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J. Polk
M. Linsner
Cisco Systems
M. Thomson
Andrew Corporation
B. Aboba, Ed.
Microsoft Corporation

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Dynamic Host Configuration Protocol Options for Coordinate-Based Location Configuration Information

Abstract

This document specifies Dynamic Host Configuration Protocol options (both DHCPv4 and DHCPv6) for the coordinate-based geographic location of the client. The Location Configuration Information (LCI) includes Latitude, Longitude, and Altitude, with resolution or uncertainty indicators for each. Separate parameters indicate the reference datum for each of these values. This document obsoletes RFC 3825.

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 5741.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at http://www.rfc-editor.org/info/rfc6225.

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1. Introduction

The physical location of a network device has a range of applications. In particular, emergency telephony applications rely on knowing the location of a caller in order to determine the correct emergency center.

The location of a device can be represented either in terms of geospatial (or geodetic) coordinates, or as a civic address. Different applications may be more suited to one form of location information; therefore, both the geodetic and civic forms may be used simultaneously.

This document specifies Dynamic Host Configuration Protocol v4 (DHCPv4) [RFC2131] and DHCPv6 [RFC3315] options for the coordinate-based geographic location of the client, to be provided by the server. "Dynamic Host Configuration Protocol (DHCPv4 and DHCPv6) Option for Civic Addresses Configuration Information" [RFC4776] specifies DHCP options for civic addresses.

The geodetic coordinate options defined in this document and the civic address options defined in RFC 4776 [RFC4776] enable a DHCP client to obtain its location. For example, a wired Ethernet host might use these options for location determination. In this case, the location information could be derived from a wiremap by the DHCP server, using the Circuit ID Relay Agent Information Option (RAIO) defined (as Sub-Option 1) in RFC 3046 [RFC3046]. The DHCP server could correlate the Circuit ID with the geographic location where the identified circuit terminates (such as the location of the wall jack).

The mechanism defined here may also be utilized to provide location to wireless hosts. DHCP relay agent sub-options (RAIO) [RFC3046] provide one method a DHCP server might use to perform host location determination. Currently, the relay agent sub-options do not include data sets required for device-level location determination of wireless hosts. In cases where the DHCP server uses RAIO for location determination, a wireless host can use this mechanism to discover the location of the radio access point, or the area of coverage for the radio access point.

An important feature of this specification is that after the relevant DHCP exchanges have taken place, the location information is stored on the end device rather than somewhere else, where retrieving it might be difficult in practice.

1.1. Conventions Used in This Document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

1.2. Resolution and Uncertainty

The DHCP options defined in this document include fields quantifying the resolution or uncertainty associated with a target location. No inferences relating to privacy policies can be drawn from either uncertainty or resolution values.

As utilized in this document, resolution refers to the accuracy of a reported location, as expressed by the number of valid bits in each of the Latitude, Longitude, and Altitude fields.

The Latitude (LaRes), Longitude (LoRes), and Altitude (AltRes) Resolution fields are encoded as 6-bit, unsigned integer values. In the DHCPv4 GeoConf Option 123, the LaRes, LoRes, and AltRes fields are used to encode the number of bits of resolution. The resolution sub-fields accommodate the desire to easily adjust the precision of a reported location. Contents beyond the claimed resolution MAY be randomized to obscure greater precision that might be available.

In the context of location technology, uncertainty is a quantification of errors. Any method for determining location is subject to some sources of error; uncertainty describes the amount of error that is present. Uncertainty might be the coverage area of a wireless transmitter, the extent of a building, or a single room.

Uncertainty is usually represented as an area within which the target is located. In this document, each of the three axes can be assigned an uncertainty value. In effect, this describes a rectangular prism, which may be used as a coarse representation of a more complex shape that fits within it. See Section 2.3.2 for more detail on the correspondence between shapes and uncertainty.

When representing locations from sources that can quantify uncertainty, the goal is to find the smallest possible rectangular prism that this format can describe. This is achieved by taking the minimum and maximum values on each axis and ensuring that the final encoding covers these points. This increases the region of uncertainty, but ensures that the region that is described encompasses the target location.

The DHCPv4 option formats defined in this document support resolution and uncertainty parameters. The DHCPv4 GeoConf Option 123 includes a resolution parameter for each of the dimensions of location. Since this resolution parameter need not apply to all dimensions equally, a resolution value is included for each of the three location elements. The DHCPv4 GeoLoc Option 144 as well as the DHCPv6 GeoLoc Option 63 format utilize an uncertainty parameter.

Appendix A describes the mapping of DHCP option values to the Geography Markup Language (GML). Appendix B of this document provides examples showing the calculation of resolution values. Appendix C provides an example demonstrating calculation of uncertainty values.

Since the Presence Information Data Format Location Object (PIDF-LO) [RFC4119] [RFC5491] is used to convey location and the associated uncertainty within an emergency call [Convey], a mechanism is needed to convert the information contained within the DHCPv4 and DHCPv6 options to PIDF-LO. This document describes the following conversions:

- o DHCPv4 GeoConf Option 123 to PIDF-LO
- o DHCPv4 GeoLoc Option 144 and DHCPv6 GeoLoc Option 63 to PIDF-LO
- o PIDF-LO to DHCP GeoLoc Option 144 and DHCPv6 GeoLoc Option 63

Conversion to PIDF-LO does not increase uncertainty; conversion from PIDF-LO to the DHCPv4 GeoLoc Option 144 and the DHCPv6 GeoLoc Option 63 increases uncertainty by less than a factor of 2 in each dimension. Since it is not possible to translate an arbitrary PIDF-LO to the DHCP GeoConf Option 123 with a bounded increase in uncertainty, the conversion is not specified.

2. DHCP Option Formats

This section defines the format for the DHCPv4 and DHCPv6 options. These options utilize a similar format, differing primarily in the option code.

2.1. DHCPv6 GeoLoc Option

The format of the DHCPv6 [RFC3315] GeoLoc Option is as follows:

```
  0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |       Option Code (63)        |          OptLen               |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |  LatUnc   |                  Latitude                         +
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 | Lat (cont'd)  |  LongUnc  |              Longitude            +
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |    Longitude (cont'd)       | AType |   AltUnc  |  Altitude +
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |              Altitude (cont'd)              |Ver| Res |Datum|
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Code: 16 bits. The code for the DHCP Option Code (63).

OptLen: Option Length. For version 1, the option length is 16.

LatUnc: 6 bits. When the Ver field = 1, this field represents latitude uncertainty. The contents of this field are undefined for other values of the Ver field.

Latitude: A 34-bit fixed-point value consisting of 9 bits of integer and 25 bits of fraction, interpreted as described in Section 2.3.

LongUnc: 6 bits. When the Ver field = 1, this field represents longitude uncertainty. The contents of this field are undefined for other values of the Ver field.

Longitude: A 34-bit fixed-point value consisting of 9 bits of integer and 25 bits of fraction, interpreted as described in Section 2.3.

AType: 4 bits. Altitude Type, defined in Section 2.4.

AltUnc: 6 bits. When the Ver field = 1, this field represents altitude uncertainty. The contents of this field are undefined for other values of the Ver field.

Altitude: A 30-bit value defined by the AType field, described in Section 2.4.

Ver: The Ver field is 2 bits, providing for four potential versions. This specification defines the behavior of version 1. The Ver field is always located at the same offset from the beginning of the option, regardless of the version in use. DHCPv6 clients implementing this specification MUST support receiving version 1 responses. DHCPv6 servers implementing this specification MUST send version 1 responses.

Res: 3 bits. The Res field is reserved. These bits have been used by [IEEE-802.11y], but are not defined within this specification.

Datum: 3 bits. The Map Datum used for the coordinates given in this option.

2.2. DHCPv4 Options

2.2.1. DHCPv4 GeoConf Option

The format of the DHCPv4 GeoConf Option is as follows:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Code 123    |    Length     |   LaRes   |     Latitude      +
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                Latitude (cont'd)              |   LoRes   |   +
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             Longitude                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| AType |   AltRes  |                Altitude                   +
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Alt.(cont'd)  |    Res  |Datum|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Code: 8 bits. The code for the DHCPv4 GeoConf Option (123).

Length: 8 bits. The length of the option, in octets. The option length is 16.

LaRes: 6 bits. This field represents latitude resolution.

Latitude: A 34-bit fixed-point value consisting of 9 bits of signed integer and 25 bits of fraction, interpreted as described in Section 2.3.

LoRes: 6 bits. This field represents longitude resolution.

Longitude: A 34-bit fixed-point value consisting of 9 bits of signed integer and 25 bits of fraction, interpreted as described in Section 2.3.

AType: 4 bits. Altitude Type, defined in Section 2.4.

AltRes: 6 bits. This field represents altitude resolution.

Altitude: A 30-bit value defined by the AType field, described in Section 2.4.

Res: 5 bits. The Res field is reserved. These bits have been used by IEEE 802.11y [IEEE-802.11y], but are not defined within this specification.

Datum: 3 bits. The Map Datum used for the coordinates given in this option.

2.2.2. DHCPv4 GeoLoc Option

The format of the DHCPv4 GeoLoc Option is as follows:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Code 144    |    Length     |   LatUnc  |     Latitude      +
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|               Latitude (cont'd)              | LongUnc  |   +
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Longitude                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| AType |   AltUnc  |                Altitude                   +
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Alt.(cont'd)  |Ver| Res |Datum|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Code: 8 bits. The code for the DHCPv4 GeoLoc Option (144).

Length: 8 bits. The length of the option, in octets. For version 1, the option length is 16.

LatUnc: 6 bits. When the Ver field = 1, this field represents latitude uncertainty. The contents of this field are undefined for other values of the Ver field.

Latitude: A 34-bit fixed-point value consisting of 9 bits of integer and 25 bits of fraction, interpreted as described in Section 2.3.

LongUnc: 6 bits. When the Ver field = 1, this field represents longitude uncertainty. The contents of this field are undefined for other values of the Ver field.

Longitude: A 34-bit fixed-point value consisting of 9 bits of integer and 25 bits of fraction, interpreted as described in Section 2.3.

AType: 4 bits. Altitude Type, defined in Section 2.4.

AltUnc: 6 bits. When the Ver field = 1, this field represents altitude uncertainty. The contents of this field are undefined for other values of the Ver field.

Altitude: A 30-bit value defined by the AType field, described in Section 2.4.

Ver: The Ver field is 2 bits, providing for four potential versions. This specification defines the behavior of version 1. The Ver field is always located at the same offset from the beginning of the option, regardless of the version in use.

Res: 3 bits. The Res field is reserved. These bits have been used by [IEEE-802.11y], but are not defined within this specification.

Datum: 3 bits. The Map Datum used for the coordinates given in this option.

2.2.3. Option Support

2.2.3.1. Client Support

DHCPv4 clients implementing this specification MUST support receiving the DHCPv4 GeoLoc Option 144 (version 1), and MAY support receiving the DHCPv4 GeoConf Option 123 (originally defined in RFC 3825 [RFC3825]).

DHCPv4 clients request the DHCPv4 server to send GeoConf Option 123, GeoLoc Option 144, or both via inclusion of the Parameter Request List option. As noted in Section 9.8 of RFC 2132 [RFC2132]:

> This option is used by a DHCP client to request values for specified configuration parameters. The list of requested parameters is specified as n octets, where each octet is a valid DHCP option code as defined in this document.
>
> The client MAY list the options in order of preference. The DHCP server is not required to return the options in the requested order, but MUST try to insert the requested options in the order requested by the client.

When DHCPv4 and DHCPv6 clients implementing this specification do not understand a datum value, they MUST assume a World Geodetic System 1984 (WGS84) [WGS84] datum (European Petroleum Survey Group (EPSG) [EPSG] 4326 or 4979, depending on whether there is an altitude value present) and proceed accordingly. Assuming that a less accurate location value is better than none, this ensures that some (perhaps less accurate) location is available to the client.

2.2.3.2. Server Option Selection

A DHCPv4 server implementing this specification MUST support sending GeoLoc Option 144 version 1 and SHOULD support sending GeoConf Option 123 in responses.

A DHCPv4 server that provides location information SHOULD honor the Parameter Request List included by the DHCPv4 client in order to decide whether to send GeoConf Option 123, GeoLoc Option 144, or both in the Response.

2.3. Latitude and Longitude Fields

The latitude and longitude values in this specification are encoded as 34-bit, two’s complement, fixed-point values with 9 integer bits and 25 fractional bits. The exact meaning of these values is determined by the datum; the description in this section applies to the datums defined in this document. This document uses the same definition for all datums it specifies.

When encoding, latitude and longitude values are rounded to the nearest 34-bit binary representation. This imprecision is considered acceptable for the purposes to which this form is intended to be applied and is ignored when decoding.

Positive latitudes are north of the equator, and negative latitudes are south of the equator. Positive longitudes are east of the Prime Meridian, and negative (two’s complement) longitudes are west of the Prime Meridian.

Within the coordinate reference systems defined in this document (Datum values 1-3), longitude values outside the range of -180 to 180 decimal degrees or latitude values outside the range of -90 to 90 degrees MUST be considered invalid. Server implementations SHOULD prevent the entry of invalid values within the selected coordinate reference system. Location consumers MUST ignore invalid location coordinates and SHOULD log errors related to invalid location.

2.3.1. Latitude and Longitude Resolution

In the DHCPv4 GeoConf Option 123, the LaRes value encodes the number of high-order latitude bits that MUST be considered valid. Any bits entered to the right of this limit MUST NOT be considered valid and might be purposely false, or zeroed by the sender. The examples in Appendix B illustrate that a smaller value in the resolution field increases the area within which the device is located. A value of 2 in the LaRes field indicates a precision of no greater than 1/6th that of the globe (see the first example of Appendix B). A value of 34 in the LaRes field indicates a precision of about 3.11 mm in latitude at the equator.

In the DHCPv4 GeoConf Option 123, the LoRes value encodes the number of high-order longitude bits that MUST be considered valid. Any bits entered to the right of this limit MUST NOT be considered valid and might be purposely false, or zeroed by the sender. A value of 2 in the LoRes field indicates precision of no greater than 1/6th that of the globe (see the first example of Appendix B). A value of 34 in the LoRes field indicates a precision of about 2.42 mm in longitude (at the equator). Because lines of longitude converge at the poles, the distance is smaller (better precision) for locations away from the equator.

2.3.2. Latitude and Longitude Uncertainty

In the DHCPv6 GeoLoc Option 63 and the DHCPv4 GeoLoc Option 144, the Latitude and Longitude Uncertainty fields (LatUnc and LongUnc) quantify the amount of uncertainty in each of the latitude and longitude values, respectively. A value of 0 is reserved to indicate that the uncertainty is unknown; values greater than 34 are reserved.

A point within the region of uncertainty is selected to be the encoded point; the centroid of the region is often an appropriate choice. The value for uncertainty is taken as the distance from the selected point to the furthest extreme of the region of uncertainty on that axis. This is demonstrated in the figure below, which shows a two-dimensional polygon that is projected on each axis. In the figure, "X" marks the point that is selected; the ranges marked with "U" indicate the uncertainty.

```
           ___          ___________
           ^ |         /           |
           | |        /            |
           | |       /             |
           U |      /              |
           | |     (               |
           V |     |               |
           --X     |         X     |
             |     |               `---------.
             |     |                         |
             |     |                         |
             |     |                         |
             -     `-------------------------'

                   |---------X---------------|
                             |<------U------>|
```

Key

V, ^ = vertical arrows, delimiting the vertical uncertainty range.
<>   = horizontal arrows, delimiting the horizontal uncertainty range.

Uncertainty applies to each axis independently.

The amount of uncertainty can be determined from the encoding by taking 2 to the power of 8, less the encoded value, as is shown in the following formula, where "x" is the encoded integer value:

uncertainty = 2 ^ (8 - x)

The result of this formula is expressed in degrees of latitude or longitude. The uncertainty is added to the base latitude or longitude value to determine the maximum value in the uncertainty range; similarly, the uncertainty is subtracted from the base value to determine the minimum value. Note that because lines of longitude converge at the poles, the actual distance represented by this uncertainty changes with the distance from the equator.

If the maximum or minimum latitude values derived from applying uncertainty are outside the range of -90 to +90, these values are trimmed to within this range. If the maximum or minimum longitude values derived from applying uncertainty are outside the range of -180 to +180, then these values are normalized to this range by adding or subtracting 360 as necessary.

The encoded value is determined by subtracting the next highest whole integer value for the base 2 logarithm of uncertainty from 8, as is shown by the following formula, where uncertainty is the midpoint of the known range less the lower bound of that range:

x = 8 - ceil(log2(uncertainty))

Note that the result of encoding this value increases the range of uncertainty to the next available power of two; subsequent repeated encodings and decodings do not change the value. Only increasing uncertainty means that the associated confidence does not have to decrease.

2.4. Altitude

How the altitude value is interpreted depends on the Altitude Type (AType) value and the selected datum. Three Altitude Type values are defined in this document: unknown (0), meters (1), and floors (2).

2.4.1. No Known Altitude (AType = 0)

In some cases, the altitude of the location might not be provided. An Altitude Type value of zero indicates that the altitude is not given to the client. In this case, the Altitude and Altitude Uncertainty fields can contain any value and MUST be ignored.

2.4.2. Altitude in Meters (AType = 1)

If the Altitude Type has a value of one, altitude is measured in meters, in relation to the zero set by the vertical datum. For AType = 1, the altitude value is expressed as a 30-bit, fixed-point, two's complement integer with 22 integer bits and 8 fractional bits.

2.4.3. Altitude in Floors (AType = 2)

A value of two for Altitude Type indicates that the altitude value is measured in floors. Since altitude in meters may not be known within a building, a floor indication may be more useful. For AType = 2, the altitude value is expressed as a 30-bit, fixed-point, two's complement integer with 22 integer bits and 8 fractional bits.

This value is relevant only in relation to a building; the value is relative to the ground level of the building. Floors located below ground level are represented by negative values. In some buildings, it might not be clear which floor is at ground level, or an intermediate floor might be hard to identify as such. Determining what floor is at ground level and what constitutes a sub-floor as opposed to a naturally numbered floor is left to local interpretation.

Larger values represent floors that are farther away from floor 0 such that:

- if positive, the floor value is farther above the ground floor.

- if negative, the floor value is farther below the ground floor.

Non-integer values can be used to represent intermediate or sub-floors, such as mezzanine levels. Example: a mezzanine between floor 1 and floor 2 could be represented as a value of 1.25. Example: mezzanines between floor 4 and floor 5 could be represented as values of 4.5 and 4.75.

2.4.4. Altitude Resolution

In the DHCPv4 GeoConf Option 123, the altitude resolution (AltRes) value encodes the number of high-order altitude bits that should be considered valid. Values above 30 (decimal) are undefined and reserved.

If the Altitude Type value is one (AType = 1), an AltRes value of 0.0 would indicate an unknown altitude. The most precise altitude would have an AltRes value of 30. Many values of AltRes would obscure any variation due to vertical datum differences.

The AltRes field SHOULD be set to maximum precision when AType = 2 (floors) when a floor value is included in the DHCP Reply, or when AType = 0, to denote that the floor isn't known. An altitude coded as AType = 2, AltRes = 30, and Altitude = 0.0 is meaningful even outside a building, and represents ground level at the given latitude and longitude.

2.4.5. Altitude Uncertainty

In the DHCPv6 GeoLoc Option 63 or the DHCPv4 GeoLoc Option 144, the AltUnc value quantifies the amount of uncertainty in the altitude value. As with LatUnc and LongUnc, a value of 0 for AltUnc is reserved to indicate that altitude uncertainty is not known; values above 30 are also reserved. Altitude uncertainty only applies to Altitude Type 1.

The amount of altitude uncertainty can be determined by the following formula, where x is the encoded integer value:

Uncertainty = 2 ^ (21 - x)

This value uses the same units as the associated altitude.

Similarly, a value for the encoded integer value can be derived by the following formula:

x = 21 - ceil(log2(uncertainty))

2.5. Datum

The Datum field determines how coordinates are organized and related to the real world. Three datums are defined in this document, based on the definitions in [OGP.Geodesy]:

1: WGS84 (Latitude, Longitude, Altitude): The World Geodetic System 1984 [WGS84] coordinate reference system.

This datum is identified by the European Petroleum Survey Group (EPSG)/International Association of Oil & Gas Producers (OGP) with the code 4979, or by the URN "urn:ogc:def:crs:EPSG::4979". Without altitude, this datum is identified by the EPSG/OGP code 4326 and the URN "urn:ogc:def:crs:EPSG::4326".

2: NAD83 (Latitude, Longitude) + NAVD88: This datum uses a combination of the North American Datum 1983 (NAD83) for horizontal (Latitude and Longitude) values, plus the North American Vertical Datum of 1988 (NAVD88) vertical datum.

This datum is used for referencing location on land (not near tidal water) within North America.

NAD83 is identified by the EPSG/OGP code of 4269, or the URN "urn:ogc:def:crs:EPSG::4269". NAVD88 is identified by the EPSG/OGP code of 5703, or the URN "urn:ogc:def:crs:EPSG::5703".

3: NAD83 (Latitude, Longitude) + MLLW: This datum uses a combination of the North American Datum 1983 (NAD83) for horizontal (Latitude and Longitude) values, plus the Mean Lower Low Water (MLLW) vertical datum.

This datum is used for referencing location on or near tidal water within North America.

NAD83 is identified by the EPSG/OGP code of 4269, or the URN "urn:ogc:def:crs:EPSG::4269". MLLW does not have a specific code or URN.

All hosts MUST support the WGS84 datum (Datum 1).

3. Security Considerations

Geopriv requirements (including security requirements) are discussed in "Geopriv Requirements" [RFC3693]. A threat analysis is provided in "Threat Analysis of the Geopriv Protocol" [RFC3694].

Since there is no privacy protection for DHCP messages, an eavesdropper who can monitor the link between the DHCP server and requesting client can discover this LCI.

To minimize the unintended exposure of location information, the LCI option SHOULD be returned by DHCP servers only when the DHCP client has included this option in its 'parameter request list' (Section 3.5 of [RFC2131], Section 9.8 of [RFC2132]).

Where critical decisions might be based on the value of this option, DHCP authentication as defined in "Authentication for DHCP Messages" [RFC3118] and "Dynamic Host Configuration Protocol for IPv6 (DHCPv6)" [RFC3315] SHOULD be used to protect the integrity of the DHCP options.

Link-layer confidentiality and integrity protection may also be employed to reduce the risk of location disclosure and tampering.

4. IANA Considerations

4.1. DHCP Options

This document defines the DHCPv6 GeoLoc Option (see Section 2.1), which has been assigned a DHCPv6 option code of 63 per [RFC3315]:

Value	Description	Reference
63	OPTION_GEOLOCATION	RFC 6225

This document defines the DHCPv4 GeoConf Option (see Section 2.2.1), which has been assigned a DHCPv4 option code of 123 from the DHCP Option space.

This document also defines the DHCPv4 GeoLoc Option (see Section 2.2.2), which has been assigned a DHCPv4 option code of 144 per [RFC2132] [RFC2939]:

Tag	Name	Data Length	Meaning	Reference
144	GeoLoc	16	Geospatial Location with Uncertainty	RFC 6225

4.2. Altitude Type Registry

IANA has created and now maintains the Altitude Type registry following the guidelines below.

The registry consists of three values: Altitude Type, Description, and Reference. These are described below.

Altitude Type: An integer, refers to the value used in the DHCPv4 GeoConf and the DHCPv4 and DHCPv6 GeoLoc options described in this document. Values 0 - 2 are assigned. Values 3 - 15 are Unassigned [RFC5226].

Description: The description of the altitude described by this code.

Reference: The reference to the document that describes the altitude code. This reference MUST define the way that the 30-bit altitude values and the associated 6-bit uncertainty are interpreted.

Initial values are given below; new assignments are to be made following the "Standards Action" policies [RFC5226].

#	Description	Reference
0	No known altitude	RFC 6225
1	Altitude in meters	RFC 6225
2	Altitude in floors	RFC 6225
3-15	Unassigned	

4.3. Datum Registry

IANA has created and now maintains the Datum registry following the guidelines below.

The registry consists of three values: Datum, Description, and Reference. These are described below.

Datum: An integer, refers to the value used in the DHCPv4 GeoConf and the DHCPv4 and DHCPv6 GeoLoc options described in this document. Value 0 is Reserved. Values 1 - 3 are assigned. Values 4 - 7 are Unassigned [RFC5226].

Description: The description of the altitude described by this code.

Reference: The reference to the document that describes the Datum code. This reference MUST include specification of both the horizontal and vertical datum, and MUST define the way that the 34-bit values and the respective 6-bit uncertainties are interpreted.

Initial values are given below; new assignments are to be made following the "Standards Action" policies [RFC5226].

#	Description	Reference
0	Reserved	RFC 6225
1	Vertical datum WGS 84 defined by EPSG CRS Code 4327	RFC 6225
2	Vertical datum NAD83 defined by EPSG CRS Code 4269 with North American Vertical Datum of 1988 (NAVD88)	RFC 6225
3	Vertical datum NAD83 defined by EPSG CRS Code 4269 with Mean Lower Low Water (MLLW) as associated vertical datum	RFC 6225
4-7	Unassigned	

4.4. GeoLoc Option Version Registry

IANA has created and now maintains the GeoLoc Option Version registry following the guidelines below.

The registry consists of three values: GeoLoc Option Version, Description, and Reference. These are described below.

GeoLoc Option Version: An integer; refers to the version used in the DHCPv4 and DHCPv6 GeoLoc options described in this document. Value 0 is Reserved. Value 1 has been assigned. Values 2 - 3 are Unassigned [RFC5226].

Description: The description of the version described by this code.

Reference: The reference to the document that describes the Version code.

Initial values are given below; new assignments are to be made following the "Standards Action" policies [RFC5226].

#	Description	Reference
0	Reserved	RFC 6225
1	Implementations utilizing uncertainty parameters for both DHCPv4 and DHCPv6 GeoLoc options	RFC 6225
2-3	Unassigned	

5. Acknowledgments

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6. References

6.1. Normative References

[EPSG] European Petroleum Survey Group, <http://www.epsg.org/> and <http://www.epsg-registry.org/>.

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Appendix A. GML Mapping

The GML representation of a decoded DHCP option depends on what fields are specified. The DHCP format for location logically describes a geodetic prism, rectangle, or point, depending on whether altitude and uncertainty values are provided. In the absence of uncertainty information, the value decoded from the DHCP form can be expressed as a single point; this is true regardless of whether the version 0 or version 1 interpretations of the uncertainty fields are used. If the point includes altitude, it uses a three-dimensional Coordinate Reference System (CRS); otherwise, it uses a two-dimensional CRS. If all fields are included along with uncertainty, the shape described is a rectangular prism. Note that this is necessary given that uncertainty for each axis is provided independently.

If altitude or altitude uncertainty (AltUnc) is not specified, the shape is described as a rectangle using the "gml:Polygon" shape. If altitude is available, a three-dimensional CRS is used; otherwise, a two-dimensional CRS is used.

For Datum values of 2 or 3 (NAD83), there is no available CRS URN that covers three-dimensional coordinates. By necessity, locations described in these datums can be represented by two-dimensional shapes only; that is, either a two-dimensional point or a polygon.

If the Altitude Type is 2 (floors), then this value can be represented using a civic address object [RFC5139] that is presented alongside the geodetic object.

This Appendix describes how the location value encoded in DHCP format for geodetic location can be expressed in GML. The mapping is valid for the DHCPv6 GeoLoc Option as well as both of the DHCPv4 GeoConf and GeoLoc options, and for the currently defined datum values (1, 2, and 3). Further version or datum definitions should provide similar mappings.

These shapes can be mapped to GML by first computing the bounds that are described using the coordinate and uncertainty fields, then encoding the result in a GML Polygon or Prism shape.

A.1. GML Templates

If altitude is provided in meters (AType 1) and the datum value is WGS84 (value 1), then the proper GML shape is a Prism, with the following form (where $value$ indicates a value computed from the DHCP option as described below):

```
<gs:Prism srsName="urn:ogc:def:crs:EPSG::4979"
          xmlns:gs="http://www.opengis.net/pidflo/1.0"
          xmlns:gml="http://www.opengis.net/gml">
  <gs:base>
    <gml:Polygon>
      <gml:exterior>
        <gml:LinearRing>
          <gml:posList>
            $lowLatitude$ $lowLongitude$ $lowAltitude$
            $lowLatitude$ $highLongitude$ $lowAltitude$
            $highLatitude$ $highLongitude$ $lowAltitude$
            $highLatitude$ $lowLongitude$ $lowAltitude$
            $lowLatitude$ $lowLongitude$ $lowAltitude$
          </gml:posList>
        </gml:LinearRing>
      </gml:exterior>
    </gml:Polygon>
  </gs:base>
  <gs:height uom="urn:ogc:def:uom:EPSG::9001">
    $highAltitude - lowAltitude$
  </gs:height>
</gs:Prism>
```

The Polygon shape is used if altitude is omitted or specified in floors, or if either NAD83 datum is used (value 2 or 3). The corresponding GML Polygon has the following form:

```
<gml:Polygon srsName="$2D-CRS-URN$"
             xmlns:gml="http://www.opengis.net/gml">>
  <gml:exterior>
    <gml:LinearRing>
      <gml:posList>
        $lowLatitude$ $lowLongitude$
        $lowLatitude$ $highLongitude$
        $highLatitude$ $highLongitude$
        $highLatitude$ $lowLongitude$
        $lowLatitude$ $lowLongitude$
      </gml:posList>
    </gml:LinearRing>
  </gml:exterior>
</gml:Polygon>
```

The value "2D-CRS-URN" is defined by the datum value: If the datum is WGS84 (value 1), then the 2D-CRS-URN is "urn:ogc:def:crs:EPSG::4326". If the datum is NAD83 (value 2 or 3), then the 2D-CRS-URN is "urn:ogc:def:crs:EPSG::4269".

A Polygon shape with the WGS84 three-dimensional CRS is used if the datum is WGS84 (value 1) and the altitude is specified in meters (Altitude Type 1), but no altitude uncertainty is specified (that is, AltUnc is 0). In this case, the value of the Altitude field is added after each of the points above, and the srsName attribute is set to the three-dimensional WGS84 CRS, namely "urn:ogc:def:crs:EPSG::4979".

A simple point shape is used if either latitude uncertainty (LatUnc) or longitude uncertainty (LongUnc) is not specified. With altitude, this uses a three-dimensional CRS; otherwise, it uses a two-dimensional CRS.

```
<gml:Point srsName="$CRS-URN$"
           xmlns:gml="http://www.opengis.net/gml">
  <gml:pos>$Latitude$ $Longitude$ $[Altitude]$</gml:pos>
</gml:Point>
```

A.1.1. Finding Low and High Values Using Uncertainty Fields

For the DHCPv4 GeoConf Option 123, resolution fields are used (LaRes, LoRes, AltRes), indicating how many bits of a value contain information. Any bits beyond those indicated can be either zero or one.

For the DHCPv6 GeoLoc Option 63 and DHCPv4 GeoLoc Option 144, the LatUnc, LongUnc, and AltUnc fields indicate uncertainty distances, denoting the bounds of the location region described by the DHCP location object.

The two sections below describe how to compute the latitude, longitude, and altitude bounds (e.g., $lowLatitude$, $highAltitude$) in the templates above. The first section describes how these bounds are computed in the "resolution encoding" (DHCPv4 GeoConf Option 123), while the second section addresses the "uncertainty encoding" (DHCPv6 GeoLoc Option 63 and DHCPv4 GeoLoc Option 144).

A.1.1.1. Resolution Encoding

Given a number of resolution bits (i.e., the value of a resolution field), if all bits beyond those bits are set to zero, this gives the lowest possible value. The highest possible value can be found setting all bits to one.

If the encoded value of latitude/longitude and resolution (LaRes, LoRes) are treated as 34-bit unsigned integers, the following can be used (where ">>" is a bitwise right shift, "&" is a bitwise AND, "~" is a bitwise negation, and "|" is a bitwise OR).

```
mask = 0x3fffffff >> resolution
lowvalue = value & ~mask
highvalue = value | mask + 1
```

Once these values are determined, the corresponding floating-point numbers can be computed by dividing the values by 2^25 (since there are 25 bits of fraction in the fixed-point representation).

Alternatively, the lowest possible value can be found by using resolution to determine the size of the range. This method has the advantage that it operates on the decoded floating-point values. It is equivalent to the first mechanism, to a possible error of 2^-25 (2^-8 for altitude).

```
scale = 2 ^ ( 9 - resolution )
lowvalue = floor( value / scale ) * scale
highvalue = lowvalue + scale
```

Altitude resolution (AltRes) uses the same process with different constants. There are 22 whole bits in the altitude encoding (instead of 9) and 30 bits in total (instead of 34).

A.1.1.2. Uncertainty Encoding

In the uncertainty encoding, the uncertainty fields (LongUnc/LatUnc) directly represent the logarithms of uncertainty distances. So the low and high bounds are computed by first computing the uncertainty distances, then adding and subtracting these from the value provided. If "uncertainty" is the unsigned integer value of the uncertainty field and "value" is the value of the coordinate field:

```
distance = 2 ^ (8 - uncertainty)
lowvalue = value - distance
highvalue = value + distance
```

Altitude uncertainty (AltUnc in version 1) uses the same process with different constants:

```
distance = 2 ^ (21 - uncertainty)
lowvalue = value - distance
```

Appendix B. Calculations of Resolution

The following examples for two different locations demonstrate how the resolution values for latitude, longitude, and altitude (used in DHCPv4 GeoConf Option 123) can be calculated. In both examples, the geo-location values were derived from maps using the WGS84 map datum; therefore, in these examples, the Datum field would have a value = 1 (00000001, or 0x01).

B.1. Location Configuration Information of "White House" (Example 1)

The grounds of the White House in Washington D.C. (1600 Pennsylvania Ave. NW, Washington, DC 20006) can be found between 38.895375 and 38.898653 degrees North and 77.037911 and 77.035116 degrees West. In this example, we assume that we are standing on the sidewalk on the north side of the White House, between driveways. Since we are not inside a structure, we assume an altitude value of 15 meters, interpolated from the US Geological survey map, Washington, Washington West quadrangle.

The address was NOT picked for any political reason and can easily be found on the Internet or mapping software, but was picked as an easily identifiable location on our planet.

In this example, the requirement of emergency responders in North America via their National Emergency Number Association (NENA) Model Legislation [NENA] could be met by a LaRes value of 21 and a LoRes value of 20. This would yield a geo-location that is latitude 38.8984375 north to latitude 38.8988616 north and longitude -77.0371094 to longitude -77.0375977. This is an area of approximately 89 feet by 75 feet or 6669 square feet, which is very close to the 7000 square feet requested by NENA. In this example, a service provider could enforce that a device send location configuration information with this minimum amount of resolution for this particular location when calling emergency services.

An approximate representation of this location might be provided using the DHCPv4 GeoConf Option 123 encoding as follows:

```
  0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Code (123)  |  OptLen (16)  |   LaRes   |     Latitude      .
 |0 1 1 1 1 0 1 1|0 0 0 1 0 0 0 0|0 1 0 0 1 0|0 0 0 1 0 0 1 1 0 1.
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 .                Latitude (cont'd)             |   LoRes   |   .
 .1 1 0 0 1 0 1 1 1 0 0 1 1 0 0 0 0 1 1 0 0 0 1 1|0 1 0 0 0 1|1 1.
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 .                       Longitude (cont'd)                      |
 .0 1 1 0 0 1 0 1 1 1 1 0 1 1 0 1 0 1 0 0 0 0 1 0 1 1 0 0 0 1 0 0|
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 | AType |   AltRes  |                Altitude                   .
 |0 0 0 1|0 1 0 0 0 1|0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1.
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 .  Alt (cont'd) |   Res   |Datum|
 .0 0 0 0 0 0 0 0|0 0 0 0 0|0 0 1|
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

In hexadecimal, this is 7B10484D CB986347 65ED42C4 1440000F 0001.

B.1.1. Decoding Location Configuration Information with Resolution

Decoding this option gives a latitude of 38.897647 (to 7 decimal places) with 18 bits of resolution, a longitude of -77.0366000 with 17 bits of resolution, an Altitude Type of meters with a value of 15 and 17 bits of resolution, version 0 (resolution), and the WGS84 datum.

For the latitude value, 18 bits of resolution allow for values in the range from 38.8964844 to 38.8984375. For the longitude value, 17 bits of resolution allow for values in the range from -77.0390625 to -77.0351563. Having 17 bits of resolution in the altitude allows for values in the range from 0 to 32 meters.

B.1.2. GML Representation of Decoded Location Configuration Information

The following GML shows the value decoded in the previous example as a point in a three-dimensional CRS:

```
<gml:Point srsName="urn:ogc:def:crs:EPSG::4979"
           xmlns:gml="http://www.opengis.net/gml">
  <gml:pos>38.897647 -77.0366 15</gml:pos>
</gml:Point>
```

This representation ignores the values included in the resolution parameters. If resolution values are provided, a rectangular prism can be used to represent the location.

The following example uses all of the decoded information from the previous example:

```
<gs:Prism srsName="urn:ogc:def:crs:EPSG::4979"
    xmlns:gs="http://www.opengis.net/pidflo/1.0"
    xmlns:gml="http://www.opengis.net/gml">
  <gs:base>
    <gml:Polygon>
     <gml:exterior>
        <gml:LinearRing>
         <gml:posList>
            38.8964844 -77.0390625 0
            38.8964844 -77.0351563 0
            38.8984375 -77.0351563 0
            38.8984375 -77.0390625 0
            38.8964844 -77.0390625 0
          </gml:posList>
        </gml:LinearRing>
      </gml:exterior>
    </gml:Polygon>
  </gs:base>
  <gs:height uom="urn:ogc:def:uom:EPSG::9001">
    32
  </gs:height>
</gs:Prism>
```

B.2. Location Configuration Information of "Sears Tower" (Example 2)

Postal Address:

Sears Tower
103rd Floor
233 S. Wacker Dr.
Chicago, IL 60606

Viewing the Chicago area from the Observation Deck of the Sears Tower:

```
Latitude 41.87884 degrees North (or +41.87884 degrees)
Using two’s complement, 34-bit fixed point, 25 bits of fraction
Latitude = 0x053c1f751,
Latitude = 0001010011110000011111011101010001
Longitude 87.63602 degrees West (or -87.63602 degrees)
Using two’s complement, 34-bit fixed point, 25 bits of fraction
Longitude = 0xf50ba5b97,
Longitude = 1101010000101110100101101110010111

Altitude 103
```

In this example, we are inside a structure; therefore, we will assume an altitude value of 103 to indicate the floor we are on. The Altitude Type value is 2, indicating floors. The AltRes field would indicate that all bits in the Altitude field are true, as we want to accurately represent the floor of the structure where we are located.

```
AltRes = 30, 0x1e, 011110
AType = 2, 0x02, 000010
Altitude = 103, 0x00006700, 000000000000000110011100000000
```

For the accuracy of the latitude and longitude, the best information available to us was supplied by a generic mapping service that shows a single geo-loc for all of the Sears Tower. Therefore, we are going to show LaRes as value 18 (0x12 or 010010) and LoRes as value 18 (0x12 or 010010). This would be describing a geo-location area that is latitude 41.8769531 to latitude 41.8789062 and extends from -87.6367188 degrees to -87.6347657 degrees longitude. This is an area of approximately 373412 square feet (713.3 ft. x 523.5 ft.).

Appendix C. Calculations of Uncertainty

The following example demonstrates how uncertainty values for latitude, longitude, and altitude (LatUnc, LongUnc, and AltUnc used in the DHCPv6 GeoLoc Option 63 as well as DHCPv4 GeoLoc Option 144) can be calculated.

C.1. Location Configuration Information of "Sydney Opera House" (Example 3)

This section describes an example of encoding and decoding the geodetic DHCP Option. The textual results are expressed in GML [OGC-GML3.1.1] form, suitable for inclusion in PIDF-LO [RFC4119].

These examples all assume a datum of WGS84 (datum = 1) and an Altitude Type of meters (AType = 1).

C.1.1. Encoding a Location into DHCP Geodetic Form

This example draws a rough polygon around the Sydney Opera House. This polygon consists of the following six points:

```
33.856625 S, 151.215906 E
33.856299 S, 151.215343 E
33.856326 S, 151.214731 E
33.857533 S, 151.214495 E
33.857720 S, 151.214613 E
33.857369 S, 151.215375 E
```

The top of the building is 67.4 meters above sea level, and a starting altitude of 0 meters above the WGS84 geoid is assumed.

The first step is to determine the range of latitude and longitude values. Latitude ranges from -33.857720 to -33.856299; longitude ranges from 151.214495 to 151.215906.

For this example, the point that is encoded is chosen by finding the middle of each range, that is (-33.8570095, 151.2152005). This is encoded as (1110111100010010010011011000001101, 0100101110011011100010111011000011) in binary, or (3BC49360D, 12E6E2EC3) in hexadecimal notation (with an extra 2 bits of leading padding on each). Altitude is set at 33.7 meters, which is 000000000000000010000110110011 (binary) or 000021B3 (hexadecimal).

The latitude uncertainty (LatUnc) is given by inserting the difference between the center value and the outer value into the formula from Section 2.3.2. This gives:

```
x = 8 - ceil( log2( -33.8570095 - -33.857720 ) )
```

The result of this equation is 18; therefore, the uncertainty is encoded as 010010 in binary.

Similarly, longitude uncertainty (LongUnc) is given by the formula:

```
x = 8 - ceil( log2( 151.2152005 - 151.214495 ) )
```

The result of this equation is also 18, or 010010 in binary.

Altitude uncertainty (AltUnc) uses the formula from Section 2.4.5:

```
x = 21 - ceil( log2( 33.7 - 0 ) )
```

The result of this equation is 15, which is encoded as 001111 in binary.

Adding an Altitude Type of 1 (meters) and a Datum of 1 (WGS84), this gives the following DHCPv4 GeoLoc Option 144 form:

```
     0                   1                   2                   3
     0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |   Code (144)  |  OptLen (16)  |  LatUnc   |     Latitude      .
    |0 1 1 1 1 0 1 1|0 0 0 1 0 0 0 0|0 1 0 0 1 0|1 1 1 0 1 1 1 1 0 0.
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    .                Latitude (cont'd)            | LongUnc   |   .
    .0 1 0 0 1 0 0 1 0 0 1 1 0 1 1 0 0 0 0 0 1 1 0 1|0 1 0 0 1 0|0 1.
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    .                       Longitude (cont'd)                      |
    .0 0 1 0 1 1 1 0 0 1 1 0 1 1 1 0 0 0 1 0 1 1 1 0 1 1 0 0 0 0 1 1|
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    | AType |   AltUnc  |                Altitude                   .
    |0 0 0 1|0 0 1 1 1 1|0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1.
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    .  Alt (cont'd) |Ver| Res |Datum|
    .1 0 1 1 0 0 1 1|0 1|0 0 0|0 0 1|
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

In hexadecimal, this is 7B104BBC 49360D49 2E6E2EC3 13C00021 B341. The DHCPv6 form only differs in the code and option length portion.

C.1.2. Decoding a Location from DHCP Geodetic Form

If receiving the binary form created in the previous section, this section describes how that would be interpreted. The result is then represented as a GML object, as defined in [GeoShape].

A latitude value of 1110111100010010010011011000001101 decodes to a value of -33.8570095003 (to 10 decimal places). The longitude value of 0100101110011011100010111011000011 decodes to 151.2152005136.

Decoding Tip: If the raw values of latitude and longitude are placed in integer variables, the actual value can be derived by the following process:

1. If the highest order bit is set (i.e., the number is a two's complement negative), then subtract 2 to the power of 34 (the total number of bits).

2. Divide the result by 2 to the power of 25 (the number of fractional bits) to determine the final value.

   The same principle can be applied when decoding altitude values, except with different powers of 2 (30 and 8, respectively).

The latitude and longitude uncertainty are both 18, which gives an uncertainty value of 0.0009765625 using the formula from Section 2.3.2. Therefore, the decoded latitude is -33.8570095003 +/- 0.0009765625 (or the range from -33.8579860628 to -33.8560329378) and the decoded longitude is 151.2152005136 +/- 0.0009765625 (or the range from 151.2142239511 to 151.2161770761).

The encoded altitude of 000000000000000010000110110011 decodes to 33.69921875. The encoded uncertainty of 15 gives a value of 64; therefore, the final uncertainty is 33.69921875 +/- 64 (or the range from -30.30078125 to 97.69921875).

C.1.2.1. GML Representation of Decoded Locations

The following GML shows the value decoded in the previous example as a point in a three-dimensional CRS:

```
<gml:Point srsName="urn:ogc:def:crs:EPSG::4979"
           xmlns:gml="http://www.opengis.net/gml">
  <gml:pos>-33.8570095003 151.2152005136 33.69921875</gml:pos>
</gml:Point>
```

The following example uses all of the decoded information from the previous example:

```
<gs:Prism srsName="urn:ogc:def:crs:EPSG::4979"
    xmlns:gs="http://www.opengis.net/pidflo/1.0"
    xmlns:gml="http://www.opengis.net/gml">
  <gs:base>
    <gml:Polygon>
      <gml:exterior>
        <gml:LinearRing>
          <gml:posList>
            -33.8579860628 151.2142239511 -30.30078125
            -33.8579860628 151.2161770761 -30.30078125
            -33.8560329378 151.2161770761 -30.30078125
            -33.8560329378 151.2142239511 -30.30078125
            -33.8579860628 151.2142239511 -30.30078125
          </gml:posList>
        </gml:LinearRing>
      </gml:exterior>
    </gml:Polygon>
  </gs:base>
  <gs:height uom="urn:ogc:def:uom:EPSG::9001">
    128
  </gs:height>
</gs:Prism>
```

Note that this representation is only appropriate if the uncertainty is sufficiently small. [GeoShape] recommends that distances between polygon vertices be kept short. A GML representation like this one is only appropriate where uncertainty is less than 1 degree (an encoded value of 9 or greater).

Appendix D. Changes from RFC 3825

This section lists the major changes between RFC 3825 and this document. Minor changes, including style, grammar, spelling, and editorial changes, are not mentioned here.

- o Section 1 now includes clarifications on wired and wireless uses.
- o The former Sections 1.2 and 1.3 have been removed. Section 1.2 now defines the concepts of uncertainty and resolution, as well as conversion between the DHCP option formats and PIDF-LO.
- o A DHCPv6 GeoLoc Option is now defined (Section 2.1) as well as a new DHCPv4 GeoLoc Option (Section 2.2.2).
- o The former Datum field has been split into three fields: Ver, Res, and Datum. These fields are used in both the DHCPv4 GeoLoc Option and the DHCPv6 GeoLoc Option.
- o Section 2.2.3 has been added, describing option support requirements on DHCP clients and servers.
- o Section 2.3 has been added, describing the Latitude and Longitude fields.
- o Section 2.3.1 has been added, covering latitude and longitude resolution.
- o Section 2.3.2 has been added, covering latitude and longitude uncertainty.
- o Section 2.4 has been added, covering values of the Altitude field (Sections 2.4.1, 2.4.2, and 2.4.3), altitude resolution (Section 2.4.4), and altitude uncertainty (Section 2.4.5).
- o Section 2.5 has been added, covering the Datum field.
- o Section 3 (Security Considerations) has added a recommendation on link-layer confidentiality.

- Section 4 (IANA Considerations) has consolidated material relating to parameter allocation for both the DHCPv4 and DHCPv6 option parameters, and has been rewritten to conform to the practices recommended in RFC 5226.

- The material formerly in Appendix A has been updated and shortened and has been moved to Appendix B.

- An Appendix A on GML mapping has been added.

- Appendix C has been added, providing an example of uncertainty encoding.

- Appendix D has been added, detailing the changes from RFC 3825.

Authors' Addresses

James M. Polk
Cisco Systems
2200 East President George Bush Turnpike
Richardson, TX 75082
USA

EMail: jmpolk@cisco.com

Marc Linsner
Cisco Systems
Marco Island, FL 34145
USA

EMail: marc.linsner@cisco.com

Martin Thomson
Andrew Corporation
PO Box U40
Wollongong University Campus, NSW 2500
AU

EMail: martin.thomson@andrew.com

Bernard Aboba (editor)
Microsoft Corporation
One Microsoft Way
Redmond, WA 98052
USA

EMail: bernard_aboba@hotmail.com