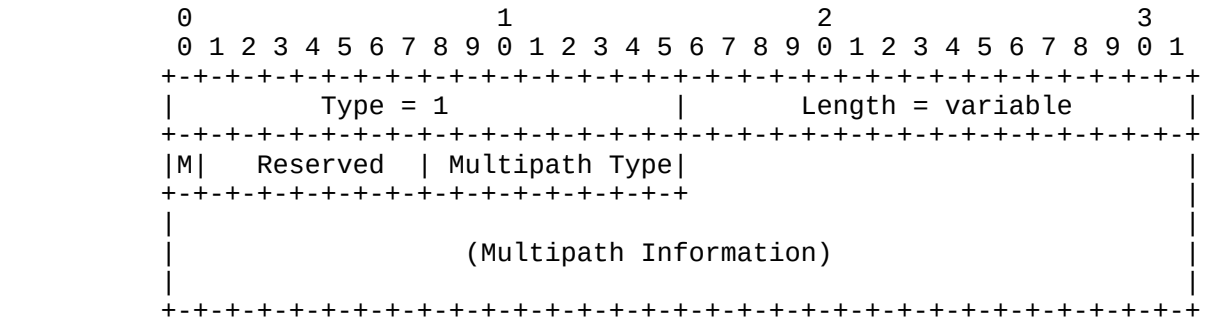


Figure 9: The Format of the Multipath Data Blob

M Flag This flag is set to 0 if all packets will be forwarded out

through the interface defined in the DDMAP TLV. When set to 1, Multipath Information will be defined by the Bit masked Entropy data.

Reserved The value MUST be zeroed on transmission and ignored on receipt.

The interpretaion of the Multipath Type field and Multipath Entropy Data encoding options are the same defined in Section 3.4.1.1 of [RFC8029].

#### 3.4.4.1.2. Egress BitString Sub-TLV

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

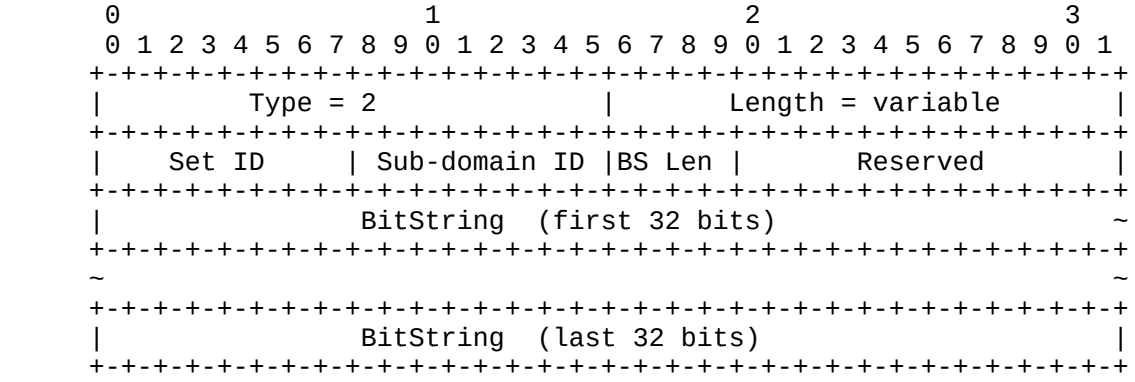


Figure 10: The Egress BitString Sub-TLV Format

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

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

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

Reserved - the value MUST be zeroed on transmission and ignored on receipt.

The BitString field copies the rewritten BitString in the downstream interface as defined in Section 6.1 of [RFC8279].

### 3.4.5. Responder BFER TLV

The BFER replying to the request MAY include the Responder BFER TLV in its BIER Echo Reply. An Initiator MUST NOT include this TLV in Echo Request. This TLV identifies the originator of BIER Echo Reply. This TLV has the following format:

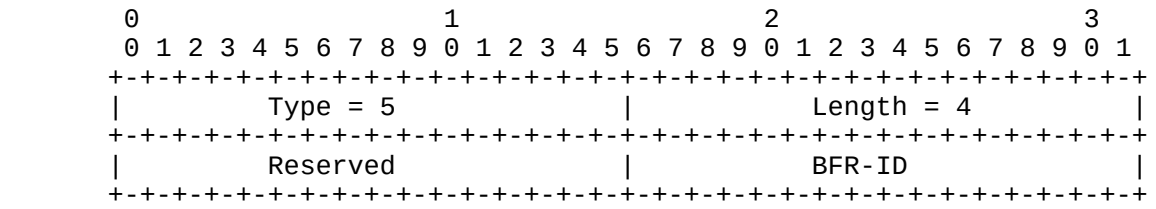


Figure 11: The Responder BFER TLV Format

Length A two-octet field. The value MUST be set to four.

Reserved A two-octet field. The value MUST be zeroed on transmission and ignored on receipt.

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

### 3.4.6. Responder BFR TLV

Any transit BFR replying to the request MAY include the Responder BFR TLV in its BIER Echo Reply. An Initiator MUST NOT include this TLV in Echo Request. This is used to identify the replying BFR without BFR-ID. This TLV has the following format:

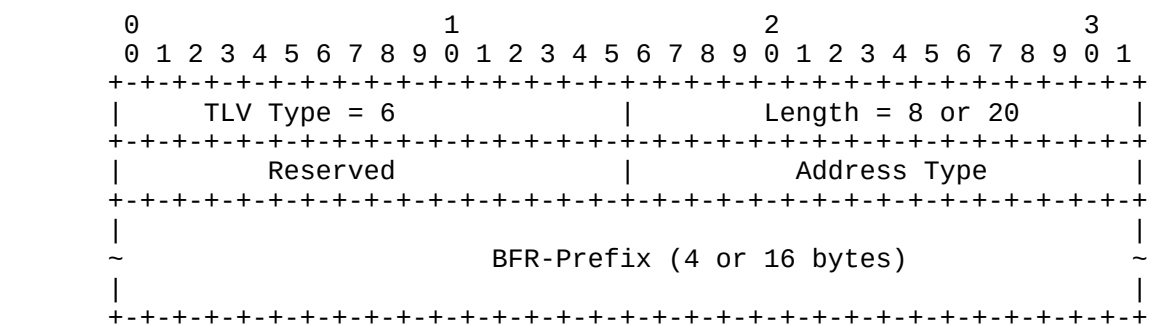


Figure 12: The Responder BFR TLV Format

Length The Length field, depending on the Address Type value - 8 or

20.

Reserved A two-octet field. The value MUST be zeroed on transmission and ignored on receipt.

Address Type A two-octet field. Set according to Table 7. Any other value is invalid.

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.

| Value | Address Type |
|---|---|
| 1 | IPv4 Address |
| 2 | IPv6 Address |

Table 7: The Address Types

### 3.4.7. Ingress Interface TLV

The BFR replying to the request MUST include the Ingress Interface TLV. This TLV identifies the incoming interface on which the Echo Request was received. This TLV has the following format:

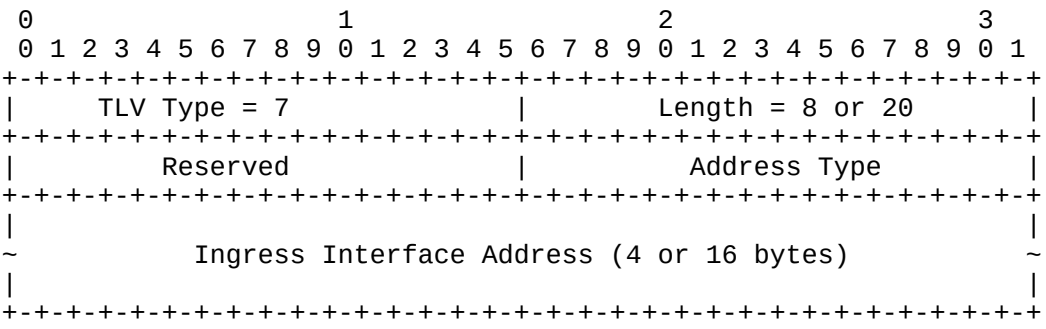


Figure 13: The Ingress Interface TLV Format

Length The Length field, depending on the Address Type value - 8 or 20.

Reserved A two-octet field. The value MUST be zeroed on transmission and ignored on receipt.

Address Type A two-octet field. Set its value according to Table 4.

Ingress Interface Address
A four or sixteen-octet-long field. It lists an address associated with the interface on which the BIER Echo Request received.

### 3.4.8. Erroneous Echo Request TLV

The BFER replying to the request MAY include the Erroneous Echo Request TLV. This TLV provides information about the type and location of the problem in the BIER Echo Request. This TLV has the following format:

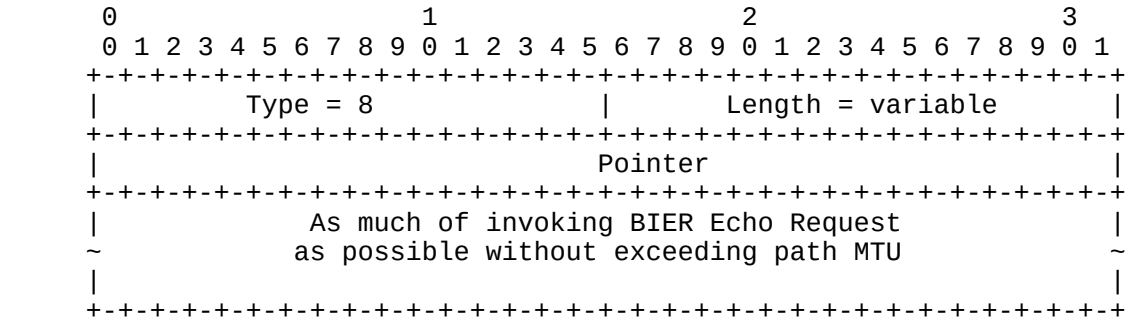


Figure 14: The Erroneous Echo Request TLV Format

Pointer A four-octet field that identifies the octet offset within the received BIER Echo Request message where the error was detected. The Pointer will point beyond the end of the BIER Echo Reply message if the field in error is beyond what can fit in the resulting packet.

## 4. BIER Ping and Traceroute Operations

This section describes aspects of BIER ping and traceroute operations.

### 4.1. BIER OAM Processing

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

* The receiving BFR is a BFER.

* TTL of the BIER header (Section 2.1.1.1 of [RFC8296]) expired.

* Hop Limit in the IPv6 header (Section 2 of [I-D.ietf-bier-bierin6]) expired.

The use of the Router Alert label has been deprecated by [RFC9570].

Processing of the received BIER OAM packet with an unknown value of the Message Type field (Figure 1) is stopped, and the event MUST be logged through the rate-controlling system.

A transit BFR, i.e., one that does not punt the BIER OAM packet to the BIER control plane, forwards the BIER OAM packet according to the rules specified in Section 6.5 of [RFC8279].

### 4.2. BFER ECMP Discovery Within a BIER Domain with MPLS Underlay

As defined in [RFC8279], BIER follows the unicast forwarding path and allows load balancing over ECMP paths between BFIR and BFER. BIER OAM is expected to 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 a 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 the required information in the BIER OAM message.

When an operator performs BFER ECMP discovery within a BIER domain over MPLS underlay, the Initiator MUST include MPLS Multipath Entropy Data Sub-TLV in DDMAPTLV. It MUST also include the BFER in the BitString TLV to which the Multipath query is performed.

Any transit BFR will transmit the BIER Echo Reply to the Initiator 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 the 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 the Initiator SHOULD monotonically increase the Sequence Number, e.g., increment it by one for every, subsequent Echo Request. The QTF field is set to Initiator’s local timestamp format, and the 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 traceroute 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 the Return code "Replying BFR is the only BFER in the header BitString" or "Replying router is one of the BFERs in header BitString" MUST unset the respective BFR-ID from Target SI-BitString for any subsequent Echo Request.

The Initiator MAY include DDMAP TLV (Section 3.4.4) in the Echo Request to query additional information from transit BFRs and BFERs. In case of ECMP discovery within a BIER domain with the MPLS underlay, the Initiator MUST include the MPLS Multipath Entropy Data Sub-TLV and MUST set the Target SI-BitString TLV carrying a specific BFER ID.

The Initiator MUST encapsulate the OAM packet with the BIER header and MUST set the Proto as 5. In ping mode, the TTL field in the BIER header MUST be set to 255. In traceroute mode, the TTL in the BIER header 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 an Echo Request MUST perform the basic sanity check, including, but not limited to, checking values of the fields with a priori known values, e.g., Ver, Type and Length if any TLV is present. If, at any stage of processing the received BIER Echo Request, the BFR encounters an error, it MUST stop processing and transmit BIER Echo Reply with the Return Code set accordingly. If the BFR cannot parse the OAM packet 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. The Erroneous Echo Request TLV (Section 3.4.8) MUST be included in the BIER Echo Reply. If the packet sanity check is fine, it MUST 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 populate the Ingress Interface TLV.

BIFT-id-L
: The BIFT-id field in the BIER header of the received BIER 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 replying with MPLS Multipath Entropy Data Sub-TLV.

Best-return-code
: contains the Return Code for the echo reply packet as currently best known. As the algorithm progresses, this code may change depending on the results of further checks that it performs.

BFR MUST initialize the internal, to the implementation, 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 value from the BIFT-id field of the BIER header of the received BIER Echo Request is copied to BIFT-id-L, and the BIER header is copied to Header-H. If the received Echo Request carries Target SI-BitString TLV, a BFR MUST run the 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 BIFT-id-L does not correspond to the BIFT-id 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.

The step above 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.

* If the value in the Reply Mode field is unknown, the Receiver MUST set Reply-Flag=0 and go to Section 4.5.

* The Receiver sets the Best-return-code to "Malformed Echo Request received" if the value of the QTF field is neither 2, nor 3. Also, the Erroneous Echo Request TLV (Section 3.4.8) MUST be included in the BIER Echo Reply. Go to Section 4.5.

* The Receiver sets the Best-return-code to "Malformed Echo Request received" if none or more than one Original SI-BitString TLV found in the received BIER Echo Request. Also, the Erroneous Echo Request TLV (Section 3.4.8) MUST be included in the BIER Echo Reply. Go to Section 4.5.

* The Receiver sets the Best-return-code to "Malformed Echo Request received" if DDMAP TLV is present in the BIER Echo Request message and none or more than one Target SI-BitString TLVs found. Also, the Erroneous Echo Request TLV (Section 3.4.8) MUST be included in the BIER Echo Reply. Go to Section 4.5.

* The Receiver sets the Best-return-code to "Malformed Echo Request received" if the Incoming S_-BitString TLV is present in the BIER Echo Request message. Also, the Erroneous Echo Request TLV (Section 3.4.8) MUST be included in the BIER Echo Reply. Go to Section 4.5.

* Set the Best-return-code to "One or more of the TLVs is 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.

The step above 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 MPLS 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 MPLS 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 the BIER header BitString left for forwarding.

* Set the Best-return-code to "Replying router is one of the BFERs in BIER header BitString", and include DDMAP 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.

The step above 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 DDMAP 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 MUST 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 BIFT-id-L. Responder BFR MUST include the Ingress Interface TLV and populate the address from Interface-I.

When the Best-return-code is "Replying BFR is one of the BFERs 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 3.4.4 for each downstream interface over which the packet will be replicated and include the respective Multipath Entropy Data Sub-TLV. For each downstream interface, the 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 3.4.4 for each downstream interface over which the packet will be replicated. For each downstream 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 as BIER-encapsulated, or IP/UDP encapsulated, depending on the Reply Mode in the received Echo Request. When the Reply Mode in the received Echo Request is set to 3, Responder appends the BIER header listing the BitString with BFIR ID (from Header-H), sets the Proto to 5, and sets the BFIR as 0. When the Reply Mode in the received Echo Request is set to 2, Responder encapsulates with the IP/UDP header. The UDP destination

port MUST be set to TBD1 (Section 5.1), and the source port MAY be set to TBD1 or other value selected from the Dynamic range of port numbers. The source IP address is any non-link-local address associated with the Responder, and the destination IP address is derived from the BFIR-id of the BIER header [RFC8296] in the received Echo Request.

### 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 has DDMAP TLV, the Initiator MUST copy the TLV to subsequent Echo Request(s).

If one of the Echo Reply is received with Return Code as "Replying BFR is one of the BFERs 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

The terms used in the IANA Considerations below are intended to be consistent with [RFC8126].

### 5.1. UDP Port Number

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

Service Name bier-echo

Transport Protocol UDP, TCP

Assignee IESG iesg@ietf.org

Contact IETF Chair chair@ietf.org

Description The UDP destination port number for the IP/UDP encapsulated BIER Echo Reply message.

Reference This document

Port Number TBD1

### 5.2. BIER OAM as BIER NEXT Protocol

IANA is requested to update the BIER Next Protocol Identifiers registry as follows:

| Value | Description | Reference |
|---|---|---|
| 5 | OAM Packet | This document |

Table 8: BIER OAM as BIER Next Protocol

### 5.3. BIER OAM Registry Group

IANA is requested to create and maintain the "BIER OAM" registry group containing the registries listed below.

### 5.4. BIER OAM Message Type

IANA is requested to create in the BIER OAM Message Type registry in the BIER OAM registry group as follows:

Registry Name: BIER OAM Message Type.

Assignment Policy:

0-58 - IETF Review

59 - 61 - Experimental Use (Reserved, not to be assigned)

62 - 63 - Private Use (Reserved, not to be assigned)

| Value | Description | Reference |
|---|---|---|
| 0 | Reserved | This document |
| 1 | BIER Echo Request/Echo Reply | This document |
| 2 - 58 | Unassigned | This document |
| 59 - 61 | Reserved for Experimental Use | This document |
| 62 - 63 | Reserved for Private Use | This document |

Table 9: BIER OAM Message Type

### 5.5. BIER Echo Request/Echo Reply Registries

IANA is requested to create three BIER Echo Request/Echo Reply registries in the BIER OAM registry group, as described below.

#### 5.5.1. BIER Echo Request/Echo Reply Message Types

IANA is requested to create in the in the BIER OAM registry group the BIER Echo Types registry as follows:

Registry Name: BIER Echo Types

Assignment Policy:

0 - 247 - IETF Review

248 - 251 - Experimental Use (Reserved, not to be assigned)

252 - 255 - Private Use (Reserved, not to be assigned)

| Value | Description | Reference |
|---|---|---|
| 0 | Reserved | This document |
| 1 | BIER Echo Request | This document |
| 2 | BIER Echo Reply | This document |
| 3 - 175 | Unassigned | This document |
| 176 - 247 | Unassigned | This document |
| 248-251 | Reserved for Experimental Use | This document |
| 252-255 | Reserved for Private Use | This document |

Table 10: BIER Echo Types

#### 5.5.2. BIER Echo Reply Modes

IANA is requested to create in the BIER OAM registry group the new BIER Echo Reply Mode registry as follows:

Registry Name: BIER Echo Reply Mode

Assignment Policy:

0 - 247 - IETF Review

248 - 251 - Experimental Use (Reserved, not to be assigned)

252 - 255 - Private Use (Reserved, not to be assigned)

| Value | Description | Reference |
|---|---|---|
| 0 | Reserved | This document |
| 1 | Do Not Reply | This document |
| 2 | Reply via an IPv4/IPv6 UDP Packet | This document |
| 3 | Reply via a BIER packet | This document |
| 4 - 191 | Unassigned | This document |
| 192 - 247 | Unassigned | This document |
| 248-251 | Reserved for Experimental Use | This document |
| 252-255 | Reserved for Private Use | This document |

Table 11: BIER Echo Reply Modes

### 5.5.3. BIER Echo Return Codes

IANA is requested to create in the BIER OAM registry group the new BIER Echo Return Codes registry as follows:

Registry Name: BIER Echo Return Codes

Assignment Policy:

0 - 247 - IETF Review

248 - 251 - Experimental Use (Reserved, not to be assigned)

252 - 255 - Private Use (Reserved, not to be assigned)

| Value | Description | Reference |
|---|---|---|
| 0 | No Return Code | This document |
| 1 | Malformed Echo Request received | This document |
| 2 | One or more of the TLVs is not supported | This document |
| 3 | Replying BFR is the only BFER in header BitString | This document |
| 4 | Replying BFR is one of the BFERs in header BitString | This document |
| 5 | Packet-Forward-Success | This document |
| 6 | Invalid Multipath Info Request | This document |
| 7 | Unassigned | This document |
| 8 | No matching entry in the forwarding table | This document |
| 9 | Set-Identifier Mismatch | This document |
| 10 | DDMAP Mismatch | This document |
| 11 - 247 | Unassigned | This document |
| 248-251 | Reserved for Experimental Use | This document |
| 252-255 | Reserved for Private Use | This document |

Table 12: BIER Echo Return Codes

## 5.6. Common Registration Procedures for TLVs and Sub-TLVs

This section describes registration procedures for Type registries in BIER Echo Request/Reply TLVs and sub-TLVs.

| Range | Registration Procedures | Note |
|---|---|---|
| 0-16383 | Standards Action | This range is for TLVs and sub-TLVs that require an error message if not recognized. |
| 16384-31739 | RFC Required | This range is for TLVs and sub-TLVs that require an error message if not recognized. |
| 31740-31743 | Experimental Use | Not to be assigned. |
| 31744-32767 | First Come, First Served | This range is for TLVs and sub-TLVs that require an error message if not recognized. |
| 32768-49161 | Standards Action | This range is for TLVs and sub-TLVs that can be silently dropped if not recognized. |
| 49162-64507 | RFC Required | This range is for TLVs and sub-TLVs that can be silently dropped if not recognized. |
| 64508-64511 | Experimental Use | Not to be assigned. |
| 64512-65535 | First Come, First Served | This range is for TLVs and sub-TLVs that can be silently dropped if not recognized. |

Table 13: TLVs

### 5.6.1. TLVs

IANA is requested to create in the BIER OAM registry group a registry for the Type field of top-level TLVs. as well as sub-registries for the associated sub-TLVs. Note that the meaning of a sub-TLV is scoped by the TLV. The number of spaces for the sub-TLVs of various TLVs is independent.

Registry Name: TLVs

Assignment Policy: Section 5.6

The TLVs requested by this document for the IANA consideration are listed in Table 14.

| Type | TLV Name | Reference | Sub-TLV Registry |
|---|---|---|---|
| 0 | Reserved | This document | |
| 1 | Original SI-BitString | This document | No Sub-TLVs |
| 2 | Target SI-BitString | This document | No Sub-TLVs |
| 3 | Incoming SI-BitString | This document | No Sub-TLVs |
| 4 | Downstream Detailed Mapping | This document | Link the Sub-TLVs for TLV Type 4 sub-registry |
| 5 | Responder BFER | This document | No Sub-TLVs |
| 6 | Responder BFR | This document | No Sub-TLVs |
| 7 | Ingress Interface | This document | No Sub-TLVs |

Table 14: TLVs

### 5.6.2. Sub-TLVs for TLV Type 4

IANA is requested to create in the registry for the Type 4 (Downstream Detailed Mapping) a sub-registry Sub-TLVs for Type 4.

Registry Name: Sub-TLVs for Type 4

Assignment Policy: Section 5.6

| Type | Sub-TLV Name | Reference |
|---|---|---|
| 0 | Reserved | This document |
| 1 | MPLS Multipath Entropy Data | This document |
| 2 | Egress BitString | This document |

Table 15: TLVs

## 6. Security Considerations

The security considerations of [RFC8296], and through it of [RFC8279], apply to this specification.

The security considerations for BIER Ping are similar to ICMP [RFC0792], ICMPv6 [RFC4443], and 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. Specifically, a rate limiter SHOULD be applied to the well-known UDP port defined in Section 5.1. Although using BIER Echo Request in a DoS amplification attack is theoretically possible, spoofing BFIR ID in the BIER Header presents itself as a serious challenge. As a result, this threat is not a big concern.

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 locally secured list before processing the message further.

In some BIER environments, transmitting a single BIER Echo Request message can result in the sender receiving an overwhelming number of BIER Echo Reply messages. In that case, an operator MAY choose to address the BIER Echo Request to a subset of BFERs rather than to all BFERs in the domain.

## 7. Acknowledgement

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