SemBeacon: A Semantic Proximity Beacon Solution for Discovering and Detecting the Position of Physical Things

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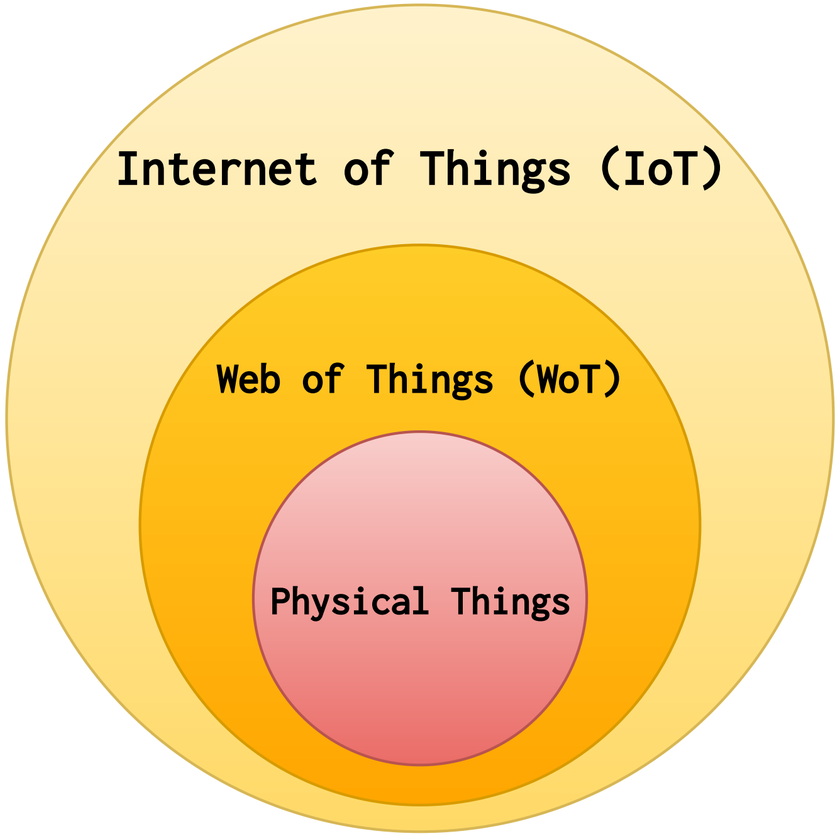
SemBeacon

Overview

*"A Physical Thing is an abstraction of a **physical** entity that provides **interactions** to and participates in the Web of Things"*

- W3C Web of Things (WoT) Thing Description 1.1



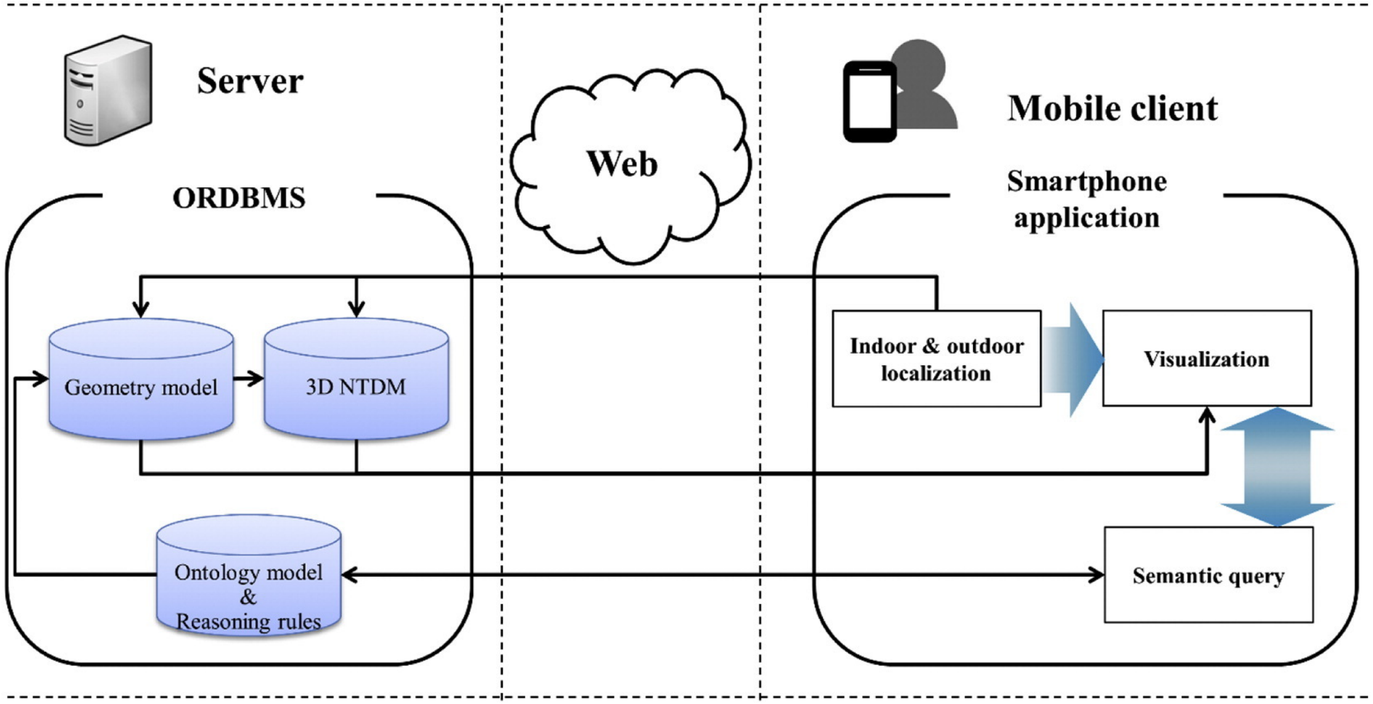
Problem Statement

"How to discover and track Physical Things indoors?"

"How to provide context to places?"

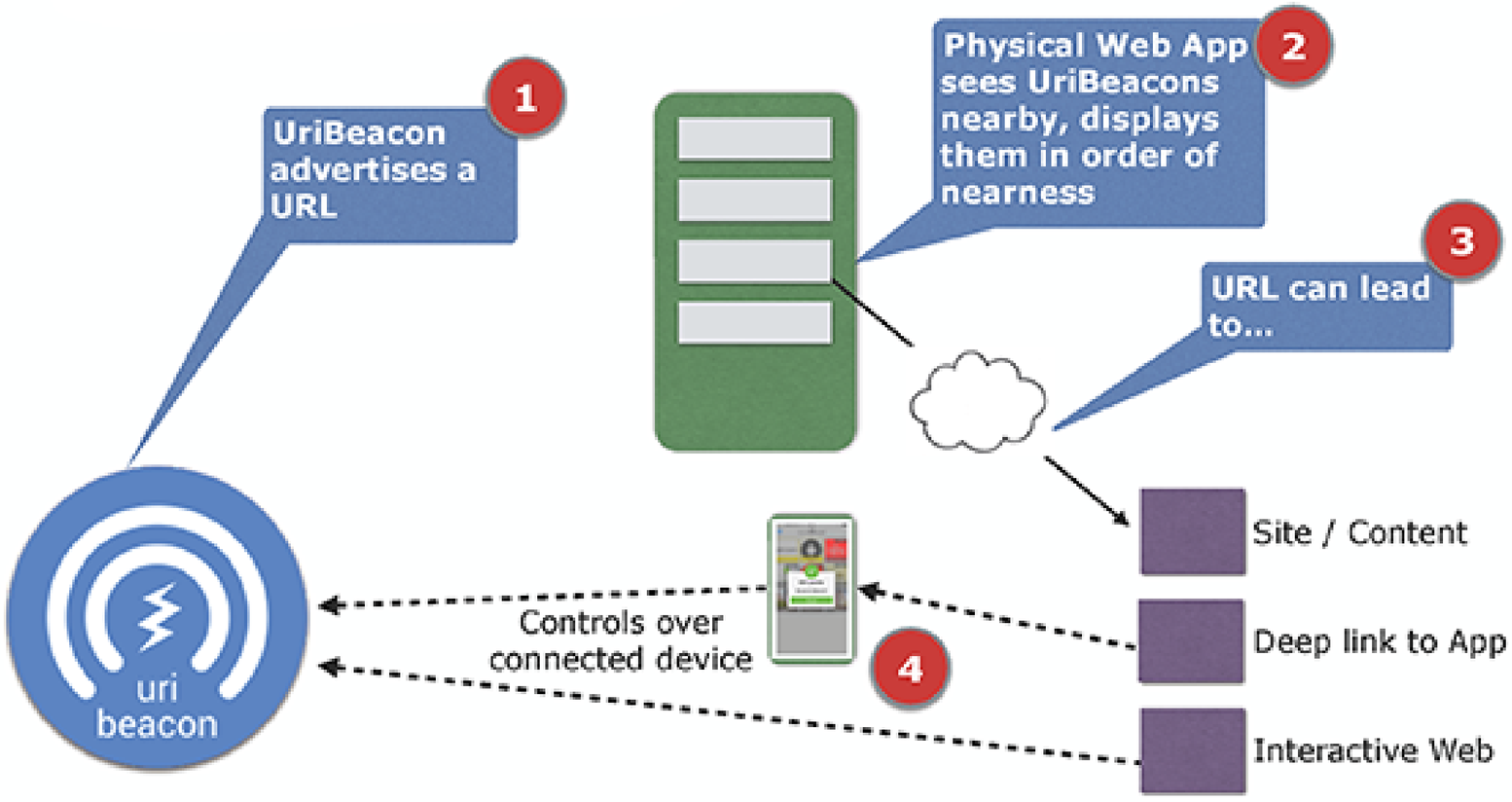
Related Work

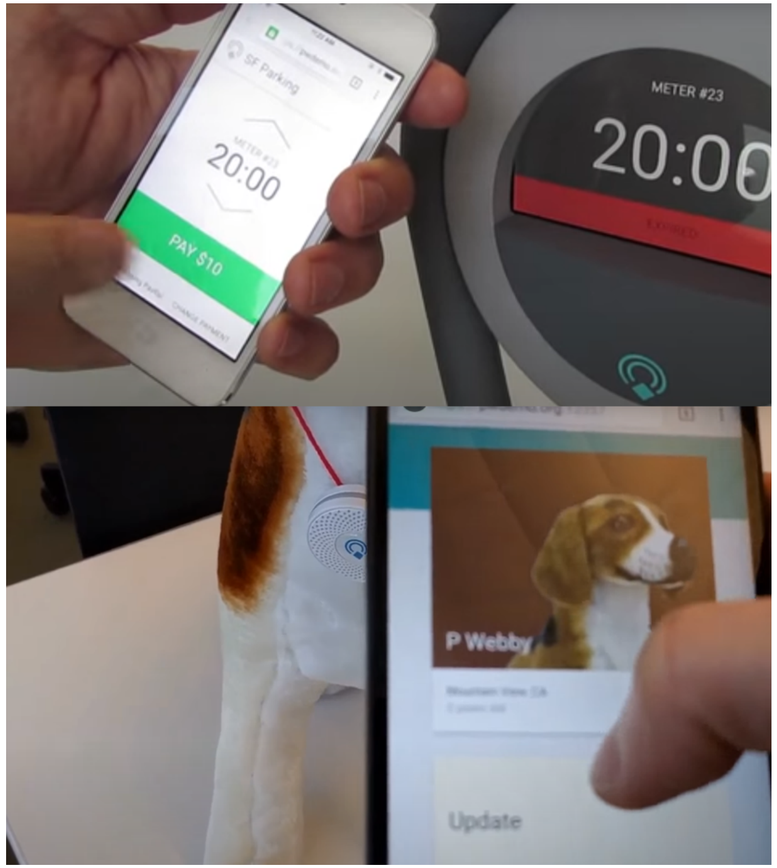
- HP CoolTown Beacon (2000) [26]



- Location-based service using ontology-based semantic queries (2017) [18]

Related Work > Physical Web

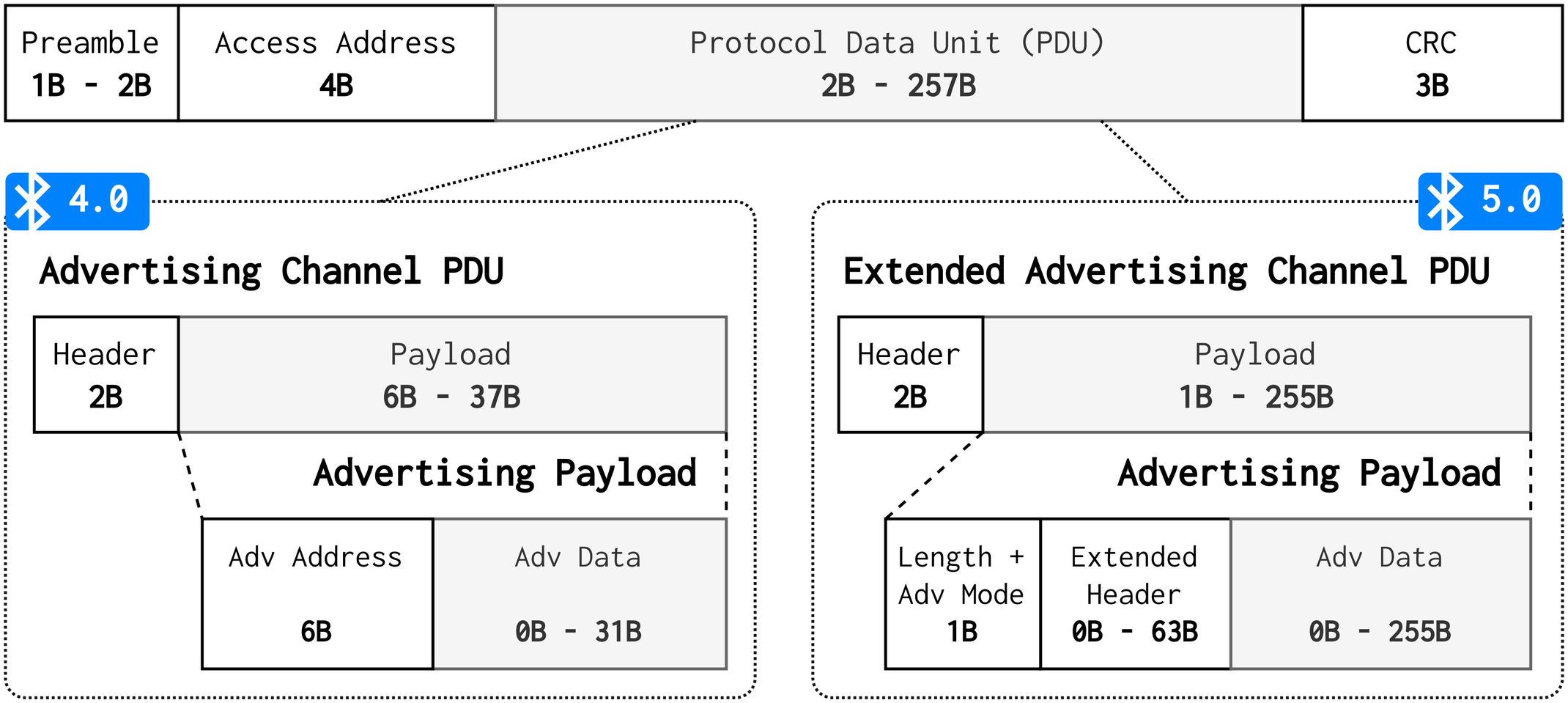




- Manfred Sneps-Sneppe, Dmitry Namiot, "On Physical Web models" (2016)

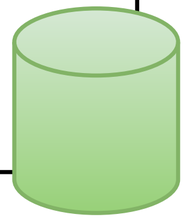
Bluetooth Low Energy (BLE)

BLE Packet

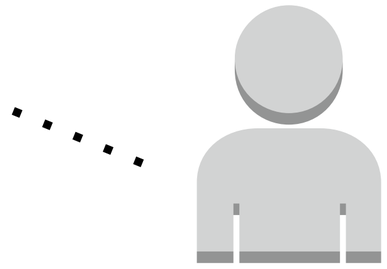


Bluetooth Low Energy (BLE) > Positioning

Database (local/cloud)	
ID	**Location**
1	X=2, Y=3
...	...
3	X=4, Y=3



I am ID=1



I am ID=2

I am ID=3

BLE Specifications > Eddystone

Adv Flags **3B**	Service List **4B**	Len **1B**	Type **1B**	UUID **2B**	Eddystone Frame **2B - 20B**
-	0x0303,0xFEAA	0x??	0x16	0xFEAA	...

Len **1B**	Type **1B**	UUID **2B**
0x03	0x03	0xFEAA

UID

Frame Type **1B**	TX @ 0m **1B**	Namespace ID **10B**	Instance ID **6B**	Reserved **2B**
0x00	*int8*	*uint8[]*	*uint8[]*	0x0000

URL

Frame Type **1B**	TX @ 0m **1B**	URL Prefix **1B**	Encoded URL **0B - 17B**
0x10	*int8*	*uint8*	*uint8[]*

BLE Specifications > iBeacon & AltBeacon

iBeacon Advertisement Data (30 bytes)

Adv Flags **3B**	Len **1B**	Type **1B**	Company ID **2B**	Beacon Type **1B**	Beacon Len **1B**	Proximity UUID **16B**	Major **2B**	Minor **2B**	TX @ 1m **1B**	
-	0x1A	0xFF	0x4C00	0x02	0x15	*uint8[]*	*uint16*	*uint16*	*int8*	

AltBeacon Advertisement Data (31 bytes)

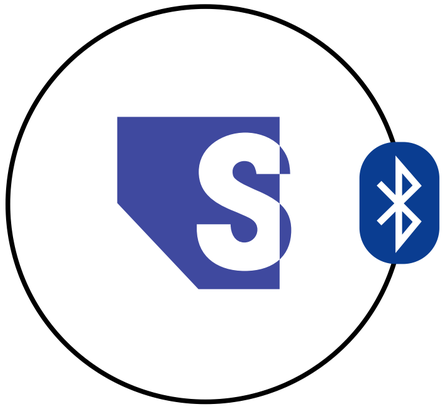
Adv Flags **3B**	Len **1B**	Type **1B**	Company ID **2B**	Beacon Code **2B**	Beacon ID **20B**	TX @ 1m **1B**	Unused **1B**
-	0x1B	0xFF	*uint16*	0xBEAC	*uint8[]*	*int8*	-

BLE Specifications > Bluetooth IPS

Adv Flags	Len	Type	Flags	Lat	Long	North	East	TX Power	Floor	Altitude	Uncertainty	RFU
3B	1B	1B	1B	4B	4B	2B	2B	1B	1B	2B	1B	1B

Bit (MSB)	Description
0	Presence of coordinates in advertising packet
1	Coordinate system used (WGS84 or *local*)
2	Presence of TX Power field in advertising packet
3	Presence of Altitude field in advertising packet
4	Presence of Floor Number in advertising packet
5	Presence of Uncertainty in advertising packet
6	Location Name avaiable in GATT database

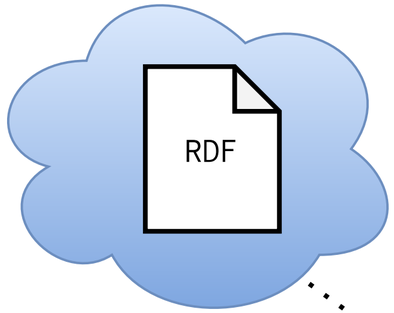
SemBeacon



Hey I am a 0xBEAC with <namespace> <instance> !

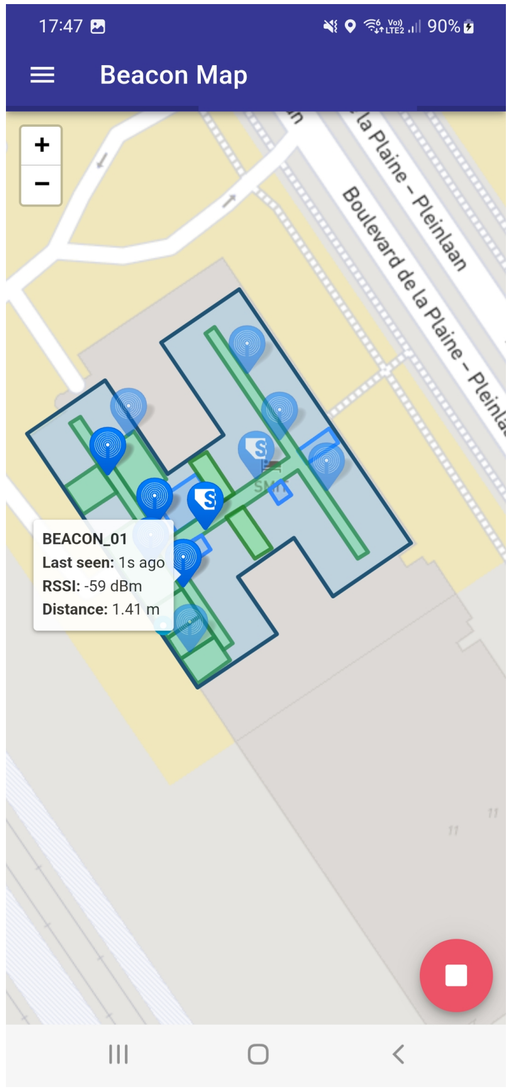
I do not know your namespace

Check https://bit.ly/3JsEnF9



HTTP GET (Accept: text/turtle, application/rdf+xml)

Linked data response



Check cache

Cache <namespace> and all beacons within response

POSO

Open Geospatial Consortium

SemBeacon > Bluetooth Specification

BLE 4.X

SemBeacon Advertisement Data (31 bytes)

4.0

Adv Flags **3B**	Len **1B**	Type **1B**	Company ID **2B**	Beacon Code **2B**	Namespace ID **16B**	Instance ID **4B**	TX @ 1m **1B**	Flags **1B**
-	0x1B	0xFF	*uint16*	0xBEAC	*128-bit UUID*	*32-bit UUID*	*int8*	-

SemBeacon Scan Response Data (max 24 bytes)

4.0

Len **1B**	Type **1B**	UUID **2B**	Frame **1B**	TX @ 0m **1B**	URI Prefix **1B**	Encoded Short Resource URI **0B - 17B**
0x??	0x16	0xFEAA	0x10	*int8*	*uint8*	*uint8[]*

Eddystone-URL
compatible service

```
0x00 'http://www.'
0x01 'https://www.'
0x02 'http://'
0x03 'https://'
0x04 'urn:uuid:'
```

US-ASCII URL

```
0x00 '.com/'      0x06 '.com'
0x01 '.org/'      0x07 '.org'
0x02 '.edu/'      0x08 '.edu'
0x03 '.info/'     0x09 '.info'
0x04 '.biz/'      0x0A '.biz'
0x05 '.gov/'      0x0B '.gov'
```

SemBeacon > Bluetooth Specification

Flags

Based on UriBeacon, Bluetooth IPS and Eddystone frames

Bit (MSB)	Description	Example
0	Indicates if the beacon has a position.	0 = Unsure, 1 = Yes
1	Indicates if the beacon is private.	0 = Public, 1 = Private
2	Indicates if the beacon is attached to a moving object.	0 = No, 1 = Yes
3	Indicates if the beacon has a positioning system.	0 = No, 1 = Yes
4	Indicates if the beacon has telemetry data.	0 = No, 1 = Yes
5 - 7	*Reserved for future use.*	

SemBeacon > Bluetooth Specification

BLE 5.X (Work in Progress)

SemBeacon Extended Advertisement Data (max 156 bytes) — 5.0

SemBeacon Service **4B**	Namespace ID **16B**	Instance ID **4B**	TX @ 1m **1B**	Version **1B**	Flags **1B**	URI Prefix **1B**	Encoded Resource URI **0B - 128B**
-	*128-bit UUID*	*32-bit UUID*	*int8*	0x10	-	*uint8*	*uint8[]*

Len **1B**	Type **1B**	UUID **4B**
0x??	0x20	0x00BEAC00

Major **4b**	Minor **4b**
0001	0000

```
...
0x05 'urn:'
0x06 'tag:'
0x06 'http://purl.org/'
0x07 'https://purl.org/'
0x08 'http://w3id.org/'
0x09 'https://w3id.org/'
```

```
...
0x0C '.rdf#'
0x0D '.ttl#'
0x0E '.rdf'
0x0F '.ttl'
0x10 '.jsonld'
```

SemBeacon > Namespace and Instance

http://example.org/beacons.ttl#

MD5("http://example.org/beacons.ttl#") =
24d72e569889db5328be761d8488688d

http://other.org/beacons.ttl#

MD5("http://other.org/beacons.ttl#") = 08483bc99d448c83bff6cb9d5bccd40d

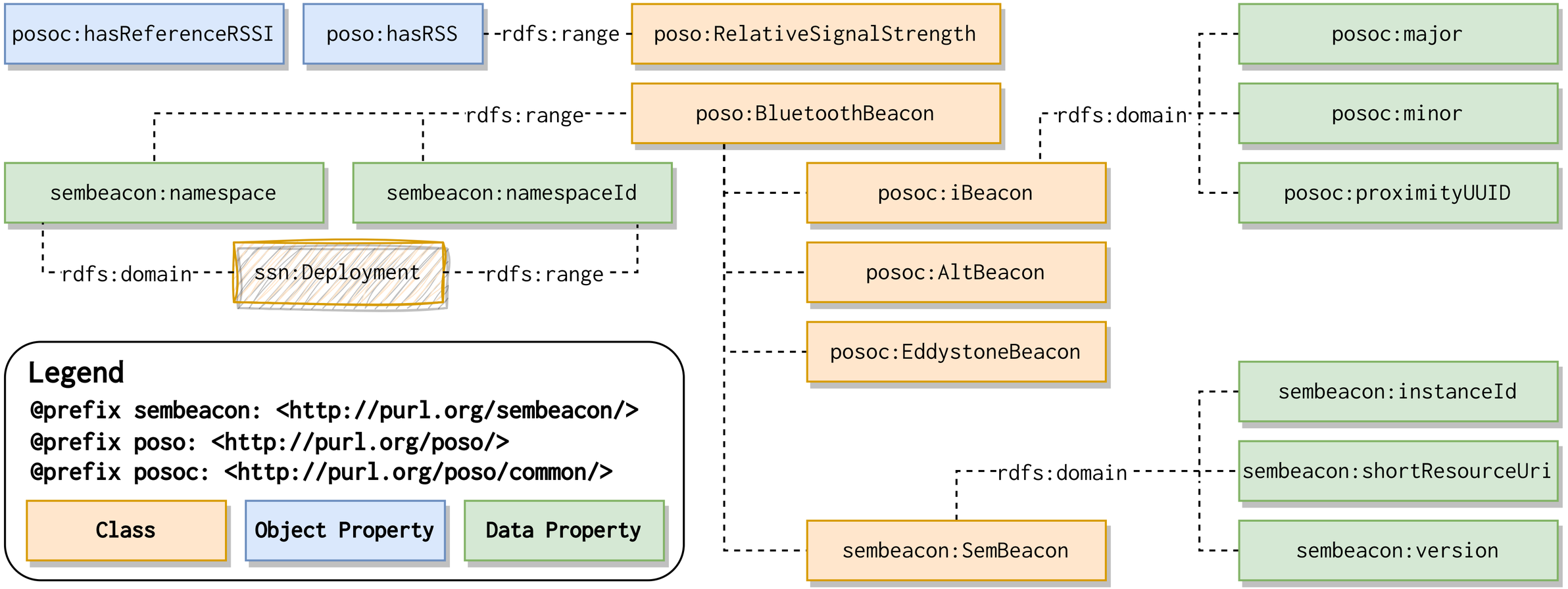
Namespace ID: 0x24d72e569889db5328be761d8488688d
Instance ID: 0x00000001
Resource URI: http://example.org/beacons.ttl#b1
Short Resource URI: https://tinyurl.com/3u9tpt7k

Namespace ID: 0x08483bc99d448c83bff6cb9d5bccd40d
Instance ID: 0x00000001
Resource URI: http://other.org/beacons.ttl#b1
Short Resource URI: https://tinyurl.com/bdmbu7jb

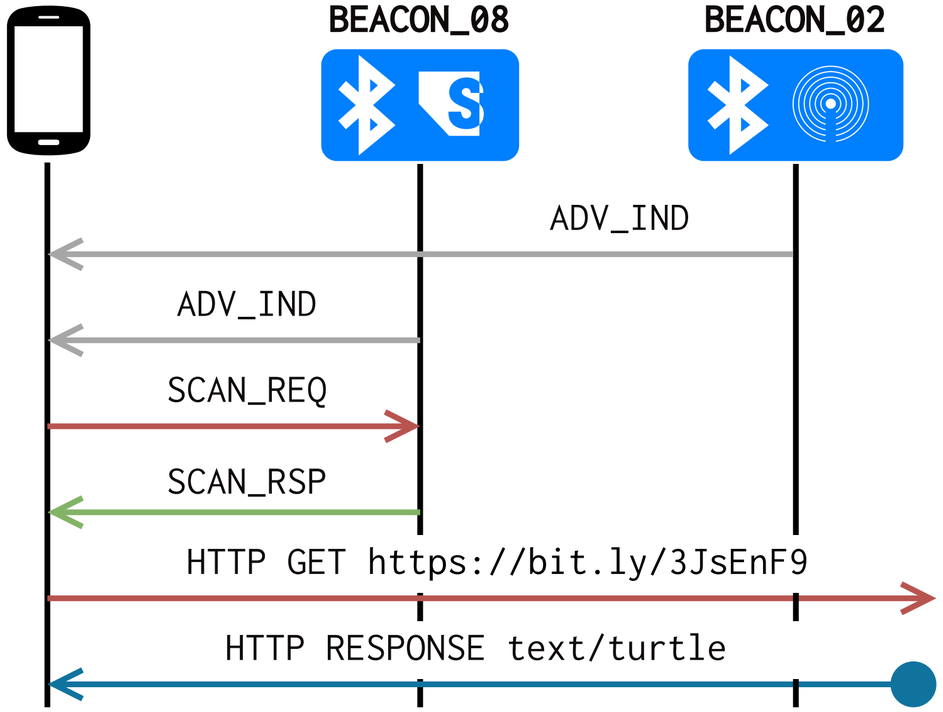
Type: iBeacon
UUID: 0x24d72e569889db5328be761d8488688d
Major: 0x0000 **Minor:** 0x0003

Type: AltBeacon
ID: 0x08483bc99d448c83bff6cb9d5bccd40d00000003

SemBeacon > POSO Extension



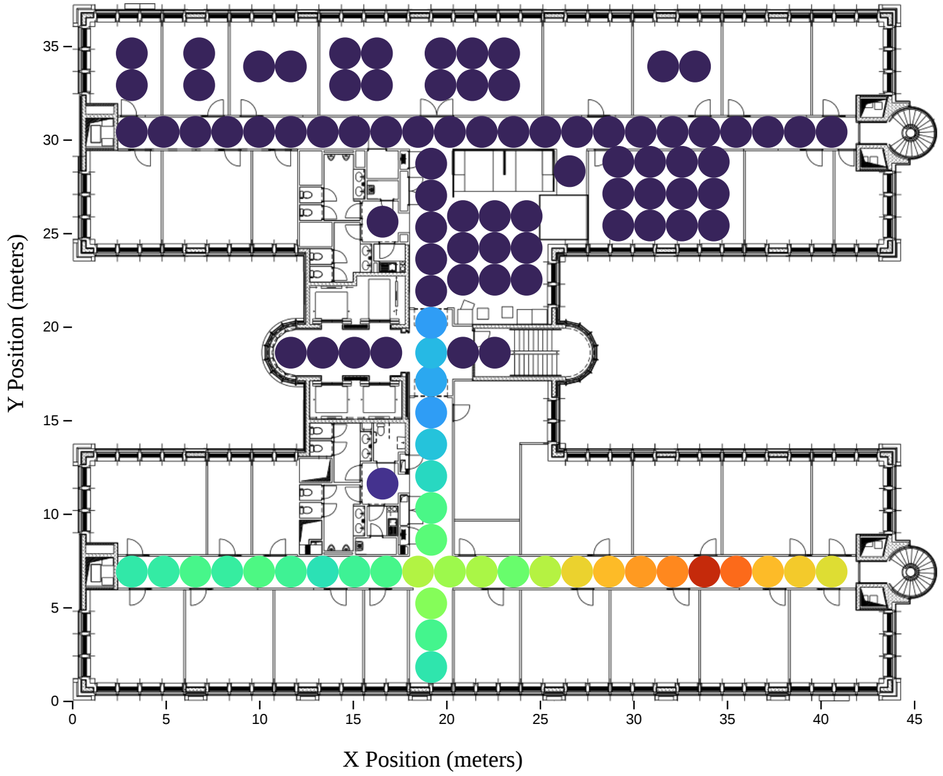
SemBeacon > Method of Discovery



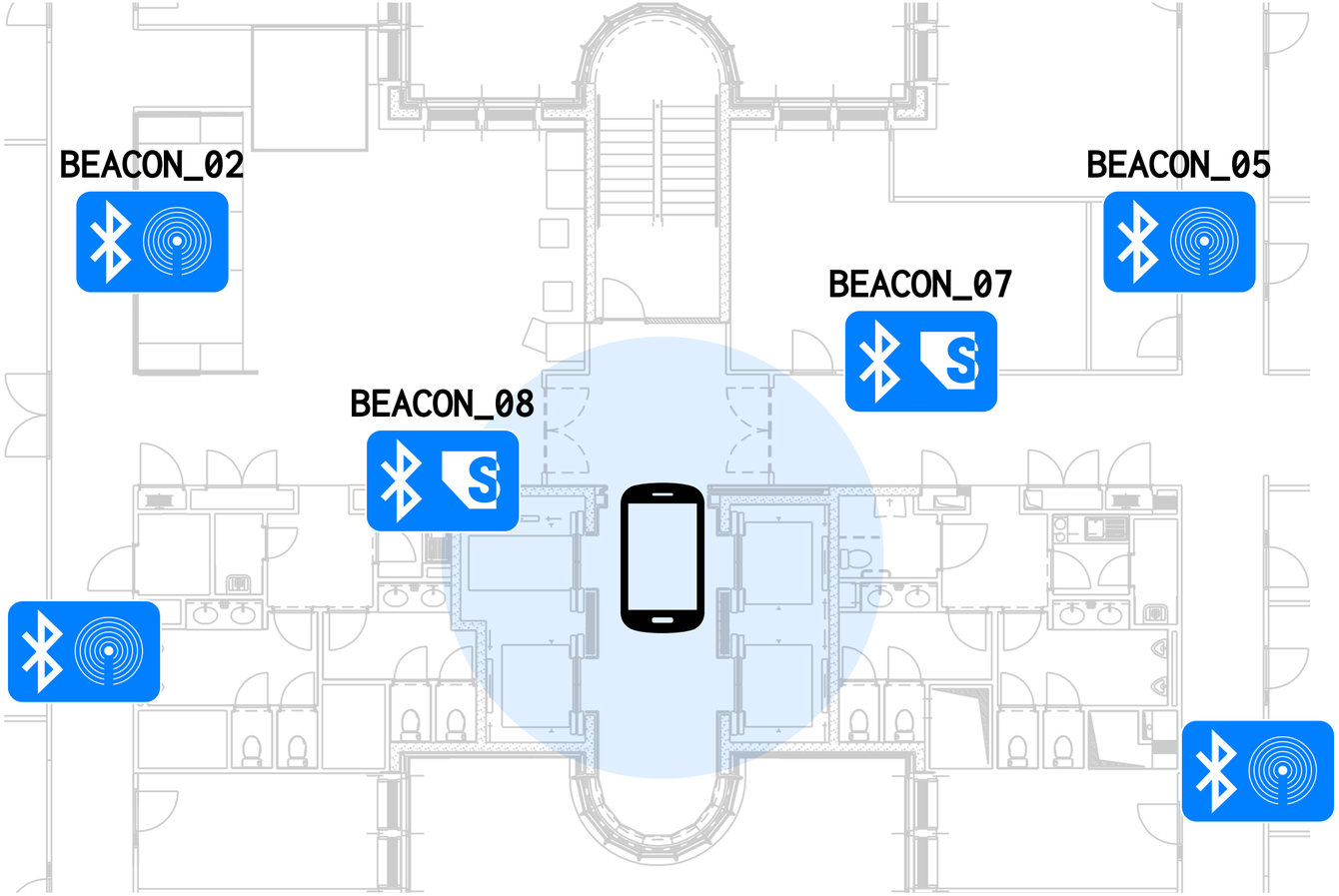

```
:building_a a ssn:Deployment ;
    rdfs:label "Building A" ;
    sembeacon:namespaceId "e19c5e1ed6a14d..."^^xsd:hexBinary .

:room_a1_2 a sembeacon:SemBeacon ;
    rdfs:label "SemBeacon Room A1.2"@en ;
    rdfs:isDefinedBy <http://sembeacon.org/example.ttl#> ;
    sembeacon:namespace :building_a ;
    sembeacon:instanceId "beac0101"^^xsd:hexBinary ;
    hardware:mac "00:11:22:33:44:55" ;
    posoc:referenceRSSI [ # Reference RSSI is a ...
        # ... factory calibrated signal strength
        poso:hasRSS [
            qudt:unit unit:DeciB_M ; qudt:numericValue -56 ] ;
        # ... measured at a specific distance
        poso:hasRelativeDistance [
            unit:Meter ; qudt:value "1.0"^^xsd:double ] .
    ] ;
    poso:hasPosition [ a poso:AbsolutePosition ;
        poso:hasAccuracy [ ... ] ; poso:xAxisValue [ ... ] ;
        poso:yAxisValue [ ... ] ; poso:zAxisValue [ ... ] ] .
```

Demonstrator > Dataset & Recreation



- M. Van de Wynckel & B. Signer, OpenHPS Single Floor Dataset (2021)



Demonstrator > Transformation

https://sembeacon.org/examples/openhps2021/beacons.ttl

```
:pl9_3_lobby_1 a schema:Place, ssn:Deployment, sosa:FeatureOfInterest, ogc:SpatialObject;
    ogc:hasGeometry [ a ogc:Geometry;
        ogc:asWKT "POLYGON Z((4.392281317197596 50.82061024217639 92,
            4.39223788808538 50.82065085654958 92, 4.392153959019106 50.82061503844629 92,
            4.392197388204323 50.8205744240731 92, 4.392281317197596 50.820610242176386 94,
            4.392237888085379 50.82065085654958 95, 4.392153959019106 50.82061503844629 95,
            4.392197388204322 50.8205744240731 94,
            4.392281317197596 50.82061024217639 92))"^^ogc:wktLiteral;
        ogc:coordinateDimension 3; ogc:spatialDimension 3; ogc:dimension 3 ];
    rdfs:label "Lobby #1" .
:pl9_3_lobby_2 a schema:Place, ssn:Deployment, sosa:FeatureOfInterest, ogc:SpatialObject;
    ogc:hasGeometry [ a ogc:Geometry;
        ogc:asWKT "POLYGON Z((4.392530671545053 50.820691696024596 92,
            4.392512343770305 50.82070883604012 92, 4.392448113920621 50.820681425129145 92,
            4.392466441718948 50.820664285113615 92, 4.392530671545053 50.820691696024596 95,
            4.3925123437703055 50.82070883604012 95, 4.392448113920621 50.820681425129145 95,
            4.392466441718948 50.82066428511362 95,
            4.392530671545053 50.820691696024596 92))"^^ogc:wktLiteral;
        ogc:coordinateDimension 3; ogc:spatialDimension 3; ogc:dimension 3 ];
    rdfs:label "Lobby #2" .
```

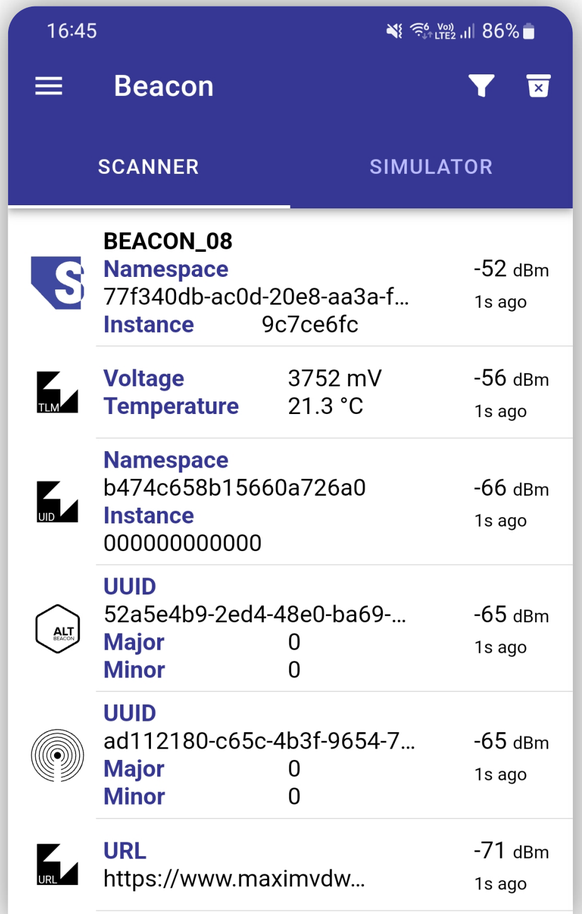
Demonstrator > Transformation

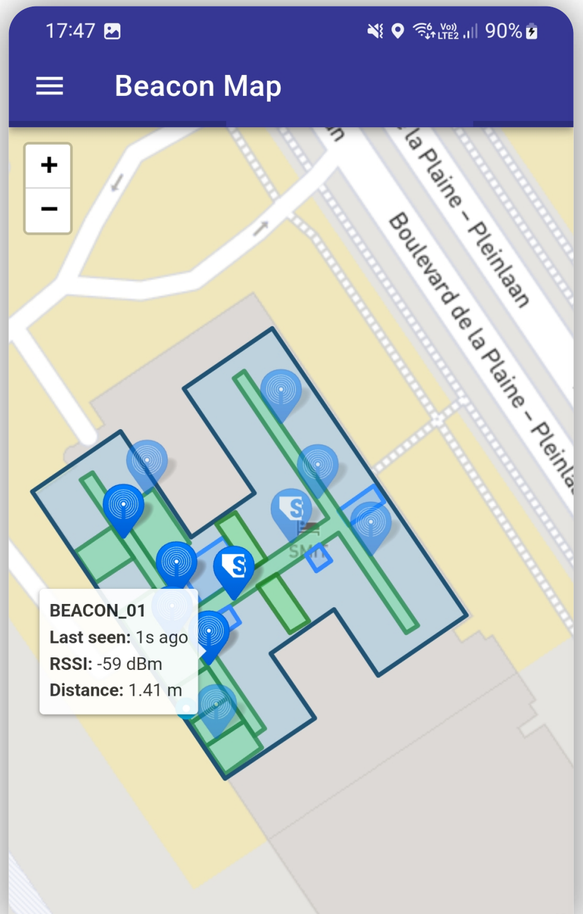
https://sembeacon.org/examples/openhps2021/beacons.ttl

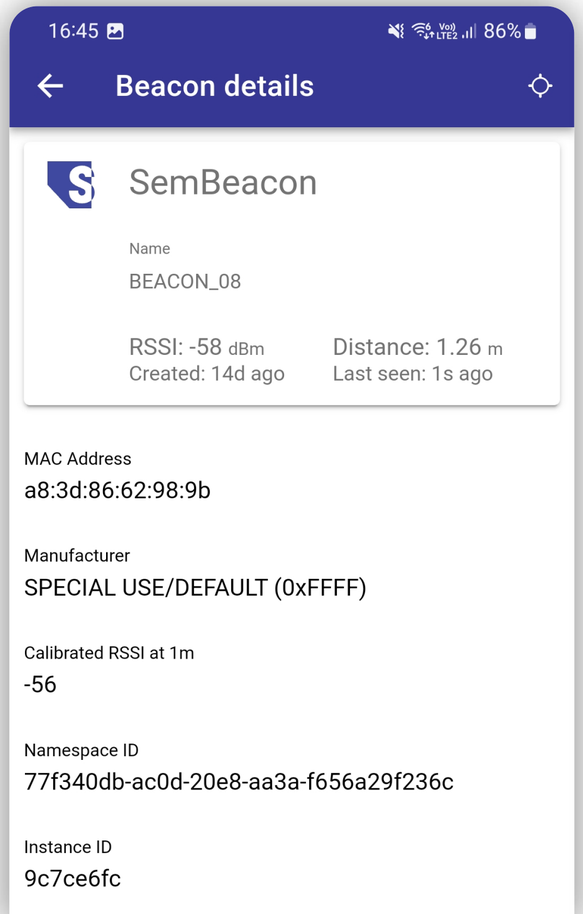
```
:BEACON_08 a sosa:FeatureOfInterest, ogc:SpatialObject, poso:RFLandmark,
        poso:BluetoothBeacon, sembeacon:SemBeacon;
    rdfs:label "BEACON_08";
    poso:hasPosition [ a geo:Point, poso:AbsolutePosition;
        ogc:asWKT "POINT Z(4.392253994600526 50.82057562786381 93.5999999962747)"^^ogc:wktLitera
        ogc:coordinateDimension 3; ogc:spatialDimension 3; ogc:dimension 3;
        dcmi:created "2023-06-22T21:12:23.638Z"^^xsd:dateTime;
        schema:latitude "50.82057562786"^^xsd:double; schema:longitude "4.392253994600"^^xsd:doul
        schema:elevation "93.5999999962"^^xsd:double ];
    posoc:hasReferenceRSSI [ a poso:RelativeSignalStrength;
        poso:hasRSS [ a qudt:QuantityValue;
                qudt:unit unit:DeciB_M;
                qudt:numericValue -56 ];
        poso:hasRelativeDistance [ a qudt:QuantityValue;
            qudt:unit unit:M;
            qudt:numericValue 1 ]];
    hardware:macAddress "f7:5c:38:a4:45:ec";
    ogc:sfWithin :pl9_3_corridor;
    sembeacon:namespace :pl9_3;
    sembeacon:shortResourceURI "https://bit.ly/3JsEnF9"^^xsd:anyURI;
    sembeacon:instanceId "c187d748"^^xsd:hexBinary.
```

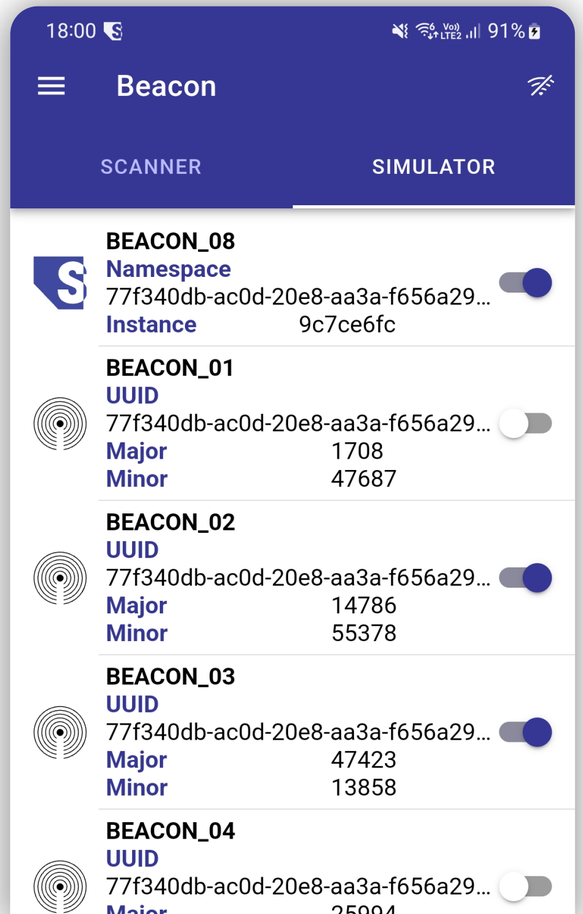
Demonstrator > Mobile Application

- **Scans** and **Simulates** SemBeacon, iBeacon, AltBeacon and Eddystone
- **Extracts** and visualizes SemBeacon encoded information
- Implements HTTP **caching** and namespace mapping to environments









Supplemental Material

- Android Application to scan and broadcast SemBeacons

  Created using Ionic Capacitor and @sembeacon/openhps

- Arduino ESP32 Library to advertise SemBeacon

  Available in the Arduino IDE as "ESP32_SemBeacon"

- Android library extension to identify SemBeacons

  Using the AltBeacon Beacon Library

- TypeScript library to create and detect SemBeacons

  Using the OpenHPS framework (@sembeacon/openhps)

Conclusion and Future Work

- We presented our semantic beacon solution called SemBeacon
- Backwards compatible, offline identification
- Expandable with additional vocabularies
- Expanding to non-BLE beacons (e.g. Ultrawide-band)
- Expanding the vocabulary to facilitate device interactions

https://github.com/SemBeacon/

https://sembeacon.org/

Android App on Google Play Store

Slides can be found on the website