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Locator/ID Separation Protocol (LISP) Control-Plane
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Abstract

This document describes the Control-Plane and Mapping Service for the Locator/ID Separation Protocol (LISP), implemented by two new types of LISP-speaking devices -- the LISP Map-Resolver and LISP Map-Server -- that provides a simplified "front end" for one or more Endpoint ID to Routing Locator mapping databases.

By using this Control-Plane service interface and communicating with Map-Resolvers and Map-Servers, LISP Ingress Tunnel Routers (ITRs) and Egress Tunnel Routers (ETRs) are not dependent on the details of mapping database systems, which facilitates modularity with different database designs. Since these devices implement the "edge" of the LISP Control-Plane infrastructure, connecting EID addressable nodes of a LISP site, their implementation and operational complexity reduces the overall cost and effort of deploying LISP.

This document obsoletes RFC 6830 and 6833.

Status of This Memo

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1. Introduction

The Locator/ID Separation Protocol [I-D.ietf-lisp-rfc6830bis] (see also [I-D.ietf-lisp-introduction]) specifies an architecture and mechanism for dynamic tunneling by logically separating the addresses currently used by IP in two separate name spaces: Endpoint IDs (EIDs), used within sites; and Routing Locators (RLOCs), used on the transit networks that make up the Internet infrastructure. To achieve this separation, LISP defines protocol mechanisms for mapping from EIDs to RLOCs. In addition, LISP assumes the existence of a database to store and propagate those mappings across mapping system nodes. Several such databases have been proposed; among them are the Content distribution Overlay Network Service for LISP-NERD (a Not-so-novel EID-to-RLOC Database) [RFC6837], LISP Alternative Logical Topology (LISP-ALT) [RFC6836], and LISP Delegated Database Tree (LISP-DDT) [RFC8111].

The LISP Mapping Service defines two new types of LISP-speaking devices: the Map-Resolver, which accepts Map-Requests from an Ingress Tunnel Router (ITR) and "resolves" the EID-to-RLOC mapping using a mapping database; and the Map-Server, which learns authoritative EID-to-RLOC mappings from an Egress Tunnel Router (ETR) and publishes them in a database.

This LISP Control-Plane Mapping Service can be used by many different encapsulation-based or translation-based Data-Planes which include but are not limited to the ones defined in LISP RFC 6830bis [I-D.ietf-lisp-rfc6830bis], LISP-GPE [I-D.ietf-lisp-gpe], VXLAN [RFC7348], VXLAN-GPE [I-D.ietf-nvo3-vxlan-gpe], GRE [RFC2890], GTP [GTP-3GPP], ILA [I-D.herbert-intarea-ila], and Segment Routing (SRv6) [RFC8402].

Conceptually, LISP Map-Servers share some of the same basic configuration and maintenance properties as Domain Name System (DNS) [RFC1035] servers; likewise, Map-Resolvers are conceptually similar to DNS caching resolvers. With this in mind, this specification borrows familiar terminology (resolver and server) from the DNS specifications.

Note this document doesn't assume any particular database mapping infrastructure to illustrate certain aspects of Map-Server and Map-Resolver operation. The Mapping Service interface can (and likely will) be used by ITRs and ETRs to access other mapping database systems as the LISP infrastructure evolves.

LISP is not intended to address problems of connectivity and scaling on behalf of arbitrary communicating parties. Relevant situations are described in the scoping section of the introduction to [I-D.ietf-lisp-rfc6830bis].

This document obsoletes RFC 6830 and 6833.

1.1. Scope of Applicability

LISP was originally developed to address the Internet-wide route scaling problem [RFC4984].. While there are a number of approaches of interest for that problem, as LISP as been developed and refined, a large number of other LISP uses have been found and are being used. As such, the design and development of LISP has changed so as to focus on these use cases. The common property of these uses is a large set of cooperating entities seeking to communicate over the public Internet or other large underlay IP infrastructures, while keeping the addressing and topology of the cooperating entities separate from the underlay and Internet topology, routing, and addressing.

2. Requirements Notation

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. Definition of Terms

Map-Server: A network infrastructure component that learns of EID-Prefix mapping entries from an ETR, via the registration mechanism described below, or some other authoritative source if one exists. A Map-Server publishes these EID-Prefixes in a mapping database.

Map-Request: A LISP Map-Request is a Control-Plane message to query the mapping system to resolve an EID. A LISP Map-Request can also be sent to an RLOC to test for reachability and to exchange security keys between an encapsulator and a decapsulator. This type of Map-Request is also known as an RLOC-Probe Request.

Map-Reply: A LISP Map-Reply is a Control-Plane message returned in response to a Map-Request sent to the mapping system when resolving an EID. A LISP Map-Reply can also be returned by a decapsulator in response to a Map-Request sent by an encapsulator to test for reachability. This type of Map-Reply is known as a RLOC-Probe Reply.

Encapsulated Map-Request: A LISP Map-Request carried within an Encapsulated Control Message (ECM), which has an additional LISP header prepended. Sent to UDP destination port 4342. The "outer" addresses are routable IP addresses, also known as RLOCs. Used by an ITR when sending to a Map-Resolver and by a Map-Server when forwarding a Map-Request to an ETR.

Map-Resolver: A network infrastructure component that accepts LISP Encapsulated (ECM) Map-Requests, typically from an ITR, and determines whether or not the destination IP address is part of the EID namespace; if it is not, a Negative Map-Reply is returned. Otherwise, the Map-Resolver finds the appropriate EID-to-RLOC mapping by consulting a mapping database system.

Negative Map-Reply: A LISP Map-Reply that contains an empty Locator-Set. Returned in response to a Map-Request if the destination EID is not registered in the mapping system, is policy denied or fails authentication.

Map-Register message: A LISP message sent by an ETR to a Map-Server to register its associated EID-Prefixes. In addition to the set of EID-Prefixes to register, the message includes one or more RLOCs to reach ETR(s). The Map-Server uses these RLOCs when forwarding Map-Requests (re-formatted as Encapsulated Map-Requests). An ETR MAY request that the Map-Server answer Map-Requests on its behalf by setting the "proxy Map-Reply" flag (P-bit) in the message.

Map-Notify message: A LISP message sent by a Map-Server to an ETR to confirm that a Map-Register has been received and processed. An ETR requests that a Map-Notify be returned by setting the "want-map-notify" flag (M-bit) in the Map-Register message. Unlike a Map-Reply, a Map-Notify uses UDP port 4342 for both source and destination. Map-Notify messages are also sent to ITRs by Map-Servers when there are RLOC-set changes.

For definitions of other terms, notably Ingress Tunnel Router (ITR), Egress Tunnel Router (ETR), and Re-encapsulating Tunnel Router (RTR), refer to the LISP Data-Plane specification [I-D.ietf-lisp-rfc6830bis].

4. Basic Overview

A Map-Server is a device that publishes EID-Prefixes in a LISP mapping database on behalf of a set of ETRs. When it receives a Map Request (typically from an ITR), it consults the mapping database to find an ETR that can answer with the set of RLOCs for an EID-Prefix. To publish its EID-Prefixes, an ETR periodically sends Map-Register messages to the Map-Server. A Map-Register message contains a list of EID-Prefixes plus a set of RLOCs that can be used to reach the ETRs.

When LISP-ALT [RFC6836] is used as the mapping database, a Map-Server connects to the ALT network and acts as a "last-hop" ALT-Router. Intermediate ALT-Routers forward Map-Requests to the Map-Server that advertises a particular EID-Prefix, and the Map-Server forwards them to the owning ETR, which responds with Map-Reply messages.

When LISP-DDT [RFC8111] is used as the mapping database, a Map-Server sends the final Map-Referral messages from the Delegated Database Tree.

A Map-Resolver receives Encapsulated Map-Requests from its client ITRs and uses a mapping database system to find the appropriate ETR to answer those requests. On a LISP-ALT network, a Map-Resolver acts as a "first-hop" ALT-Router. It has Generic Routing Encapsulation (GRE) tunnels configured to other ALT-Routers and uses BGP to learn

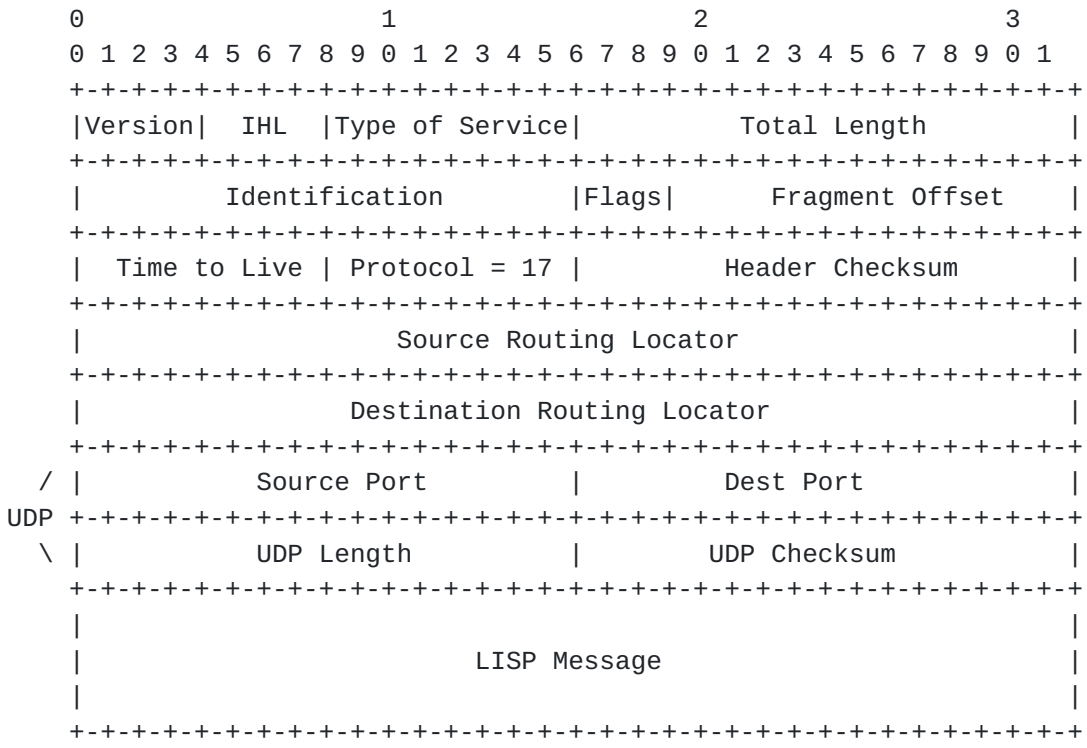
paths to ETRs for different prefixes in the LISP-ALT database. The Map-Resolver uses this path information to forward Map-Requests over the ALT to the correct ETRs. On a LISP-DDT network [RFC8111], a Map-Resolver maintains a referral-cache and acts as a "first-hop" DDT-node. The Map-Resolver uses the referral information to forward Map-Requests.

Note that while it is conceivable that a Map-Resolver could cache responses to improve performance, issues surrounding cache management will need to be resolved so that doing so will be reliable and practical. As initially deployed, Map-Resolvers will operate only in a non-caching mode, decapsulating and forwarding Encapsulated Map Requests received from ITRs. Any specification of caching functionality is out of scope for this document.

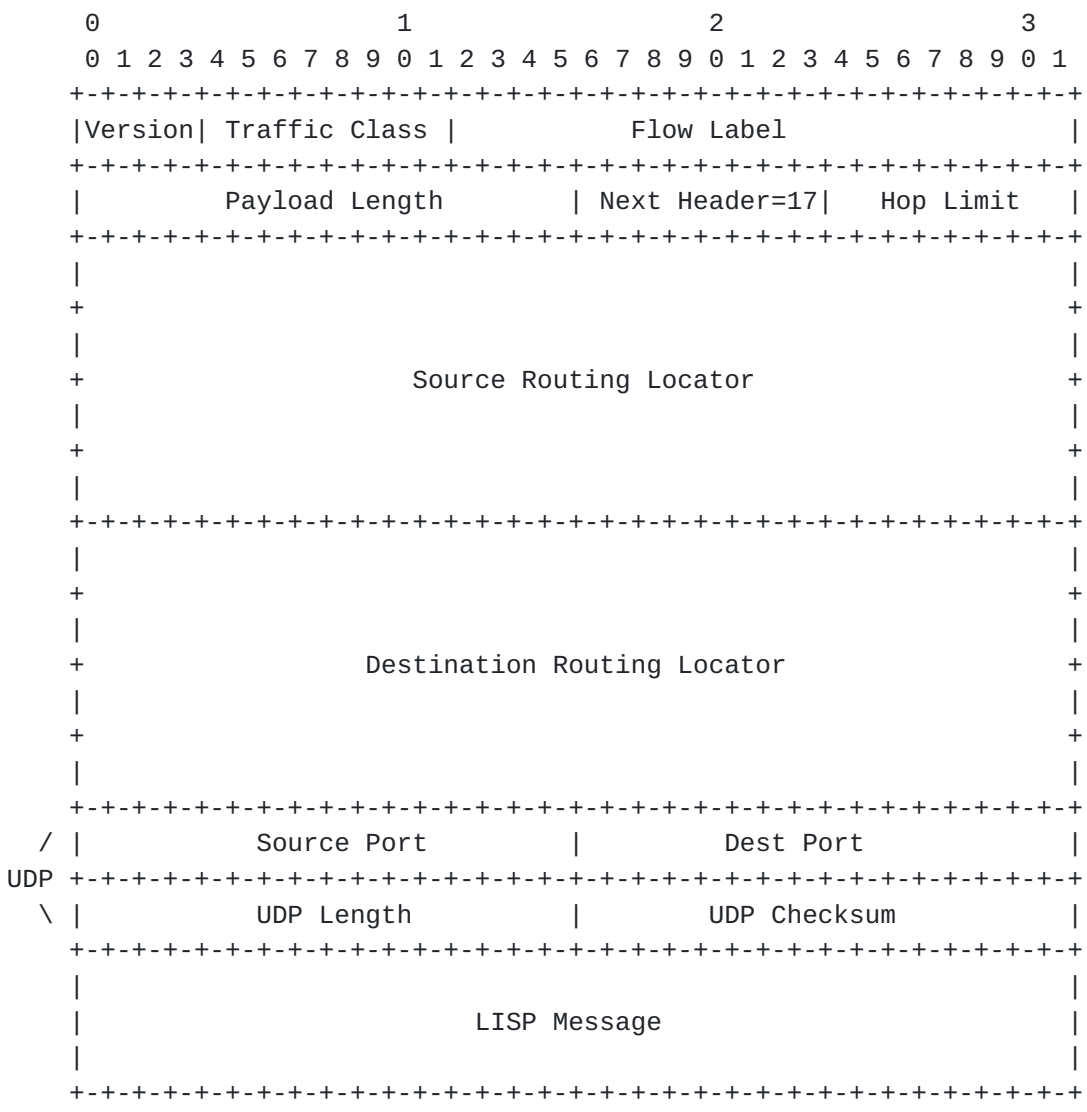
Note that a single device can implement the functions of both a Map-Server and a Map-Resolver, and in many cases the functions will be co-located in that way. Also, there can be ALT-only nodes and DDT-only nodes, when LISP-ALT and LISP-DDT are used, respectively, to connecting Map-Resolvers and Map-Servers together to make up the Mapping System.

5. LISP IPv4 and IPv6 Control-Plane Packet Formats

The following UDP packet formats are used by the LISP control plane.



IPv4 UDP LISP Control Message



IPv6 UDP LISP Control Message

When a UDP Map-Request, Map-Register, or Map-Notify (when used as a notification message) are sent, the UDP source port is chosen by the sender and the destination UDP port number is set to 4342. When a UDP Map-Reply, Map-Notify (when used as an acknowledgement to a Map-Register), or Map-Notify-Ack are sent, the source UDP port number is set to 4342 and the destination UDP port number is copied from the source port of either the Map-Request or the invoking data packet. Implementations MUST be prepared to accept packets when either the source port or destination UDP port is set to 4342 due to NATs changing port number values.

The 'UDP Length' field will reflect the length of the UDP header and the LISP Message payload. Implementations should follow the

procedures from [RFC8085] to determine the maximum size used for any LISP control message.

The UDP checksum is computed and set to non-zero for all messages sent to or from port 4342. It MUST be checked on receipt, and if the checksum fails, the control message MUST be dropped [RFC1071].

The format of control messages includes the UDP header so the checksum and length fields can be used to protect and delimit message boundaries.

5.1. LISP Control Packet Type Allocations

This section defines the LISP control message formats and summarizes for IANA the LISP Type codes assigned by this document. For completeness, the summary below includes the LISP Shared Extension Message assigned by [RFC8113]. Message type definitions are:

Reserved:	0	b'0000'	
LISP Map-Request:	1	b'0001'	
LISP Map-Reply:	2	b'0010'	
LISP Map-Register:	3	b'0011'	
LISP Map-Notify:	4	b'0100'	
LISP Map-Notify-Ack:	5	b'0101'	
LISP Map-Referral:	6	b'0110'	
Not Assigned	7	b'0111'	
LISP Encapsulated Control Message:	8	b'1000'	
Not Assigned	9-14	b'1001'- b'1110'	
LISP Shared Extension Message:	15	b'1111'	[RFC8113]

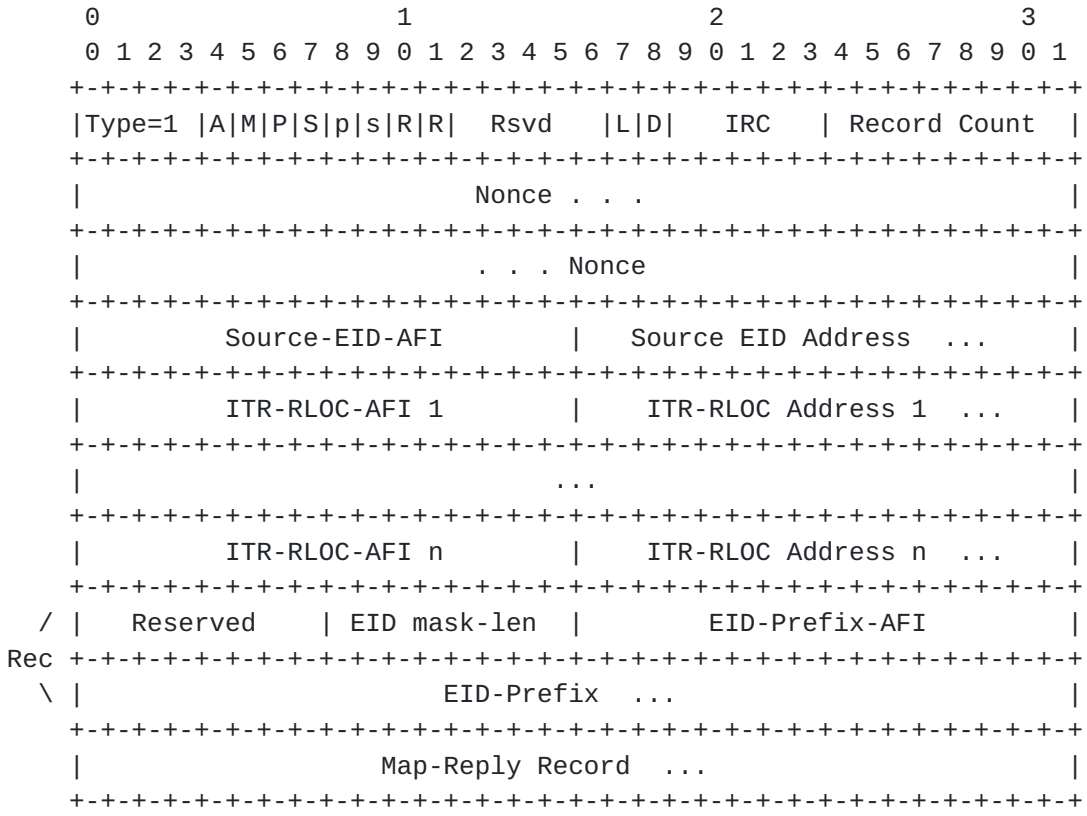
Values in the "Not Assigned" range can be assigned according to procedures in [RFC8126].

Protocol designers experimenting with new message formats are recommended to use the LISP Shared Extension Message Type described in [RFC8113].

All LISP Control-Plane messages use Address Family Identifiers (AFI) [AFI] or LISP Canonical Address Format (LCAF) [RFC8060] formats to encode either fixed or variable length addresses. This includes explicit fields in each control message or part of EID-records or RLOC-records in commonly formatted messages.

The LISP control-plane describes how other data-planes can encode messages to support the Soliciting of Map-Requests as well as RLOC-probing procedures.

5.2. Map-Request Message Format



Packet field descriptions:

Type: 1 (Map-Request)

A: This is an authoritative bit, which is set to 0 for UDP-based Map-Requests sent by an ITR. It is set to 1 when an ITR wants the destination site to return the Map-Reply rather than the mapping database system returning a Map-Reply.

M: This is the map-data-present bit. When set, it indicates that a Map-Reply Record segment is included in the Map-Request.

P: This is the probe-bit, which indicates that a Map-Request SHOULD be treated as a Locator reachability probe. The receiver SHOULD respond with a Map-Reply with the probe-bit set, indicating that the Map-Reply is a Locator reachability probe reply, with the nonce copied from the Map-Request. See RLOC-Probing Section 7.1 for more details. This RLOC-probe Map-Request MUST not be sent to the mapping system. If a Map-Resolver or Map-Server receives a Map-Request with the probe-bit set, it MUST drop the message.

S: This is the Solicit-Map-Request (SMR) bit. See Solicit-Map-Request (SMRs) Section 6.1 for details.

p: This is the PITR bit. This bit is set to 1 when a PITR sends a Map-Request.

s: This is the SMR-invoked bit. This bit is set to 1 when an xTR is sending a Map-Request in response to a received SMR-based Map-Request.

R: This reserved and unassigned bit MUST be set to 0 on transmit and MUST be ignored on receipt.

Rsvd: This field MUST be set to 0 on transmit and MUST be ignored on receipt.

L: This is the local-xtr bit. It is used by an xTR in a LISP site to tell other xTRs in the same site that it is part of the RLOC-set for the LISP site. The L-bit is set to 1 when the RLOC is the sender's IP address.

D: This is the dont-map-reply bit. It is used in the SMR procedure described in Section 6.1. When an xTR sends an SMR Map-Request message, it doesn't need a Map-Reply returned. When this bit is set, the receiver of the Map-Request does not return a Map-Reply.

IRC: This 5-bit field is the ITR-RLOC Count, which encodes the additional number of ('ITR-RLOC-AFI', 'ITR-RLOC Address') fields present in this message. At least one (ITR-RLOC-AFI, ITR-RLOC-Address) pair MUST be encoded. Multiple 'ITR-RLOC Address' fields are used, so a Map-Replier can select which destination address to use for a Map-Reply. The IRC value ranges from 0 to 31. For a value of 0, there is 1 ITR-RLOC address encoded; for a value of 1, there are 2 ITR-RLOC addresses encoded, and so on up to 31, which encodes a total of 32 ITR-RLOC addresses.

Record Count: This is the number of records in this Map-Request message. A record is comprised of the portion of the packet that is labeled 'Rec' above and occurs the number of times equal to Record Count. For this version of the protocol, a receiver MUST accept and process Map-Requests that contain one or more records, but a sender MUST only send Map-Requests containing one record. Support for processing multiple EIDs in a single Map-Request message will be specified in a future version of the protocol.

Nonce: This is an 8-octet random value created by the sender of the Map-Request. This nonce will be returned in the Map-Reply. The security of the LISP mapping protocol critically depends on the

strength of the nonce in the Map-Request message. The nonce MUST be generated by a properly seeded pseudo-random (or strong random) source. See [RFC4086] for advice on generating security-sensitive random data.

Source-EID-AFI: This is the address family of the 'Source EID Address' field.

Source EID Address: This is the EID of the source host that originated the packet that caused the Map-Request. When Map-Requests are used for refreshing a Map-Cache entry or for RLOC-Probing, an AFI value 0 is used and this field is of zero length.

ITR-RLOC-AFI: This is the address family of the 'ITR-RLOC Address' field that follows this field.

ITR-RLOC Address: This is used to give the ETR the option of selecting the destination address from any address family for the Map-Reply message. This address MUST be a routable RLOC address of the sender of the Map-Request message.

EID mask-len: This is the mask length for the EID-Prefix.

EID-Prefix-AFI: This is the address family of the EID-Prefix according to [AFI] and [RFC8060].

EID-Prefix: This prefix address length is 4 octets for an IPv4 address family and 16 octets for an IPv6 address family when the EID-Prefix-AFI is 1 or 2, respectively. For other AFIs [AFI], the address length varies and for the LCAF AFI the format is defined in [RFC8060]. When a Map-Request is sent by an ITR because a data packet is received for a destination where there is no mapping entry, the EID-Prefix is set to the destination IP address of the data packet, and the 'EID mask-len' is set to 32 or 128 for IPv4 or IPv6, respectively. When an xTR wants to query a site about the status of a mapping it already has cached, the EID-Prefix used in the Map-Request has the same mask-length as the EID-Prefix returned from the site when it sent a Map-Reply message.

Map-Reply Record: When the M-bit is set, this field is the size of a single "Record" in the Map-Reply format. This Map-Reply record contains the EID-to-RLOC mapping entry associated with the Source EID. This allows the ETR that will receive this Map-Request to cache the data if it chooses to do so.

5.3. EID-to-RLOC UDP Map-Request Message

A Map-Request is sent from an ITR when it needs a mapping for an EID, wants to test an RLOC for reachability, or wants to refresh a mapping before TTL expiration. For the initial case, the destination IP address used for the Map-Request is the data packet's destination address (i.e., the destination EID) that had a mapping cache lookup failure. For the latter two cases, the destination IP address used for the Map-Request is one of the RLOC addresses from the Locator-Set of the Map-Cache entry. The source address is either an IPv4 or IPv6 RLOC address, depending on whether the Map-Request is using an IPv4 or IPv6 header, respectively. In all cases, the UDP source port number for the Map-Request message is a 16-bit value selected by the ITR/PITR, and the UDP destination port number is set to the well-known destination port number 4342. A successful Map-Reply, which is one that has a nonce that matches an outstanding Map-Request nonce, will update the cached set of RLOCs associated with the EID-Prefix range.

One or more Map-Request ('ITR-RLOC-AFI', 'ITR-RLOC-Address') fields MUST be filled in by the ITR. The number of fields (minus 1) encoded MUST be placed in the 'IRC' field. The ITR MAY include all locally configured Locators in this list or just provide one locator address from each address family it supports. If the ITR erroneously provides no ITR-RLOC addresses, the Map-Replier MUST drop the Map-Request.

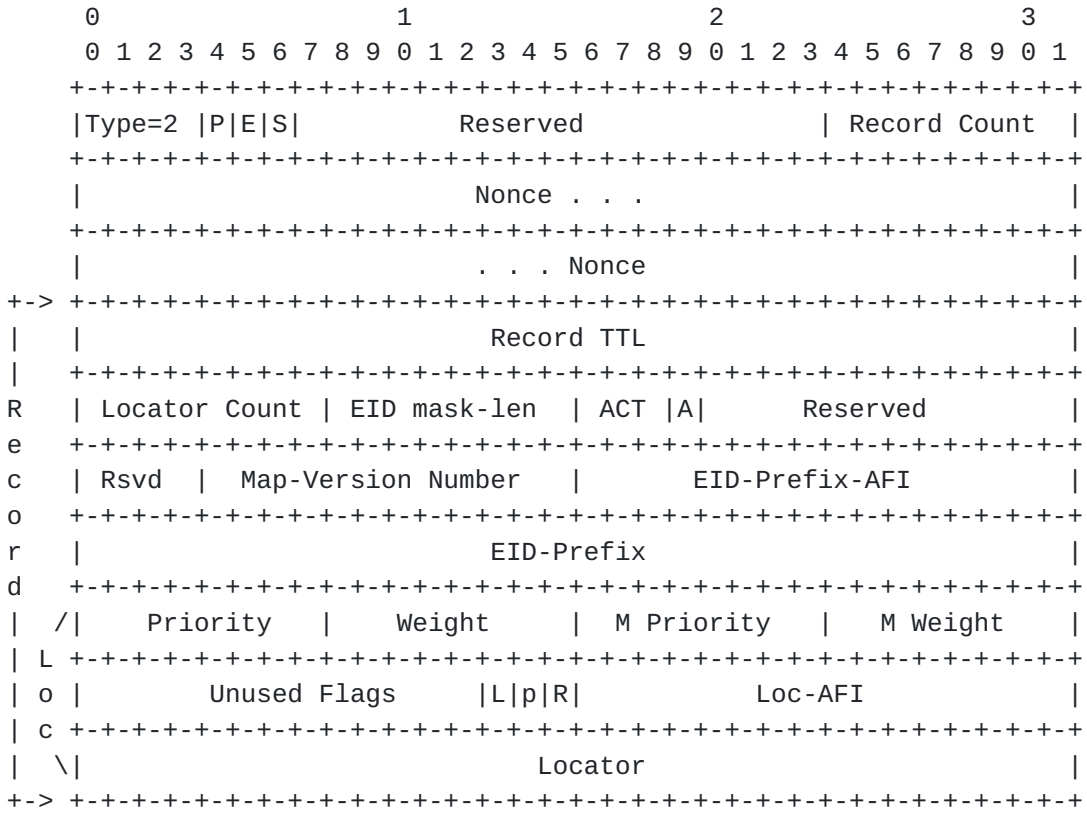
Map-Requests can also be LISP encapsulated using UDP destination port 4342 with a LISP Type value set to "Encapsulated Control Message", when sent from an ITR to a Map-Resolver. Likewise, Map-Requests are LISP encapsulated the same way from a Map-Server to an ETR. Details on Encapsulated Map-Requests and Map-Resolvers can be found in Section 5.8.

Map-Requests MUST be rate-limited. It is RECOMMENDED that a Map-Request for the same EID-Prefix be sent no more than once per second. However, recommendations from [RFC8085] SHOULD be considered.

An ITR that is configured with mapping database information (i.e., it is also an ETR) MAY optionally include those mappings in a Map-Request. When an ETR configured to accept and verify such "piggybacked" mapping data receives such a Map-Request and it does not have this mapping in the Map-Cache, it MAY originate a "verifying Map-Request", addressed to the map-requesting ITR and the ETR MAY add a Map-Cache entry. If the ETR (when it is an xTR co-located as an ITR) has a Map-Cache entry that matches the "piggybacked" EID and the RLOC is in the Locator-Set for the entry, then it MAY send the "verifying Map-Request" directly to the originating Map-Request

source. If the RLOC is not in the Locator-Set, then the ETR MUST send the "verifying Map-Request" to the "piggybacked" EID. Doing this forces the "verifying Map-Request" to go through the mapping database system to reach the authoritative source of information about that EID, guarding against RLOC-spoofing in the "piggybacked" mapping data.

5.4. Map-Reply Message Format



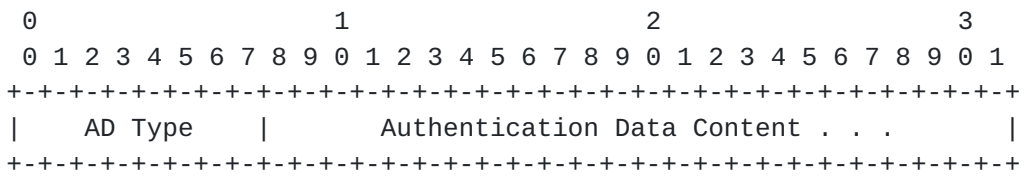
Packet field descriptions:

Type: 2 (Map-Reply)

P: This is the probe-bit, which indicates that the Map-Reply is in response to a Locator reachability probe Map-Request. The 'Nonce' field MUST contain a copy of the nonce value from the original Map-Request. See RLOC-probing Section 7.1 for more details. When the probe-bit is set to 1 in a Map-Reply message, the A-bit in each EID-record included in the message MUST be set to 1.

E: This bit indicates that the ETR that sends this Map-Reply message is advertising that the site is enabled for the Echo-Nonce Locator reachability algorithm. See Echo-Nonce [I-D.ietf-lisp-rfc6830bis] for more details.

S: This is the Security bit. When set to 1, the following authentication information will be appended to the end of the Map-Reply. The details of signing a Map-Reply message can be found in [I-D.ietf-lisp-sec].



Reserved: This unassigned field MUST be set to 0 on transmit and MUST be ignored on receipt.

Record Count: This is the number of records in this reply message. A record is comprised of that portion of the packet labeled 'Record' above and occurs the number of times equal to Record Count.

Nonce: This 64-bit value from the Map-Request is echoed in this 'Nonce' field of the Map-Reply.

Record TTL: This is the time in minutes the recipient of the Map-Reply will store the mapping. If the TTL is 0, the entry MUST be removed from the cache immediately. If the value is 0xffffffff, the recipient can decide locally how long to store the mapping.

Locator Count: This is the number of Locator entries. A Locator entry comprises what is labeled above as 'Loc'. The Locator count can be 0, indicating that there are no Locators for the EID-Prefix.

EID mask-len: This is the mask length for the EID-Prefix.

ACT: This 3-bit field describes Negative Map-Reply actions. In any other message type, these bits are set to 0 and ignored on receipt. These bits are used only when the 'Locator Count' field is set to 0. The action bits are encoded only in Map-Reply messages. They are used to tell an ITR or PITR why a empty locator-set was returned from the mapping system and how it stores the map-cache entry.

(0) No-Action: The Map-Cache is kept alive, and no packet encapsulation occurs.

(1) Natively-Forward: The packet is not encapsulated or dropped but natively forwarded.

(2) Send-Map-Request: The Map-Cache entry is created and flagged that any packet matching this entry invokes sending a Map-Request.

(3) Drop/No-Reason: A packet that matches this Map-Cache entry is dropped. An ICMP Destination Unreachable message SHOULD be sent.

(4) Drop/Policy-Denied: A packet that matches this Map-Cache entry is dropped. The reason for the Drop action is that a Map-Request for the target-EID is being policy denied by either an xTR or the mapping system.

(5) Drop/Authentication-Failure: A packet that matches this Map-Cache entry is dropped. The reason for the Drop action is that a Map-Request for the target-EID fails an authentication verification-check by either an xTR or the mapping system.

A: The Authoritative bit, when set to 1, is always set to 1 by an ETR. When a Map-Server is proxy Map-Replying for a LISP site, the Authoritative bit is set to 0. This indicates to requesting ITRs that the Map-Reply was not originated by a LISP node managed at the site that owns the EID-Prefix.

Map-Version Number: When this 12-bit value is non-zero, the Map-Reply sender is informing the ITR what the version number is for the EID record contained in the Map-Reply. The ETR can allocate this number internally but MUST coordinate this value with other ETRs for the site. When this value is 0, there is no versioning information conveyed. The Map-Version Number can be included in Map-Request and Map-Register messages. See Map-Versioning [I-D.ietf-lisp-6834bis] for more details.

EID-Prefix-AFI: Address family of the EID-Prefix according to [AFI] and [RFC8060].

EID-Prefix: This prefix is 4 octets for an IPv4 address family and 16 octets for an IPv6 address family.

Priority: Each RLOC is assigned a unicast Priority. Lower values are more preferable. When multiple RLOCs have the same Priority, they may be used in a load-split fashion. A value of 255 means the RLOC MUST NOT be used for unicast forwarding.

Weight: When priorities are the same for multiple RLOCs, the Weight indicates how to balance unicast traffic between them. Weight is encoded as a relative weight of total unicast packets that match the mapping entry. For example, if there are 4 Locators in a Locator-Set, where the Weights assigned are 30, 20, 20, and 10, the first Locator will get 37.5% of the traffic, the 2nd and 3rd Locators will get 25% of the traffic, and the 4th Locator will get 12.5% of the traffic. If all Weights for a Locator-Set are equal,

the receiver of the Map-Reply will decide how to load-split the traffic. See RLOC-hashing [I-D.ietf-lisp-rfc6830bis] for a suggested hash algorithm to distribute the load across Locators with the same Priority and equal Weight values.

M Priority: Each RLOC is assigned a multicast Priority used by an ETR in a receiver multicast site to select an ITR in a source multicast site for building multicast distribution trees. A value of 255 means the RLOC MUST NOT be used for joining a multicast distribution tree. For more details, see [RFC6831].

M Weight: When priorities are the same for multiple RLOCs, the Weight indicates how to balance building multicast distribution trees across multiple ITRs. The Weight is encoded as a relative weight (similar to the unicast Weights) of the total number of trees built to the source site identified by the EID-Prefix. If all Weights for a Locator-Set are equal, the receiver of the Map-Reply will decide how to distribute multicast state across ITRs. For more details, see [RFC6831].

Unused Flags: These are set to 0 when sending and ignored on receipt.

L: When this bit is set, the Locator is flagged as a local Locator to the ETR that is sending the Map-Reply. When a Map-Server is doing proxy Map-Replying for a LISP site, the L-bit is set to 0 for all Locators in this Locator-Set.

p: When this bit is set, an ETR informs the RLOC-Probing ITR that the locator address for which this bit is set is the one being RLOC-probed and may be different from the source address of the Map-Reply. An ITR that RLOC-probes a particular Locator MUST use this Locator for retrieving the data structure used to store the fact that the Locator is reachable. The p-bit is set for a single Locator in the same Locator-Set. If an implementation sets more than one p-bit erroneously, the receiver of the Map-Reply MUST select the first set p-bit Locator. The p-bit MUST NOT be set for Locator-Set records sent in Map-Request and Map-Register messages.

R: This is set when the sender of a Map-Reply has a route to the Locator in the Locator data record. This receiver may find this useful to know if the Locator is up but not necessarily reachable from the receiver's point of view. See also EID-Reachability Section 7.1 for another way the R-bit may be used.

Locator: This is an IPv4 or IPv6 address (as encoded by the 'Loc-AFI' field) assigned to an ETR and used by an ITR as a destination RLOC address in the outer header of a LISP encapsualted packet.

Note that the destination RLOC address of a LISP encapsulated packet MAY be an anycast address. A source RLOC of a LISP encapsulated packet can be an anycast address as well. The source or destination RLOC MUST NOT be the broadcast address (255.255.255.255 or any subnet broadcast address known to the router) and MUST NOT be a link-local multicast address. The source RLOC MUST NOT be a multicast address. The destination RLOC SHOULD be a multicast address if it is being mapped from a multicast destination EID.

5.5. EID-to-RLOC UDP Map-Reply Message

A Map-Reply returns an EID-Prefix with a mask-length that is less than or equal to the EID being requested. The EID being requested is either from the destination field of an IP header of a Data-Probe or the EID record of a Map-Request. The RLOCs in the Map-Reply are routable IP addresses of all ETRs for the LISP site. Each RLOC conveys status reachability but does not convey path reachability from a requester's perspective. Separate testing of path reachability is required. See RLOC-reachability Section 7.1 for details.

Note that a Map-Reply MAY contain different EID-Prefix granularity (prefix + mask-length) than the Map-Request that triggers it. This might occur if a Map-Request were for a prefix that had been returned by an earlier Map-Reply. In such a case, the requester updates its cache with the new prefix information and granularity. For example, a requester with two cached EID-Prefixes that are covered by a Map-Reply containing one less-specific prefix replaces the entry with the less-specific EID-Prefix. Note that the reverse, replacement of one less-specific prefix with multiple more-specific prefixes, can also occur, not by removing the less-specific prefix but rather by adding the more-specific prefixes that, during a lookup, will override the less-specific prefix.

When an EID moves out of a LISP site [I-D.ietf-lisp-eid-mobility], the database mapping system may have overlapping EID-prefixes. Or when a LISP site is configured with multiple sets of ETRs that support different EID-prefix mask-lengths, the database mapping system may have overlapping EID-prefixes. When overlapping EID-prefixes exist, a Map-Request with an EID that best matches any EID-Prefix MUST be returned in a single Map-Reply message. For instance, if an ETR had database mapping entries for EID-Prefixes:

```
2001:db8::/16
2001:db8:1::/24
2001:db8:1:1::/32
2001:db8:1:2::/32
```

A Map-Request for EID 2001:db8:1:1::1 would cause a Map-Reply with a record count of 1 to be returned with a mapping record EID-Prefix of 2001:db8:1:1::/32.

A Map-Request for EID 2001:db8:1:5::5 would cause a Map-Reply with a record count of 3 to be returned with mapping records for EID-Prefixes 2001:db8:1::/24, 2001:db8:1:1::/32, 2001:db8:1:2::/32, filling out the /24 with more-specifics that exist in the mapping system.

Note that not all overlapping EID-Prefixes need to be returned but only the more-specific entries (note that in the second example above 2001:db8::/16 was not returned for requesting EID 2001:db8:1:5::5) for the matching EID-Prefix of the requesting EID. When more than one EID-Prefix is returned, all SHOULD use the same Time to Live value so they can all time out at the same time. When a more-specific EID-Prefix is received later, its Time to Live value in the Map-Reply record can be stored even when other less-specific entries exist. When a less-specific EID-Prefix is received later, its Map-Cache expiration time SHOULD be set to the minimum expiration time of any more-specific EID-Prefix in the Map-Cache. This is done so the integrity of the EID-Prefix set is wholly maintained and so no more-specific entries are removed from the Map-Cache while keeping less-specific entries.

Map-Replies SHOULD be sent for an EID-Prefix no more often than once per second to the same requesting router. For scalability, it is expected that aggregation of EID addresses into EID-Prefixes will allow one Map-Reply to satisfy a mapping for the EID addresses in the prefix range, thereby reducing the number of Map-Request messages.

Map-Reply records can have an empty Locator-Set. A Negative Map-Reply is a Map-Reply with an empty Locator-Set. Negative Map-Replies convey special actions by the sender to the ITR or PITR that have solicited the Map-Reply. There are two primary applications for Negative Map-Replies. The first is for a Map-Resolver to instruct an ITR or PITR when a destination is for a LISP site versus a non-LISP site, and the other is to source quench Map-Requests that are sent for non-allocated EIDs.

For each Map-Reply record, the list of Locators in a Locator-Set MUST appear in the same order for each ETR that originates a Map-Reply message. The Locator-Set MUST be sorted in order of ascending IP address where an IPv4 locator address is considered numerically 'less than' an IPv6 locator address.

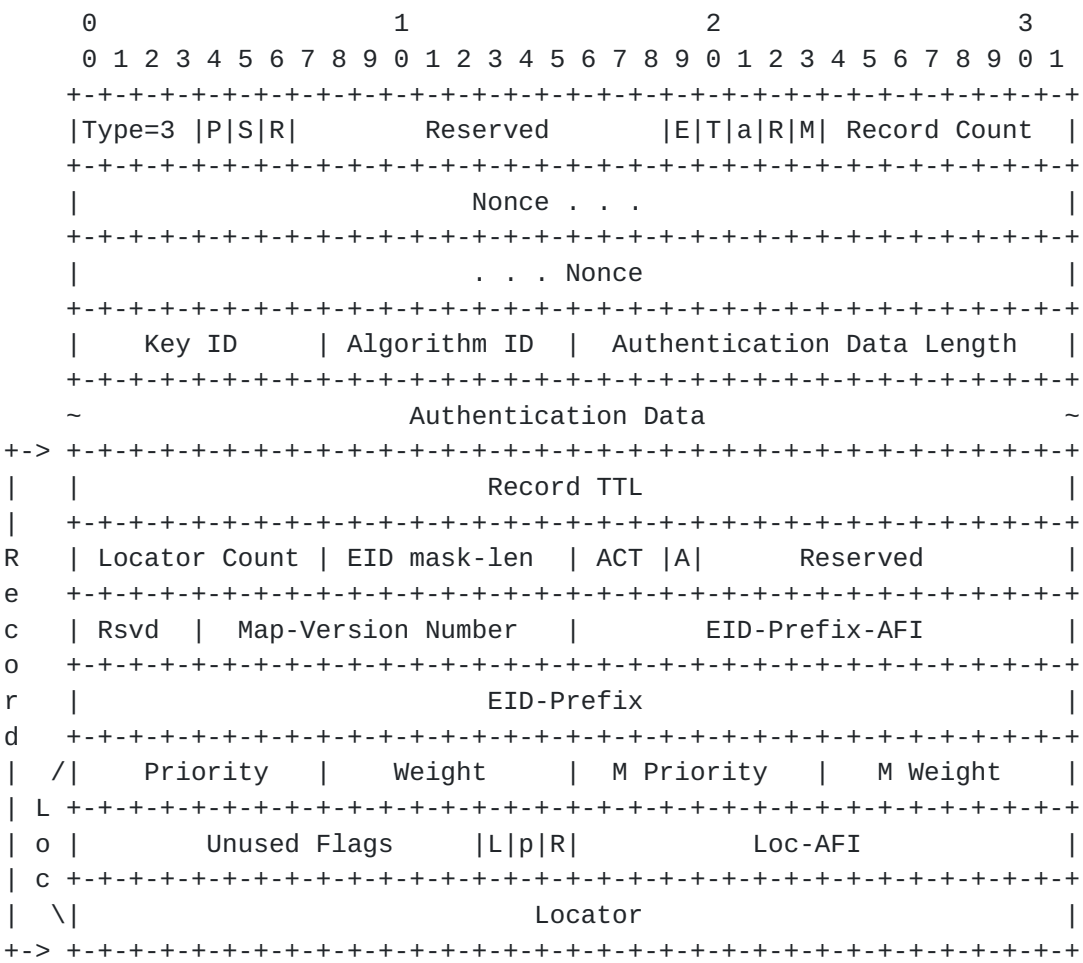
When sending a Map-Reply message, the destination address is copied from one of the 'ITR-RLOC' fields from the Map-Request. The ETR can

choose a locator address from one of the address families it supports. For Data-Probes, the destination address of the Map-Reply is copied from the source address of the Data-Probe message that is invoking the reply. The source address of the Map-Reply is one of the local IP addresses chosen, to allow Unicast Reverse Path Forwarding (uRPF) checks to succeed in the upstream service provider. The destination port of a Map-Reply message is copied from the source port of the Map-Request or Data-Probe, and the source port of the Map-Reply message is set to the well-known UDP port 4342.

5.6. Map-Register Message Format

This section specifies the encoding format for the Map-Register message. The message is sent in UDP with a destination UDP port of 4342 and a randomly selected UDP source port number.

The Map-Register message format is:



Packet field descriptions:

Type: 3 (Map-Register)

P: This is the proxy Map-Reply bit. When set to 1, an ETR sends a Map-Register message requesting the Map-Server to proxy a Map-Reply. The Map-Server will send non-authoritative Map-Replies on behalf of the ETR.

S: This is the security-capable bit. When set, the procedures from [I-D.ietf-lisp-sec] are supported.

Reserved: This unassigned field MUST be set to 0 on transmit and MUST be ignored on receipt.

E: This is the Map-Register EID-notify bit. This is used by a First-Hop-Router (FHR) which discovers a dynamic-EID. This EID-notify based Map-Register is sent by the FHR to the same site xTR that propogates the Map-Register to the mapping system. The site xTR keeps state to later Map-Notify the FHR after the EID has moves away. See [I-D.ietf-lisp-eid-mobility] for a detailed use-case.

T: This is the use-TTL for timeout bit. When set to 1, the xTR wants the Map-Server to time out registrations based on the value in the "Record TTL" field of this message. Otherwise, the default timeout described in Section 8.2 is used.

a: This is the merge-request bit. When set to 1, the xTR requests to merge RLOC-records from different xTRs registering the same EID-record. See signal-free multicast [RFC8378] for one use case example.

R: This reserved and unassigned bit MUST be set to 0 on transmit and MUST be ignored on receipt.

M: This is the want-map-notify bit. When set to 1, an ETR is requesting a Map-Notify message to be returned in response to sending a Map-Register message. The Map-Notify message sent by a Map-Server is used to acknowledge receipt of a Map-Register message.

Record Count: This is the number of records in this Map-Register message. A record is comprised of that portion of the packet labeled 'Record' above and occurs the number of times equal to Record Count.

Nonce: This 8-octet 'Nonce' field is incremented each time a Map-Register message is sent. When a Map-Register acknowledgement is requested, the nonce is returned by Map-Servers in Map-Notify messages. Since the entire Map-Register message is authenticated, the 'Nonce' field serves to protect against Map-Register replay attacks. An ETR that registers to the mapping system SHOULD store the last nonce sent in persistent storage so when it restarts it can continue using an incrementing nonce. If the the ETR cannot support saving the nonce, then when it restarts it MUST use a new authentication key to register to the mapping system. A Map-Server MUST track and save in persistent storage the last nonce received for each ETR that registers to it. If a Map-Register is received with a nonce value that is not greater than the saved

nonce, it drops the Map-Register message and logs the fact a replay attack could have occurred.

Key ID: This is a configured key-id value that corresponds to a shared-secret password that is used to authenticate the sender. Multiple shared-secrets can be used to roll over keys in a non-disruptive way.

Algorithm ID: This is the configured Message Authentication Code (MAC) algorithm value used for the authentication function. See Algorithm ID Numbers in the Section 12.5 for codepoint assignments.

Authentication Data Length: This is the length in octets of the 'Authentication Data' field that follows this field. The length of the 'Authentication Data' field is dependent on the MAC algorithm used. The length field allows a device that doesn't know the MAC algorithm to correctly parse the packet.

Authentication Data: This is the output of the MAC algorithm. The entire Map-Register payload (from and including the LISP message type field through the end of the last RLOC record) is authenticated with this field preset to 0. After the MAC is computed, it is placed in this field. Implementations of this specification MUST include support for either HMAC-SHA-1-96 [RFC2404] and HMAC-SHA-256-128 [RFC4868] where the latter is RECOMMENDED.

The definition of the rest of the Map-Register can be found in EID-record description in Section 5.4.

5.7. Map-Notify/Map-Notify-Ack Message Format

This section specifies the encoding format for the Map-Notify and Map-Notify-Ack messages. The messages are sent inside a UDP packet with source and destination UDP ports equal to 4342.

The Map-Notify and Map-Notify-Ack message formats are:

Packet field descriptions:

Type: 4/5 (Map-Notify/Map-Notify-Ack)

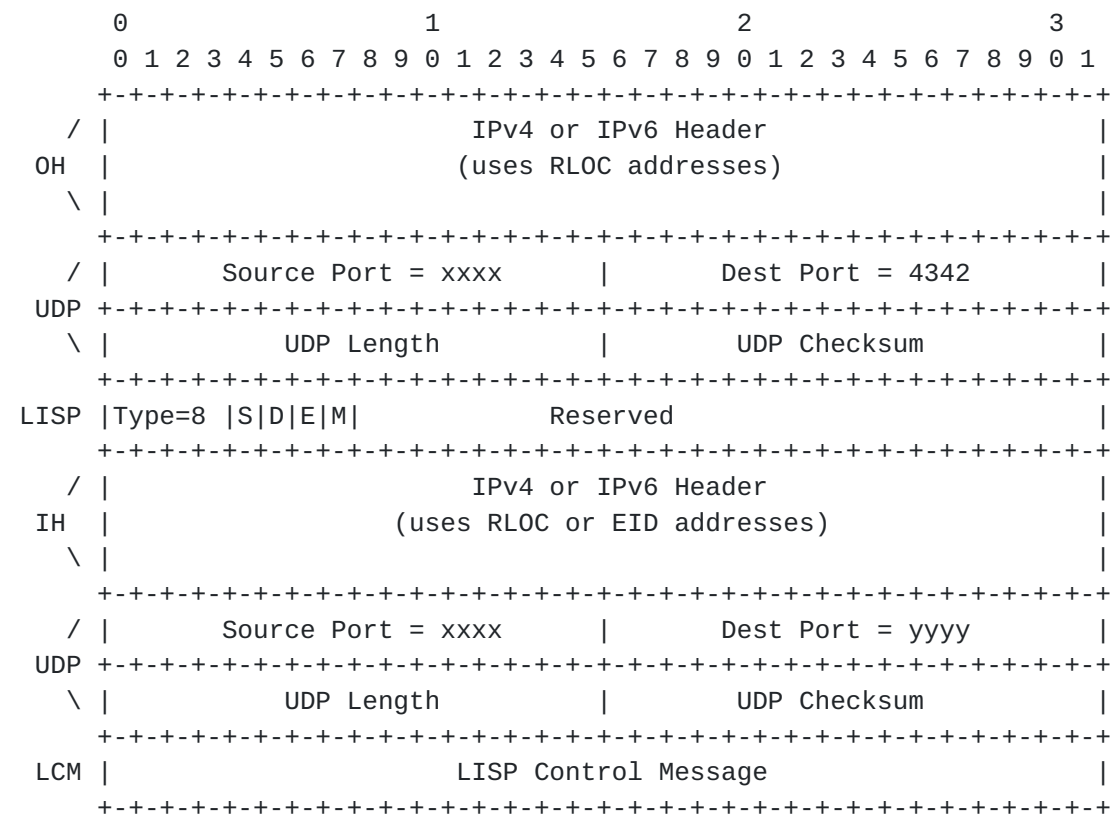
The Map-Notify message has the same contents as a Map-Register message. See the Map-Register section for field descriptions.

The Map-Notify-Ack message has the same contents as a Map-Notify message. It is used to acknowledge the receipt of a Map-Notify and for the sender to stop retransmitting a Map-Notify with the same nonce.

A Map-Server sends an unsolicited Map-Notify message (one that is not used as an acknowledgment to a Map-Register message) that follows the Congestion Control And Relability Guideline sections of [RFC8085]. A Map-Notify is retransmitted until a Map-Notify-Ack is received by the Map-Server with the same nonce used in the Map-Notify message. If a Map-Notify-Ack is never received by the Map-Server, it issues a log message. An implementation SHOULD retransmit up to 3 times at 3 second retransmission intervals, after which time the retransmission interval is exponentially backed-off for another 3 retransmission attempts. After this time, an xTR can only get the RLOC-set change by later querying the mapping system or by RLOC-probing one of the RLOCs of the existing cached RLOC-set to get the new RLOC-set.

5.8. Encapsulated Control Message Format

An Encapsulated Control Message (ECM) is used to encapsulate control packets sent between xTRs and the mapping database system.



Packet header descriptions:

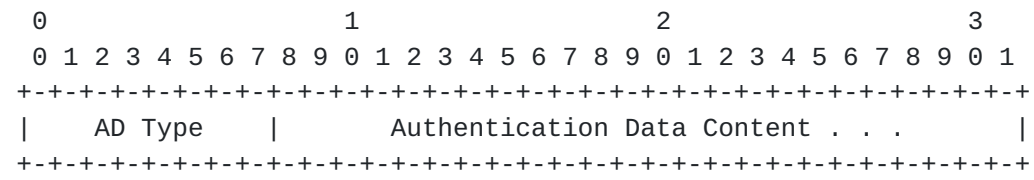
OH: The outer IPv4 or IPv6 header, which uses RLOC addresses in the source and destination header address fields.

UDP: The outer UDP header with destination port 4342. The source port is randomly allocated. The checksum field MUST be non-zero.

LISP: Type 8 is defined to be a "LISP Encapsulated Control Message", and what follows is either an IPv4 or IPv6 header as encoded by the first 4 bits after the 'Reserved' field.

Type: 8 (Encapsulated Control Message (ECM))

S: This is the Security bit. When set to 1, the field following the 'Reserved' field will have the following Authentication Data format and follow the procedures from [I-D.ietf-lisp-sec].



D: This is the DDT-bit. When set to 1, the sender is requesting a Map-Referral message to be returned. The details of this procedure are described in [RFC8111].

E: This is the to-ETR bit. When set to 1, the Map-Server's intention is to forward the ECM to an authoritative ETR.

M: This is the to-MS bit. When set to 1, a Map-Request is being sent to a co-located Map-Resolver and Map-Server where the message can be processed directly by the Map-Server versus the Map-Resolver using the LISP-DDT procedures in [RFC8111].

IH: The inner IPv4 or IPv6 header, which can use either RLOC or EID addresses in the header address fields. When a Map-Request is encapsulated in this packet format, the destination address in this header is an EID.

UDP: The inner UDP header, where the port assignments depend on the control packet being encapsulated. When the control packet is a Map-Request or Map-Register, the source port is selected by the ITR/PITR and the destination port is 4342. When the control packet is a Map-Reply, the source port is 4342 and the destination port is assigned from the source port of the invoking Map-Request. Port number 4341 MUST NOT be assigned to either port. The checksum field MUST be non-zero.

LCM: The format is one of the control message formats described in this section. Map-Request messages are allowed to be Control-Plane (ECM) encapsulated. When Map-Requests are sent for RLOC-Probing purposes (i.e. the probe-bit is set), they MUST NOT be sent inside Encapsulated Control Messages. PIM Join/Prune messages [RFC6831] are also allowed to be Control-Plane (ECM) encapsulated.

6. Changing the Contents of EID-to-RLOC Mappings

In the LISP architecture ITRs/PITRs use a local Map-Cache to store EID-to-RLOC mappings for forwarding. When an ETR updates a mapping a mechanism is required to inform ITRs/PITRs that are using such mappings.

The LISP Data-Plane defines several mechanism to update mappings [I-D.ietf-lisp-rfc6830bis]. This document specifies the Solicit-Map Request (SMR), a Control-Plane push-based mechanism. An additional Control-Plane mechanism based on the Publish/subscribe paradigm is specified in [I-D.ietf-lisp-pubsub].

6.1. Solicit-Map-Request (SMR)

Soliciting a Map-Request is a selective way for ETRs, at the site where mappings change, to control the rate they receive requests for Map-Reply messages. SMRs are also used to tell remote ITRs to update the mappings they have cached.

Since ETRs are not required to keep track of remote ITRs that have cached their mappings, they do not know which ITRs need to have their mappings updated. As a result, an ETR will solicit Map-Requests (called an SMR message) to those sites to which it has been sending LISP encapsulated data packets for the last minute. In particular, an ETR will send an SMR to an ITR to which it has recently sent encapsulated data. This can only occur when both ITR and ETR functionality reside in the same router.

An SMR message is simply a bit set in a Map-Request message. An ITR or PITR will send a Map-Request when they receive an SMR message. Both the SMR sender and the Map-Request responder MUST rate-limit these messages. Rate-limiting can be implemented as a global rate-limiter or one rate-limiter per SMR destination.

The following procedure shows how an SMR exchange occurs when a site is doing Locator-Set compaction for an EID-to-RLOC mapping:

1. When the database mappings in an ETR change, the ETRs at the site begin to send Map-Requests with the SMR bit set for each Locator in each Map-Cache entry the ETR (when it is an xTR co-located as an ITR) caches.

2. A remote ITR that receives the SMR message will schedule sending a Map-Request message to the source locator address of the SMR message or to the mapping database system. A newly allocated random nonce is selected, and the EID-Prefix used is the one copied from the SMR message. If the source Locator is the only

Locator in the cached Locator-Set, the remote ITR SHOULD send a Map-Request to the database mapping system just in case the single Locator has changed and may no longer be reachable to accept the Map-Request.

3. The remote ITR MUST rate-limit the Map-Request until it gets a Map-Reply while continuing to use the cached mapping. When Map-Versioning as described in [I-D.ietf-lisp-6834bis] is used, an SMR sender can detect if an ITR is using the most up-to-date database mapping.

4. The site sending SMR messages will reply to the Map-Request with a Map-Reply message that has a nonce from the SMR-invoked Map-Request. The Map-Reply messages MUST be rate-limited according to procedures in [RFC8085]. This is important to avoid Map-Reply implosion.

5. The ETRs at the site with the changed mapping record the fact that the site that sent the Map-Request has received the new mapping data in the Map-Cache entry for the remote site so the Locator-Status-Bits are reflective of the new mapping for packets going to the remote site. The ETR then stops sending SMR messages.

For security reasons, an ITR MUST NOT process unsolicited Map-Replies. To avoid Map-Cache entry corruption by a third party, a sender of an SMR-based Map-Request MUST be verified. If an ITR receives an SMR-based Map-Request and the source is not in the Locator-Set for the stored Map-Cache entry, then the responding Map-Request MUST be sent with an EID destination to the mapping database system. Since the mapping database system is a more secure way to reach an authoritative ETR, it will deliver the Map-Request to the authoritative source of the mapping data.

When an ITR receives an SMR-based Map-Request for which it does not have a cached mapping for the EID in the SMR message, it SHOULD NOT send an SMR-invoked Map-Request. This scenario can occur when an ETR sends SMR messages to all Locators in the Locator-Set it has stored in its Map-Cache but the remote ITRs that receive the SMR may not be sending packets to the site. There is no point in updating the ITRs until they need to send, in which case they will send Map-Requests to obtain a Map-Cache entry.

7. Routing Locator Reachability

This document defines several Control-Plane mechanisms for determining RLOC reachability. Please note that additional Data-

Plane reachability mechanisms are defined in [I-D.ietf-lisp-rfc6830bis].

1. An ITR may receive an ICMP Network Unreachable or Host Unreachable message for an RLOC it is using. This indicates that the RLOC is likely down. Note that trusting ICMP messages may not be desirable, but neither is ignoring them completely. Implementations are encouraged to follow current best practices in treating these conditions [I-D.ietf-opsec-icmp-filtering].

2. When an ITR participates in the routing protocol that operates in the underlay routing system, it can determine that an RLOC is down when no Routing Information Base (RIB) entry exists that matches the RLOC IP address.

3. An ITR may receive an ICMP Port Unreachable message from a destination host. This occurs if an ITR attempts to use interworking [RFC6832] and LISP-encapsulated data is sent to a non-LISP-capable site.

4. An ITR may receive a Map-Reply from an ETR in response to a previously sent Map-Request. The RLOC source of the Map-Reply is likely up, since the ETR was able to send the Map-Reply to the ITR.

5. An ITR/ETR pair can use the 'RLOC-Probing' mechanism described below.

When ITRs receive ICMP Network Unreachable or Host Unreachable messages as a method to determine unreachability, they will refrain from using Locators that are described in Locator lists of Map-Replies. However, using this approach is unreliable because many network operators turn off generation of ICMP Destination Unreachable messages.

If an ITR does receive an ICMP Network Unreachable or Host Unreachable message, it MAY originate its own ICMP Destination Unreachable message destined for the host that originated the data packet the ITR encapsulated.

Also, BGP-enabled ITRs can unilaterally examine the RIB to see if a locator address from a Locator-Set in a mapping entry matches a prefix. If it does not find one and BGP is running in the Default-Free Zone (DFZ), it can decide to not use the Locator even though the Locator-Status-Bits indicate that the Locator is up. In this case, the path from the ITR to the ETR that is assigned the Locator is not available. More details are in [I-D.meyer-loc-id-implications].

Optionally, an ITR can send a Map-Request to a Locator, and if a Map-Reply is returned, reachability of the Locator has been determined. Obviously, sending such probes increases the number of control messages originated by Tunnel Routers for active flows, so Locators are assumed to be reachable when they are advertised.

This assumption does create a dependency: Locator unreachability is detected by the receipt of ICMP Host Unreachable messages. When a Locator has been determined to be unreachable, it is not used for active traffic; this is the same as if it were listed in a Map-Reply with Priority 255.

The ITR can test the reachability of the unreachable Locator by sending periodic Requests. Both Requests and Replies MUST be rate-limited. Locator reachability testing is never done with data packets, since that increases the risk of packet loss for end-to-end sessions.

7.1. RLOC-Probing Algorithm

RLOC-Probing is a method that an ITR or PITR can use to determine the reachability status of one or more Locators that it has cached in a Map-Cache entry. The probe-bit of the Map-Request and Map-Reply messages is used for RLOC-Probing.

RLOC-Probing is done in the control plane on a timer basis, where an ITR or PITR will originate a Map-Request destined to a locator address from one of its own locator addresses. A Map-Request used as an RLOC-probe is NOT encapsulated and NOT sent to a Map-Server or to the mapping database system as one would when soliciting mapping data. The EID record encoded in the Map-Request is the EID-Prefix of the Map-Cache entry cached by the ITR or PITR. The ITR MAY include a mapping data record for its own database mapping information that contains the local EID-Prefixes and RLOCs for its site. RLOC-probes are sent periodically using a jittered timer interval.

When an ETR receives a Map-Request message with the probe-bit set, it returns a Map-Reply with the probe-bit set. The source address of the Map-Reply is set to the IP address of the outgoing interface the Map-Reply destination address routes to. The Map-Reply SHOULD contain mapping data for the EID-Prefix contained in the Map-Request. This provides the opportunity for the ITR or PITR that sent the RLOC-probe to get mapping updates if there were changes to the ETR's database mapping entries.

There are advantages and disadvantages of RLOC-Probing. The main benefit of RLOC-Probing is that it can handle many failure scenarios allowing the ITR to determine when the path to a specific Locator is

reachable or has become unreachable, thus providing a robust mechanism for switching to using another Locator from the cached Locator. RLOC-Probing can also provide rough Round-Trip Time (RTT) estimates between a pair of Locators, which can be useful for network management purposes as well as for selecting low delay paths. The major disadvantage of RLOC-Probing is in the number of control messages required and the amount of bandwidth used to obtain those benefits, especially if the requirement for failure detection times is very small.

8. Interactions with Other LISP Components

8.1. ITR EID-to-RLOC Mapping Resolution

An ITR is configured with one or more Map-Resolver addresses. These addresses are "Locators" (or RLOCs) and MUST be routable on the underlying core network; they MUST NOT need to be resolved through LISP EID-to-RLOC mapping, as that would introduce a circular dependency. When using a Map-Resolver, an ITR does not need to connect to any other database mapping system. In particular, the ITR need not connect to the LISP-ALT infrastructure or implement the BGP and GRE protocols that it uses.

An ITR sends an Encapsulated Map-Request to a configured Map-Resolver when it needs an EID-to-RLOC mapping that is not found in its local Map-Cache. Using the Map-Resolver greatly reduces both the complexity of the ITR implementation and the costs associated with its operation.

In response to an Encapsulated Map-Request, the ITR can expect one of the following:

- An immediate Negative Map-Reply (with action code of "Natively-Forward", 15-minute Time to Live (TTL)) from the Map-Resolver if the Map-Resolver can determine that the requested EID does not exist. The ITR saves the EID-Prefix returned in the Map-Reply in its cache, marks it as non-LISP-capable, and knows not to attempt LISP encapsulation for destinations matching it.

- A Negative Map-Reply, with action code of "Natively-Forward", from a Map-Server that is authoritative for an EID-Prefix that matches the requested EID but that does not have an actively registered, more-specific ID-prefix. In this case, the requested EID is said to match a "hole" in the authoritative EID-Prefix. If the requested EID matches a more-specific EID-Prefix that has been delegated by the Map-Server but for which no ETRs are currently registered, a 1-minute TTL is returned. If the requested EID matches a non-delegated part of the authoritative EID-Prefix, then

it is not a LISP EID and a 15-minute TTL is returned. See Section 8.2 for discussion of aggregate EID-Prefixes and details of Map-Server EID-Prefix matching.

- A LISP Map-Reply from the ETR that owns the EID-to-RLOC mapping or possibly from a Map-Server answering on behalf of the ETR. See Section 8.4 for more details on Map-Resolver message processing.

Note that an ITR may be configured to both use a Map-Resolver and to participate in a LISP-ALT logical network. In such a situation, the ITR SHOULD send Map-Requests through the ALT network for any EID-Prefix learned via ALT BGP. Such a configuration is expected to be very rare, since there is little benefit to using a Map-Resolver if an ITR is already using LISP-ALT. There would be, for example, no need for such an ITR to send a Map-Request to a possibly non-existent EID (and rely on Negative Map-Replies) if it can consult the ALT database to verify that an EID-Prefix is present before sending that Map-Request.

8.2. EID-Prefix Configuration and ETR Registration

An ETR publishes its EID-Prefixes on a Map-Server by sending LISP Map-Register messages. A Map-Register message includes authentication data, so prior to sending a Map-Register message, the ETR and Map-Server SHOULD be configured with a shared secret or other relevant authentication information. A Map-Server's configuration SHOULD also include a list of the EID-Prefixes for which each ETR is authoritative. Upon receipt of a Map-Register from an ETR, a Map-Server accepts only EID-Prefixes that are configured for that ETR. Failure to implement such a check would leave the mapping system vulnerable to trivial EID-Prefix hijacking attacks. As developers and operators gain experience with the mapping system, additional, stronger security measures may be added to the registration process.

In addition to the set of EID-Prefixes defined for each ETR that may register, a Map-Server is typically also configured with one or more aggregate prefixes that define the part of the EID numbering space assigned to it. When LISP-ALT is the database in use, aggregate EID-Prefixes are implemented as discard routes and advertised into ALT BGP. The existence of aggregate EID-Prefixes in a Map-Server's database means that it may receive Map Requests for EID-Prefixes that match an aggregate but do not match a registered prefix; Section 8.3 describes how this is handled.

Map-Register messages are sent periodically from an ETR to a Map-Server with a suggested interval between messages of one minute. A Map-Server SHOULD time out and remove an ETR's registration if it has not received a valid Map-Register message within the past

three minutes. When first contacting a Map-Server after restart or changes to its EID-to-RLOC database mappings, an ETR MAY initially send Map-Register messages at an increased frequency, up to one every 20 seconds. This "quick registration" period is limited to five minutes in duration.

An ETR MAY request that a Map-Server explicitly acknowledge receipt and processing of a Map-Register message by setting the "want-map-notify" (M-bit) flag. A Map-Server that receives a Map-Register with this flag set will respond with a Map-Notify message. Typical use of this flag by an ETR would be to set it for Map-Register messages sent during the initial "quick registration" with a Map-Server but then set it only occasionally during steady-state maintenance of its association with that Map-Server. Note that the Map-Notify message is sent to UDP destination port 4342, not to the source port specified in the original Map-Register message.

Note that a one-minute minimum registration interval during maintenance of an ETR-Map-Server association places a lower bound on how quickly and how frequently a mapping database entry can be updated. This may have implications for what sorts of mobility can be supported directly by the mapping system; shorter registration intervals or other mechanisms might be needed to support faster mobility in some cases. For a discussion on one way that faster mobility may be implemented for individual devices, please see [I-D.ietf-lisp-mn].

An ETR MAY also request, by setting the "proxy Map-Reply" flag (P-bit) in the Map-Register message, that a Map-Server answer Map-Requests instead of forwarding them to the ETR. See Section 7.1 for details on how the Map-Server sets certain flags (such as those indicating whether the message is authoritative and how returned Locators SHOULD be treated) when sending a Map-Reply on behalf of an ETR. When an ETR requests proxy reply service, it SHOULD include all RLOCs for all ETRs for the EID-Prefix being registered, along with the routable flag ("R-bit") setting for each RLOC. The Map-Server includes all of this information in Map-Reply messages that it sends on behalf of the ETR. This differs from a non-proxy registration, since the latter need only provide one or more RLOCs for a Map-Server to use for forwarding Map-Requests; the registration information is not used in Map-Replies, so it being incomplete is not incorrect.

An ETR that uses a Map-Server to publish its EID-to-RLOC mappings does not need to participate further in the mapping database protocol(s). When using a LISP-ALT mapping database, for example, this means that the ETR does not need to implement GRE or BGP, which greatly simplifies its configuration and reduces its cost of operation.

Note that use of a Map-Server does not preclude an ETR from also connecting to the mapping database (i.e., it could also connect to the LISP-ALT network), but doing so doesn't seem particularly useful, as the whole purpose of using a Map-Server is to avoid the complexity of the mapping database protocols.

8.3. Map-Server Processing

Once a Map-Server has EID-Prefixes registered by its client ETRs, it can accept and process Map-Requests for them.

In response to a Map-Request (received over the ALT if LISP-ALT is in use), the Map-Server first checks to see if the destination EID matches a configured EID-Prefix. If there is no match, the Map-Server returns a Negative Map-Reply with action code "Natively-Forward" and a 15-minute TTL. This can occur if a Map Request is received for a configured aggregate EID-Prefix for which no more-specific EID-Prefix exists; it indicates the presence of a non-LISP "hole" in the aggregate EID-Prefix.

Next, the Map-Server checks to see if any ETRs have registered the matching EID-Prefix. If none are found, then the Map-Server returns a Negative Map-Reply with action code "Natively-Forward" and a 1-minute TTL.

If the EID-prefix is either registered or not registered to the mapping system and there is a policy in the Map-Server to have the requestor drop packets for the matching EID-prefix, then a Drop/Policy-Denied action is returned. If the EID-prefix is registered or not registered and there is a authentication failure, then a Drop/Authentication- failure action is returned. If either of these actions result as a temporary state in policy or authentication then a Send-Map-Request action with 1-minute TTL MAY be returned to allow the requestor to retry the Map-Request.

If any of the registered ETRs for the EID-Prefix have requested proxy reply service, then the Map-Server answers the request instead of forwarding it. It returns a Map-Reply with the EID-Prefix, RLOCs, and other information learned through the registration process.

If none of the ETRs have requested proxy reply service, then the Map-Server re-encapsulates and forwards the resulting Encapsulated Map-Request to one of the registered ETRs. It does not otherwise alter the Map-Request, so any Map-Reply sent by the ETR is returned to the RLOC in the Map-Request, not to the Map-Server. Unless also acting as a Map-Resolver, a Map-Server should never receive Map-Replies; any such messages SHOULD be discarded without response, perhaps

accompanied by the logging of a diagnostic message if the rate of Map-Replies is suggestive of malicious traffic.

8.4. Map-Resolver Processing

Upon receipt of an Encapsulated Map-Request, a Map-Resolver decapsulates the enclosed message and then searches for the requested EID in its local database of mapping entries (statically configured or learned from associated ETRs if the Map-Resolver is also a Map-Server offering proxy reply service). If it finds a matching entry, it returns a LISP Map-Reply with the known mapping.

If the Map-Resolver does not have the mapping entry and if it can determine that the EID is not in the mapping database (for example, if LISP-ALT is used, the Map-Resolver will have an ALT forwarding table that covers the full EID space), it immediately returns a negative LISP Map-Reply, with action code "Natively-Forward" and a 15-minute TTL. To minimize the number of negative cache entries needed by an ITR, the Map-Resolver SHOULD return the least-specific prefix that both matches the original query and does not match any EID-Prefix known to exist in the LISP-capable infrastructure.

If the Map-Resolver does not have sufficient information to know whether the EID exists, it needs to forward the Map-Request to another device that has more information about the EID being requested. To do this, it forwards the unencapsulated Map-Request, with the original ITR RLOC as the source, to the mapping database system. Using LISP-ALT, the Map-Resolver is connected to the ALT network and sends the Map-Request to the next ALT hop learned from its ALT BGP neighbors. The Map-Resolver does not send any response to the ITR; since the source RLOC is that of the ITR, the ETR or Map-Server that receives the Map-Request over the ALT and responds will do so directly to the ITR.

8.4.1. Anycast Operation

A Map-Resolver can be set up to use "anycast", where the same address is assigned to multiple Map-Resolvers and is propagated through IGP routing, to facilitate the use of a topologically close Map-Resolver by each ITR.

ETRs MAY have anycast RLOC addresses which are registered as part of their RLOC-set to the mapping system. However, registrations MUST use their unique RLOC addresses or distinct authentication keys to identify security associations with the Map-Servers.

9. Security Considerations

A complete LISP threat analysis can be found in [RFC7835]. In what follows we highlight security considerations that apply when LISP is deployed in environments such as those specified in Section 1.1, where the following assumptions hold:

1. The Mapping System is secure and trusted, and for the purpose of this security considerations the Mapping System is considered as one trusted element.

2. The ETRs have a pre-configured trust relationship with the Mapping System, which includes some form of shared keys, and the Mapping System is aware of which EIDs an ETR can advertise. How those keys and mappings gets established is out of the scope of this document.

3. LISP-SEC [I-D.ietf-lisp-sec] MUST be implemented. Network operartors should carefully weight how the LISP-SEC threat model applies to their particular use case or deployment. If they decide to ignore a particular recommendation, they should make sure the risk associated with the corresponding threats is well understood.

The Map-Request/Map-Reply message exchange can be exploited by an attacker to mount DoS and/or amplification attacks. Attackers can send Map-Requests at high rates to overload LISP nodes and increase the state maintained by such nodes or consume CPU cycles. Such threats can be mitigated by systematically applying filters and rate limiters.

The 2-way LISP control-plane header nonce exchange can be used to avoid ITR spoofing attacks, but active on-path attackers (e.g 'man-in-the-middle') capable of intercepting the nonce can exploit the Map-Request/Map-Reply message exchange to inject forged mappings directly in the ITR EID-to-RLOC map-cache. In addition, valid ETRs in the system can perform overclaiming attacks. In this case, attackers can claim to own an EID-prefix that is larger than the prefix owned by the ETR. Such attacks can be addressed by using LISP-SEC [I-D.ietf-lisp-sec]. The LISP-SEC protocol defines a mechanism for providing origin authentication, integrity, anti-replay, protection, and prevention of 'man-in-the-middle' and 'prefix overclaiming' attacks on the Map-Request/Map-Reply exchange. In addition and while beyond the scope of securing an individual Map-Server or Map-Resolver, it should be noted that LISP-SEC can be complemented by additional security mechanisms defined by the Mapping System Infrastructure. For instance, BGP-based LISP-ALT [RFC6836]

can take advantage of standards work on adding security to BGP while LISP-DDT [RFC8111] defines its own additional security mechanisms.

To publish an authoritative EID-to-RLOC mapping with a Map-Server using the Map-Register message, an ETR includes authentication data that is a MAC of the entire message using a pair-wise shared key. An implementation MUST support use of HMAC-SHA-1-96 [RFC2104] and SHOULD support use of HMAC-SHA-256-128 [RFC6234] (SHA-256 truncated to 128 bits). The Map-Register message is vulnerable to replay attacks by a man-in-the-middle. Deployments that are concerned with active man-in-the-middle attacks to the Map-Register message SHOULD use a transport-level integrity and anti-reply protection mechanism such as IPSEC [RFC6071]. In addition, a compromised ETR can overclaim the prefix it owns and successfully register it on its corresponding Map-Server. To mitigate this and as noted in Section 8.2, a Map-Server SHOULD verify that all EID-Prefixes registered by an ETR match the configuration stored on the Map-Server.

A complete LISP threat analysis has been published in [RFC7835]. Please refer to it for more detailed security related details.

10. Privacy Considerations

As noted by [RFC6973] privacy is a complex issue that greatly depends on the specific protocol use-case and deployment. As noted in section 1.1 of [I-D.ietf-lisp-rfc6830bis] LISP focuses on use-cases where entities communicate over the public Internet while keeping separate addressing and topology. In what follows we detail the privacy threats introduced by the LISP Control Plane, the analysis is based on the guidelines detailed in [RFC6973].

LISP can use long-lived identifiers (EIDs) that survive mobility events. Such identifiers bind to the RLOCs of the nodes, which represents the topological location with respect to the specific LISP deployments. In addition, EID-to-RLOC mappings are typically considered public information within the LISP deployment when control-plane messages are not encrypted, and can be eavesdropped while Map-Request messages are sent to the corresponding Map-Resolvers or Map-Register messages to Map-Servers.

In this context, attackers can correlate the EID with the RLOC and track the corresponding user topological location and/or mobility. This can be achieved by off-path attackers, if they are authenticated, by querying the mapping system. Deployments concerned about this threat can use access control-lists or stronger authentication mechanisms [I-D.ietf-lisp-ecdsa-auth] in the mapping system to make sure that only authorized users can access this information (data minimization). Use of ephemeral EIDs

[I-D.ietf-lisp-eid-anonymity] to achieve anonymity is another mechanism to lessen persistency and identity tracking.

11. Changes since RFC 6833

For implementation considerations, the following changes have been made to this document since RFC 6833 was published:

- A Map-Notify-Ack message is added in this document to provide reliability for Map-Notify messages. Any receiver of a Map-Notify message must respond with a Map-Notify-Ack message. Map-Servers who are senders of Map-Notify messages, must queue the Map-Notify contents until they receive a Map-Notify-Ack with the nonce used in the Map-Notify message. Note that implementations for Map-Notify-Ack support already exist and predate this document.

- This document is incorporating the codepoint for the Map-Referral message from the LISP-DDT specification [RFC8111] to indicate that a Map-Server must send the final Map-Referral message when it participates in the LISP-DDT mapping system procedures.

- The "m", "I", "L", and "D" bits are added to the Map-Request message. See Section 5.3 for details.

- The "S", "I", "E", "T", "a", and "m" bits are added to the Map-Register message. See Section 5.6 for details.

- The 16-bit Key-ID field of the Map-Register message has been split into a 8-bit Key-ID field and a 8-bit Algorithm-ID field.

- This document adds two new Action values that are in an EID-record that appear in Map-Reply, Map-Register, Map-Notify, and Map-Notify-Ack messages. The Drop/Policy-Denied and Drop/Auth-Failure are the descriptions for the two new action values. See Section 5.4 for details.

12. IANA Considerations

This section provides guidance to the Internet Assigned Numbers Authority (IANA) regarding registration of values related to this LISP Control-Plane specification, in accordance with BCP 26 [RFC8126].

There are three namespaces (listed in the sub-sections below) in LISP that have been registered.

- LISP IANA registry allocations should not be made for purposes unrelated to LISP routing or transport protocols.

- The following policies are used here with the meanings defined in BCP 26: "Specification Required", "IETF Review", "Experimental Use", and "First Come First Served".

12.1. LISP UDP Port Numbers

The IANA registry has allocated UDP port number 4342 for the LISP Control-Plane. IANA has updated the description for UDP port 4342 as follows:

Keyword	Port	Transport Layer	Description
lisp-control	4342	udp	LISP Control Packets

12.2. LISP Packet Type Codes

It is being requested that the IANA be authoritative for LISP Packet Type definitions and it is requested to replace the [RFC6830] registry message references with the RFC number assigned to this document.

Based on deployment experience of [RFC6830], the Map-Notify-Ack message, message type 5, was added by this document. This document requests IANA to add it to the LISP Packet Type Registry.

Name	Number	Defined in
LISP Map-Notify-Ack	5	RFC6833bis

12.3. LISP ACT and Flag Fields

New ACT values can be allocated through IETF review or IESG approval. Four values have already been allocated by [RFC6830], IANA is requested to replace the [RFC6830] reference for this registry with the RFC number assigned to this document and the [RFC6830]. Action values references with the RFC number assigned to this document. This specification changes the name of ACT type 3 value from "Drop" to "Drop/No-Reason" as well as adding two new ACT values, the "Drop/Policy-Denied" (type 4) and "Drop/Authentication-Failure" (type 5).

Value	Action	Description	Reference
4	Drop/ Policy-Denied	A Packet matching this Map-Cache entry is dropped because the target EID is policy-denied by the xTR or the mapping system.	RFC6833bis
5	Drop/ Auth-Failure	A Packet matching this Map-Cache entry is dropped because the Map-Request for target EID fails an authentication check by the xTR or the mapping system.	RFC6833bis

In addition, LISP has a number of flag fields and reserved fields, such as the LISP header flags field [I-D.ietf-lisp-rfc6830bis]. New bits for flags in these fields can be implemented after IETF review or IESG approval, but these need not be managed by IANA.

12.4. LISP Address Type Codes

LISP Canonical Address Format (LCAF) [RFC8060] is an 8-bit field that defines LISP-specific encodings for AFI value 16387. LCAF encodings are used for specific use-cases where different address types for EID-records and RLOC-records are required.

The IANA registry "LISP Canonical Address Format (LCAF) Types" is used for LCAF types. The registry for LCAF types use the Specification Required policy [RFC8126]. Initial values for the registry as well as further information can be found in [RFC8060].

Therefore, there is no longer a need for the "LISP Address Type Codes" registry requested by [RFC6830]. This document requests to remove it.

12.5. LISP Algorithm ID Numbers

In [RFC6830], a request for a "LISP Key ID Numbers" registry was submitted. This document renames the registry to "LISP Algorithm ID Numbers" and requests the IANA to make the name change.

The following Algorithm ID values are defined by this specification as used in any packet type that references a 'Algorithm ID' field:

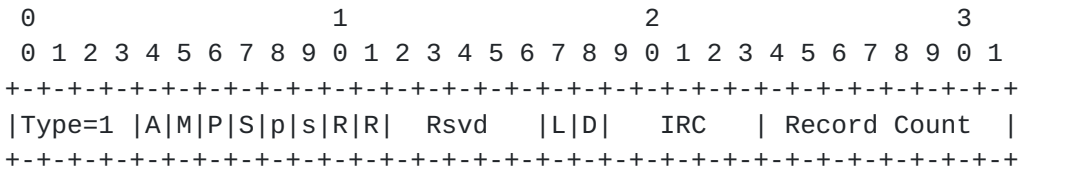
Name	Number	Defined in
None	0	RFC6833bis
HMAC-SHA-1-96	1	[RFC2404]
HMAC-SHA-256-128	2	[RFC4868]

Number values are in the range of 0 to 255. The allocation of values is on a first come first served basis.

12.6. LISP Bit Flags

This document asks IANA to create a registry for allocation of bits in several headers of the LISP control plane, namely in the Map-Request, Map-Reply, Map-Register, Encapsulated Control Message (ECM) messages. Bit allocations are also requested for EID-records and RLOC-records. The registry created should be named "LISP Control Plane Header Bits". A sub-registry needs to be created per each message and record. The name of each sub-registry is indicated below, along with its format and allocation of bits defined in this document. Any additional bits allocation, requires a specification, according with [RFC5226] policies.

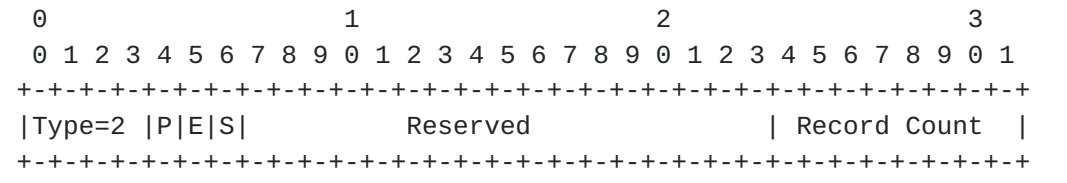
Sub-Registry: Map-Request Header Bits [Section 5.2]:



Spec Name	IANA Name	Bit Position	Description
A	map-request-A	4	Authoritative Bit
M	map-request-M	5	Map Data Present Bit
P	map-request-P	6	RLOC-Probe Request Bit
S	map-request-S	7	Solicit Map-Request (SMR) Bit
p	map-request-p	8	Proxy-ITR Bit
s	map-request-s	9	Solicit Map-Request Invoked Bit
L	map-request-L	17	Local xTR Bit
D	map-request-D	18	Don't Map-Reply Bit

LISP Map-Request Header Bits

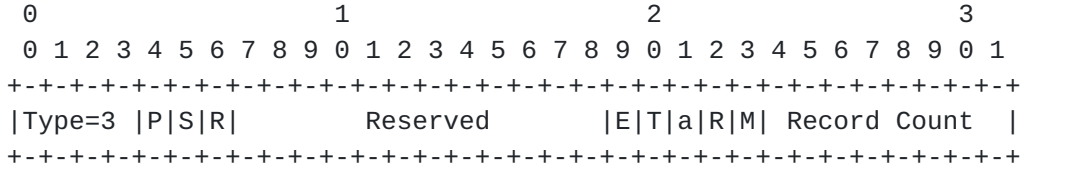
Sub-Registry: Map-Reply Header Bits [Section 5.4]:



Spec Name	IANA Name	Bit Position	Description
P	map-reply-P	4	RLOC-Probe Bit
E	map-reply-E	5	Echo Nonce Capable Bit
S	map-reply-S	6	Security Bit

LISP Map-Reply Header Bits

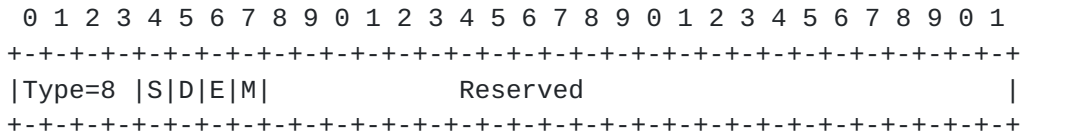
Sub-Registry: Map-Register Header Bits [Section 5.6]:



Spec Name	IANA Name	Bit Position	Description
P	map-register-P	4	Proxy Map-Reply Bit
S	map-register-S	5	LISP-SEC Capable Bit

LISP Map-Register Header Bits

Sub-Registry: Encapsulated Control Message (ECM) Header Bits [Section 5.8]:



Spec Name	IANA Name	Bit Position	Description
S	ecm-S	4	Security Bit
D	ecm-D	5	LISP-DDT Bit
E	ecm-E	6	Forward to ETR Bit
M	ecm-M	7	Destined to Map-Server Bit

LISP Encapsulated Control Message (ECM) Header Bits

Sub-Registry: EID-Record Header Bits [Section 5.4]:

Spec Name	IANA Name	Bit Position	Description
A	eid-record-A	19	Authoritative Bit

LISP EID-Record Header Bits

Sub-Registry: RLOC-Record Header Bits [Section 5.4]:

Spec Name	IANA Name	Bit Position	Description
L	rloc-record-L	13	Local RLOC Bit
p	rloc-record-p	19	RLOC-Probe Reply Bit
R	rloc-record-R	19	RLOC Reachable Bit

LISP RLOC-Record Header Bits

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Appendix B. Document Change Log

[RFC Editor: Please delete this section on publication as RFC.]

B.1. Changes to draft-ietf-lisp-rfc6833bis-20

- Posted late October 2018.
- Changed description about "reserved" bits to state "reserved and unassigned".
- Make it more clear how Map-Register nonce processing is performed in an ETR and Map-Server.

B.2. Changes to draft-ietf-lisp-rfc6833bis-19

- Posted mid October 2018.
- Added Fabio text to the Security Considerations section.

B.3. Changes to draft-ietf-lisp-rfc6833bis-18

- Posted mid October 2018.
- Fixed comments from Eric after more email clarity.

B.4. Changes to draft-ietf-lisp-rfc6833bis-17

- Posted early October 2018.
- Changes to reflect comments from Sep 27th Telechat.
- Added all flag bit definitions as request for allocation in IANA Considersations section.
- Added an applicability statement in section 1 to address security concerns from Telechat.
- Moved m-bit description and IANA request to draft-ietf-lisp-mn.
- Moved I-bit description and IANA request to draft-ietf-lisp-pubsub.

B.5. Changes to draft-ietf-lisp-rfc6833bis-16

- Posted Late-September 2018.
- Re-wrote Security Considerations section. Thanks Albert.
- Added Alvaro text to be more clear about IANA actions.

B.6. Changes to draft-ietf-lisp-rfc6833bis-15

- Posted mid-September 2018.
- Changes to reflect comments from Colin and Mirja.

B.7. Changes to draft-ietf-lisp-rfc6833bis-14

- Posted September 2018.
- Changes to reflect comments from Genart, RTGarea, and Secdir reviews.

B.8. Changes to draft-ietf-lisp-rfc6833bis-13

- Posted August 2018.
- Final editorial changes before RFC submission for Proposed Standard.
- Added section "Changes since RFC 6833" so implementators are informed of any changes since the last RFC publication.

B.9. Changes to draft-ietf-lisp-rfc6833bis-12

- Posted late July 2018.
- Moved RFC6830bis and RFC6834bis to Normative References.

B.10. Changes to draft-ietf-lisp-rfc6833bis-11

- Posted July 2018.
- Fixed Luigi editorial comments to ready draft for RFC status and ran through IDNITs again.

B.11. Changes to draft-ietf-lisp-rfc6833bis-10

- Posted after LISP WG at IETF week March.
- Move AD field encoding after S-bit in the ECM packet format description section.
- Say more about when the new Drop actions should be sent.

B.12. Changes to draft-ietf-lisp-rfc6833bis-09

- Posted March IETF week 2018.
- Fixed editorial comments submitted by document shepherd Luigi Iannone.

B.13. Changes to draft-ietf-lisp-rfc6833bis-08

- Posted March 2018.
- Added RLOC-probing algorithm.
- Added Solicit-Map Request algorithm.
- Added several mechanisms (from 6830bis) regarding Routing Locator Reachability.
- Added port 4342 to IANA Considerations section.

B.14. Changes to draft-ietf-lisp-rfc6833bis-07

- Posted December 2017.
- Make it more clear in a couple of places that RLOCs are used to locate ETRs more so than for Map-Server Map-Request forwarding.

- Make it clear that "encapsualted" for a control message is an ECM based message.

- Make it more clear what messages use source-port 4342 and which ones use destinatino-port 4342.

- Don't make DDT references when the mapping transport system can be of any type and the referneced text is general to it.

- Generalize text when referring to the format of an EID-prefix. Can use othe AFIs then IPv4 and IPv6.

- Many editorial changes to clarify text.

- Changed some "must", "should", and "may" to capitalized.

- Added definitions for Map-Request and Map-Reply messages.

- Ran document through IDNITs.

B.15. Changes to draft-ietf-lisp-rfc6833bis-06

- Posted October 2017.

- Spec the I-bit to include the xTR-ID in a Map-Request message to be consistent with the Map-Register message and to anticipate the introduction of pubsub functionality to allow Map-Requests to subscribe to RLOC-set changes.

- Updated references for individual submissions that became working group documents.

- Updated references for working group documents that became RFCs.

B.16. Changes to draft-ietf-lisp-rfc6833bis-05

- Posted May 2017.

- Update IANA Considerations section based on new requests from this document and changes from what was requested in [RFC6830].

B.17. Changes to draft-ietf-lisp-rfc6833bis-04

- Posted May 2017.

- Clarify how the Key-ID field is used in Map-Register and Map-Notify messages. Break the 16-bit field into a 8-bit Key-ID field and a 8-bit Algorithm-ID field.

- Move the Control-Plane codepoints from the IANA Considerations section of RFC6830bis to the IANA Considerations section of this document.

- In the "LISP Control Packet Type Allocations" section, indicate how message Types are IANA allocated and how experimental RFC8113 sub-types should be requested.

B.18. Changes to draft-ietf-lisp-rfc6833bis-03

- Posted April 2017.

- Add types 9-14 and specify they are not assigned.

- Add the "LISP Shared Extension Message" type and point to RFC8113.

B.19. Changes to draft-ietf-lisp-rfc6833bis-02

- Posted April 2017.

- Clarify that the LISP Control-Plane document defines how the LISP Data-Plane uses Map-Requests with either the SMR-bit set or the P-bit set supporting mapping updates and RLOC-probing. Indicating that other Data-Planes can use the same mechanisms or their own defined mechanisms to achieve the same functionality.

B.20. Changes to draft-ietf-lisp-rfc6833bis-01

- Posted March 2017.

- Include references to new RFCs published.

- Remove references to self.

- Change references from RFC6830 to RFC6830bis.

- Add two new action/reasons to a Map-Reply has posted to the LISP WG mailing list.

- In intro section, add refernece to I-D.ietf-lisp-introduction.

- Removed Open Issues section and references to "experimental".

B.21. Changes to draft-ietf-lisp-rfc6833bis-00

- Posted December 2016.

- Created working group document from draft-farinacci-lisp-rfc6833-00 individual submission. No other changes made.

B.22. Changes to draft-farinacci-lisp-rfc6833bis-00

- Posted November 2016.
- This is the initial draft to turn RFC 6833 into RFC 6833bis.
- The document name has changed from the "Locator/ID Separation Protocol (LISP) Map-Server Interface" to the "Locator/ID Separation Protocol (LISP) Control-Plane".
- The fundamental change was to move the Control-Plane messages from RFC 6830 to this document in an effort so any IETF developed or industry created Data-Plane could use the LISP mapping system and Control-Plane.
- Update Control-Plane messages to incorporate what has been implemented in products during the early phase of LISP development but wasn't able to make it into RFC6830 and RFC6833 to make the Experimental RFC deadline.
- Indicate there may be nodes in the mapping system that are not MRs or MSs, that is a ALT-node or a DDT-node.
- Include LISP-DDT in Map-Resolver section and explain how they maintain a referral-cache.
- Removed open issue about additional state in Map-Servers. With [RFC8111], Map-Servers have the same registration state and can give Map-Resolvers complete information in ms-ack Map-Referral messages.
- Make reference to the LISP Threats Analysis RFC [RFC7835].

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