



IoT

Indoor Positioning with BLE Beacons

Author: Uday Agarwal

Contents

Introduction	1
Bluetooth Low Energy and RSSI	2
Factors Affecting RSSI	3
Distance Calculation	4
Approach to Indoor Positioning	5
Zone Based Approach and Calibration	6
Hardware Setup	7
Indoor Positioning Tests	8
Test Results	9
Conclusion	10
References	10



Introduction

Indoor Positioning is an increasingly interesting topic nowadays. As satellite based navigation technology has improved, outdoor positioning has become a de-facto feature in many products. Companies now deploy maps extensively for tracking and navigation, and there is a growing focus on how the same can be done indoors.

There is a lot of active research in this area, and a lot of approaches have been proposed, such as using the Bluetooth Low Energy beacons, using Wi-Fi Access Points, and with magnetic fingerprinting. Other examples include infra-red sensing and sensor fusion technologies.

In this whitepaper, we evaluate Bluetooth Low Energy (BLE) Beacons acting as the primary technology for indoor positioning, and discuss its pros and cons. At the end of the whitepaper, we present the results of our evaluation.

Bluetooth Low Energy and RSSI

BLE shows a lot of promise in the form of a low powered wireless network. The hardware is portable, easy to deploy, and readily available. Nearly all smartphones today support BLE and there is a large developer community. A beacon is a BLE hardware capable of advertising data at regular intervals. A smartphone can listen to a beacon and get data from the beacon without a physical connection. This means that a smartphone can listen to a lot of beacons at the same time, getting all the nearby data quickly and easily. This connection-less data transfer is the biggest strength of the beacons.

Beacons can also be used to estimate distance to the receiver using a concept called the Receiver Signal Strength Indicator (RSSI). It is the signal strength (in decibels) measured by the receiver (ex. smartphone) when receiving packets from the transmitter (ex. beacon). RSSI reduces as the distance increases, so that we can approximate the distance using the reading.

A Beacon's data typically contains the following information:

- ▶ ID – unique to a beacon
- ▶ Name (optional)
- ▶ Calibrated RSSI at 1m (iBeacon)
- ▶ Calibrated RSSI at 0m (Eddystone)

The calibrated RSSI is the expected value of RSSI read by the receiver when it is at the corresponding distance from the beacon. This value is found by actual measurements and then coded into the beacon to transmit. This value is very useful, as explained in the Distance Calculation section.

Factors Affecting RSSI

The RSSI measured for a beacon can be affected due to a lot of factors, which include:

- ▶ **Distance** – the larger the distance between transmitter and receiver, the lower the RSSI.
- ▶ **Environment** – walls, furniture, and other objects which cause signal attenuation, absorption, or reflection. Each of these would reduce the RSSI value compared to the Line of Sight (LoS) reception.
- ▶ **Obstructions** – (such as people) in between the transmitter and the receiver reduce the RSSI value.
- ▶ **Transmitter antenna power** – the higher the power, the higher the RSSI value, but lower the battery life.
- ▶ **Receiver antenna sensitivity and gain setting** – more sensitive devices read higher RSSI values.
- ▶ **Transmitter and Receiver orientations**
- ▶ **Air density affects the path loss which in turn affects RSSI values.**

Most of these factors are not in the user's control, and so the RSSI readings obtained over time contain a lot of noise. It can get difficult to get a constant RSSI value, even if the user doesn't move an inch.

Distance Calculation

Since RSSI falls with increasing distance, it can be used to approximately derive the distance of the smartphone from the beacon. A commonly used equation to calculate distance from RSSI value is given below.

Equation 1: Distance from RSSI

$$\text{Distance} = 10^{\left(\frac{\text{RSSI 1m} - \text{RSSI measured}}{10 \times \text{Path loss}}\right)}$$

RSSI1m is the RSSI value seen by the receiver, when it is 1 meter from the transmitter. This value is obtained from the calibrated RSSI value which is a part of the beacon's data. Path Loss indicates the environment factor and the value can be between 2 to 4. However, this equation may not be very accurate and results vary between use cases. A plot of the equation with RSSI1m of -77 dB and Path Loss of 2 is shown in Figure 1.

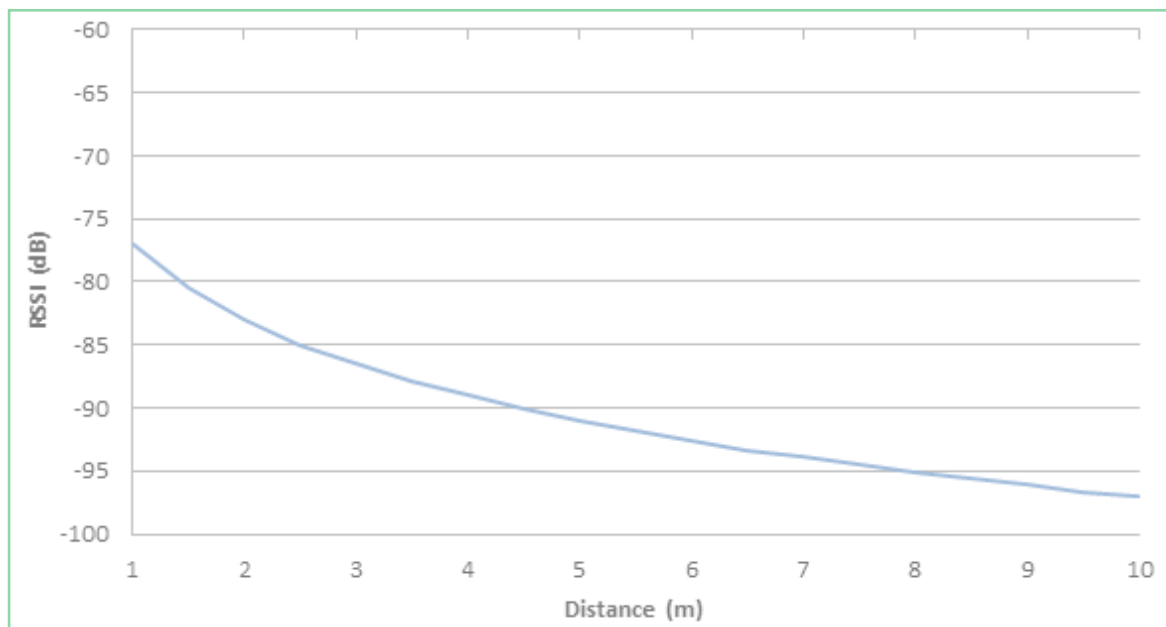


Figure 1: Distance calculation per Equation 1 with RSSI1m = -77 dB & Path Loss = 2

Approach to Indoor Positioning

Indoor positioning can be generally approached in two ways: precise and zone based. Precise indoor positioning implies identifying the exact user position at all times, with an accuracy of up to one meter. It involves measuring the distance of the user from fixed points nearby, whose positions are pre-known (these fixed points can be beacons in case of BLE, and Wi-Fi Access Points in case of Wi-Fi, etc.), and using trilateration to calculate the user position. Trilateration is also used by GPS for outdoor positioning.

Zone based indoor positioning involves creating multiple zones to cover an indoor location, and then identifying the zone in which the user is currently present. The zones could be as small as 1m x 1m (for example, adjacent to a painting in a museum), or as large as 10m x 10m (for example, a hall). Thus, the zone size could be

decided by the administrator during initial setup, depending on the accuracy desired. For BLE, this approach uses the concept of proximity from a beacon, where we classify a user as located Immediate, Near, or Far from a beacon. This gives us an estimate of the user's position without involving too much computation. Immediate range is usually defined as less than one (or sometimes two) meter(s). Near range is usually between two and six meters. Far range is usually beyond six meters.

BLE Beacons work best with the zone-based approach because the noise in RSSI leads to error-prone distance calculations preventing a precise positioning. In the remainder of this whitepaper, we discuss the experiments and results of the zone based approach.

Zone Based Approach and Calibration

In case of the zone based approach, a system calibration must be done to define the values of Immediate, Near, and Far ranges. For example, the Immediate range could be under a meter, the Near range could be between one and six meters, and the Far range could be beyond six meters. In this case, the user can stand exactly one meter away from the beacon, facing it, and record the RSSI readings on his/her phone. The mean value of these readings would define the boundary of the Immediate range. Similarly, the mean value of the RSSI readings at six meters, combined with those at one meter, would define the Near range, and likewise the Far range. Once the calibration procedure is complete, the recorded values are stored in a database, which would then be queried at runtime to establish the zone for a given beacon, using the measured RSSI value.

Such an implementation results in gradual boundaries instead of sharp ones, since the RSSI can vary slightly at the edges of the various ranges. As an example, the Near range could have an upper limit falling between 5 and 7 meters, rather than a crisp 6 meters. This variation is usually acceptable in most scenarios.

RSSI values depend on the transmit power, so different beacons with different configurations of transmit power would result in different RSSI values at the same distance.

Thus, ensure that beacons have the same transmit power before proceeding with calibration. Another important point is that RSSI readings vary from handset to handset, and this is a key problem considering different Android based phones. One way to compensate for this variation is to use a good quality (high sensitivity) phone and calibrate while standing a little further away from the desired range limit. For example, when calibrating for Immediate range to be up to one meter, calibrate while standing at 1.2-1.5 meters. The signal level picked up by a high sensitive phone at 1.2-1.5 meters can be at the same level as a low sensitive phone at one meter. Similarly, Near range could be calibrated at 7 meters instead of 6 meters. This way we can accommodate various handset models.

Hardware Setup

For the purpose of our experiments, we used beacons manufactured by Kontakt.io[1]. These beacons have Nordic Semiconductor's nRF51822 chip, and have a CR2477 battery.

We configured the beacons for Eddystone UID format, with an advertisement interval of 350 ms. We tried different values of the transmit power, from 0 dBm down to -30 dBm. As we lowered the transmit power, the signal range reduced, until it was about a meter at -30 dBm.

We used various android phones for our tests. The most important ones being:

1. OnePlus 3T (Android 7.1)
2. Motorola G5 (Android 6.0)

Many of the previous generation phones had poor BLE hardware, so they couldn't perform as well (there were lots of dropped packets). Apart from the ones mentioned above, a few other phones that worked reasonably well were: Nexus 5, Samsung Galaxy S5, and Motorola G3.

Indoor Positioning Tests

We started by plotting the RSSI graphs at various distances, using multiple sets of beacons and phones. First, we placed 10 beacons in a grid based layout in an office space (30m x 30m). Any two beacons had about 6 meters space between them. These beacons were pasted on the walls or pillars, with a placement height of 2 meters from the floor. We recorded RSSI values for a particular beacon, facing it; with the phone held horizontally at a height of about 1.2 meters from the floor (this scenario imitates a user standing with the phone in his/her hand). The beacon was always at line-of-sight from the phone. We started close to the beacon (1 meter apart)

and gradually walked backwards, crossing 5 meters, facing the beacon all the while. For the purpose of this whitepaper, we set the beacons to -12 dBm of transmit power. When varying the transmit power, we observed similar behavioural patterns (higher power leads to higher RSSI). We created a custom app to measure RSSI values, and also used the Beacon Toy[2] app to confirm that our app performed similar to a known app in the field. The result for one such measurement is shown in Figure 2. Note that Kontakt.io mentions that for a beacon transmitting at -12 dBm, the RSSI1m should be -77 dB[3], the reference graph for which is shown in Figure 1.

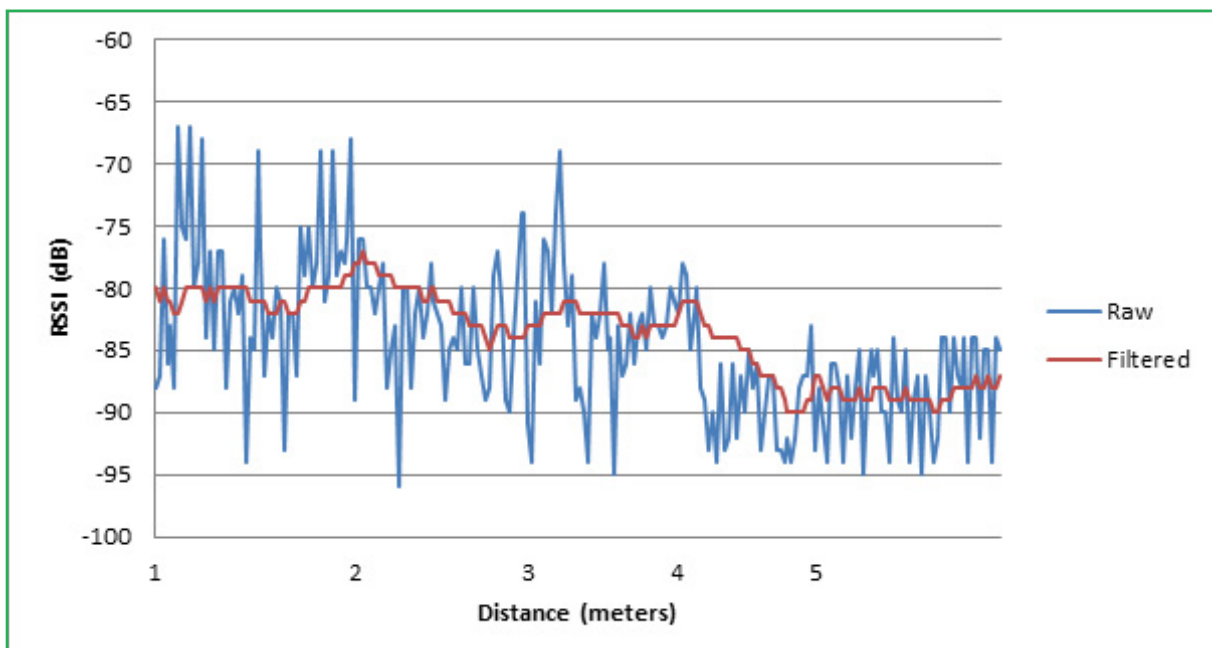


Figure 2: RSSI Graph indoors as we move away from a beacon, Transmit Power = -12 dBm

Test Results

In Figure 2, the blue graph shows the raw RSSI values, while the red graph is the filtered version. As seen here, a lot of noise is present in the readings, due to which it is hard to know the accurate value. To compensate for this noise, we created a custom low-pass filter with a thresholding technique, such that sudden large variations in RSSI were ignored, and gradual small ones were accumulated. The filtered output was then used for our zone-based approach.

Another important observation is that **RSSI does not vary much over distance, which means that it is very hard to determine the distance a given RSSI corresponds to.**

But it is relatively easier to decide the zone for the beacon since each zone has a corresponding range of RSSI values.

Conclusion

For indoor positioning using BLE Beacons alone, a zone-based approach is a better alternative to precise positioning. This is because the RSSI value has a large amount of noise, which leads to uncertainty in the user's position. A zone based approach supports a range of RSSI values for each zone, and hence can be used much more effectively.

In order to get a precise location, beacons are not enough, and some sensors must also be leveraged. The most important sensor is the accelerometer, which can be used to compute the distance travelled by the user over time. Furthermore, the compass can be used to know

the user's direction at all times. The gyroscope gives us information of when the user turns, and a fusion of these three sensors can give us the overall movement of the user over time.

If we take beacons as the fixed points (just like in the precise positioning approach) and know a precise location at some point in time (for example when the user is in the Immediate range of a beacon, say at the entrance of the building), we can calculate the next position based on the sensor data. The beacons would then serve as the anchor points for coarse position, while the sensor data will help with finding the fine position.

References

1. Kontakt.io Beacon
2. Beacon Toy app
3. Kontakt.io – Transmission Power, Range and RSSI

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Office No. 501, Amar Megaplex Baner, Pune 411045

Tel: +91 20 4660 4000 | Fax: +91 20 4075 6699

www.talentica.com

