

LISP Working Group
Internet-Draft
Intended status: Informational
Expires: January 1, 2022

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September 8, 2021

**Network-Hexagons: H3-LISP GeoState & Mobility Network
draft-ietf-lisp-nexagon-18**

Abstract

This document specifies the use of H3 and LISP for Geolocation Services. Geolocation Services utilize geospatial data for: Fresh HDMaps, Intelligent Driving, Cruise and Parking assists. Geospatial utilization is delivered using in-network compute: verification, localization, and brokering of data, using:

- EID addressable geospatial tiled-abstraction of road-segments.
- EID Interface for detections and uploads to a geospatial-context.
- EID Routing-Sharing hazards, blockages, parking, road-inventory.
- EID geospatial themed multicast channels to subscribed clients.

Status of This Memo

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[1.](#) Introduction

The Locator/ID Separation Protocol (LISP) [[I-D.ietf-lisp-rfc6830bis](#)] splits IP addresses in two different namespaces, Endpoint Identifiers (EIDs) and Routing Locators (RLOCs). LISP uses map-and-encap approach (1) a Mapping System (distributed database) that stores and resolves EID-RLOC mappings and on (2) LISP tunnel routers (xTRs) encapsulating and decapsulating data packets based on content of those mappings.

H3 (<https://h3geo.org>) is a geospatial indexing system using hexagonal grid that can be subdivided into finer and finer hexagonal grids, combining the benefits of a hexagonal grid with hierarchy.

H3 supports sixteen resolutions. Each finer resolution has cells with 1/7 the area of the coarser resolution. Hexagons cannot be perfectly subdivided into seven hexagons, so the finer cells are approximately contained within a parent cell. Each cell is identified by 64bit HID.

The Berkeley Deep Drive (BDD) (<https://bdd-data.berkeley.edu>) Industry Consortium investigates computer vision technologies for automotive applications and for taxonomy of published automotive classification.

These standards are combined to create an in-network state reflecting condition of each hexagonal tile (~1sqm) in every road. The mobility H3-LISP network maps & encapsulates traffic between client endpoint identifiers (EID) and addressable geospatial contexts (H3-HID=>EID).

The H3-LISP mobility network bridges timing and location gaps between production and consumption of information by clients of mobility data:

- o information producers: vision, sensory, LIADR, AI applications
- o information consumers: driving-apps, map-apps, command & control

This is achieved by putting the physical world on a shared addressable geospatial context-grid of road-segments represented at the edge. Geospatial state sharing is done using this brokered-network of tile representation, an indirection which solves key issues in v2v information sharing. For example multiple vision perspectives, geo privacy, cyber security. These challenges arise when clients are asked to communicate directly when they do not really need to. A communication pattern which causes complexity and exposures.

In non brokered v2v models, for a situation observable by some end points, it is unclear if the need-to-know end-points will receive: i. consistent, ii. conflicting, iii. multiple, or iv. no indications. As an example, when a vehicle experiences a sudden highway slow-down, sees brake lights or senses an accelerometer slowdown, there is no clear way for it to share this data with vehicles 20-30sec away. Or, when a vehicle crosses an intersection, observing opposite-lane obstruction such as: construction, double-park, commercial loading, garbage truck, or stopped school-bus.. there is no clear way for it to alert approachers from another direction as it drives away.

Geospatial context indirection helps communicate advanced vision and radar annotations. As these are evolving technologies, relaying road enumerations using peer-to-peer poses interoperability challenges.

These peer-to-peer limitations are inherent yet unnecessary, in most situations vehicles are not really proper peers. They happen to be in the same place at the same time. H3-LISP mobility network solves these limitations of direct vehicle-to-vehicle communication by brokering exchanges using addressable geospatial context. Bridging timing, security, privacy, and interoperability gaps between endpoints. Brokering is achieved by clients communicating via context, addressable tiles which aggregated and relay data using H3 EIDs.

Clients can provide drivers with heads-up alerts on hazards/obstacles beyond the line of sight of driver and in-car sensors: over traffic, around blocks, far-side junction, beyond road turns or curvatures. This highlights the importance of networks for road safety and role in Autonomous Vehicle (AV) operation support (AV-OSS).

To summarize the H3-LISP mobility use-case solution principles are:

- (1) MicroPartition: 64bit indexed geo-state per H3.r15 road-tiles
- (2) EnumState: 64bit state values of tile condition representation
- (3) Grouping: EID per H3.r9 geo-context for its H3.r15 road-tiles
- (4) Channels: H3.r9 EIDs multicast address for geo-state updates
- (5) Scale: EID addressable contexts distributed for throughput
- (6) Overlay: tunneled-network routes the mobility-network traffic
- (7) Signal-free: overlay is used to map-register for mcast channels
- (8) Layering: overlay tunnels used between client EIDs and H3 EIDs
- (9) Access: client/server XTRs tunnel traffic to-from the LISP RTRs
- (10) Control: RTRs register-resolve H3 EIDs and mcast subscriptions

```

|-0-|-1-|-2-|-3-|-4-|-5-|-6-|-7-|-8-|-9-|-A-|-B-|-C-|-D-|-E-|-F-|
|                                     H3 Hexagon ID Key          |
|-0-|-1-|-2-|-3-|-4-|-5-|-6-|-7-|-8-|-9-|-A-|-B-|-C-|-D-|-E-|-F-|
|                                     H3 Hexagon State-Value      |
|-----|

```

Figure 1: 64 bit H3 ID, 64 bit compiled state value

Each H3.r9 hexagon is an EID context with corresponding H3 hexagon ID. Bound to that context is a LISP xTR specified to encapsulate packets to and from EID context and LISP Edge. Edge RTRs are used to re-tunnel packets from clients to services. Each service is also a multicast source for updating clients on the state of the H3.r15 tiles, aggregated by the EID addressable geospatial context.

2. Definition of Terms

H3ServiceEID: Is an addressable aggregation of H3.r15 tiles.

It functions as geospatial data association context for filtering, verifying, localizing, and propagating vehicles data uploads.

It is a designated destination for physical world annotations, and an (s,g) source of multicast themed update channels.

H3ServiceEID is itself an H3 hexagon, large enough to provide geo-spatial compute context, but not too large as to over-burden subscribers with too much information. For Mobility Network it is H3.r9. It has a light-weight LISP protocol stack to tunnel packets aka ServerXTR. The EID is an IPv6 EID that contains the H3 64-bit address numbering scheme.

ServerXTR: Is a data-plane only LISP protocol stack implementation, it co-exists with H3ServiceEID process. When the server roams, the xTR is with it. ServerXTR encaps & decaps packets to/from EdgeRTRs.

MobilityClient: Is a roaming application that may be a part of an automobile, part of a navigation application, part of municipal, state or federal government command and control application, or a street view consumer application. It has a light-weight LISP data-plane stack to tunnel packets, aka ClientXTR.

MobilityClient EID: Is the IPv6 EID used by the Mobility Clients to source packets. The destination of such packets are only H3ServiceEIDs. The EID format is opaque and is assigned as part of the MobilityClient mobility-network authorization.

ClientXTR: Is a data-plane only LISP protocol stack implementation co-located with the Mobility Client application. It encaps/decaps packets from/to applications to/from EdgeRTRs.

EdgeRTR: Is the core scale and structure of the LISP mobility network. EdgeRTRs proxy H3ServiceEIDs and MobilityClient H3ServiceEID mcast registration. EdgeRTRs aggregate MobilityClients/H3Services using tunnels to facilitate hosting-providers and mobile-providers for accessing the mobility network. EdgeRTRs decapsulate packets from ClientXTRs, ServerXTRs and re-encaps packets to the clients and servers tunnels. EdgeRTRs glean H3ServiceEIDs/MobilityClient EIDs when they decapsulates packets. EdgeRTRs store H3ServiceEIDs and RLOCs of where the H3ServiceEID is currently reachable from the map-cache. These mappings are registered to the LISP mapping. These mappings may be provisioned when H3Services are assigned EdgeRTRs. EdgeRTRs do not register MobilityClients' EIDs. Enterprises may provide their own EdgeRTRs to protect geo-privacy.

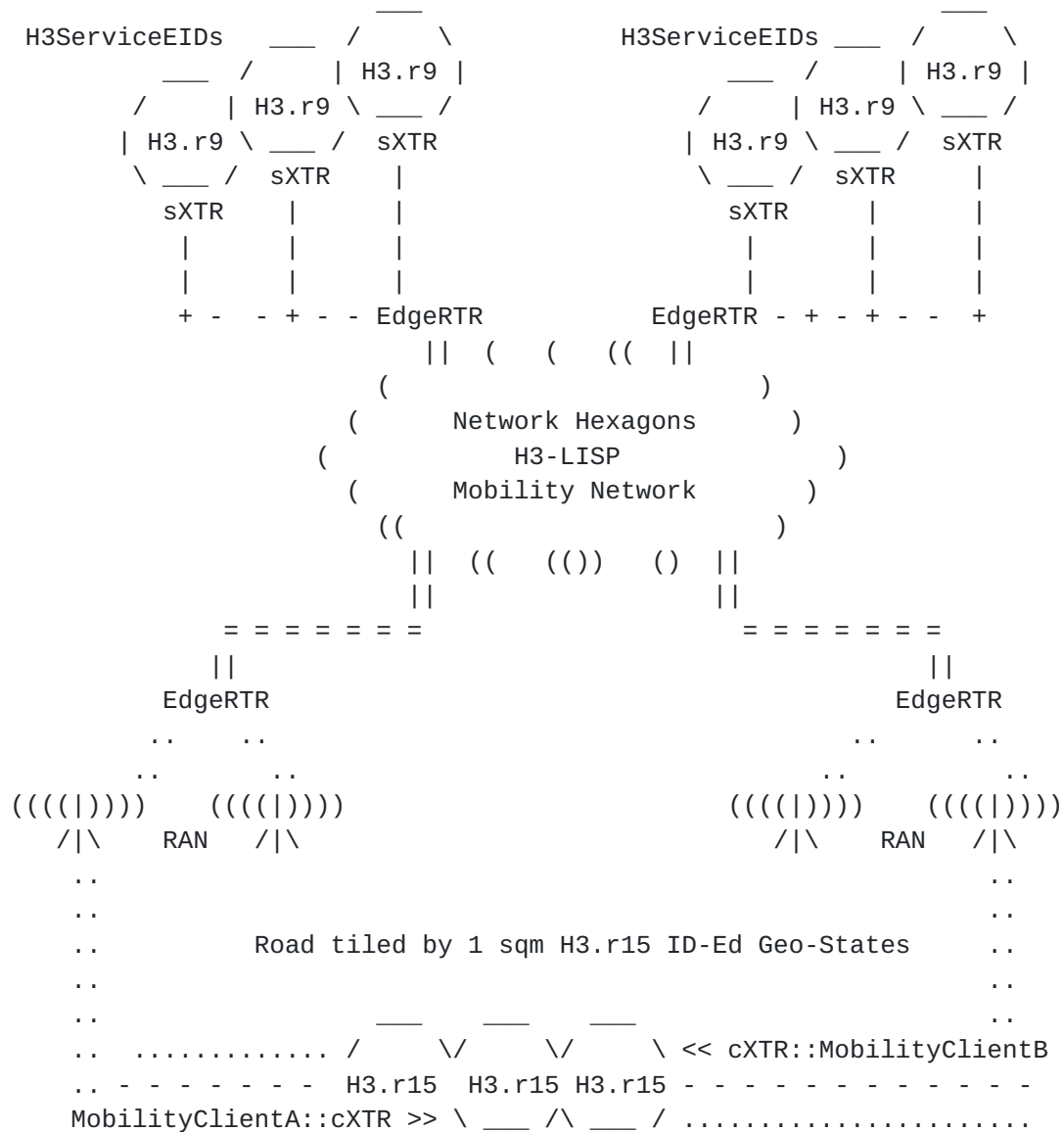


Figure 2: H3.r15 state representation, H3.r9 state aggregation

Figure 2 above describes the following entities:

- **MobilityClientA** sees **MobilityClientB** future, and, vice versa
- **Clients**: share information using addressable state routed by LISP
- **ClientXTR (cXTR)**: encapsulates over access network to **EdgeRTR**
- **ServerXTR (sXTR)**: encapsulates over cloud network to **EdgeRTR**
- **H3-LISP Mobility**: overlay which spans cXTRs to sXTRs
- **Uploads**: routed to appropriate tile by the LISP network
- **EdgeRTRs**: perform multicast replication to edges and then cXTRs
- **Clients**: receive tile-by-tile geo-state updates via the multicast

3. Deployment Assumptions

The specification described in this document makes the following deployment assumptions:

- (1) Unique 64-bit HID is associated with each H3 geo-spatial tile
- (2) MobilityClients and H3ServiceEIDs share this well known index
- (3) 64-bit BDD state value is associated with each H3-indexed tile
- (4) Tile state is compiled 16 fields of 4-bits, or max 16 enums

```

0          1          2          3          4          5          6          7
+-----+-----+-----+-----+-----+-----+-----+-----+
|-0-|-1-|-2-|-3-|-4-|-5-|-6-|-7-|-8-|-9-|-A-|-B-|-C-|-D-|-E-|-F-|
|01230123012301230123012301230123012301230123012301230123|
+-----+-----+-----+-----+-----+-----+-----+

```

Figure 3: Nibble based representation, 16 fields x 16 enumerations

We name the nibbles using hexadecimal index according to the position where the most significant nibble has index 0. Values are defined in [section 8](#).

Subscription of MobilityClients to mobility-network is renewed while on the move and is not intended as the basic connectivity. MobilityClients use DNS/AAA to obtain temporary EIDs/EdgeRTRs and use (LISP) data-plane tunnels to communicate using their temporary EIDs with the dynamically assigned EdgeRTRs.

MobilityClient are otherwise unaware of the LISP network control plane and simply regard the data-plane tunnels as a virtual private network (VPN) that supports IPv6 EID to upload (Ucast) and Subscribe-to (Mcast) H3Services.

In order to get access to the MobilityVPN, MobilityClients first authenticate with the MobilityVPN AAA Server. DIAMETER [[RFC6733](#)] based AAA is typically done at the provider edge (PE) by gateways. However, the typical case involves several types of CPE connected to a specific service provider. The Mobility VPN, on the other hand, may overlay a number of wireless networks and cloud-edge providers. It also involves dozens of Car-OEM, Driving-Applications, Smart-City vendors. This is why we require clients to first go through AAA in order to get both a MobilityClientEID and EdgeRTR RLOC.

ClientXTR performs the following steps to use the mobility network:

- 1) obtain the address of the mobility network AAA server using DNS
- 2) obtain MobilityClientEID and EdgeRTR(s) from AAA DIAMETER server
- 3) renew authorization from AAA while using the mobility network

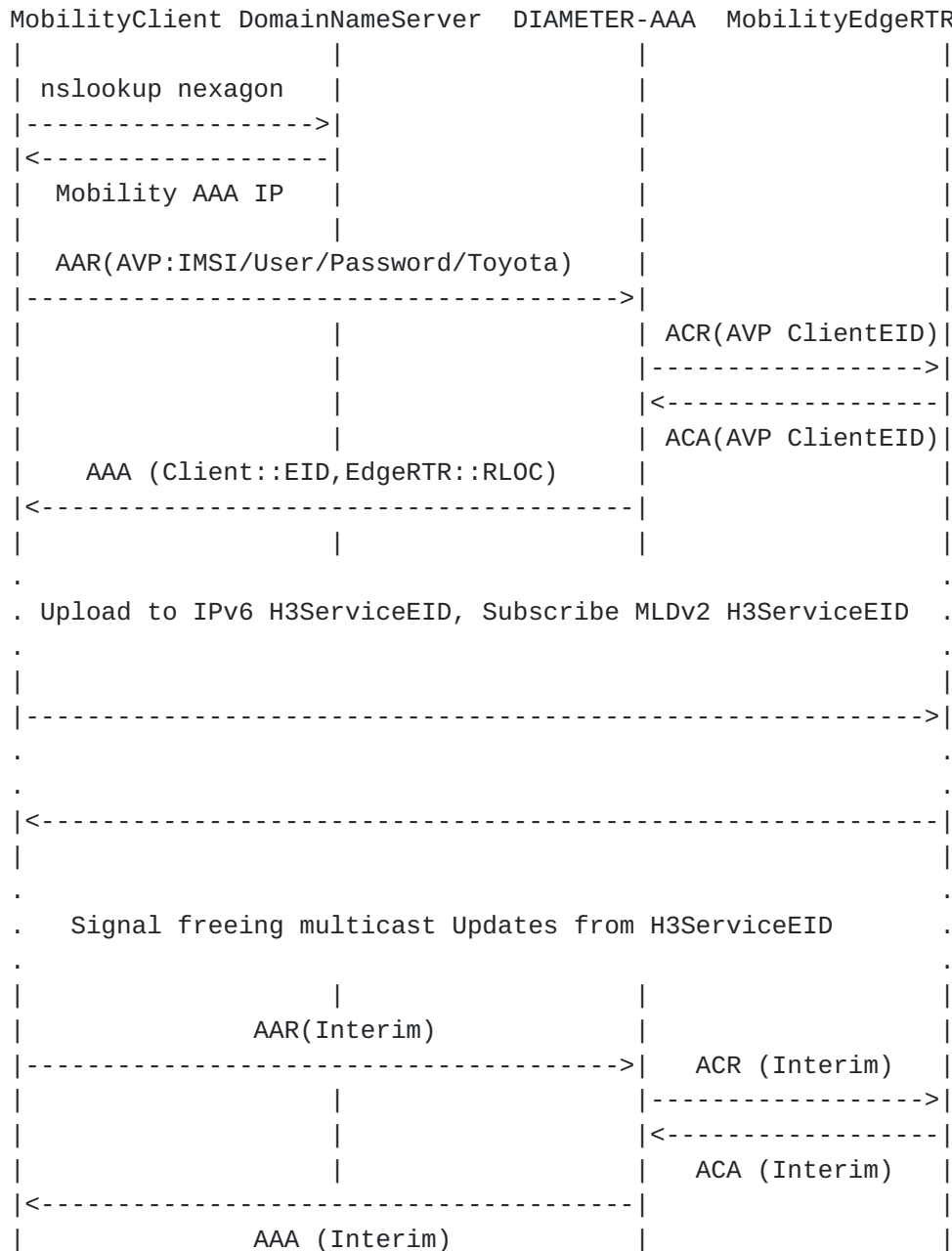


Figure 4: DNS and AAA Exchange for nexagon-network login

Using this network login and re-login method we ensure that:

- MobilityClientEIDs serve as credentials with the EdgeRTRs
- EdgeRTRs are provisioned to whitelist MobilityClient EIDs
- EdgeRTRs are not tightly coupled to H3.r9 areas (privacy/balance)
- MobilityClients do not need to update EdgeRTRs while roaming

The same EdgeRTR may serve several H3.r9 areas for ride continuity and several EdgeRTRs may load balance an H3.r9 area with high density of MobilityClients. When a MobilityClient ClientXTR is homed to EdgeRTR, it is able to communicate with H3ServiceEIDs.

4. Mobility Clients Network Services

The mobility network functions as a standard LISP overlay.

The overlay delivers unicast and multicast packets across:

- multiple access-networks and radio-access specifications
- multiple edge providers, public, private, and hybrid clouds

We use data-plane XTRs in the stack of each mobility client/server. ClientXTRs and ServerXTRs are homed to one or more EdgeRTRs. This structure allows for MobilityClients to "show up" at any time, behind any network provider in a given mobility network admin/NAT domain, and for any H3ServiceEID to be instantiated, moved, or failed-over to any rack in any cloud-provider. LISP overlay enables these roaming mobility network elements to communicate uninterrupted. This quality is insured by the LISP RFCs. The determination of identities for MobilityClients to always refer to the correct H3ServiceEID is insured by H3 geo-spatial HIDs.

There are two options to associate ClientXTRs with LISP EdgeRTRs:

i. Semi-random load-balancing by DNS/AAA

In this option we assume that in a given metro edge a pool of EdgeRTRs can distribute the Mobility Clients load randomly between them and that EdgeRTRs are topologically equivalent. Each RTR uses LISP to tunnel traffic to and from other EdgeRTRs for MobilityClient with H3Service exchanges. MobilityClients home to EdgeRTRs.

ii. Topological by anycast

In this option we align an EdgeRTR with topological aggregation. Mobility Clients are roaming in an area home to that RTR and so is the H3 Server. There is only one hop across the edge overlay between clients and servers and mcast replication is more focused, but clients need to keep re-homing as they move.

To summarize the H3LISP mobility network layout:

- (1) Mobility-Clients traffic is tunneled via data-plane ClientXTRs
ClientXTRs are (multi) homed to EdgeRTR(s)
- (2) H3ServiceEID traffic is tunneled via data-plane ServerXTR
ServerXTRs are (multi) homed to EdgeRTR(s)
- (3) EdgeRTRs use mapping service to resolve Ucast HIDs to RTR RLOCs
EdgeRTRs also register to (Source, Group) H3ServiceEID multicasts

```

MobilityClients <> ClientXTR <Access Provider > EdgeRTR  v
                                                         v
v < < < < Map-Assisted Mobility-Network Overlay < < < < v
v
> > > > EdgeRTR <Cloud Provider> ServerXTR <> H3ServiceEID

```

Figure 5: The Data Flow Between MobilityClients and H3ServiceEIDs

5. Mobility Unicast and Multicast

Regardless of the way a given ClientXTR was associated with EdgeRTR, an authenticated MobilityClient EID can send: [64bitH3.15ID :: 64bitState]annotations to the H3.r9 H3ServiceEID. The H3.r9 EID can be calculated by clients algorithmically from the H3.15 localization.

The ClientXTR encapsulates MobilityClient EID and H3ServiceEID from the ClientXTR with the destination of the EdgeRTR RLOC LISP port. EdgeRTRs then re-encapsulate annotation packets to remote EdgeRTR. The remote EdgeRTR aggregating H3ServiceEIDs re-encapsulates MobilityClient EID to the ServerXTR, to the H3ServiceEID.

The headers consist of the following fields:

```

Outer headers = 40 (IPv6) + 8 (UDP) + 8 (LISP) = 56
Inner headers = 40 (IPv6) + 8 (UDP) + 4 (Nexagon Header) = 52
1500 (MTU) - 56 - 52 = 1392 bytes of effective payload

```

Nexagon Header Type allows for kv tuples or vkkk flooding

Type 0:reserved

Type 1:key-value, key-value.. $1392 / (8 + 8) = 87$ pairs

Type 2:value, key,key,key.. $(1392 - 8) / 8 = 173$ H3-R15 IDs

Type 3-255: unassigned

Nexagon Header GZIP field: 0x000 no compression, or GZIP version.

Nexagon Header Reserved bits

Nexagon Header kv count (in any format)



Figure 6: Uploaded detections packet format

To Summarize Unicast Uploads:

- (1) MobilityClients can send annotations are localized to H3.r15 tile. These annotations are sent to H3.r9 mobility H3ServiceEIDs
- (2) MobilityClient EID and H3ServiceEID HID are encapsulated:
XTR <> RTR <> RTR <> XTR
* RTRs can map-resolve re-tunnel HIDs
- (3) RTRs re-encapsulate original source-dest to ServerXTRs
ServerXTRs decapsulate packets to H3ServiceEID

Each H3.r9 Server is also an IP Multicast Source used to update subscribers on the aggregate state of the H3.r15 tiles in the H3.r9 server. This forms a multipoint to multipoint state channel per H3 location, where the aggregation has compute-first propagation.

We use [[RFC8378](#)] signal-free multicast to implement mcast channels in the overlay. The mobility network has many channels, with thousands subscribers per channel. MobilityClients driving through/subscribing to an H3.r9 area can explicitly issue an [[RFC4604](#)] MLDv2 in order to subscribe, or, may be subscribed implicitly by the EdgeRTR.

The advantage of explicit client MLDv2 registration as [[RFC8378](#)] trigger is that clients manage their own mobility mcast handover per location-direction vectors, and that it allows for otherwise silent non annotating clients. The advantage of EdgeRTR implicit registration is that less signaling required.

MLDv2 signaling messages are encapsulated between the ClientXTR and EdgeRTR, therefore there is no requirement for the underlying network to support native multicast. If native access multicast is supported then MobilityClient registration to H3ServiceEID safety channels may be integrated with it, in which case mobile packet-core element supporting it will use this standard to register with the appropriate H3.r9 channels in its area.

Multicast update packets are of the following structure:

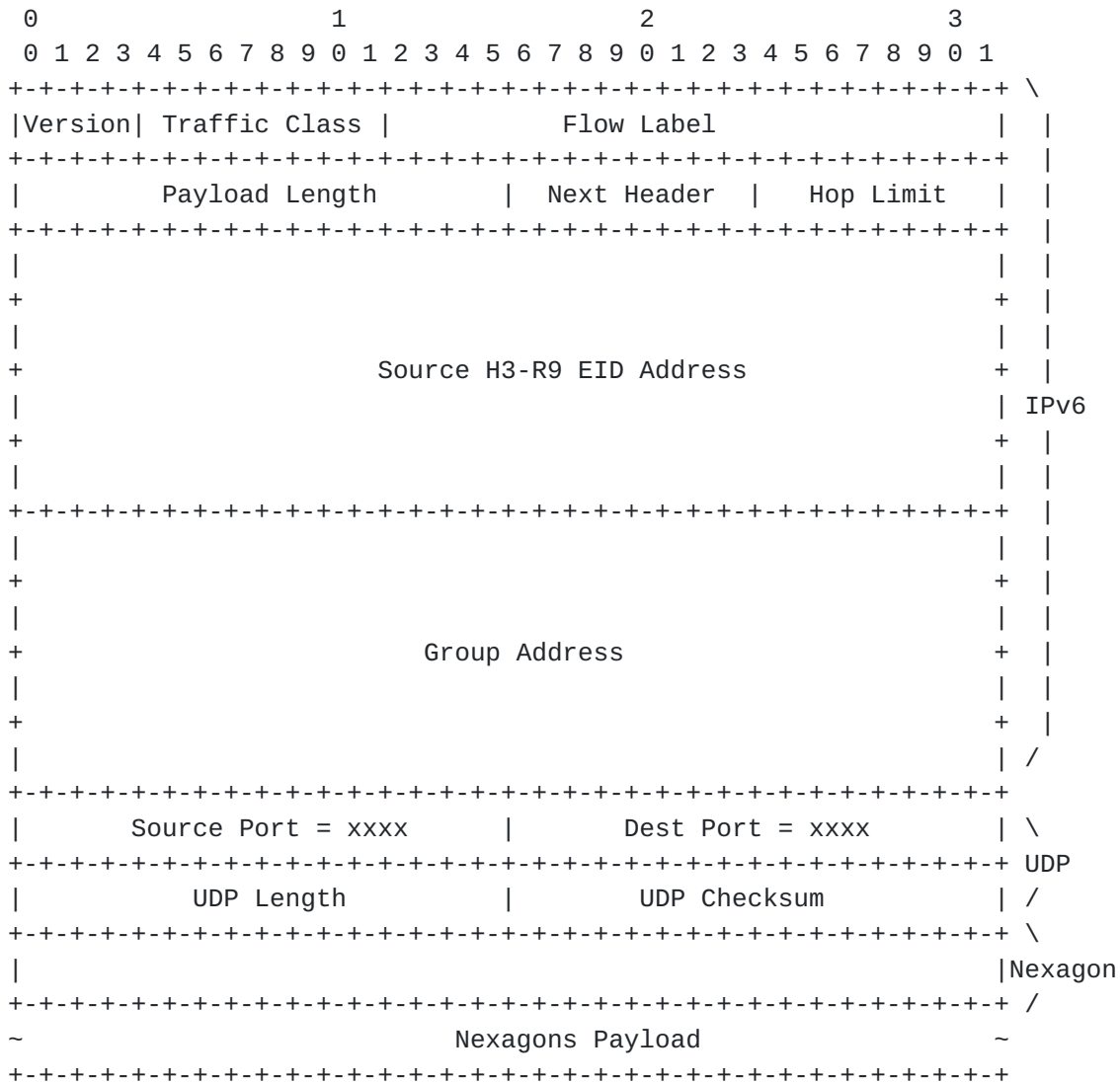


Figure 7: Mcast update packet header

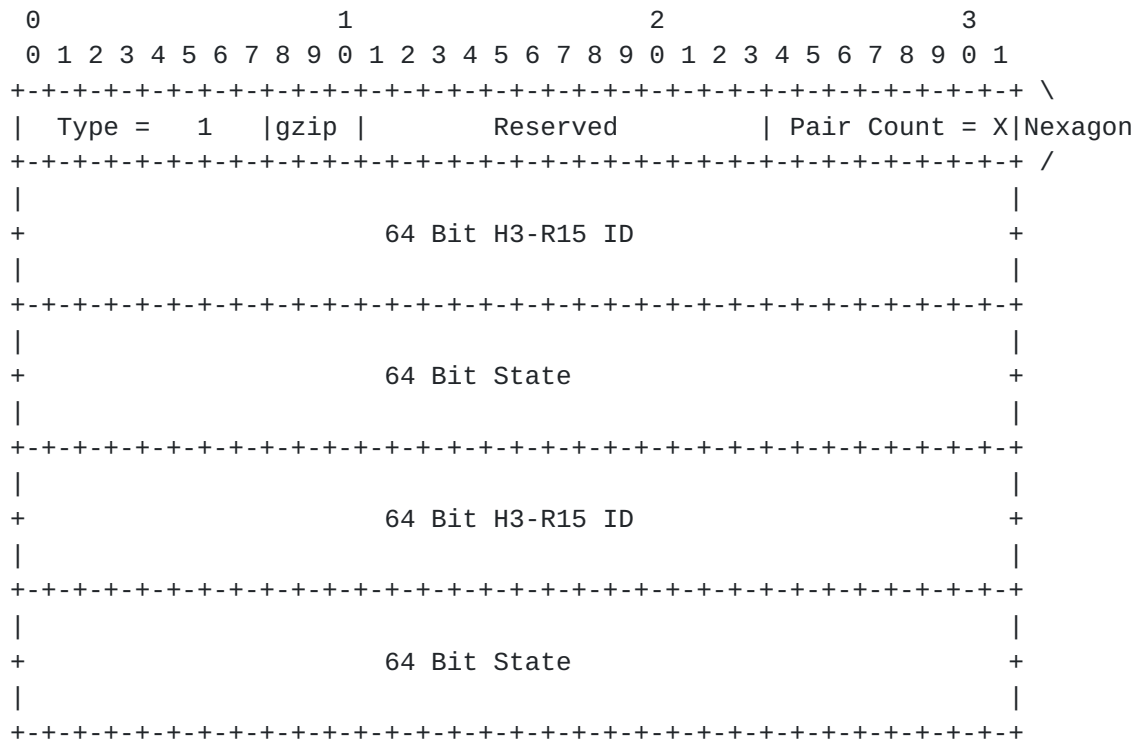


Figure 8: Mcast update payload, key-value, key-value..

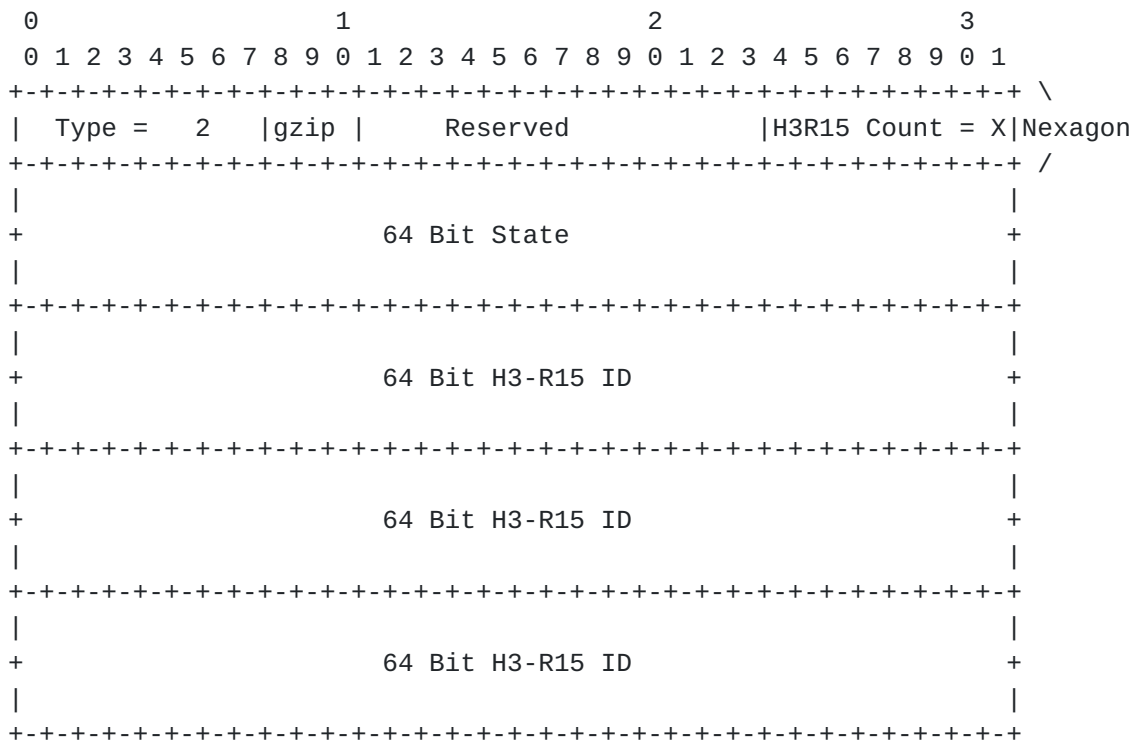


Figure 9: Mcast update payload, value, key, key.. for larger areas

The remote EdgeRTRs homing MobilityClients in turn replicate the packet to the MobilityClients registered with them.

We expect an average of 600 H3.r15 tiles of the full 7^6 (~100K) possible in H3.r9 to be part of any road. The H3.r9 server can transmit the status of all 600 or just those with meaningful states based on updated SLA and policy.

To Summarize:

- (1) H3LISP Clients tune to H3.r9 mobility updates using [\[RFC8378\]](#)
H3LISP Client issue MLDv2 registration to H3.r9 HIDs
ClientXTRs encapsulate MLDv2 to EdgeRTRs who register (s,g).
- (2) ServerXTRs encapsulate updates to EdgeRTRs who map-resolve (s,g)
RLOCs EdgeRTRs replicate mobility update and tunnel to registered
EdgeRTRs Remote EdgeRTRs replicate updates to ClientXTRs.

6. Security Considerations

The nexagon layer3 v2n network is inherently more secure and private than peer to peer alternatives because of the indirection. No car or infrastructure element communicates directly with MobilityClients. All information is conveyed using shared addressable geo-state. MobilityClients receive information only from geospatial channels originating from a trusted broker. MobilityClients have no indication as to the origin of the information. This is an important step towards better privacy, security, extendability, and interoperability compared with legacy layer2 protocols.

In order to be able to use the nexagon mobility network for a given period, the mobility clients go through a DNS/AAA stage by which they obtain their clientEID identifiers-credentials and the RLOCs of EdgeRTRs they may use as gateways to the network. This MobilityClient <> EdgeRTR interface is the most sensitive in this network to privacy and security considerations.

The traffic on the MobilityClient<>EdgeRTR interface is tunneled, and its UDP content may be encrypted; still, the EdgeRTR will know based on the LISP headers alone the MobilityClient RLOC and H3-R9 (~0.1sqkm) geo-spatial area to which a given client uploads or subscribes to.

For this reason we envision the ability of enterprise or groups of users to "bring their own" EdgeRTRs. BYO-RTR masks individual clients' RLOC to H3-R9 association and is pre-provisioned to be able to use the mapping system and be on a white-list of EdgeRTRs aggregating H3ServiceEIDs. If the EdgeRTR functionality is delivered by 5GCore UPF then the only entity which can correlate underlay IP, User, and Geo-location is the regulated carrier, which can do so anyway.

Beyond this hop, the mapping system does not hold MobilityClientEIDs, and remote EdgeRTRs are only aware of MobilityClient ephemeral EIDs, not actual RLOC or any other mobile-device identifiers. EdgeRTRs register in the mapping (s,g) H3-R9 multicast groups. Which clients use which EdgeRTR is not in the mapping system, only the AAA server is aware of that. The H3ServiceEIDs themselves decrypt and parse actual H3-R15 annotations; they also consider during this MobilityClientEID credentials to avoid "fake-news", but again these are only temporary EIDs allocated to clients in order to be able to use the mobility network and not for their actual IP.

H3Services are provisioned to their EdgeRTRs, in the EdgeRTRs, and optionally also in the mapping system.

In summary of main risk mitigations for the lisp-nexagon interface:

(1) tapping: all communications are through dynamic tunnels therefore may be encrypted using IP-Sec or other supported point to point underlay standards. These are not static tunnels but LISP re-tunneling routers (RTRs) perform all nexagon Overlay aggregation.

(2) spoofing: it is very hard to guess a MobilityClientEID valid for a short period of time. Clients and H3Services EIDs are whitelisted in EdgeRTRs, Clients using the AAA procedure, H3Services via dev-ops.

(3) impersonating: efforts to use MobilityClients and H3Services RLOCs should be caught by the underlying service provider edge and access networks. EID impersonating is caught by EdgeRTR EID RLOC whitelist mismatch.

(4) credibility: the interface crowd-sources geo-state and does not assume to trust single detections. Credit history track to MobilityClientEIDs by as part of normal H3Services fact checking, aggregate scores affect AAA credentials.

(5) privacy: Only EdgeRTRs are aware of both clients' RLOC and geo-location, only AAA is aware of client IDs credentials and credit but not geo-location. Aggregate credit score span all H3Services administratively without source.

7. Acknowledgments

We would like to kindly thank Joel Halperin for helping structure the AAA section and Geo-Privacy provisions, Luigi Lannone for promoting such LISP Compute First Networking (CFN) use-cases, helping structure the IANA section, and shepherding this draft to completion.

8. IANA Considerations

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

IANA is asked to create a registry named NEXAGON Parameters.

Such registry should be populated with the following sub registries.

State Enumeration Field 0x0: Traffic Direction:

Value	Description	Reference
0x0	Null	[This Document]
0x1	Lane North	[This Document]
0x2	Lane North + 30	[This Document]
0x3	Lane North + 60	[This Document]
0x4	Lane North + 90	[This Document]
0x5	Lane North + 120	[This Document]
0x6	Lane North + 150	[This Document]
0x7	Lane North + 180	[This Document]
0x8	Lane North + 210	[This Document]
0x9	Lane North + 240	[This Document]
0xA	Lane North + 270	[This Document]
0xB	Lane North + 300	[This Document]
0xC	Lane North + 330	[This Document]
0xD	Junction	[This Document]
0xE	Shoulder	[This Document]
0xF	Sidewalk	[This Document]

State Enumeration Field 0x1: Persistent Condition:

Value	Description	Reference
0x0	Null	[This Document]
0x1	Pothole Light	[This Document]
0x2	Pothole Deep	[This Document]
0x3	Speed-bump Low	[This Document]
0x4	Speed-bump High	[This Document]
0x5	Icy	[This Document]
0x6	Flooded	[This Document]
0x7	Snow-cover	[This Document]
0x8	Deep Snow	[This Document]
0x9	Cone	[This Document]
0xA	Gravel	[This Document]
0xB	Choppy	[This Document]
0xC	Blind-Curve	[This Document]
0xD	Steep	[This Document]
0xE	Low-bridge	[This Document]
0xF	Other	[This Document]

State Enumeration Field 0x2: Transient Condition:

Value	Description	Reference
0x0	Null	[This Document]
0x1	Jaywalker	[This Document]
0x2	Bike or Scooter	[This Document]
0x3	Stopped Vehicle	[This Document]
0x4	Moving on Shoulder	[This Document]
0x5	First Responder	[This Document]
0x6	Sudden Slowdown	[This Document]
0x7	Oversize Vehicle	[This Document]
0x8	Light/Sign Breach	[This Document]
0x9	Collision Light	[This Document]
0xA	Collision Severe	[This Document]
0xB	Collision Debris	[This Document]
0xC	Collision Course	[This Document]
0xD	Vehicle Hard Brake	[This Document]
0xE	Vehicle Sharp Turn	[This Document]
0xF	Freed-up Parking	[This Document]

State Enumeration Field 0x3: Traffic-light Counter:

Value	Description	Reference
0x0	Null	[This Document]
0x1	1 Second to Green	[This Document]
0x2	2 Second to Green	[This Document]
0x3	3 Second to Green	[This Document]
0x4	4 Second to Green	[This Document]
0x5	5 Second to Green	[This Document]
0x6	6 Second to Green	[This Document]
0x7	7 Second to Green	[This Document]
0x8	8 Second to Green	[This Document]
0x9	9 Second to Green	[This Document]
0xA	10 Second to Green	[This Document]
0xB	20 Second to Green	[This Document]
0xC	30 Second to Green	[This Document]
0xD	60 Second to Green	[This Document]
0xE	Green Now	[This Document]
0xF	Red Now	[This Document]

State Enumeration Field 0x4: Impacted Tile:

Value	Description	Reference
0x0	Null	[This Document]
0x1	Epicenter	[This Document]
0x2	2 Tiles Away	[This Document]
0x3	3 Tiles Away	[This Document]
0x4	4 Tiles Away	[This Document]
0x5	5 Tiles Away	[This Document]
0x6	6 Tiles Away	[This Document]
0x7	7 Tiles Away	[This Document]
0x8	8 Tiles Away	[This Document]
0x9	9 Tiles Away	[This Document]
0xA	10 Tiles Away	[This Document]
0xB	20 Tiles Away	[This Document]
0xC	30 Tiles Away	[This Document]
0xD	60 Tiles Away	[This Document]
0xE	<100 Tiles Away	[This Document]
0xF	<200 Tiles Away	[This Document]

State Enumeration Field 0x5: Expected Duration:

Value	Description	Reference
0x0	Null	[This Document]
0x1	Next 1 Second	[This Document]
0x2	Next 5 Seconds	[This Document]
0x3	Next 10 Seconds	[This Document]
0x4	Next 20 Seconds	[This Document]
0x5	Next 40 Seconds	[This Document]
0x6	Next 60 Seconds	[This Document]
0x7	Next 2 Minutes	[This Document]
0x8	Next 3 Minutes	[This Document]
0x9	Next 4 Minutes	[This Document]
0xA	Next 5 Minutes	[This Document]
0xB	Next 10 Minutes	[This Document]
0xC	Next 15 Minutes	[This Document]
0xD	Next 30 Minutes	[This Document]
0xE	Next 60 Minutes	[This Document]
0xF	Next 24 Hours	[This Document]

State Enumeration Field 0x6: Lane Right Sign:

Value	Description	Reference
0x0	Null	[This Document]
0x1	Yield	[This Document]
0x2	Speed Limit	[This Document]
0x3	Straight Only	[This Document]
0x4	No Straight	[This Document]
0x5	Right Only	[This Document]
0x6	No Right	[This Document]
0x7	Left Only	[This Document]
0x8	No Left	[This Document]
0x9	Right Straight	[This Document]
0xA	Left Straight	[This Document]
0xB	No U Turn	[This Document]
0xC	No Left or U	[This Document]
0xD	Bike Lane	[This Document]
0xE	HOV Lane	[This Document]
0xF	Stop	[This Document]

State Enumeration Field 0x7: Movement Sign:

Value	Description	Reference
0x0	Null	[This Document]
0x1	Keep Right	[This Document]
0x2	Keep Left	[This Document]
0x3	Stay in Lane	[This Document]
0x4	Do Not Enter	[This Document]
0x5	No Trucks	[This Document]
0x6	No Bikes	[This Document]
0x7	No Peds	[This Document]
0x8	One Way	[This Document]
0x9	Parking	[This Document]
0xA	No Parking	[This Document]
0xB	No Standing	[This Document]
0xC	No Passing	[This Document]
0xD	Loading Zone	[This Document]
0xE	Rail Crossing	[This Document]
0xF	School Zone	[This Document]

State Enumeration Field 0x8: Curves & Intersections:

Value	Description	Reference
0x0	Null	[This Document]
0x1	Turns Left	[This Document]
0x2	Turns Right	[This Document]
0x3	Curves Left	[This Document]
0x4	Curves Right	[This Document]
0x5	Reverses Left	[This Document]
0x6	Reverses Right	[This Document]
0x7	Winding Road	[This Document]
0x8	Hair Pin	[This Document]
0x9	Pretzel Turn	[This Document]
0xA	Cross Roads	[This Document]
0xB	Cross T	[This Document]
0xC	Cross Y	[This Document]
0xD	Circle	[This Document]
0xE	Lane Ends	[This Document]
0xF	Road Narrows	[This Document]

State Enumeration Field 0x9: Tile Traffic Speed:

Value	Description	Reference
0x0	Null	[This Document]
0x1	< 1 m/sec	[This Document]
0x2	< 2 m/sec	[This Document]
0x3	< 3 m/sec	[This Document]
0x4	< 4 m/sec	[This Document]
0x5	< 5 m/sec	[This Document]
0x6	< 6 m/sec	[This Document]
0x7	< 7 m/sec	[This Document]
0x8	< 8 m/sec	[This Document]
0x9	< 9 m/sec	[This Document]
0xA	< 10 m/sec	[This Document]
0xB	< 20 m/sec	[This Document]
0xC	< 30 m/sec	[This Document]
0xD	< 40 m/sec	[This Document]
0xE	< 50 m/sec	[This Document]
0xF	> 50 m/sec	[This Document]

State Enumeration Field 0xA: Pedestrian Curb Density:

Value	Description	Reference
0x0	Null	[This Document]
0x1	100%	[This Document]
0x2	95%	[This Document]
0x3	90%	[This Document]
0x4	85%	[This Document]
0x5	80%	[This Document]
0x6	70%	[This Document]
0x7	60%	[This Document]
0x8	50%	[This Document]
0x9	40%	[This Document]
0xA	30%	[This Document]
0xB	20%	[This Document]
0xC	15%	[This Document]
0xD	10%	[This Document]
0xE	5%	[This Document]
0xF	No Peds	[This Document]

State enumeration fields 0xB, 0xC, 0xD, 0xE, 0xF, are unassigned. IANA can assign them on a "First Come First Served" basis according to [[RFC8126](#)].

9. Normative References

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Expires January 1, 2022

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