# Bluetooth Beacon Technology

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1

## What is a Beacon Bluetooth?

BLE is low-energy consuming, intelligent technology in the form of chipsets that are embedded into devices. Beacons are very small and simple devices that incorporate:

- Bluetooth Low Energy chipset
- Microprocessor and Firmware telling the beacon what it should do exactly
- Battery and/or power supply unit
- Sensor and actuators
- Device case



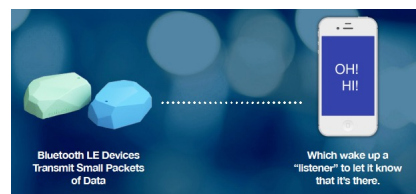UNIVERSITÀ
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2

# What is a Beacon Bluetooth?

A beacon is a small device with Bluetooth Smart connectivity and hardware designed to broadcast data to devices within a specific proximity. It transmits radio signal (advertising) at regular intervals which allows other Bluetooth Smart devices to receive a message.
- It is a one way communication
- Beacons do not transmit content (images, multimedia content etc.) but only standard messages
- The receiving device must be able to properly interpret the message to perform certain actions when enters or leaves the vicinity of a specific beacon



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3

# Beacon and mobile App

Beacons broadcast a signal that can be picked up by BLE devices such as those integrated into smartphones. Mobile Apps can be developed to listen for Beacon signals, and use them to trigger specific actions. The sort of actions that might happen include sending notifications, navigating to specific areas in the app, or navigate to a web page.

In order to respond to the signal from the beacon the user needs the corresponding app on the mobile phone.

- The custom developed App must be downloaded, installed and enabled by the user
- The notification must be enabled in the mobile phone
- The BLE must be ON in the mobile phone.
- User needs a compatible BLE device



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## Beacon and mobile App

BLE is a technology for transmitting smaller amounts of data though with low data rates. It consumes minuscule amounts of energy allowing Apps to run continuously without draining the battery life of the Mobile phone.

The Apps generally run in the background using BLE with less battery consumption and manual intervention.

Since the technology operates in the background, users don't have to remember to go through the action of opening an app while out and about in the physical world.

Beacon provides an opportunity to deliver information via a new digital channel in the physical world. It's a simple real-time communication mechanism that can be used to collect user data and record behaviour patterns.

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5

## Bluetooth Low Energy

Additional low energy protocol for rapid connection and simple messages over same spectrum.
Communication consists of:
- ➤ Advertising: Devices which want to make themselves discoverable have to transmit periodic signals containing their identification to other devices.
- ➤ Connecting: After device discovery, connection is established and it is possible to read the services that the Bluetooth device has to offer. We can use these services to read or write.

GAP (Generic Access Profile) controls connections and advertising in Bluetooth: determines how two devices can (or can't) interact with each other. GAP defines various roles for devices. Two key concepts are:
- • Peripheral devices are small, low power, resource constrained devices that advertise to connect to a much more powerful central device.
- • Central devices are usually (but not necessarily) a mobile phone or tablet with far more processing power and memory.

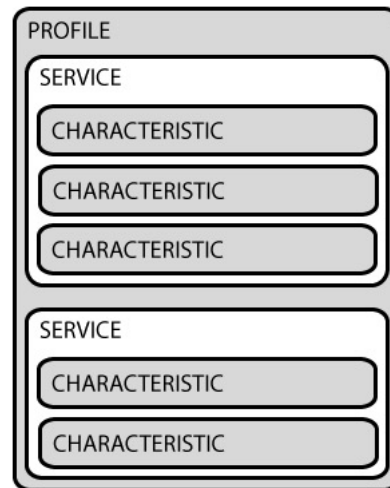UNIVERSITÀ POLITECNICA DELLE MARCHE

6

## Bluetooth Low Energy

GATT (Generic ATTribute profile) defines how two BLE devices transfer data back and forth using concepts called Services and Characteristics:
- Services are logic entities, and contain specific chunks of data called characteristics
- Characteristics encapsulate a single data point

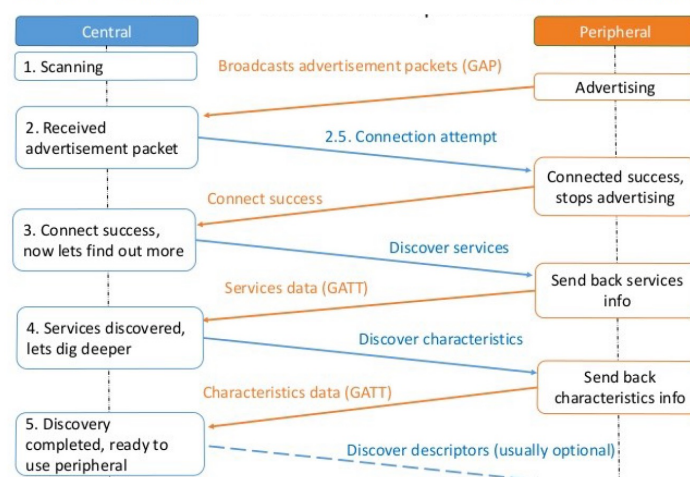Services and Char's are identified by 16-bit or 128-bit UUIDs.

PROFILE

SERVICE
- CHARACTERISTIC
- CHARACTERISTIC
- CHARACTERISTIC

SERVICE
- CHARACTERISTIC
- CHARACTERISTIC

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7

## Bluetooth Low Energy

GATT Client      GATT Server

Central     Peripheral

1. Scanning     Broadcasts advertisement packets (GAP)     Advertising

2. Received advertisement packet     2.5. Connection attempt

Connect success     Connected success, stops advertising

3. Connect success, now lets find out more     Discover services

Services data (GATT)     Send back services info

4. Services discovered, lets dig deeper     Discover characteristics

Characteristics data (GATT)     Send back characteristics info

5. Discovery completed, ready to use peripheral     Discover descriptors (usually optional)
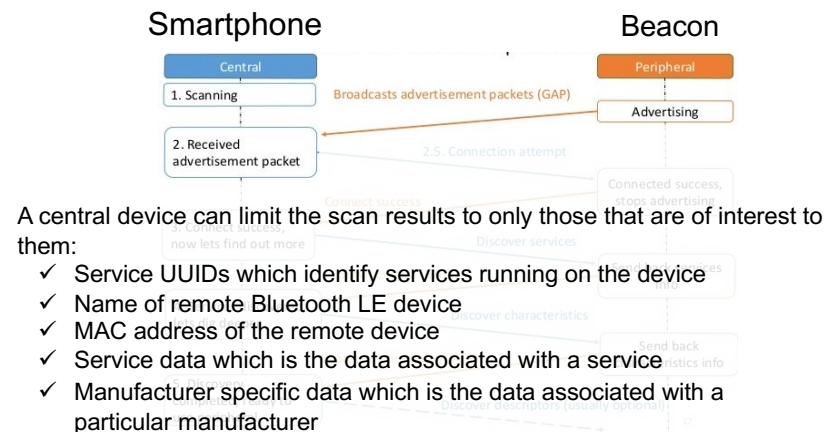
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8

4

# Bluetooth Low Energy and Beacon

BLE beacon technology uses only a portion of the Bluetooth Low Energy protocol: Broadcast advertising. BLE Beacons take advantage of the GAP advertising mode to broadcast data out in periodic, specially formatted advertising packets

Smartphone          Beacon



A central device can limit the scan results to only those that are of interest to them:
- ✓ Service UUIDs which identify services running on the device
- ✓ Name of remote Bluetooth LE device
- ✓ MAC address of the remote device
- ✓ Service data which is the data associated with a service
- ✓ Manufacturer specific data which is the data associated with a particular manufacturer

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# Advertisement Channels

The 2.4GHz spectrum for Bluetooth extends from 2402MHz to 2480MHz. LE uses 40 1MHz wide channels, numbered 0 to 39. Each is separated by 2MHz. Bluetooth Beacons broadcast advertising packets on BLE's channels 37, 38 and 39. The rest are used for data exchange during a connection
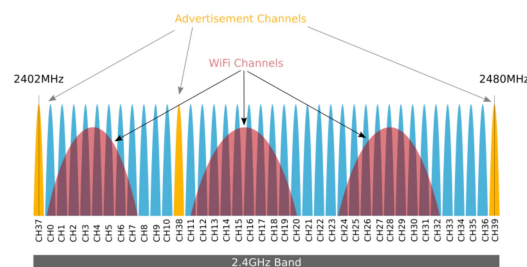


During BLE advertisement, a BLE Peripheral device transmits packets on the 3 advertising channels one after the other. A Central device scanning for devices or beacons will listen to those channels for the advertising packets, which helps it discover devices nearby.

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# Advertising Packet Format

The packet itself has several parts including a preamble and access address, as well as a CRC.
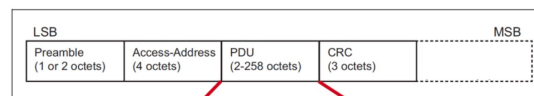


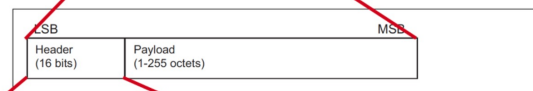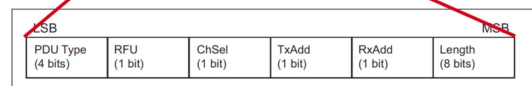Figure 2.1: Link Layer packet format for the LE Uncoded PHYs

Figure 2.4: Advertising physical channel PDU

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11

# PDU Type

There are several PDU types for the advertisements. The right Advertisement flavor to use depends on the specific Beacon application, whether you want to form a quick connection or avoid a connection completely.

- **Directed vs. Undirected**: Directed advertising types accept connection requests from a known peer device, whereas Undirected accept connection requests from any peer device.
- **Connectable vs. Non-Connectable:** determines whether an advertising device allows a connection to be established or not.
- **Scannable vs Non-Scannable**: determines whether an advertising device is capable of handling a Scan Request message from an observer or central. Scan Requests and Responses are used to allow devices to advertise more data than can fit into one advertising packet.
- …

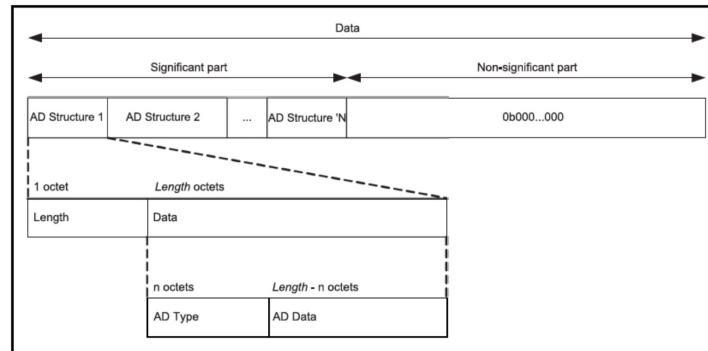UNIVERSITÀ
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12

# Advertising Data



Within the advertising packet, the data payload is structured as:
- The length field. It defines the combined size of the subsequent type and data fields
- The type field. It designates whether the data is a name, a service UUID, a Universal Resource Identifier (URI), or one of many other defined data types.
- The packet data. It is where beacons take the structure a step further, defining a sub-structure inside the data field to determine the various standards

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13

# AD Type

The different BLE advertising data types are:
- **Service UUID**: used to include a list of Service UUIDs
- **Local Name:** the device name (either Shortened or Complete)
- **Flags:** one-bit flags that are included when an advertising packet is connectable. The flags are: LE Limited Discoverable Mode, LE General Discoverable Mode, BR/EDR Not Supported, Simultaneous LE and BR/EDR to Same Device Capable (Controller), Simultaneous LE and BR/EDR to Same Device Capable (Host).
- **Manufacturer Specific Data**: used to include custom data identified by a company identifier.
- **TX Power Level**: transmit power level
- **Slave Connection Interval Range:** a way to communicate the Peripheral's preferred connection interval range in advertising packets.
- **Service Solicitation:** used to "invite" centrals that expose one or more of the specified Services to connect.
- **Service Data:** includes a Service UUID and the data associated with the service.
- …

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14

## Example of advertising data format

Advertising Data
- Flags
  - Length — 2
  - Data Type — Flags
  - LE Limited Discoverable Mode — No
  - LE General Discoverable Mode — Yes
  - BR/EDR Not Supported — Yes
  - Simultaneous LE and BR/EDR (Controller) — No
  - Simultaneous LE and BR/EDR (Host) — No
  - Reserved — 3 bits
- Manufacturer Specific Data
  - Length — 27
  - Data Type — Manufacturer Specific Data
  - Company Id — Unknown Manufacturer (0x5900)
  - Manufacturer Specific Data — 01 C0 11 11 11 11 CC 64 F0 0A 0B 0C
- Non-significant Part — 0 bytes
- CRC — Valid
- Raw Content

Raw data

Data type: Packet Raw Data

```
        0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F  0  1
0x0000: 60 25 20 30 06 18 98 DF 02 01 06 1B FF 00 59 01 C0 11
0x0018: 0A 0B 0C 0D 0E 0F 10 11 12 13 14 15 16 17 18 DB F9 3D
```
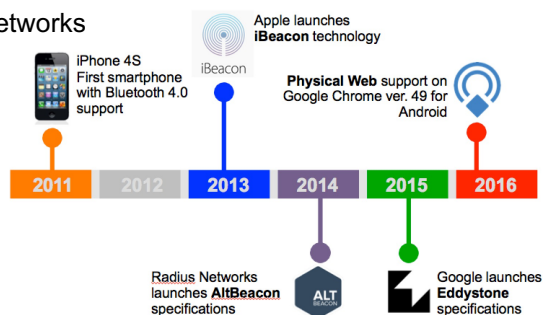
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15

## Beacon technology

The packet data of a Beacon is broadcast in a certain format, a communication protocol that describes the string of characters and numbers that make up the message

The common Beacon standards are:

✓ iBeacon by Apple

✓ AltBeacon by Radius Networks

✓ Eddystone by Google

iPhone 4S First smartphone with Bluetooth 4.0 support

Apple launches **iBeacon** technology

**Physical Web** support on Google Chrome ver. 49 for Android

2011 2012 2013 2014 2015 2016

Radius Networks launches **AltBeacon** specifications

Google launches **Eddystone** specifications

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16

# iBeacon

iBeacon technology was the first BLE Beacon technology to come out (May 2013).

The iBeacon is a proprietary, closed standard that defines advertising packet format. A license from the apple is required to incorporate iBeacon technology in a product

Devices implementing iBeacon protocol can only send one type of signal. iBeacon advertising packet includes an unique numeric identifier of the beacon, coded by three numbers (proximity-UUID, major number, minor number)

Specifications requires also:

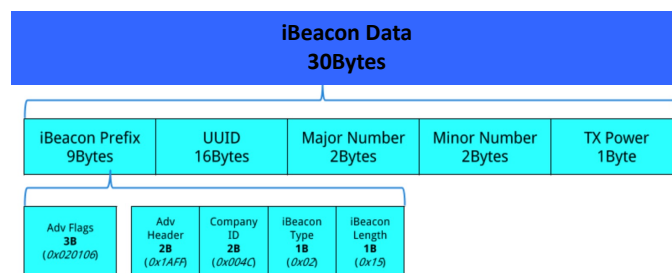. Advertising interval equal to 100msec

. Non-connectable advertising packet

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17

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# iBeacon

| iBeacon Data 30Bytes | | | | |
|---|---|---|---|---|
| iBeacon Prefix 9Bytes | UUID 16Bytes | Major Number 2Bytes | Minor Number 2Bytes | TX Power 1Byte |

| Adv Flags 3B (0x020106) | Adv Header 2B (0x1AFF) | Company ID 2B (0x004C) | iBeacon Type 1B (0x02) | iBeacon Length 1B (0x15) |
|---|---|---|---|---|

The iBeacon Prefix contains fixed data: 0x0201061AFF004C0215. This breaks down as follows:

• 0x020106 defines the advertising packet as BLE General Discoverable and BR/EDR high-speed incompatible. Effectively it says this is only broadcasting, not connecting.
• 0x1AFF says the following data is 26 bytes long and is Manufacturer Specific Data.
• 0x004C is Apple's Bluetooth Sig ID and is the part of this spec that makes it Apple-dependent.
• 0x02 is a secondary ID that denotes a proximity beacon, which is used by all iBeacons.
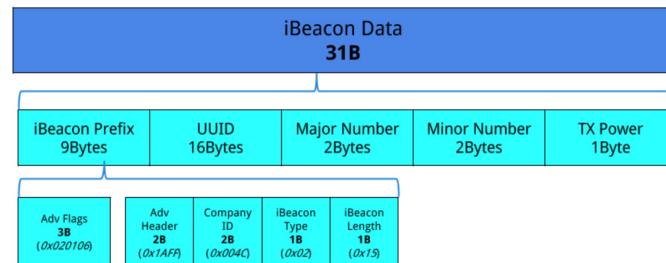• 0x15 defines the remaining length to be 21 bytes (16+2+2+1).

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18

## iBeacon

| iBeacon Data **31B** | | | | |

| iBeacon Prefix 9Bytes | UUID 16Bytes | Major Number 2Bytes | Minor Number 2Bytes | TX Power 1Byte |

| Adv Flags **3B** (*0x020106*) | Adv Header **2B** (*0x1AFF*) | Company ID **2B** (*0x004C*) | iBeacon Type **1B** (*0x02*) | iBeacon Length **1B** (*0x15*) |

- **iBeacon Prefix**. Tells if it is just broadcasting or connecting and also contains manufacturer's specific data
- **Proximity UUID = unique identifier of proximity region** (16 bytes). Refers to the ID which is unique for beacons belonging to a particular company.
- **M = major** number (2 bytes). Used to group beacons. For instance, all beacons in a store will have major number
- **m = minor** number (2 bytes). Used to identify individual beacons.
- **R = RSSI** (**Received Signal Strength Indicator) at 1mt**. Is the strength of the signal measured at 1 meter from the device. Used to estimate proximity knowing the current RSSI obtained together with the received signal.
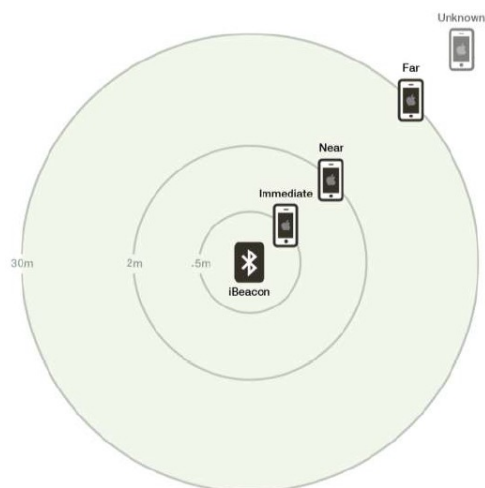
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19

## iBeacon

Leveraging Bluetooth Low Energy (BLE), a device with iBeacon technology can be used to establish a region around an object and determine when it has entered or left the region, along with an estimation of proximity to a beacon.

Ranging:
- Immediate (0.5 m)
- Near (2 m)
- Far (30 m)
- Unknown

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20

# iBeacon

Devices with Bluetooth Low Energy chip can be configured to generate iBeacon advertisements providing the following information:

| Field | Size | Description |
|---|---|---|
| UUID | 16 bytes | Application developers should define a UUID specific to their app and deployment use case. |
| Major | 2 bytes | Further specifies a specific iBeacon and use case. For example, this could define a sub-region within a larger region defined by the UUID. |
| Minor | 2 bytes | Allows further subdivision of region or use case, specified by the application developer. |

Example:

| Store Location | | San Francisco | Paris | London |
|---|---|---|---|---|
| UUID | | D9B9EC1F-3925-43D0-80A9-1E39D4CEA95C | | |
| Major | | 1 | 2 | 3 |
| Minor | Clothing | 10 | 10 | 10 |
| | Housewares | 20 | 20 | 20 |
| | Automotive | 30 | 30 | 30 |

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# AltBeacon

AltBeacons is an open-spec, free beacon design provided by Radius Networks. It is direct response to the closed source iBeacon spec of Apple.

**BLE Advertising PDU**

| 1 Byte Preamble | 4 Byte Access Address | 2 Byte PDU Header | 6 Byte AdvA | 3 Byte AD Flags | 28 Byte AltBeacon Advertisement | 3 Byte CRC |
|---|---|---|---|---|---|---|

**AltBeacon Advertisement**

| 1 Byte AD Length | 1 Byte AD Type | 2 Byte MFG ID | 2 Byte Beacon Code | 20 Byte Beacon ID | 1 Byte Ref RSSI | 1 Byte MFG RSVD |
|---|---|---|---|---|---|---|

The AltBeacon data is composed of 28bytes (26B are user modifiable).
The first two bytes of the AltBeacon are not user modifiable but are set by the BLE stack. ADV Length is 0x1B and specify the length of the advertising data packet. ADV Type is 0xFF and specifies the type as manufacturing data. After that everything is up to the user and can be shoved into an advertising manufacturer data field.
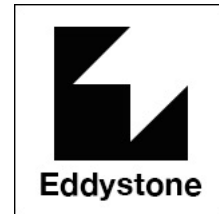
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# Eddystone

First-release Eddystone specifications (July 2015) defines 3 advertising packet formats:

- **Eddystone-UID**: similar to iBeacon (opaque unique identifier), but with a different ID structure
- **Eddystone-URL**: transmit an URL (Uniform Resource Locator) in compact form
- **Eddystone-TLM**: telemetry data (internal status) of the beacon (battery voltage, temperature, counters)
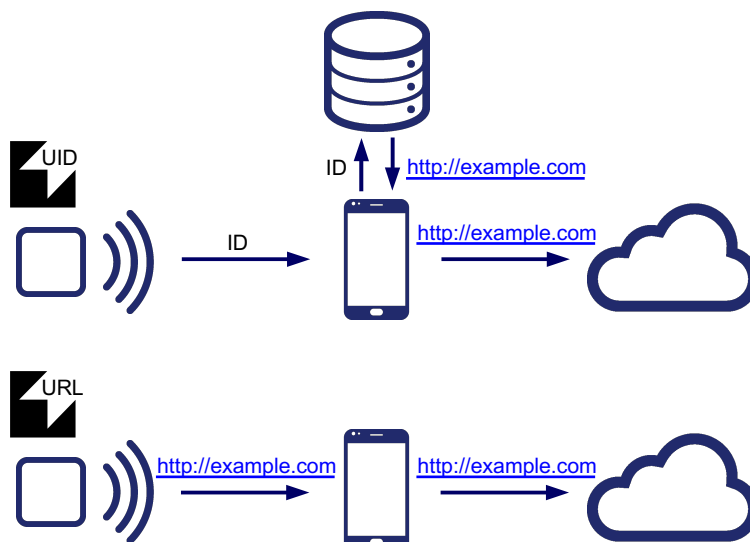
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23

# Eddystone-UID vs Eddystone-URL



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24

# Eddystone Advertising Packet

| 1 | … | 11 | 12 | … | max (31) |
|---|---|----|----|----|----------|
| | | | | | |
| 02 | … | FE | depends on frame type | | |

| 1 | 2 | 3 | 4 | 5 | 6-7 | 8 | 9 | 10 | 11 | |
|---|---|---|---|---|-----|---|---|----|----|---|
| FL | FT | fl | FL | CL | E-UUID | FL | SD | E-UUID | | ......... |
| 02 | 01 | 06 | 03 | 03 | AA FE | 0x*nn* | 0x16 | AA | FE | |

FL = Field Length
FT = Field Type
fl = LE and BR/EDR flag
CL = Complete list of service UUID
SD = Service Data
E-UUID = Eddystone UUID (0xFEAA)

The three packet formats of Eddystone standard share the first 11 bytes of the advertising packet

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25

# Eddystone-UID

| 12 | 13 | 14-23 | 24-29 | 30 | 31 |
|----|----|-------|-------|----|----|
| FT | RD | Namespace ID | Instance ID | RFU | |
| 00 | | | | | |

FL = 0x17 (23)
FT = Frame Type
RD = Ranging Data (RSSI at 0mt; = RSSI at 1mt + 41dB)
**Namespace ID**, identifies a set of beacons (10 bytes)
**Instance ID**, identifies a certain beacon within NID (6 bytes)
RFU = Reserved for Future Use

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26

# Eddystone-URL

| 12 | 13 | 14 | 15 + |
|----|----|----|------|
| FT | RD | US | Encoded URL |
| 01 | | | |

FL = variable, depends on URL length
FT = Frame Type
RD = Ranging Data (RSSI at 0mt)
US = URL Scheme prefix (0x00 = http://www.; 0x01 = https://www.;
                                        0x02 = http://; 0x03 = https://.
Encoded URL = up to 17 bytes (usually compact URL)

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27

# Eddystone-TLM

| 12 | 13 | 14-15 | 16-17 | 18-21 | 22-25 |
|----|----|-------|-------|-------|-------|
| FT | Ver. | VBATT | TEMP | ADV_CNT | SEC_CNT |
| 02 | 00 | | | | |

FL = 0x11 (17)
FT = Frame Type
Ver. = TLM-frame version (currently 0x00)
VBATT = battery voltage (mV) – 2 bytes
TEMP = beacon temperature (°C) – 2 bytes
ADV_CNT = advertising packet counter from power-up (units) – 4 bytes
SEC_CNT = time counter from power-up (0.1sec) – 4 bytes
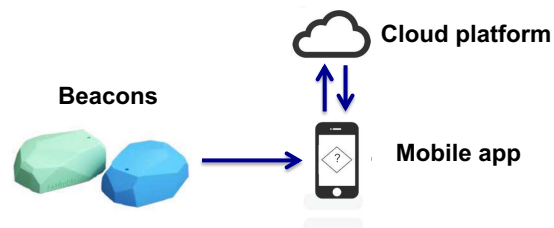
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28

# Custom Beacon system

A typical beacon ecosystem consists of the following
- **Beacons**: Bluetooth Low energy device that broadcast push notifications to Smartphones. Beacons can send iBeacon, AlBeacon or Eddystone formats based on the manufacturer.
- **Cloud platform**: Web based portal where beacons can be setup and managed, so that appropriate content can be shown on a mobile app.
- **Mobile app**: based on the signal being transmitted from beacon, the mobile app can be programmed to to do something. iOS and Android SDK are required so that apps can be beacon enabled with little addition of code.

**Cloud platform**

**Beacons**

**Mobile app**

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29

# Custom Beacon system

Beacon (Sends signal via BLE)
**Step1**

Customer's Mobile (Sense the signal)
**Step2**

**How one beacon works**

**Step 3**
Beaconly
(App sends signal to cloud)

Customer Receives offer /coupon/information
**Step 6**

10% Off

**Step 5**
Beaconly (Formats Information)

**Step 4**
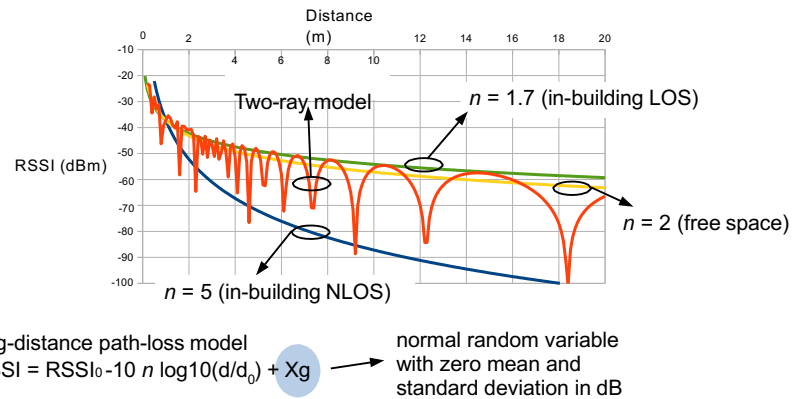Triggers Operations(Action to be performed)

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30

# Ranging with RSSI

Based on the signal being transmitted from beacon, the mobile app can determine its proximity to its beacon using the strength of the received signal (RSSI - Received Signal Strength Indication). RSSI is generally correlated to how far away a device is from the beacon.



Log-distance path-loss model
$RSSI = RSSI_0 - 10\, n \log 10(d/d_0) + Xg$ → normal random variable with zero mean and standard deviation in dB
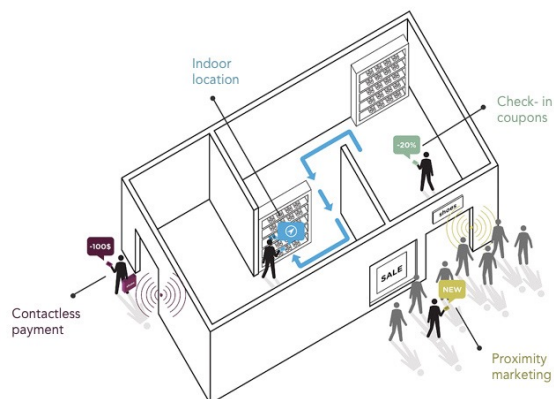
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31

# Beacon and location services

Using Beacon Bluetooth technology is possible to estimate the precise micro-location of users within a store or building redefines indoor mapping and navigation capabilities by providing a new context in which users consume information

Beacon Bluetooth technology is an emerging solution that connects what we are seeing with where we are seeing it, directly and in real-time. It's an intuitive, cost efficient option for adapting to new consumer expectations delivering the right content, at the right time, every time.



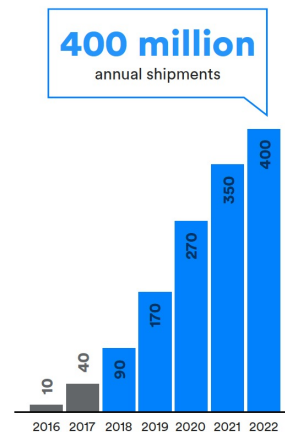UNIVERSITÀ
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32

# Beacon and location services

The Beacon technology available on Bluetooth Low Energy is ideally suited for enabling indoor positioning and location services.

- **Point-of-interest information** (PoI) - Retailers were among the first to adopt PoI beacons. Smart cities are now discovering how PoI beacons can improve the quality of life for citizens and enhance the visitor experience.
- **Indoor navigation** - Bluetooth beacon-based indoor navigation and way-finding solutions have quickly become the standard way to overcome indoor coverage challenges that GPS can't address.
- **Asset and item tracking** - Bluetooth beacons power the rapidly growing asset tracking and item finding markets, from inexpensive personal item tracking solutions to large-scale asset tracking solutions found in hospitals and factory floors.
- **Space utilization** - Bluetooth beacon solutions are being deployed within office buildings, airports, and even on city streets around the world to enable building owners and city planners to better understand how space is being used.

**Bluetooth Device Shipments**
numbers in millions

**400 million** annual shipments

10 | 40 | 90 | 170 | 270 | 350 | 400
2016 2017 2018 2019 2020 2021 2022

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33

# Areas of application

- Deliver in-store offers and e-catalogues to visitors
- Attract new customers with coupons while offering returning customers express pre-order and pick-up services
- Guide visitors with indoor maps, events and the offers to boost revenues
- Flight information, showcase duty-free promotions and special vacation deals
- Send welcome messages, seat maps, and coupons for snacks and goods
- Provide mobile tours for exhibitions as well as museum shop promotions

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34