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**Network-Hexagons: H3-LISP GeoState & Mobility Network
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Abstract

This document specifies use of H3 and LISP for geo-location services and the utilization of geo-spatial locations for mobility purposes by:

- Predefining tile-by-tile IPv6 addressable abstraction of each road-segment
- Tile by tile IP interface for detections and annotations of streets & curbs
- Sharing hazards, blockages, parking, weather, maintenance, inventory..
- Brokering production and consumption of geo-state by MobilityClients
- Reflecting state in geo-spatial IP multicast channels to subscribed clients

Status of This Memo

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[1.](#) Introduction

(1) The Locator/ID Separation Protocol (LISP) [[RFC6830](#)] splits current IP addresses in two different namespaces, Endpoint Identifiers (EIDs) and Routing Locators (RLOCs). LISP uses a map-and-encap approach that relies on (1) a Mapping System (distributed database) that stores and disseminates EID-RLOC mappings and on (2) LISP tunnel routers (xTRs) that encapsulate and decapsulate data packets based on the content of those mappings.

(2) H3 is a geospatial indexing system using a hexagonal grid that can be (approximately) subdivided into finer and finer hexagonal grids, combining the benefits of a hexagonal grid with hierarchical subdivisions. H3 supports sixteen resolutions. Each finer resolution has cells with one seventh the area of the coarser resolution. Hexagons cannot be perfectly subdivided into seven hexagons, so the finer cells are only approximately contained within a parent cell. Each cell is identified by a 64bit HID.

(3) The Berkeley Deep Drive (BDD) Industry Consortium investigates state-of-the-art technologies in computer vision and machine learning for automotive applications, and, for taxonomy of published automotive scene classification.

These standards are combined to create an in-network state which reflects the condition of each hexagonal tile (~1sqm) in every road. The lisp network maps

& encapsulates traffic between MobilityClient endpoint identifiers (EID), and addressable tile-objects (HID=>EID). objects are aggregated by H3Service EIDs.

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

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

This is achieved by putting the physical world on a shared addressable state-grid of road-segments, or digital-twins, typically at the edge. Tile by tile geo-state sharing is done using a brokered-network of these digital-twins, an indirection which solves key issues in vehicle to vehicle information sharing. For example multiple perspectives, geo-privacy, and cyber security. These challenges arise when clients are directly communicate, when they do not really need to. A communication pattern which causes unnecessary complexity and exposures.

In non brokered v2v models, given a situation observable by some end-points, it is unclear if the relevant end-points which need to know 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" many brake lights or "feels" an accelerometer slowdown, there is no clear way

for it to share this annotation with vehicles 20-30sec away, and prevent a potential pile-up. 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 vehicles approaching from another direction as it drives away.

Geo-state indirection also helps communicate advanced machine vision and/or radar annotations. These are constantly evolving technologies, and relaying road enumerations they produce, using peer-to-peer protocols, poses a significant interoperability challenge. It is hard to test each new annotation of any sensor or OEM vendor with any other driving application. Brokered IP multicast channels are themed, subscribing means interoperating.

These peer-to-peer limitations are inherent yet unnecessary, as in most road situations vehicles are not really proper peers. They just 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 digital-twin broker per geo-tile.

Bridging timing, security, privacy, and interoperability gaps. Twin brokering is achieved by MobilityClients communicating through addressable geo-states. Addressable tiles are aggregated and maintained by LISP H3ServiceEIDs.

MobilityClients can provide drivers with heads-up alerts on hazards and

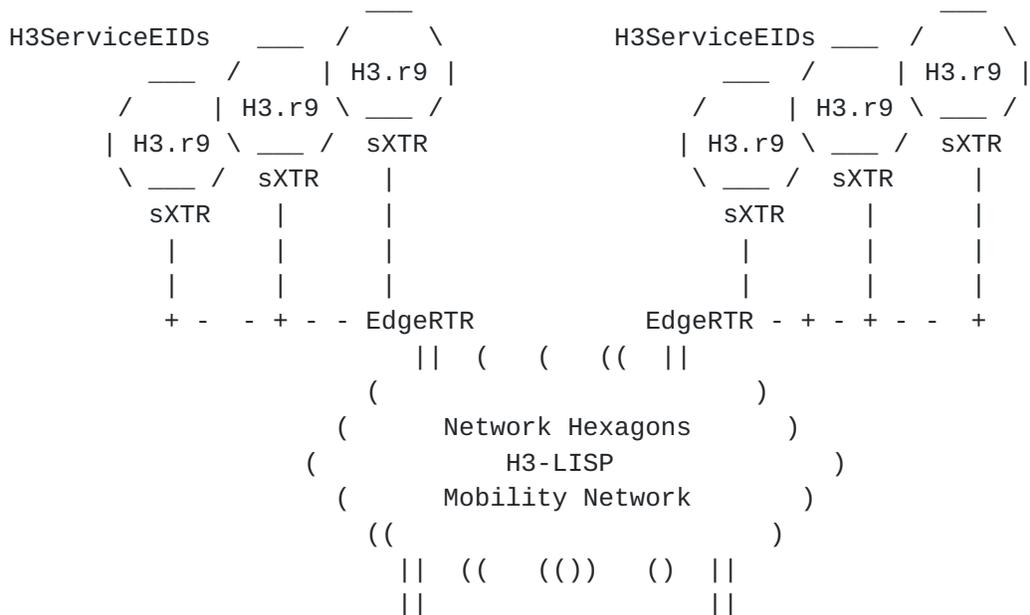
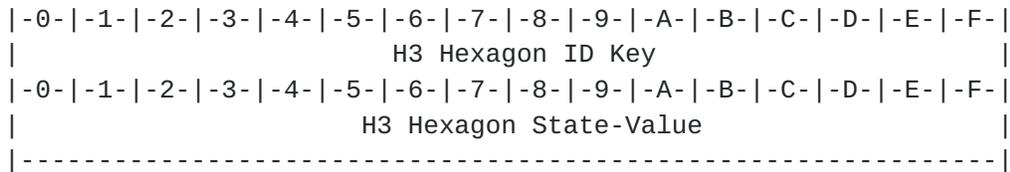
obstacles

beyond the line of sight of the driver and the in-car sensors: over traffic, around blocks, far-side junction, beyond road turns or surface curvatures. This highlights the importance of networks in providing road safety and the role networks play in future AV operation support systems (AV-OSS).

Beyond sharing use cases like finding freed-up curb-parking and help avoid construction zones, a mission critical use case for global geo-pub-sub has to do with supporting autonomous vehicle (AV) fleets.

To summarize the H3-LISP solution outline:

- (1) MicroPartition: 64bit indexed geo-spatial H3.r15 of each road-tile
- (2) EnumState: 64bit state values compile tile condition representation
- (3) Aggregation: H3.r9 H3ServiceEID group individual H3.r15 road-tiles
- (4) Channels: H3ServiceEIDs function as multicast state update channels
- (5) Scale: H3ServiceEIDs distributed for in-network for latency-throughput
- (6) Mapped Overlay: tunneled-network routes the mobility-network traffic
- (7) Signal-free: tunneled overlay is used to map-register for mcst channels
- (8) Aggregation: tunnels used between MobilityClients/H3ServiceEIDs <> edge
- (9) Access: ClientXTRs/ServerXTRs tunnel traffic to-from the LISP EdgeRTRs
- (10) Control: EdgeRTRs register-resolve H3ServiceEIDs and mcst subscription



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. See IANA consideration for details.

ServerXTR: Is a data-plane only LISP protocol stack implementation that co-exists

with H3ServiceEID process. When the server roams, the xTR roams with it. The ServerXTR encapsulates and decapsulates packets to/from EdgeRTRs.

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

MobilityClient EID: Is the IPv6 EID used by the Mobility Client applications to source packets. The destination of such packets are only H3ServiceEIDs. The EID format is opaque and is assigned as part of the MobilityClient network-as-a-service (NaaS) authorization.

ClientXTR: Is a data-plane only LISP protocol stack implementation that is co-located with the Mobility Client application. It encapsulates packets sourced by applications to EdgeRTRs and decapsulates packets from EdgeRTRs.

EdgeRTR: Is the core scale and structure of the LISP mobility network.

EdgeRTRs proxy H3ServiceEIDs and MobilityClient H3ServiceEID channel registration. EdgeRTRs aggregate MobilityClients and H3Services using tunnels to facilitate hosting-providers and mobile-hosting flexibility - for accessing the nexagon mobility network. EdgeRTRs decapsulate packets from ClientXTRs, ServerXTRs and re-encapsulates packets to the clients and servers tunnels. EdgeRTRs glean H3ServiceEIDs and glean MobilityClient EIDs when they decapsulates packets. EdgeRTRs store H3ServiceEIDs and

their

own RLOC of where the H3ServiceEID is currently reachable from in the map-cache. These mappings are registered to the LISP mapping system so other EdgeRTRs know where to encapsulate for such EIDs. These mappings may also be provisioned by dev-ops when H3Services are provisioned and

assigned

EdgeRTRs. EdgeRTRs do not register MobilityClients' EIDs at the mapping service as these are temporary-renewed while using the mobility network. Enterprises may provide their own client facing EdgeRTRs to mask their clients geo-whereabouts while using the mobility network.

4. 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

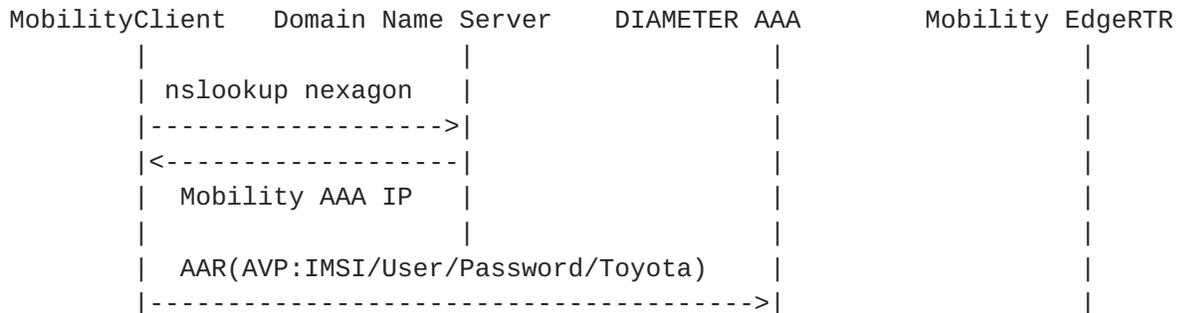
```
| -0- | -1- | -2- | -3- | -4- | -5- | -6- | -7- | -8- | -9- | -A- | -B- | -C- | -D- | -E- | -F- |
0123012301230123012301230123012301230123012301230123012301230123012301230123012301230123
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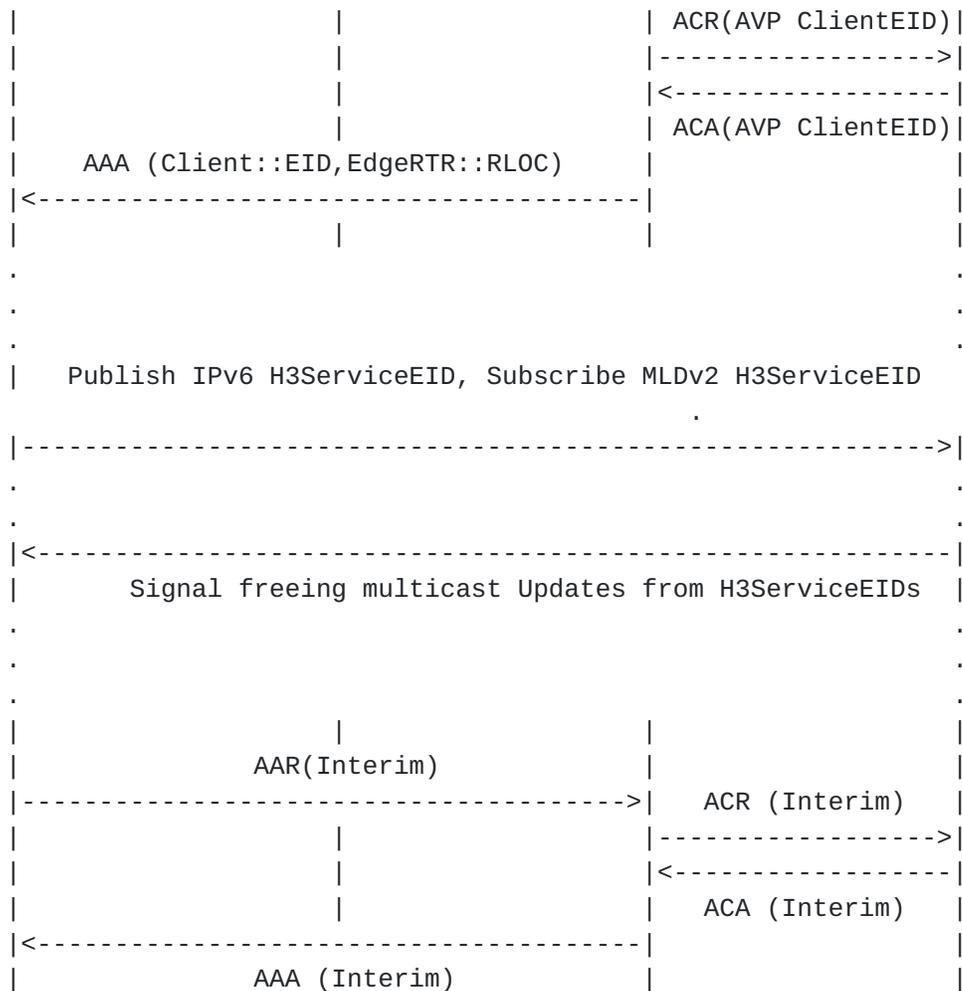
Subscription of MobilityClients to the mobility network is constantly renewed while on the move and is not intended as a means of basic connectivity. This is why MobilityClients use DNS/AAA to obtain temporary EIDs and EdgeRTRs and why they use (LISP) data-plane tunnels to communicate using their temporary EIDs with the dynamically assigned EdgeRTRs.

MobilityClient are otherwise unaware of the LISP network mechanism or mapping system and simply regard the data-plane tunnels as an application-specific virtual private network (VPN) that supports IPv6 EID addressable geo-state to publish (Ucast), Subscribe (Mcast) H3Services.

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

- ClientXTR performs the following steps in order 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 server using DIAMETER
 - 3) renew authorization from AAA while using the mobility network T1 minutes





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

- the MobilityClientEIDs serve as credentials with the specific EdgeRTRs
- EdgeRTRs are provisioned to whitelist MobilityClient EIDs assigned to them
- EdgeRTRs are not tightly coupled to H3.r9 areas for privacy/load-balance
- Mobility Clients do not need to update EdgeRTRs while roaming in an area

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

5. 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 edie providers, public, private, and hybrid clouds

We use data-plane XTRs in the stack of each mobility client and server.

ClientXTRs and ServerXTRs are homed to one or more EdgeRTRs at the LISP edge.

This structure allows for MobilityClients to "show up" at any time, behind any network provider in a given mobility network administrative domain, and for any H3ServiceEID to be instantiated, moved, or failed-over to any rack in any cloud-provider. The 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 for how we 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 more or less equivalent. Each RTR uses LISP to tunnel traffic to and from other EdgeRTRs for MobilityClient with H3Service exchanges.

MobilityClients can (multi) home to EdgeRTRs while moving.

II. Topological by anycast

In this option we align an EdgeRTR with topological aggregation like in Evolved Packet or 5GCore 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

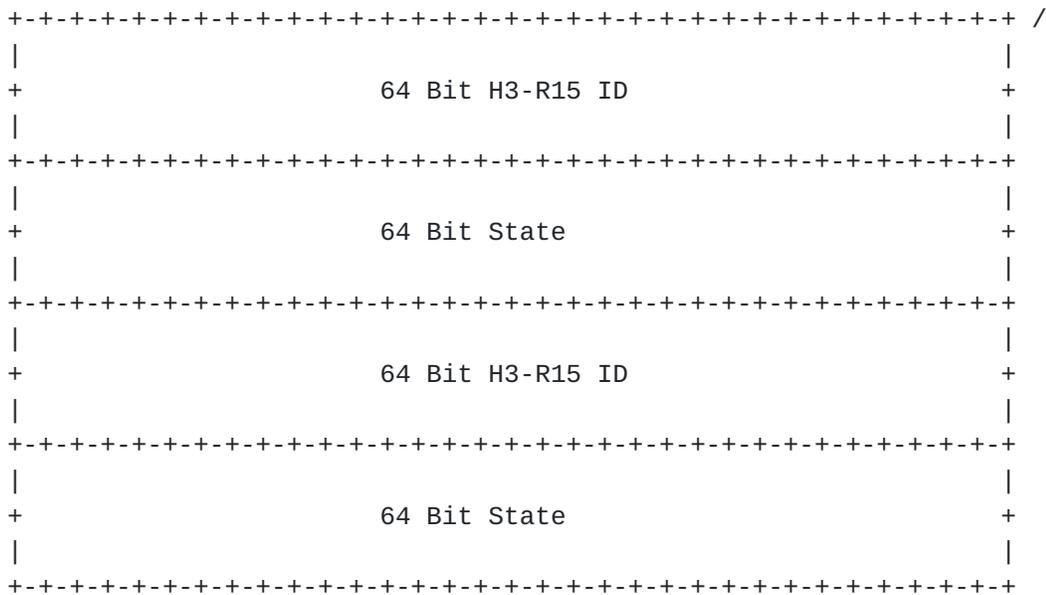
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MobilityClients <> ClientXTR <Access Provider > EdgeRTR  v
                                                         v
v      << Map-Assisted Mobility-Network Overlay <<      v
v
>> EdgeRTR <Cloud Provider> ServerXTR <> H3ServiceEID

```

6. Mobility Unicast and Multicast

Regardless of the way a given ClientXTR was associated with an 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 localized annotation snapped-to-tile.



To Summarize Unicast:

- (1) MobilityClients can send annotations which are localized to an H3.r15 tile
 - These annotations are sent to an 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 channel 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 geo-location, where the H3 hairpin aggregation point has programable propagation functionality.

We use [rfc8378](#) signal-free multicast to implement mcast channels in the overlay. The mobility network has many channels, with only a few thousands of subscribers per channel. MobilityClients driving through or subscribing to an H3.r9 area can explicitly issue an [rfc4604](#) MLDv2 in order to subscribe, or, may be subscribed implicitly by the EdgeRTR gleaning to ucast HID destination.

The advantage of an explicit client MLDv2 registration as a trigger to [rfc8378](#) is that the clients manage their own mobility mcast handover according to their

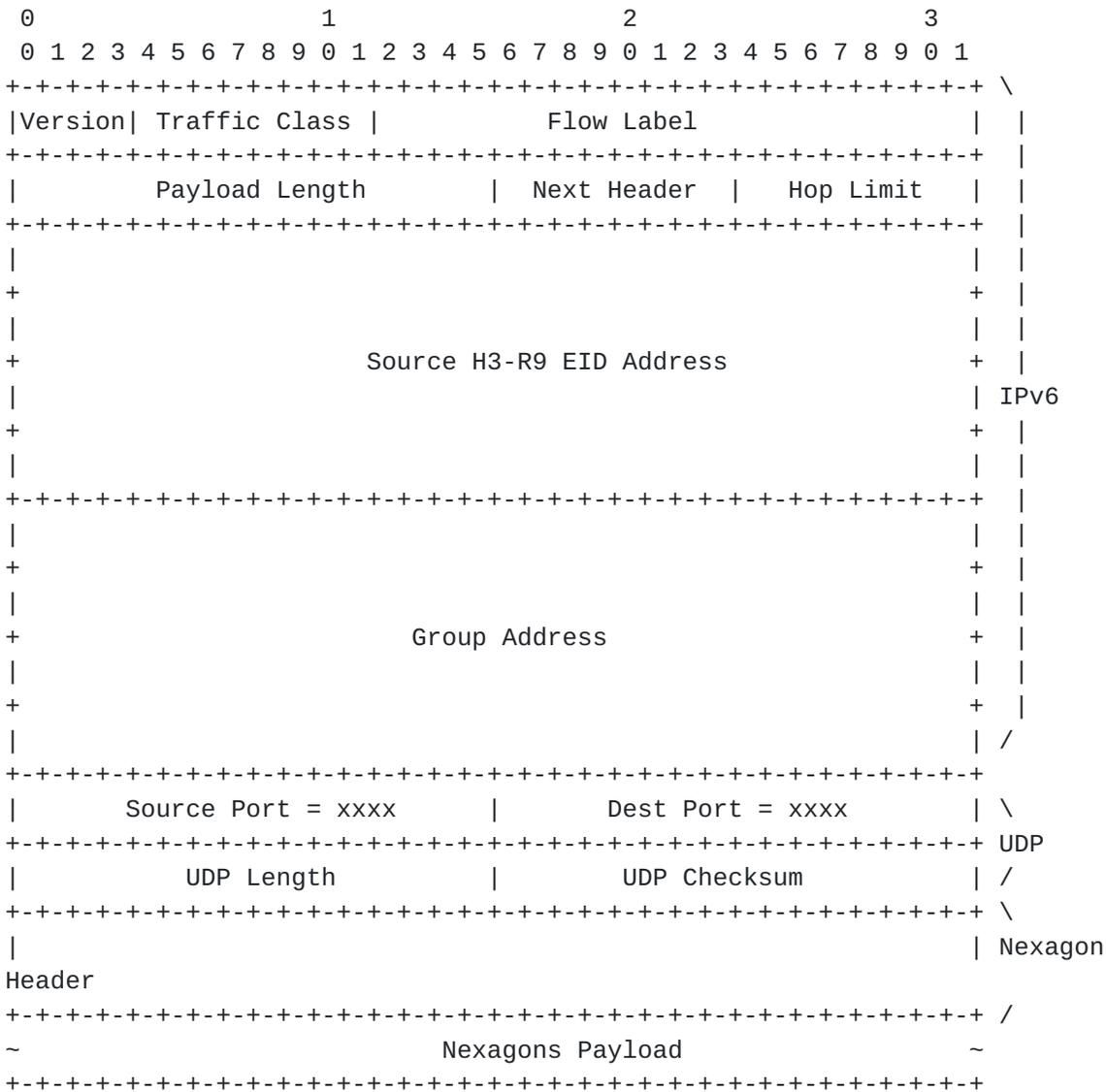
location-direction vectors, and that it allows for otherwise silent, or, non annotating clients. The advantage of EdgeRTR implicit registration is less signaling required.

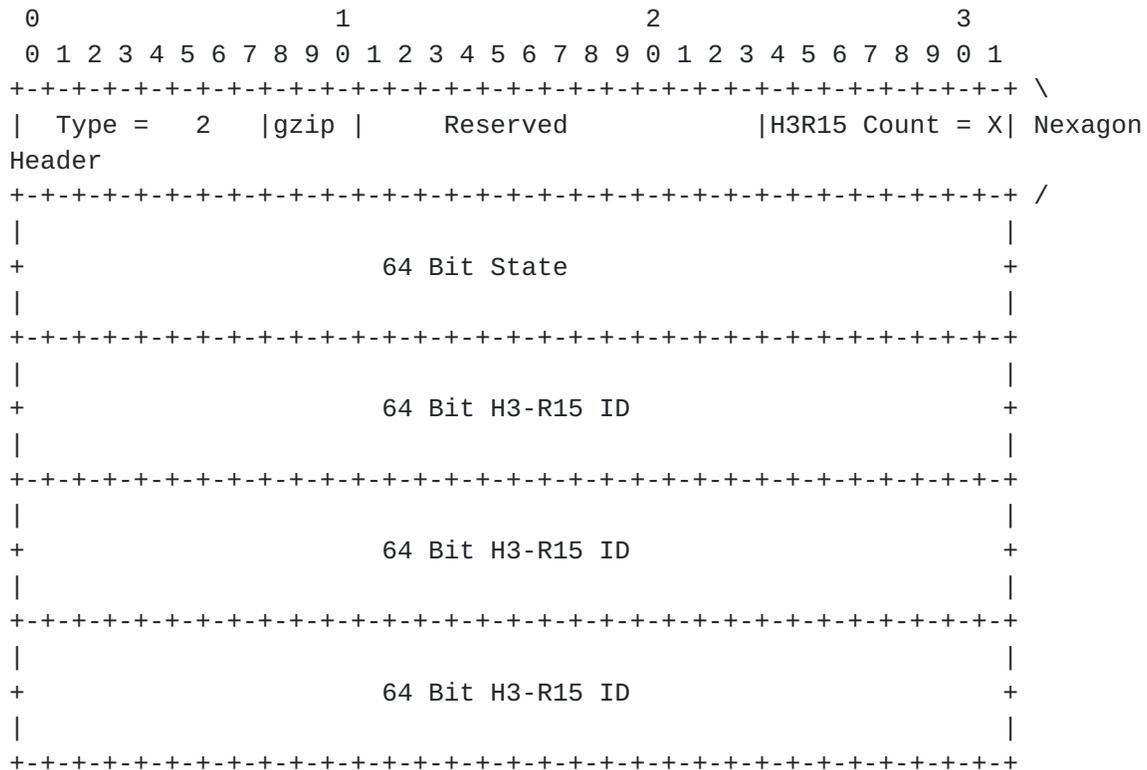
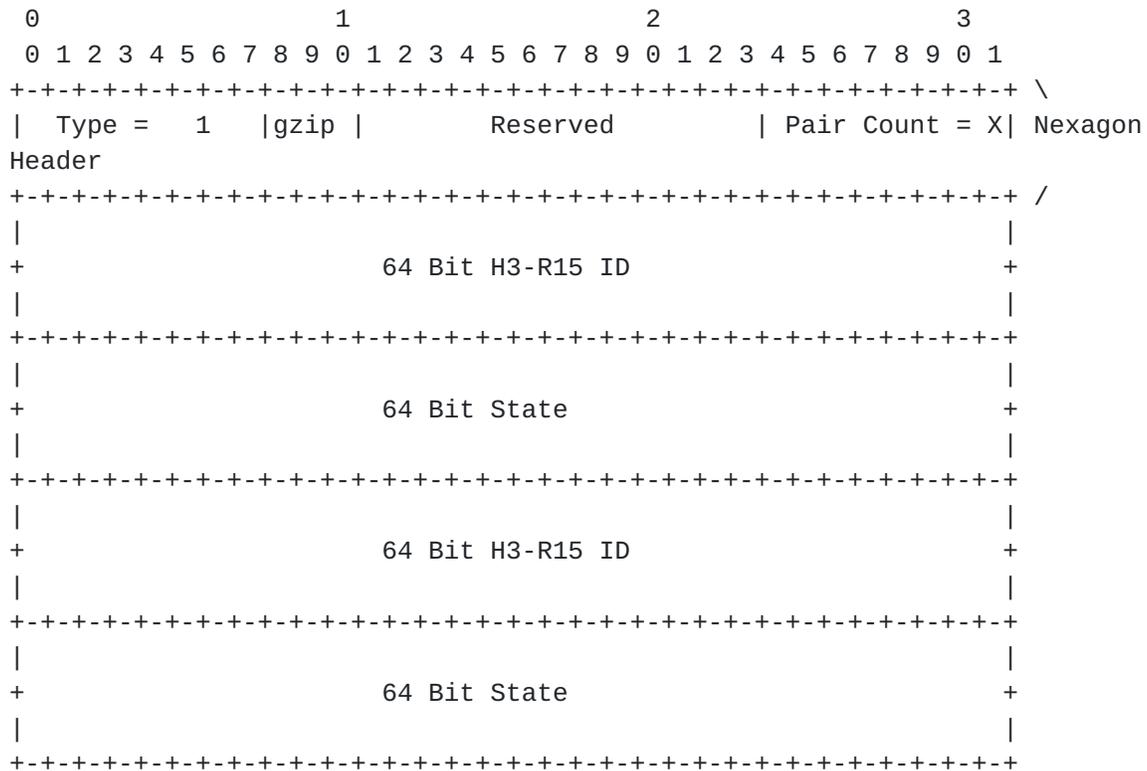
MLDv2 signaling messages are encapsulated between the ClientXTR and the LISP EdgeRTR, therefore there is no requirement for the underlying network to support native multicast. If native access multicast is supported (for example

native 5G multicast), then MobilityClient registration to H3ServiceEID safety channels may be integrated with it, in which case the mobile packet-core

(EPC) element supporting it (eNB) will use this standard to register with the appropriate H3.r9 channels in its area.

Multicast update packets are of the following structure:





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 registered ClientXTRs

7. 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 network channels published by 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 publishes 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' IP-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 sensitive hop, the mapping system does not hold MobilityClientEIDs, and remote EdgeRTRs are only aware of MobilityClient ephemeral EIDs, not their actual IP RLOC or any other mobile-device identifiers. EdgeRTRs register in the mapping (s,g) H3-R9 multicast groups, but which clients reside beyond 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 the 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 we can say:

(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.

8. Acknowledgments

This work is partly funded by the ANR LISP-Lab project #ANR-13-INFR-009 (<https://lisplab.lip6.fr>).

9. IANA Considerations

I. Formal H3 to IPv6 EID mapping

II. State enum fields of H3 tiles:

Field 0x: Traffic Direction {

- 0x - null
- 1x - Lane North
- 2x - Lane North + 30
- 3x - Lane North + 60
- 4x - Lane North + 90
- 5x - Lane North + 120
- 6x - Lane North + 150
- 7x - Lane North + 180
- 8x - Lane North + 210
- 9x - Lane North + 240
- Ax - Lane North + 270
- Bx - Lane North + 300
- Cx - Lane North + 330
- Dx - junction
- Ex - shoulder
- Fx - sidewalk

}

field 1x: Persistent or Structural {

- 0x - null
- 1x - pothole light
- 2x - pothole severe
- 3x - speed-bump low
- 4x - speed-bump high
- 5x - icy
- 6x - flooded
- 7x - snow-cover
- 8x - snow-deep
- 9x - construction cone
- Ax - gravel
- Bx - choppy
- Cx - blind-curve
- Dx - steep-slope
- Ex - low-bridge

}

field 2x: Transient Condition {

- 0x - null
- 1x - pedestrian
- 2x - bike scooter
- 3x - stopped car / truck
- 4x - moving car / truck
- 5x - first responder vehicle
- 6x - sudden slowdown
- 7x - oversized over-height vehicle
- 8x - red-light-breach
- 9x - light collision (fender bender)

- Ax - hard collision / casualty
- Bx - collision course
- Cx - collision debris
- Dx - hard brake
- Ex - sharp corner
- Fx - freeing-parking

}

field 3x: Traffic-light Cycle {

- 0x - null
- 1x - 1 seconds to green
- 2x - 2 seconds to green
- 3x - 3 seconds to green
- 4x - 4 seconds to green
- 5x - 5 seconds to green
- 6x - 6 seconds to green
- 7x - 7 seconds to green
- 8x - 8 seconds to green
- 9x - 9 seconds to green
- Ax - 10 seconds or less
- Bx - 20 seconds or less
- Cx - 30 seconds or less
- Dx - 60 seconds or less
- Ex - green now
- Fx - red now

}

field 4x: Impacted Tile from Neighboring {

- 0x - null
- 1x - epicenter
- 2x - light yellow
- 3x - yellow
- 4x - light orange
- 5x - orange
- 6x - light red
- 7x - red
- 8x - light blue
- 9x - blue
- Ax - green
- Bx - light green

}

field 5x: Transient, Cycle, Impacted, Valid for Next{

- 0x - null
- 1x - 1sec
- 2x - 5sec
- 3x - 10sec
- 4x - 20sec
- 5x - 40sec
- 6x - 60sec
- 7x - 2min

- 8x - 3min
- 9x - 4min
- Ax - 5min
- Bx - 10min
- Cx - 15min
- Dx - 30min
- Ex - 60min
- Fx - 24hours

}

field 6x: LaneRightsSigns {

- 0x - null
- 1x - yield
- 2x - speedLimit
- 3x - straightOnly
- 4x - noStraight
- 5x - rightOnly
- 6x - noRight
- 7x - rightStraight
- 8x - leftOnly
- 9x - leftStraight
- Ax - noLeft
- Bx - noUTurn
- Cx - noLeftU
- Dx - bikeLane
- Ex - HOVLane
- Fx - Stop

}

field 7x: MovementSigns {

- 0x - null
- 1x - keepRight
- 2x - keepLeft
- 3x - stayInLane
- 4x - doNotEnter
- 5x - noTrucks
- 6x - noBikes
- 7x - noPeds
- 8x - oneWay
- 9x - parking
- Ax - noParking
- Bx - noStandaing
- Cx - noPassing
- Dx - loadingZone
- Ex - railCross
- Fx - schoolZone

}

field 8x: CurvesIntersectSigns {

- 0x - null
- 1x - turnsLeft

- 2x - turnsRight
- 3x - curvesLeft
- 4x - curvesRight
- 5x - reversesLeft
- 6x - reversesRight
- 7x - windingRoad
- 8x - hairPin
- 9x - pretzelTurn
- Ax - crossRoads
- Bx - crossT
- Cx - crossY
- Dx - circle
- Ex - laneEnds
- Fx - roadNarrows

field 9x: Current Tile Speed {

- 0x - null
- 1x - < 5kmh
- 2x - < 10kmh
- 3x - < 15kmh
- 4x - < 20kmh
- 5x - < 30kmh
- 6x - < 40kmh
- 7x - < 50kmh
- 8x - < 60kmh
- 9x - < 80kmh
- Ax - < 100kmh
- Bx - < 120kmh
- Cx - < 140kmh
- Dx - < 160kmh
- Ex - > 160kmh
- Fx - queuedTraffic

field Ax: Vehicle / Pedestrian Traffic {

- 0x - null
- 1x - probability of ped/vehicle on tile close to 100%
- 2x - 95%
- 3x - 90%
- 4x - 85%
- 5x - 80%
- 6x - 70%
- 7x - 60%
- 8x - 50%
- 9x - 40%
- Ax - 30%
- Bx - 20%
- Cx - 15%
- Dx - 10%
- Ex - 5%

Fx - probability of ped/vehicle on tile close to 0%, empty
}

field Bx - reserved
field Cx - reserved
field Dx - reserved
field Ex - reserved
field Fx - reserved

10. Normative References

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