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Technical Specification
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OpenLocate Beacon Specification

Revision 0.3

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Revision History

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	0.1	06/26/2023	Ben Dunsbergen			Initial draft
	0.2	07/03/2023	Ben Dunsbergen			Added sections for signature and calibrated RSSI
	0.3	10/22/2023	Ben Dunsbergen			□ Add extension options for signature □ Add seq/frag field □ Renamed Transmit Power element to Properties element and added Flags field

Introduction

Purpose of this specification

This document describes the formatting and use of the OpenLocate Beacon. The OpenLocate Beacon is a BLE advertisement used to broadcast the physical location of the transmitter.

Terminology

-

OpenLocate Beacon

BLE devices that want to broadcast their physical location can choose to implement the OpenLocate Beacon. The goal is for receivers to understand the location of the transmitting device without any consultation of a remote API.

For example, the transmitter is a location anchor. It's mounted at a fixed location and transmits OpenLocate Beacons. The receivers are mobile devices that listen for OpenLocate Beacons. The receivers can now calculate their own location relative to the location anchors without previous knowledge about the anchors and without consulting any other APIs.

The OpenLocate Beacon support two types of location:

- Absolute location using latitude/longitude/altitude.
- Location relative to a floorplan

The amount of location information made available in the OpenLocate Beacon is flexible, it can support either absolute or relative location or both. There may or may not be uncertainty information available. Also, the latitude in absolute coordinates is optional.

Advertisement format

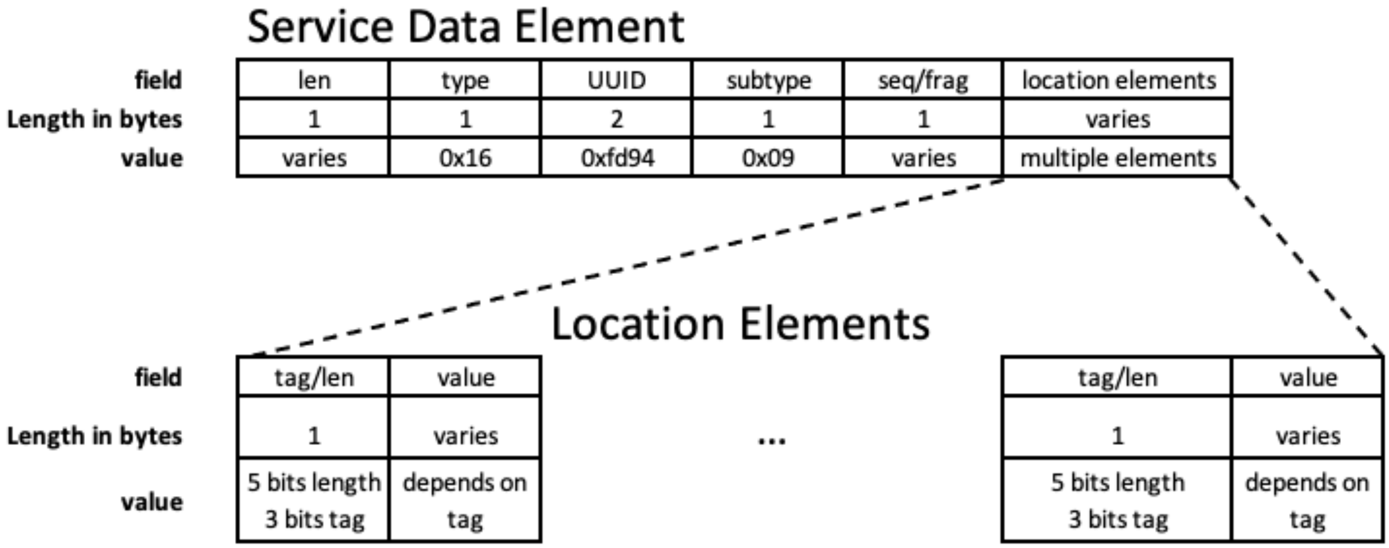
The OpenLocate Beacon will be available in either legacy format (BT 4) or current format (BT 5) or both. The main difference is that in the legacy format the payload length is only 31 bytes and multiple advertisement frames will be needed to convey the total content of the OpenLocate Beacon.

The OpenLocate Beacon data is embedded inside the Service Data Element as defined in [2], Section 1.11 using a 2-byte UUID.

The actual data in the OpenLocate Beacon consists of multiple “Location Elements”.

- Each advertisement frame can contain only one Service Data Element
- Subsequent advertisements can have differing contents (different location elements)
- Multiple location elements could occur within a single service data.
- location elements can occur in any order.

The usage of the Service Data Element is shown in Figure 1



Service Data Element

field	len	type	UUID	subtype	seq/frag	location elements
Length in bytes	1	1	2	1	1	varies
value	varies	0x16	0xfd94	0x09	varies	multiple elements

Location Elements

field	tag/len	value		tag/len	value
Length in bytes	1	varies	...	1	varies
value	5 bits length 3 bits tag	depends on tag		5 bits length 3 bits tag	depends on tag

Figure 1: Service Data Element

The seq/frag field uses 4 bits for sequence number, 3 bits for fragment number and the final bit to indicate last-fragment. See Figure 2

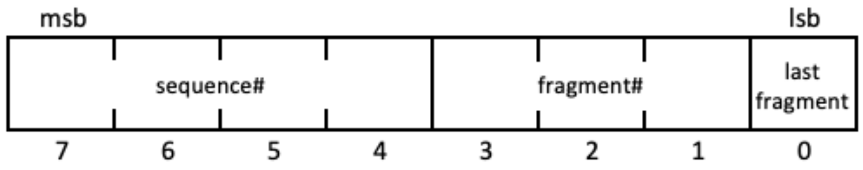


Figure 2: Seq/Frag field

The sequence# field is increased for every advertisement interval. After 16 intervals the value rolls over and restarts at 0.

The fragment number indicates the fragment. This is useful when multiple frames are required to transmit an entire OpenLocate Beacon.

The last fragment field is 0 if more fragments are expected within the advertisement interval. It is set to 1 if this is the final fragment.

Location Elements

The tag/len field uses the 3 most significant bits to indicate the tag (location element type) and the remaining 5 bits to indicate the length of the value field. Note that the byte used for tag/len is not included in the length count.

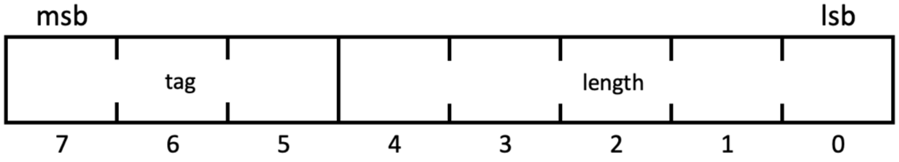


Figure 3: Tag/Len field

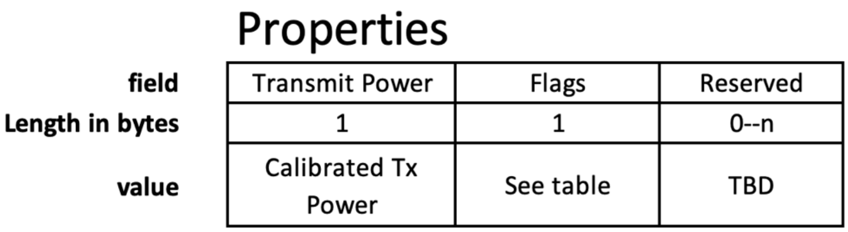
Table 1 shows the currently defined location elements and their tags:

Tag	Name	Purpose	Notes
0	Properties	Indicates the Transmit Power and flags	
1	Geo location	Location data in WGS84 coordinates	
2	Floor location	Location relative a to a floorplan	
3	Identity	Identity of the Transmitter	Helps with correlating the BLE MAC address to a more friendly identifier of the transmitter
4	URL	Points to a location with additional info regarding the transmitter	
5	Signature	Ensure integrity and authenticity of the data	
6	Reserved		Do not use
7	Extension	For future use	Once more than 7 tags are needed, the extension tag can be used to add more.

Table 1: Tag definitions for the Location Element

Properties element

The purpose of this element is to convey certain device properties that are relevant to location. This element consists of 1 byte for Transmit power followed by one byte for flags and in the future potentially additional fields. See Figure 4



Properties

field	Transmit Power	Flags	Reserved
Length in bytes	1	1	0--n
value	Calibrated Tx Power	See table	TBD

Figure 4: Properties Element

Transmit Power field

This field provides a means for the transmitter to indicate its transmit power to the receiver. In turn the receiver can use this to better estimate distance from the received signal strength. The measured power is a single byte containing a signed integer that specifies the measured signal strength at 1 meter from the transmitter.

The usage for this field follows the Proximity Beacon Spec from Apple (iBeacons). See [4], Section 2.2.

Flags field

This field contains a bitmap with flags as defined in Table 2

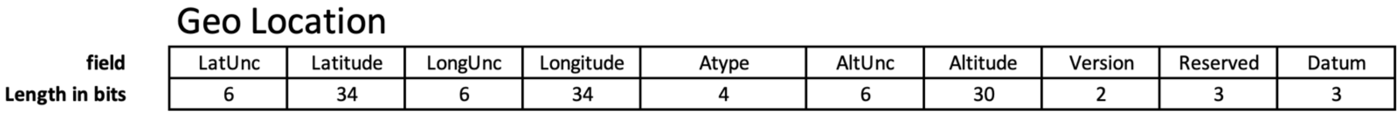
Name	Value	Usage
isMobile	0x01	1 for mobile devices 0 for stationary devices
<reserved>	0x02 … 0x80	For future use

Table 2: Device Flags

Geo location element

The geolocation element follows the definitions in RFC 6225 [3], section 2.2.2. The layout is shown in Figure 5. It is 16 bytes long.

When this element is present, it is expected that the latitude and longitude fields have valid values, The altitude fields, and the uncertainty fields may be unspecified.



Geo Location

field	LatUnc	Latitude	LongUnc	Longitude	Atype	AltUnc	Altitude	Version	Reserved	Datum
Length in bits	6	34	6	34	4	6	30	2	3	3

Figure 5: Geo location element

Notes:

- The Version field must be set to 1. Version 1 is the only version supported as of this version of the spec.
- The Datum field must be set to 1. WGS84 is the only supported Datum as of this version of the spec.
- The reserved field must be set to 0 by the transmitter and ignored by the receiver.

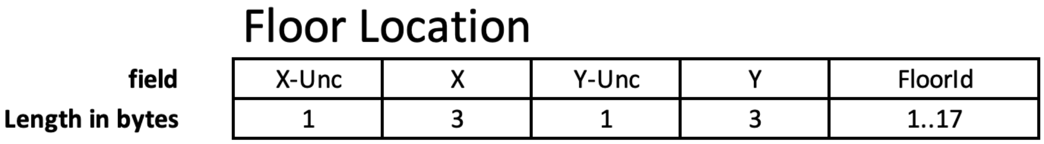
Floorplan relative location element

This element provides location relative to a floorplan. This is useful only if the receiver has a means of obtaining floorplans ahead of time. The dimensions of the floorplan also need to be obtained out of band. The method of obtaining these floorplans and dimensions is outside of the scope of this specification.

The location is indicated using an x and y coordinate in 2D space relative to the floorplan. The floorplans are assumed to be rectangular. The origin (x=0; y=0) of this coordinate system is the top-left corner of the floorplan.

The uncertainty fields are intended to provide a region in which the actual location resides. If the uncertainty fields are specified, the uncertainty region is a rectangle, centered around the provided x, y coordinates. The sides of the region are 2*X-Unc x 2*Y-Unc. So, the actual horizontal offset is somewhere in the range between [X – X-Unc … X + X-Unc].

If the uncertainty fields are not specified, it means that the given X, Y coordinates are the best estimate and there is no indication of a confidence.



Floor Location

field	X-Unc	X	Y-Unc	Y	FloorId
Length in bytes	1	3	1	3	1..17

Figure 6: Floorplan relative location element

The fields are defined as follows:

field	Purpose	Range	Notes
X	Horizontal offset	0-16,777,215 cm	
Y	Vertical offset	0-16,777,215 cm	
X-Unc	Uncertainty in the X direction	1-65,535 cm	0 indicates uncertainty is unspecified. All other values are encoded as the square root of the Uncertainty: $X_{Unc} = \sqrt{Uncertainty}.$ E.g. For an uncertainty of 100 cm, the value of X-Unc = 10
Y-Unc	Uncertainty in the Y direction	1-65,535 cm	0 indicates uncertainty is unspecified. All other values are encoded as the square root of the Uncertainty: $Y_{Unc} = \sqrt{Uncertainty}.$ E.g. For an uncertainty of 100 cm, the value of Y-Unc = 10
FloorId	Identifier that can be used to retrieve a floorplan		

Table 3: Floor Location fields

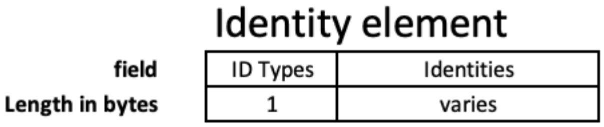
Identity element

This element provides a means for the transmitter to publish additional identities for itself.

Depending on implementation, the receiver may see the BLE mac address of the receiver or in some cases (IOS) the receiver may only see a locally generated identifier. The additional identities can help the receiver to correlate the sender to a known entity.

The element supports three different types of identifiers: a mac address, a string, or an iBeacon identity. It is possible to advertise more than one identity in this element.

The format of the Identity element is shown in Figure 7.



Identity element

field	ID Types	Identities
Length in bytes	1	varies

Figure 7: Identity element

The ID Types field is a bitmap indicating which identities are included. Usage of the ID Types field is specified in Table 4.

value	type	format
0x01	MAC address	6 bytes
0x02	Text String	1 byte length followed by 1...23 bytes UTF8 string
0x04	iBeacon id	16 bytes UUID followed by 2 bytes major# followed by 2 bytes minor#

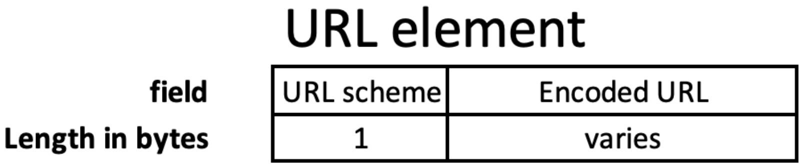
Table 4: Identity Types

If more than one identity is included, they must appear in the same order in which they are listed in Table 4. So, mac address first, string next, and iBeacon last.

URL element

This element can be used to broadcast a http/https URL where more information can be found about the transmitter. The use of the URL is outside of the scope of this spec.

The format of this element is show in Figure 8.



URL element

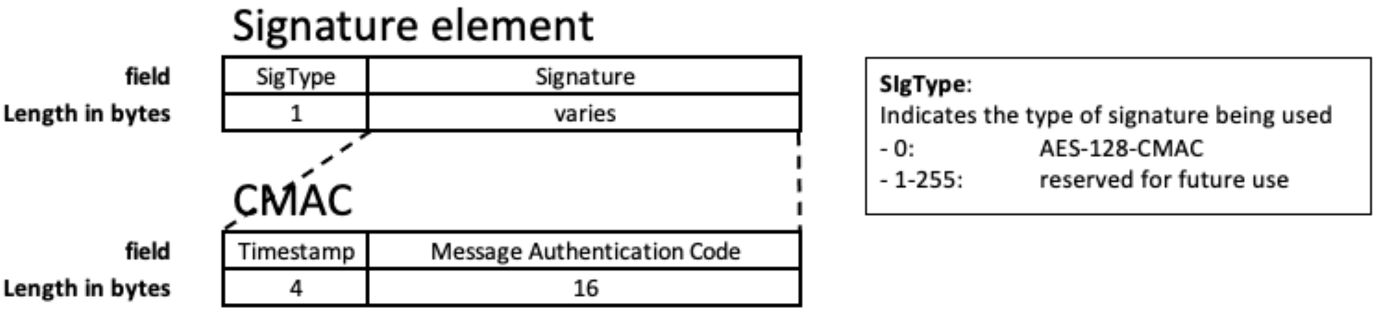
field	URL scheme	Encoded URL
Length in bytes	1	varies

Figure 8: URL Element

The URL scheme field and the Encoded URL field follow the definitions of the Eddystone-URL specification [5].

Signature element

This element provides a data integrity check and an authenticity check for the OpenLocate Beacon. The first byte specifies the type of signature. As of this version of the spec only one signature type (AES-128-CMAC) is supported. The format for the signature element is shown in Figure 9.



Signature element

field	SigType	Signature
Length in bytes	1	varies

CMAC

field	Timestamp	Message Authentication Code
Length in bytes	4	16

SIgType:
Indicates the type of signature being used
- 0: AES-128-CMAC
- 1-255: reserved for future use

Figure 9: Signature element

The size of the AES-128-CMAC Signature is 20 bytes. The content is timestamp followed by a Message Authentication Code (MAC). The algorithm used to generate the MAC is AES-128-CMAC.

Details for the generation and validation of the MAC are spelled out in Appendix A.

The timestamp field contains the number of seconds since Jan 1st, 1970. This is also known as Unix epoch time. The timestamp is encoded as an unsigned integer (no rollover until 2106). The timestamp represents UTC time. Not local time.

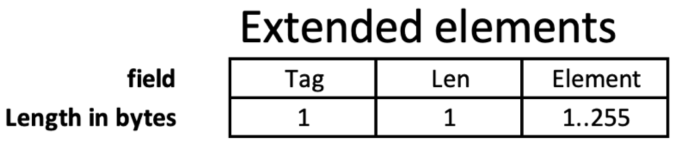
Extended elements

Tag 7 is reserved for future elements that require a tag of 8 or higher, and/or elements with a length of 32 or greater.

An extended element contains 0xE0 in the tag/len field. This element itself starts with a 1-byte tag field, followed by a 1-byte length field, followed by the contents of the extended element.

Unlike all the other elements, the extended element holds the length field inside the payload and not inside the tag/len field. It is important for receivers to handle this element correctly so that they can properly parse these elements when they start appearing in the future.

The format is shown in Figure 10.



Extended elements

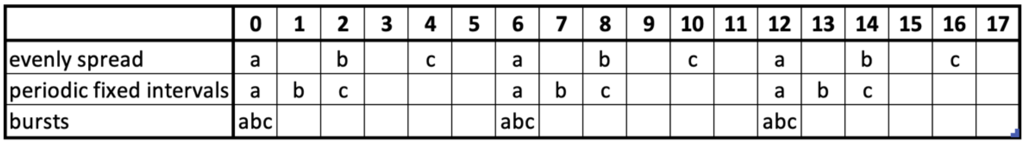
field	Tag	Len	Element
Length in bytes	1	1	1..255

Figure 10: Extended elements

Transmitter Requirements

Subset of elements. The transmitter can choose which location elements to include in the OpenLocate Beacon. The minimum required subset of elements is the Measured Power element and at least one of geolocation or floor location. Everything else is optional.

Advertisement interval. Every advertisement interval, the entire OpenLocate Beacon must be broadcasted. If a beacon requires multiple frames, then all fragments must be transmitted every advertisement interval. It is up to the transmitter to decide how the multiple frames are transmitted over time. Table 5 shows a few possible distributions for how 3 fragments (a, b, c) could be distributed over a 6 second advertisement interval.



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
evenly spread	a		b		c		a		b		c		a		b		c	
periodic fixed intervals	a	b	c				a	b	c				a	b	c			
bursts	abc						abc						abc					

Table 5: time distribution of multiple advertisements

Ordering of elements. Location elements can appear in any order. The only exception to that is that the signature element must be in the final fragment. It is recommended to combine elements in such a way that it minimizes the number of fragments.

Receiver Requirements

For the most part, the receiver can simply parse each of the frames as it arrives, parse the contents, and extract the data out of it.

Only for signature checking, it is important to make sure that all fragments from a particular interval are reassembled into a complete beacon. The Seq/frag field can be used to reassemble all the fragments of an OpenLocate Beacon.

Appendix A – MAC generation and validation procedures

Key Generation

Usage of the signature field assumes that the transmitter and receiver share a secret passphrase. Secure exchange of this secret is out of the scope of this specification.

The secret is used to generate a key that is one of the required inputs for the AES-128-CMAC algorithm. To generate the key, use the PBKDF2 algorithm. In addition to the passphrase, PBKDF2 requires the following input parameters:

- Salt: : OpenLocate
- Hashing Algorithm : SHA256
- Iterations : 10,000

So, for example, the passphrase “HPE Aruba Networking” would generate the key:

```
3d93402b633288545eb07aa716eeccca
```

Composing the Message

The message content is composed by concatenating the following:

- A 4-byte timestamp containing the Unix epoch time encoded as an unsigned integer.
- All the location elements concatenated together in the same order as they are defined in Table 1.
  - Include the tag/len field each element.
  - Do not include the signature element!
- If the identity element is present, then add nothing. If it is not present, add the 6-byte BLE transmitter mac address.

There’s no need for padding. The message can be of any length.

Here’s an example message that has a timestamp and 5 location elements: properties, geolocation, floor location, identity, and URL. (Line-breaks are added for readability. They’re not part of the actual message)

```
64A1D98F
02CE00
304c4ad6a705470c0ad9ae200000040041
530F000C4E0D000A0A466966746820466C6F6F72
72030011223344550A73657269616C23313233
850168706507
```

Generation of the Message Authentication Code

The Message Authentication Code is calculated using the AES-128-CMAC algorithm. The algorithm requires a key and a message which are explained above.

Following the same example key and message above, the generated MAC would be:

```
b6 5a e7 4d 51 95 33 04 20 a1 da 80 b8 82 f9 eb
```

Include the MAC along with the timestamp that was used in the message in the Signature element.

Validation

The receiver is expected to generate the key and the message using the same steps as the transmitter, and then calculate a MAC locally.

Note that the ordering of the location elements during verification can be different than the order in which fragments were received.

The receiver should verify that:

- The timestamp is current.
- The received MAC matches the locally calculated MAC.

Appendix B – Sample payloads

The implementer has flexibility as to which location elements are included in the OpenLocate Beacon. Below are example payloads of a minimal beacon and a fully featured beacon. Both examples use Bluetooth 4 regular advertisements.

Minimal beacon

This example contains two elements: measured power and geo location. There’s just one advertisement that holds 2 elements. The measured power at 1m is measured as -50 dBm. The location in this example is the Aruba HQ building in San Jose, CA located at latitude 37.419243 and longitude -121.978808. In this example the altitude and uncertainties are not specified. The advertisement payload is:

```
191694FD090102CE0030004AD6A705030C0AD9AE000000000041

19 – length: 24 bytes
  16 – Type: Service Data Element
    94FD – UUID: FD94 in little-endian order
        09 – Subtype: OpenLocate Beacon
          01 – Seq/Frag: sequence# 0; fragment#0; last-frag=1
            02 – Tag/Len: tag = 0 (measured power); Len = 1 byte
              CE00 – Measured Power: -50 dBm; stationary
                  30 - Tag/Len: tag = 1(geolocation); Len = 16 bytes
                    004AD6A705030C0AD9AE000000000041 – LCI: see Table 6.
```

The interpretation of the LCI value is shown in Table 6.

Field	Value	Binary Value	Interpretation
LatUnc	0	000000	Unspecified
Latitude	0x04AD6A705	00 0100 1010 1101 0110 1010 0111 0000 0101	37.419243
LongUnc	0	00000	Unspecified
Longitude	0x30C0AD9AE	11 0000 1100 0000 1010 1101 1001 1010 1110	-121.978808
AType	0	0000	No altitude specified
AltUnc	0	000000	N/A
Altitude	0	00 0000 0000 0000 0000 0000 0000 0000	N/A
Version	1	01	Version 1
Reserved	0	000	N/A
Datum	1	001	WGS84

Table 6: LCI values

Full beacon

This example contains all elements. The total beacon is too large for a single Bluetooth 4 advertisement frame. Therefore, it is split into 4 frames. This beacon advertises the following information:

- Frame 1
  - Properties: calibrated power = -50 dBm; device is stationary
  - Geolocation: Fifth floor of the Aruba HQ building in San Jose, CA, with uncertainty spanning the entire building
- Frame 2
  - Floor location: coordinates [31.5 ± 2.25, 25.7 ± 1.69] on “Fifth Floor”
- Frame 3:
  - Identities: mac address 00:11:22: 33:44:55 and string “serial#123”
  - URL: https://www.hpe.com
- Frame 4
  - Signature: generated with passphrase “HPE Aruba Networking” and timestamp 1688328591 (UTC: Sunday, July 2, 2023, 8:09:51 PM)

The payloads of these advertisements are:

```
Frame1:
191694FD094002CE00304C4AD6A705470C0AD9AE200000040041
191694FD09 – Prefix
          40 – Seq/Frag: seq=4; frag=0; last-frag=0
            02CE00 – measured power element: -50 dBm
                  304C4AD6A705470C0AD9AE200000040041 – Location info. See Table 7.
```

```
Frame2:
191694FD0942530F000C4E0D000A0A466966746820466C6F6F72
191694FD09 – Prefix
          42 – Seq/Frag: seq=4; frag=1; last-frag=0
            53 – Tag(2: floor location) / Len (19)
              0F – X-Unc: 15 -> 2.25m
                000C4E – X: 3150 -> 31.5m
                      0D – Y-Unc: 13 -> 1.69m
                        000A0A – Y: 2570 -> 25.7m
                              466966746820466C6F6F72 – “Fifth Floor”

Frame3:
1E1694FD094472030011223344550A73657269616C2331323385016870650 7
1E1694FD09 – Prefix
          44 – Seq/Frag: seq=4; frag=2; last-frag=0
            72 – Tag(3: identity) / Len (18)
              03 – Identity Types: 0x01 + 0x02 -> mac-address + string
                001122334455 – Mac address: 00:11:22:33:44:55
                            0A – id string length
                              73657269616C23313233 – “serial#123”
                                                    85 – Tag (4: URL) / Length (5)
                                                      01 – URL scheme: “https://www.”
                                                        68706507 – encoded URL: “hpe.com”


Frame4:
1B1694FD0947B50064A1D98FB65AE74D5195330420A1DA80B882F9EB
1B1694FD09 – Prefix
          47 – Seq/Frag: seq=4; frag=3; last-frag=1
            B5 – Tag (5: signature) / Len (21)
              00 – SigType: AES-128-CMAC
                64A1D98F – timestamp
                        B65AE74D5195330420A1DA80B882F9EB – Message Authentication Code
```

Alternatively, if Bluetooth 5 and extended advertisement is supported, the transmitter can opt to send the beacon in an extended advertisement frame. In this case there is a single advertisement and inside that, there is a single Service Data Element containing the entire beacon. The payload would be:

```
5C1694FD0941
  02CE00
  304C4AD6A705470C0AD9AE200000040041
  530F000C4E0D000A0A466966746820466C6F6F72
  72030011223344550A73657269616C23313233
  850168706507
  B50064A1D98F B65AE74D5195330420A1DA80B882F9EB
```

The table below shows the interpretation of the geolocation element:

Field	Value	Binary Value	Interpretation
LatUnc	19	010011	0.000488 degrees
Latitude	0x04AD6A705	00 0100 1010 1101 0110 1010 0111 0000 0101	37.419243
LongUnc	17	010001	0.000195 degrees
Longitude	0x30C0AD9AE	11 0000 1100 0000 1010 1101 1001 1010 1110	-121.978808
AType	2	0000	Altitude in Floors

Field	Value	Binary Value	Interpretation
AltUnc	0	000000	N/A
Altitude	0x00000400	00 0000 0000 0000 0000 0100 0000 0000	4 floors above ground floor. I.e., fifth floor
Version	1	01	Version 1
Reserved	0	000	N/A
Datum	1	001	WGS84

Table 7: Geolocation data for the full beacon

References

[1] "Bluetooth Core Specification", Version 5.4, https://www.bluetooth.com/specifications/specs/core-specification-5-4

[2] "Supplement to the Bluetooth Core Specification", Revision v11, https://www.bluetooth.com/specifications/specs/core-specification-supplement-11/

[3] RFC 6225, "Dynamic Host Configuration Protocol Options for Coordinate-Based Location Configuration Information", July 2011, https://datatracker.ietf.org/doc/html/rfc6225

[4] "Proximity Beacon Specification", Release R1, Apple Inc., 2015-09-04, https://developer.apple.com/ibeacon/

[5] "Eddystone-URL", Google, Jul 4, 2016, https://github.com/google/eddystone/blob/d522df8b5c60858ddd4dbaa69a53a0870e304579/eddystone-url/README.md