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

This document specifies the use of H3 and LISP for Geolocation services, the utilization of geospatial data for mobility-uses by:

- Predefined addressable geospatial abstraction of road-segments.
- Interface for detections and annotations to geospatial-context.
- Sharing hazards, blockages, parking, weather, inventory..
- Brokering the production and consumption of geo-state.
- Geospatial IP 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.

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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. LISP network maps & encapsulates traffic between client endpoint identifiers (EID) and addressable tile-objects (HID=>EID). Objects are aggregated by H3 EID services.

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

- 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 geospatial grid context of road-segments at the edge for data upload. Geospatial state sharing is done using a 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 an 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 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

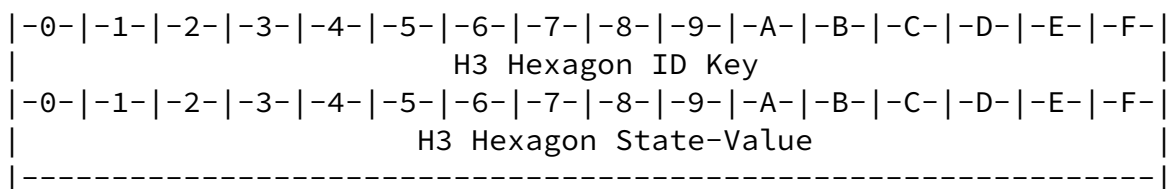


Figure 1: 64 bit H3 ID, 64 bit compiled state value

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. Requirements Language

3. 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. See IANA consideration for details.

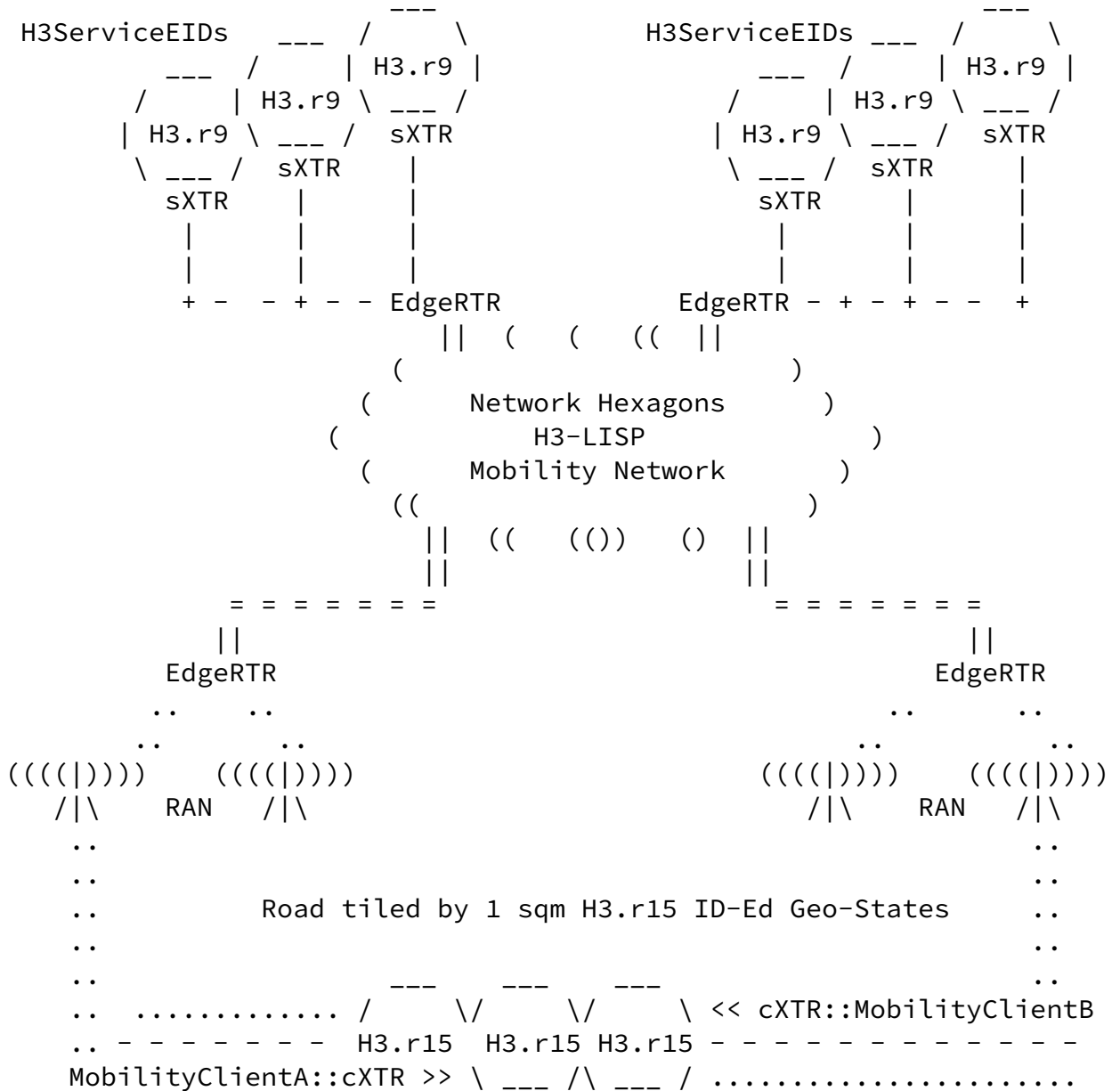
ServerXTR: Is a data-plane only LISP protocol stack implementation, it co-exists with H3ServiceEID process. When the server roams, the xTR is with it. ServerXTR encaps/decaps packets to/from EdgeRTRs.

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 so other EdgeRTRs know where to encapsulate for such EIDs. These mappings may be provisioned by dev-ops when H3Services are assigned EdgeRTRs. EdgeRTRs do not register MobilityClients' EIDs at the mapping as these are temporary-renewed while using the mobility network. Enterprises may provide their own EdgeRTRs to protect geo-privacy.



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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

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
-0-	-1-	-2-	-3-	-4-	-5-	-6-
-7-	-8-	-9-	-A-	-B-	-C-	-D-
-E-	-F-					
01230	12301	23012	30123	01230	12301	23012
30123	01230	12301	23012	30123	01230	12301
23012	30123	01230	12301	23012	30123	01230
30123	01230	12301	23012	30123	01230	12301

Figure 3: Nibble based representation- 16 fields x 16 enums

We name the nibbles using hexadecimal index according to the position where the most significant nibble has index 0. Values are defined in [section 9](#).

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.

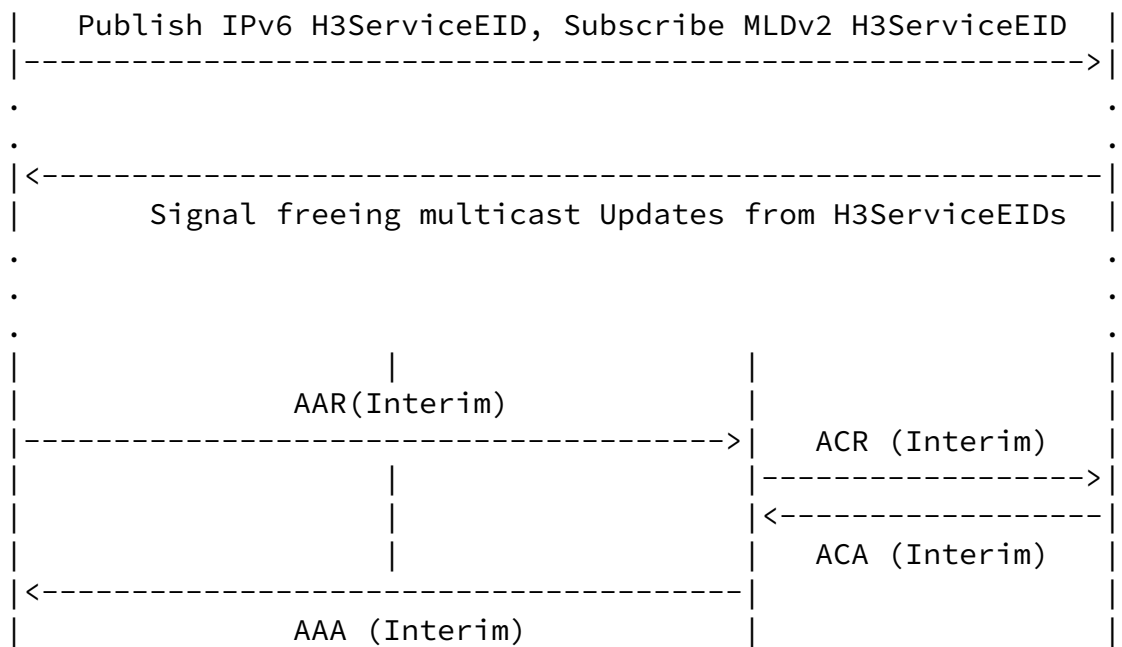


Figure 4: DNS and AAA Exchange for nexagon-network login

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.

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 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

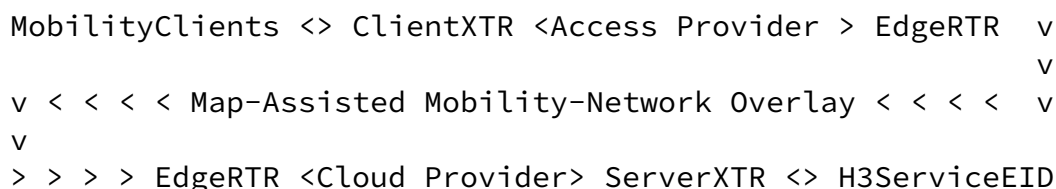


Figure 5: The Data Flow Between MobilityClients and H3ServiceEIDs

6. 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 either to a remote EdgeRTR (option 1) or to homed H3ServiceEID ServerXTR (option 2). 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 of vkkk flooding

Type 0: reserved

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

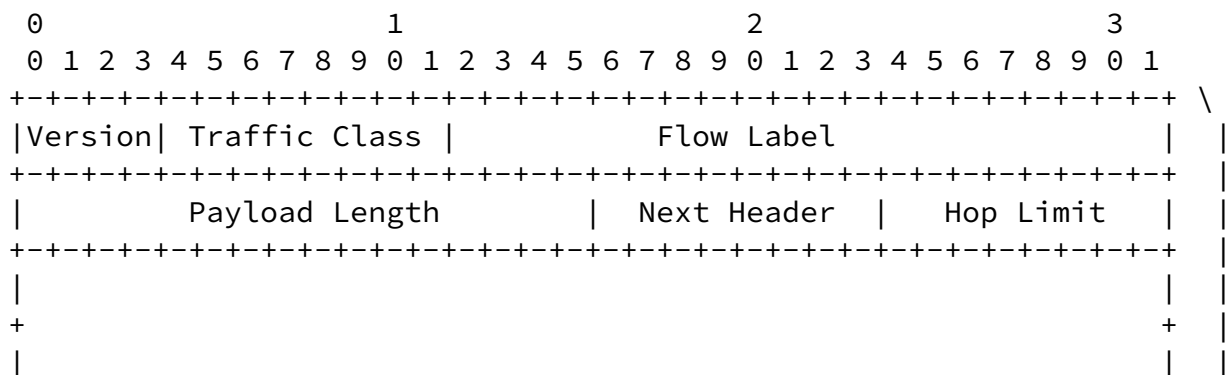
Type 2: value, key, key, key.. $(1392 - 8) / 8 = 173$ H3-R15 IDs

Type 3-255: unassigned

Nexagon Header GZIP allows for compression, very effective for H3IDs
At this point we designate 001 value if content was GZIP compressed.
Additional values may be added in the future for compression types.

Nexagon Header Reserved bits

Nexagon Header kv count (in any format)



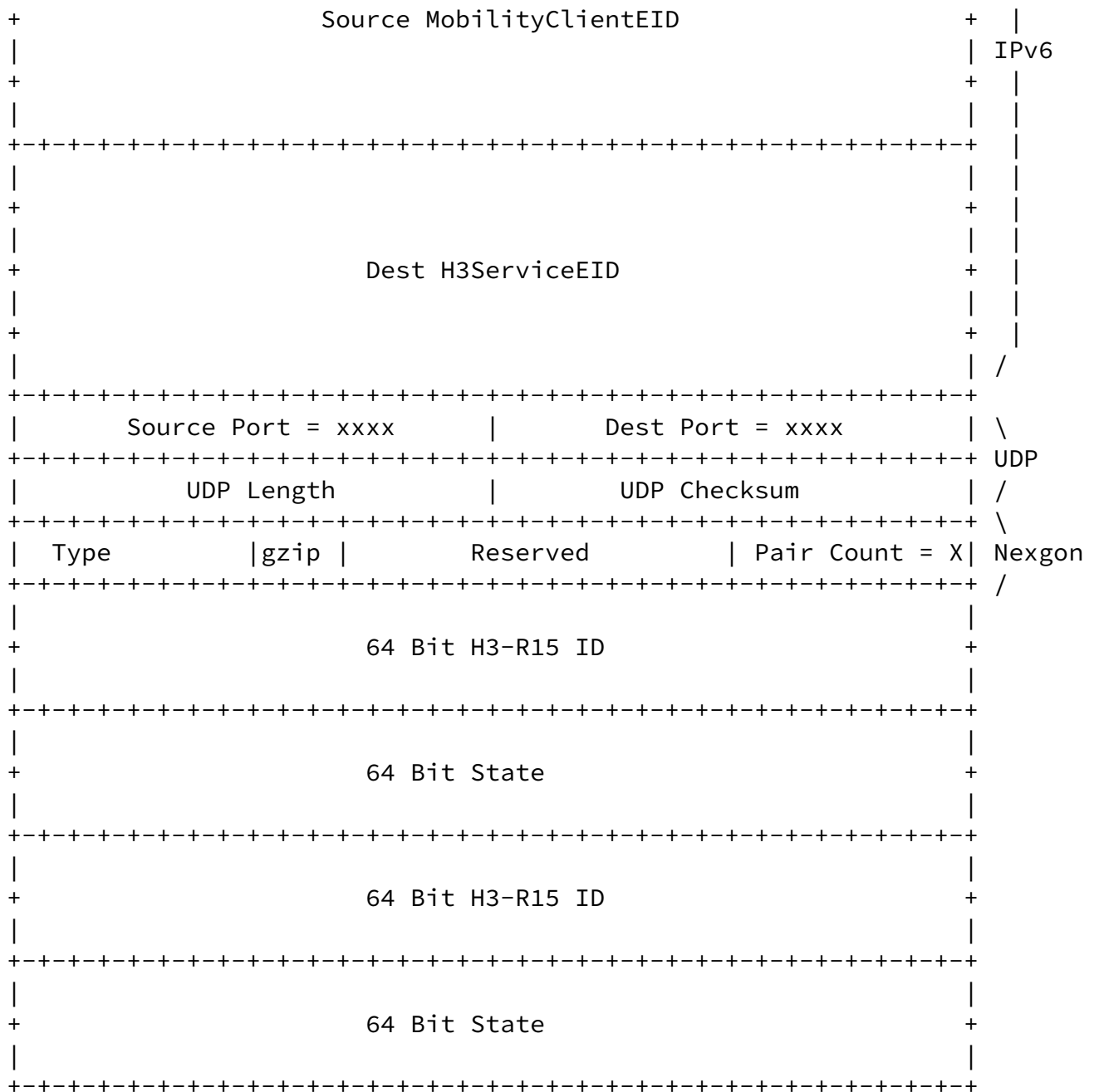


Figure 6: Published detections packet format

To Summarize Unicast:

- (1) MobilityClients can send annotations are localized to H3.r15

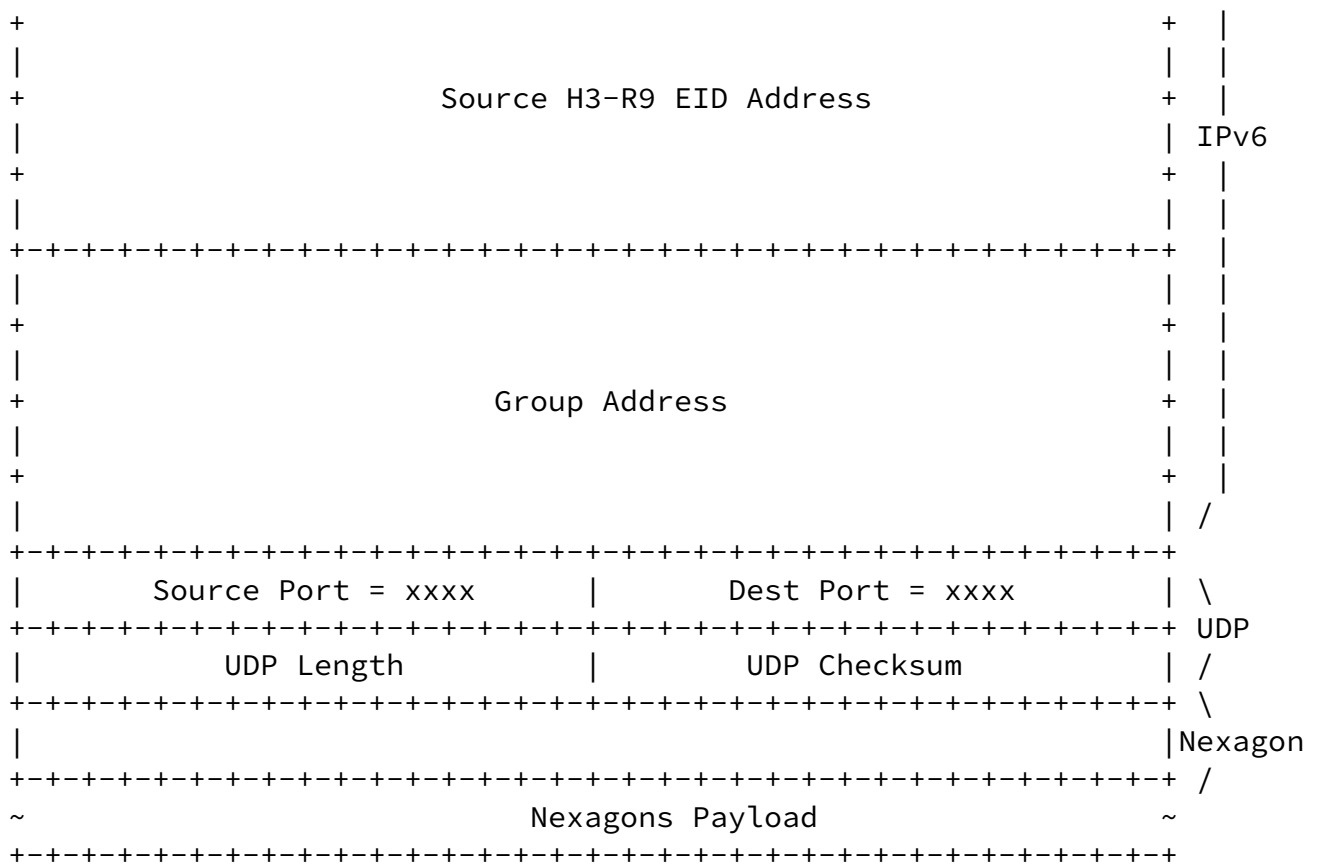
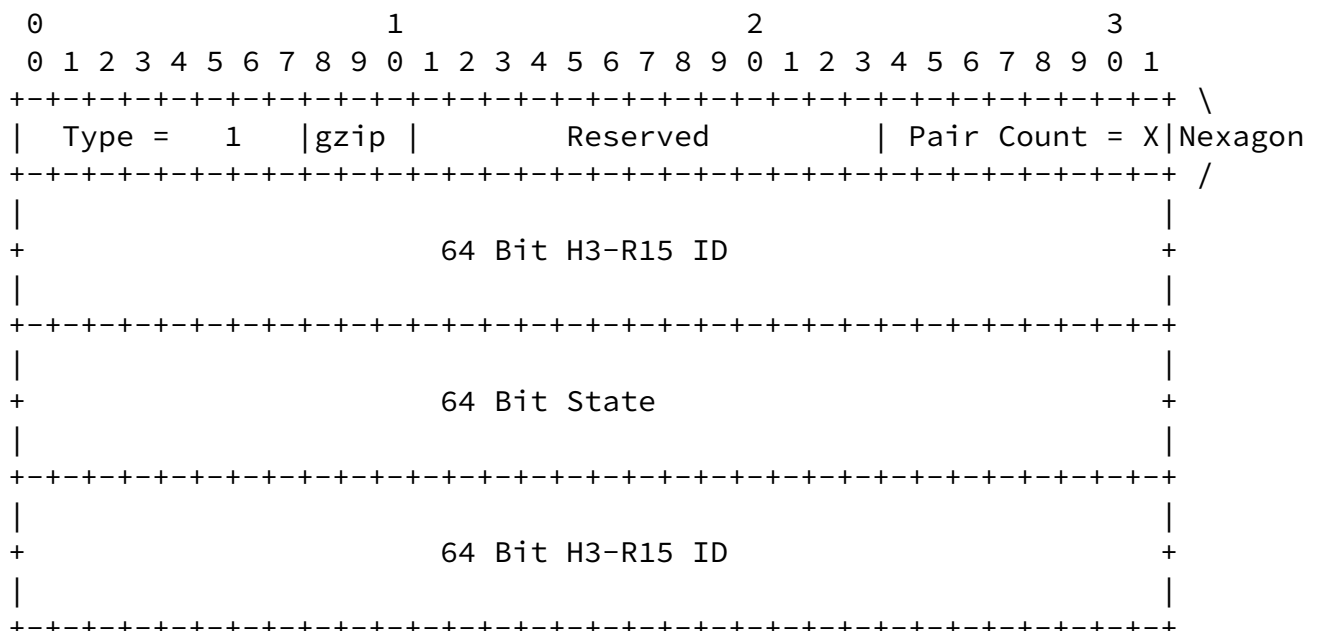


Figure 7: Mcast update packet header



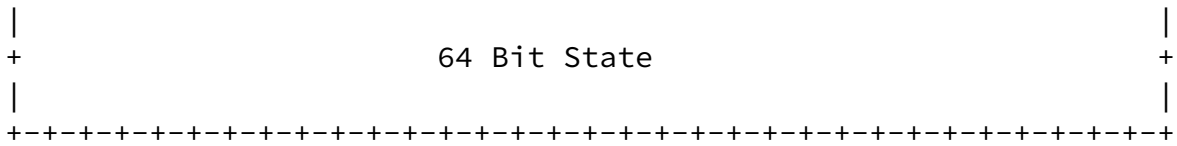


Figure 8: Mcast update payload, key-value, key-value..

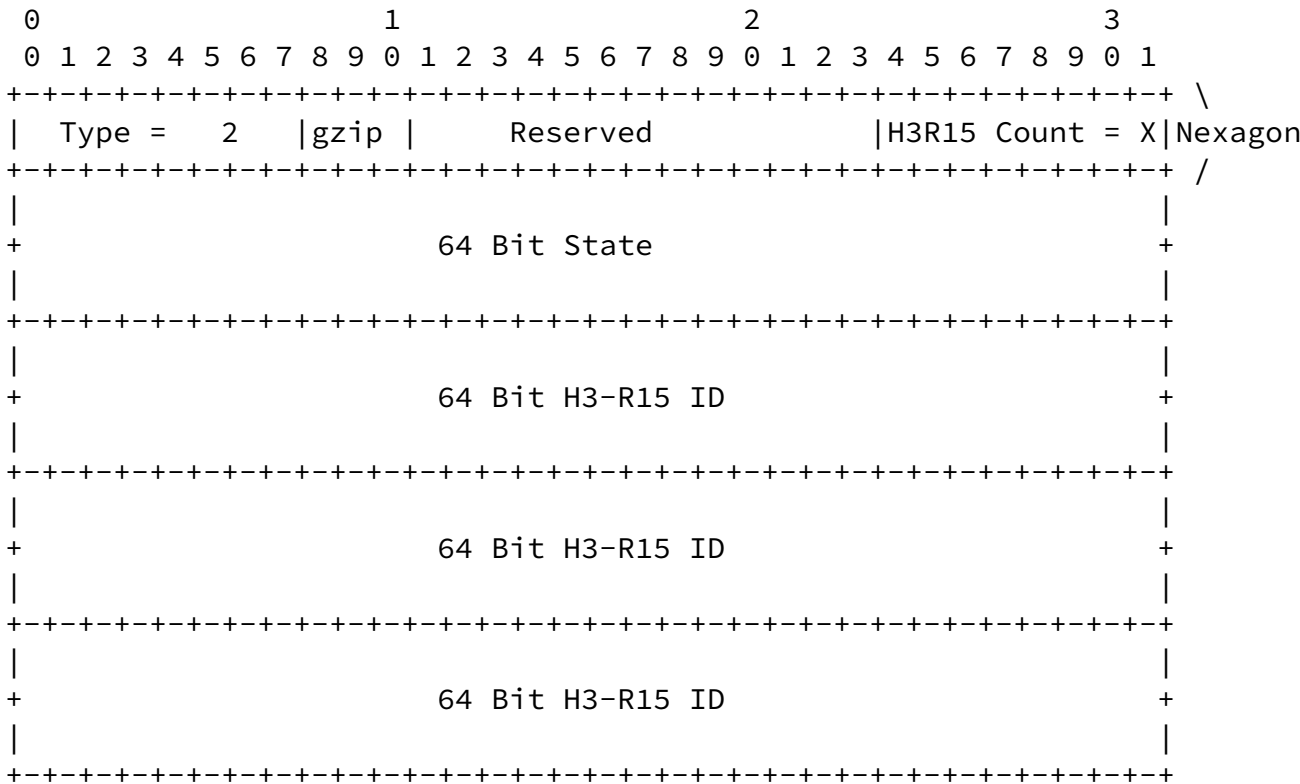


Figure 9: Mcast update payload, value, key, key.. for larger areas

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.

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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 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.

[8.](#) Acknowledgments

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

[9.](#) IANA Considerations

State enum fields of H3 tiles:

Field 0x0: Traffic Direction {
0x0 - null
0x1 - Lane North

0x2 - Lane North + 30
0x3 - Lane North + 60
0x4 - Lane North + 90
0x5 - Lane North + 120
0x6 - Lane North + 150
0x7 - Lane North + 180
0x8 - Lane North + 210
0x9 - Lane North + 240
0xA - Lane North + 270
0xB - Lane North + 300
0xC - Lane North + 330
0xD - junction
0xE - shoulder
0xF - sidewalk
}

field 0x1: Persistent or Structural {
 0x0 - null
 0x1- pothole light
 0x2 - pothole severe
 0x3 - speed-bump low
 0x4 - speed-bump high
 0x5 - icy
 0x6 - flooded
 0x7 - snow-cover
 0x8 - snow-deep
 0x9 - construction cone
 0xA - gravel
 0xB - choppy
 0xC - blind-curve
 0xD - steep-slope
 0xE - low-bridge
 0xF - unassigned
}

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field 0x2: Transient Condition {
 0x0 - null
 0x1 - pedestrian
 0x2 - bike scooter
 0x3 - stopped car / truck
 0x4 - moving car / truck
 0x5 - first responder vehicle
 0x6 - sudden slowdown
 0x7 - oversized over-height vehicle
 0x8 - red-light-breach
 0x9 - light collision (fender bender)

Ax - hard collision / casualty
0xB - collision course
0xC - collision debris
0xD - hard brake
0xE - sharp corner
0xF - freeing-parking
}

field 0x3: Traffic-light Cycle {
0x0 - null
0x1 - 1 seconds to green
0x2 - 2 seconds to green
0x3 - 3 seconds to green
0x4 - 4 seconds to green
0x5 - 5 seconds to green
0x6 - 6 seconds to green
0x7 - 7 seconds to green
0x8 - 8 seconds to green
0x9 - 9 seconds to green
0xA - 10 seconds or less
0xB - 20 seconds or less
0xC - 30 seconds or less
0xD - 60 seconds or less
0xE - green now
0xF - red now
}

field 0x4: Impacted Tile from Neighboring {
0x0 - null
0x1 - epicenter
0x2 - light yellow
0x3 - yellow
0x4 - light orange
0x5 - orange
0x6 - light red
0x7 - red
0x8 - light blue
0x9 - blue
0xA - green
0xB - light green
0xC - unassigned
0xD - unassigned
0xE - unassigned
0xF - unassigned
}

```
field 0x5: Transient, Cycle, Impacted, Valid for Next{
  0x0 - null
  0x1 - 1sec
  0x2 - 5sec
  0x3 - 10sec
  0x4 - 20sec
  0x5 - 40sec
  0x6 - 60sec
  0x7 - 2min
  0x8 - 3min
  0x9 - 4min
  0xA - 5min
  0xB - 10min
  0xC - 15min
  0xD - 30min
  0xE - 60min
  0xF - 24hours
}
field 0x6: LaneRightsSigns {
  0x0 - null
  0x1 - yield
  0x2 - speedLimit
  0x3 - straightOnly
  0x4 - noStraight
  0x5 - rightOnly
  0x6 - noRight
  0x7 - rightStraight
  0x8 - leftOnly
  0x9 - leftStraight
  0xA - noLeft
  0xB - noUTurn
  0xC - noLeftU
  0xD - bikeLane
  0xE - HOVLane
  0xF - Stop
}
```

```
field 0x7: MovementSigns {
  0x0 - null
  0x1 - keepRight
  0x2 - keepLeft
  0x3 - stayInLane
  0x4 - doNotEnter
  0x5 - noTrucks
  0x6 - noBikes
```

```
0x7 - noPeds
0x8 - oneWay
0x9 - parking
0xA - noParking
0xB - noStanding
0xC - noPassing
0xD - loadingZone
0xE - railCross
0xF - schoolZone
}
field 0x8: CurvesIntersectSigns {
0x0 - null
0x1 - turnsLeft
0x2 - turnsRight
0x3 - curvesLeft
0x4 - curvesRight
0x5 - reversesLeft
0x6 - reversesRight
0x7 - windingRoad
0x8 - hairPin
0x9 - pretzelTurn
0xA - crossRoads
0xB - crossT
0xC - crossY
0xD - circle
0xE - laneEnds
0xF - roadNarrows
}
```

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```
field 0x9: Current Tile Speed {
0x0 - null
0x1 - < 5kmh
0x2 - < 10kmh
0x3 - < 15kmh
0x4 - < 20kmh
0x5 - < 30kmh
0x6 - < 40kmh
0x7 - < 50kmh
0x8 - < 60kmh
0x9 - < 80kmh
0xA - < 100kmh
0xB - < 120kmh
0xC - < 140kmh
0xD - < 160kmh
0xE - > 160kmh
0xF - queuedTraffic
```

}

field 0xA: Vehicle / Pedestrian Traffic {

0x0 - null

0x1 - probability of ped/vehicle on tile close to 100%

0x2 - 95%

0x3 - 90%

0x4 - 85%

0x5 - 80%

0x6 - 70%

0x7 - 60%

0x8 - 50%

0x9 - 40%

0xA - 30%

0xB - 20%

0xC - 15%

0xD - 10%

0xE - 5%

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

}

field 0xB - reserved

field 0xC - reserved

field 0xD - reserved

field 0xE - reserved

field 0xF - reserved

Reserved fields and values are for future RFC extensions

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10. Normative References

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