

Feasibility of Bluetooth iBeacons for Indoor Localization

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Abstract: Location-based Services in buildings represent a great advantage for people to search places, products or people. In our paper we examine the feasibility of Bluetooth iBeacons for indoor localization. In the first part we define and evaluate the iBeacon technology through different experiments. In the second part our solution application is described. Our system is able to estimate the position of the user's smartphone based on RSSI measurements. Therefore we used the built-in smartphone sensor and a building map with required sender information. Trilateration is used as positioning technique in contrast to fingerprinting to minimize beforehand effort. Results are promising but cannot reach the same accuracy level as sensor-fusion or fingerprinting approaches.

Keywords: Location Based Services (LBS), Indoor Localization, Bluetooth iBeacon, Trilateration, RSSI (Received Signal Strength Indicator)

1 Introduction

The field of Location-based Services (LBS) is a rapidly growing market. Nowadays there are already a lot of mobile applications where Location-based services are integrated. The main impulses for this growth in the LBS sector are the fast growth in the smartphone market as well as in the telecommunication area (EDGE, UMTS and LTE). There are a lot of definitions for LBS, but in general it means that the current position of the user is used to provide context-related data. The classic and most known example for a Location-based Service application is a navigation system. The application uses the current user position in order to make position related information available like POIs, traffic jams, and more. A common example is the search for a Point of Interest (POI) like a restaurant. The navigation system then makes use of the user position, searches for restaurant in the immediate vicinity and then routes the user to the selected restaurant. But there are also a lot of other use cases like advertising, sport activity tracking, car sharing, etc.

Up to now most of those Location-based Services are designed for the usage in the outdoor area. Consequently, as Outdoor Location-based Services are a great success, the next logical step would be to realize Indoor Location-based Services (ILBS) as well, to provide those additional, position related information also in a building. However, the realization of Indoor Location-based Services is facing completely new challenges.

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ILBS provide new opportunities to increase the user experience within buildings and bears the potential for new business areas [LLG13]. Possible areas of application are for instance airports, stations, shopping centers, museums, office buildings and a lot more. Use Cases in these areas could be indoor navigation, search for POIs, get vouchers and offers in the shopping center, guiding tour through the museum, etc. Despite the facing challenges, Indoor Location-based Services becomes more important. There are several indicators which confirm that companies like Google and Apple are researching in this area. Google Maps started at the end of 2011 to offer the opportunity to integrate building maps into the map data in order to enable indoor navigation. Furthermore Apple developed an own technology based on Bluetooth Low Energy, called iBeacon

As already mentioned before, ILBS leads to some challenges. Basically, the greatest challenge is to obtain a correct and accurate localization of mobile devices within buildings. The inaccuracy can be attributed to the presently used localization techniques. At the outdoor area the localization mostly occurs based on GPS- / GSM techniques. The localization highly depends on the reception of the GPS signals. The reception of the signals is strongly affected in buildings. Due to that indoor localization is really imprecise. Indoor Location-based Services require a good accuracy in a range of a meter or even centimeters. For instance in an office building there are several rooms close together and an accuracy of 5 meters is not sufficient to navigate to a specific room. For that reason other technologies like Infrared, Wifi and Bluetooth are used to build up an Indoor Location-based Service. We will deal in our paper with an examination whether Apple iBeacon Bluetooth technology is suitable for indoor localization.

1.1 Problem description

Localization refers to the problem to calculate or estimate a user's position within a specific map area. Indoor Localization aims to solve this problem within a specific building or federation of buildings. As described earlier, GPS or other widely-available signals like cellular networks are not feasible for this task, because they require line-of-sight and are highly affected by obstacles. Therefore the current approach is to use a specific infrastructure of senders within a building. The task of indoor localization is to calculate the position of the receiver based on received signals from known senders within the map area. There are various research questions which should be considered in our study. These research questions are the following:

- Are Bluetooth iBeacons a good choice for using in indoor positioning systems?
- How accurate and precise is a Bluetooth iBeacon based indoor positioning?
- For which use cases does an indoor positioning application based on Bluetooth makes sense?
- What are advantages and disadvantages of Bluetooth?

2 Related Work

Most approaches in literature and commercial systems use radio-frequency reference signals (WiFi and Bluetooth) in combination with other sensors (inertial, barometer, compass, vision, etc). The best combination of these sensors depends on the available sensors of the devices and already installed infrastructure at the building. In our paper we restrict to only one information source, the Bluetooth signal, nevertheless we present some other approaches.

Sensor-Fusion approaches reported by Zampella et. al [ZJS13] use foot mounted inertial measurements in combination with any available radio frequency measurement. The position is calculated using a particle filter, which is updated when a step from the inertial measurement system is detected. The result is 2 meter accuracy in 90 % of the estimates. Other sensor-fusion approaches are described in [He14] and [KS13]. Real world installations in use are implemented for example from the company Infsoft. Infsoft is a german company providing indoor localization to Frankfurt Airport. They also use any kind of sensor as well as GSM and WiFi signals to estimate the user position, reporting up to 1 meter precision [In15].

Another approach is to avoid the use of signals to increase scalability, avoiding installation costs and maintenance. Woodman and Harle [WH08] use also a foot mounted inertial unit and a detailed building map model to provide absolute positioning. They could also handle stairs and multiple floors within their system. WiFi signals are used to initialize the user position.

RF signal only approaches typically use Bluetooth, WiFi or ZigBee. Adalja and Khilari report up to 2 meter accuracy using fingerprinting and Bluetooth [AK13]. Saxena et al achieve 1.1 meter accuracy with 90 % probability using WiFi and fingerprinting [SGJ08]. On the other side trilateration positioning technique and Bluetooth could only reach < 5 m precision with 85 % probability as reported by Dahlgreen and Mahmood [DM14].

3 Methodology

Our basic approach is to use the Apple API and use the Received Signal Strength Indicator (RSSI) of our Bluetooth senders to locate the user's position. Our goal is then to reach < 2 m precision, which is a sufficient value to build an Indoor Localization App that we will describe in Section 7.

Therefore we will model a map with senders S and their position $P(x,y,z)$ in cartesian coordinate system. The RSSI is then used to calculate the distance to the sender and locate the user by trilateration algorithm. Our Experiments are done with kontakt.io Bluetooth Beacons and an iPhone 5 running iOS 8. Finally, we tested the feasibility of indoor localization by the help of our developed App within the university building.

4 Bluetooth iBeacon Technology

Apple introduced a proprietary standard called iBeacon based on the Bluetooth 4.0 Low Energy (BLE) specification, which was designed to enable additional location-based services. BLE introduced a new advertisement mode. The purpose of this advertisement mode is to build low-cost and low-power devices or sensors like smart-watches or fitness wristbands. The key idea behind this concept is to use cheap Bluetooth senders (iBeacons) which broadcast advertisement packets in a specific interval using the BLE advertisement channel. iBeacon defines a specific data structure for these advertisement packets, which is shown in Table below. [Ra13]

<i>Header</i>	<i>Manufacturer</i>	<i>Company Id</i>	<i>ADV Id</i>	<i>UUID</i>	<i>major</i>	<i>minor</i>	<i>Tx Power</i>
64bit	8bit	16bit	16bit	128bit	16bit	16bit	8bit

Most of the fields are not of interest. Only the last four fields UUID, major, minor and Tx Power are useful for localization. UUID, major and minor are used to identify a specific sender. These fields can be set manually to define groups of senders. For example the UUID is typically used company-wide whereas major is used to identify buildings or floors and minor is used to identify specific beacons. Calibration of the senders is already done by the manufacturer of the iBeacon within the field Tx Power which describes the RSSI value in 1 meter distance. The iBeacon specification describes no additional field for payload data which can be used for localization. Nevertheless Apple advertises this technology to estimate the location of the user.

Besides the correct calibration of the sender other settings are of utmost importance. This includes the advertising interval, typically in a range of 100 ms up to some seconds, and also the power level, which defines the signal strength and therefore has impact on transmission range. The maximum transmission power for a Class 2 Bluetooth sender is 2,5 mW, which should cover approximately 10 m by air [Wr15]. Our used beacons reached at maximum power level (4dBm) about 35 m in Indoor environment by air, what is definitely less than the manufacturer advertises with about 70 m, but still far good for a Class 2 sender. The higher the transmission power and the lower the advertising interval, the higher is the power consumption of the iBeacon, but it also has impact on the accuracy of the localization as we will show through different experiments in the next section.

In our test Application we used the Apple CoreLocation API to retrieve the necessary information of the iBeacons in range. The API basically returns UUID, major, minor and Received Signal Strength (RSSI) for each iBeacon in range. Apple states, that the RSSI value of the API is not exactly the RSSI, but an average of multiple RSSI readings. As far as we could identify, this represents the mean RSSI value in a timeframe of one or multiple seconds. Another major drawback of this API is that it only returns data each second. Consequently, for a fast moving receiver this API can't reach a high localization precision, but it should be sufficient for a walking person. On the other hand, the API returns an

accuracy value, which estimates a distance in meter to the iBeacon using an undisclosed algorithm based on RSSI. Apple states that this value is not intended to identify a precise location of the iBeacon, but we intended to test the precision of this accuracy value [Ap14].

5 Experiments

In the following section we describe several experiments to test correlation between RSSI and distance to the sender as well as precision of API calculated accuracy value.

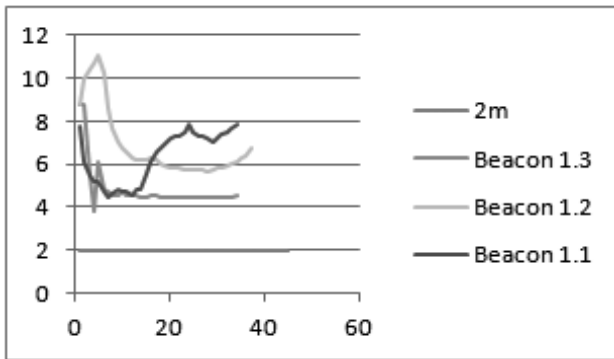


Figure 1: accuracy value vs. real distance (2m) at power level 3

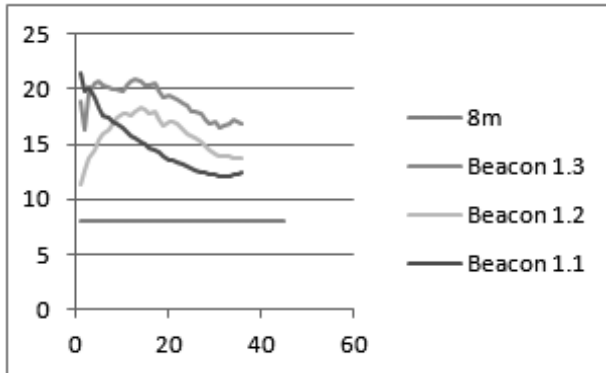


Figure 2: accuracy value vs. real distance (8m) at power level 3

Our first experiment tests the API accuracy value against the real distance at default power level 3. As you can see in Figure 1 and 2, at the beginning the values fluctuate a lot and stabilize after a few seconds. From our point of view this results due to the fact that the Apple API is using a mean value for RSSI. At this power level the accuracy values are about 2-3 times higher than the correct distance.

Now the next interesting question is how the power level influences the accuracy value. In Figure 3 you see the accuracy value at 1 meter real distance. For power level 3 the accuracy value is quite precise, but at power level 7 the value is 5 times lower than the real distance. In conclusion, we assume that the Apple algorithm works best with the power level 3 and not with the highest transmission power of 2 mW. As a result the accuracy doesn't reach the precision needed for indoor localization, instead we propose to create linear curve fit for RSSI and distance. Curve fitting reaches far better results than the Apple API. Another advantage is that it can be fitted for different power levels as well as for specific senders of different manufacturers. [SGJ08] describes results of 1.1 m precision with 90 % probability using linear RSSI distance curve fitting.

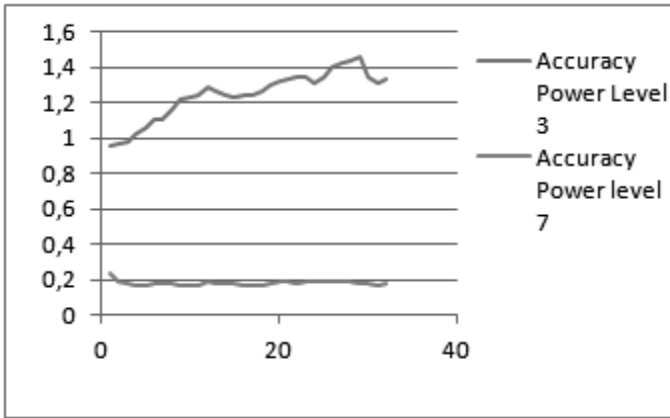


Figure 3: accuracy value at different power levels at 1m real distance

Linear curve fitting gives following relation between RSSI and distance:

$$\text{RSSI}(\text{dBm}) = -n \times \log_{10}(d) + A$$

In this formula n is the propagation constant or path-loss exponent and d is the distance in meters. A is the received signal strength in dBm at 1 meter distance, which is equivalent to the calibration Tx power the iBeacon standard wants to solve. [Og13]

In Figure 4 we plotted the RSSI values the API returns for different iBeacons. Because of external factors like absorption, interference or diffraction—the RSSI value tends to fluctuate, which is the biggest problem as you can see in our measurements. Beacon 1.3 is the most precise in our tests, whereas the other two beacons range between 10 dBm. Therefore we propose to use a mean RSSI value of 2 or 3 measurements. Further improvements could be achieved by including an obstacle factor which can be resolved from the map.

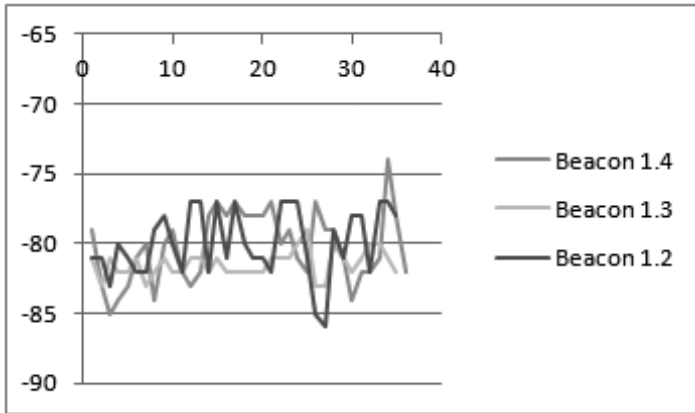


Figure 4: RSSI value (in dBm) at 8 meter real distance and power level 7

6 Positioning Techniques

There are different positioning techniques for indoor positioning systems. The most commonly used techniques are trilateration, triangulation, fingerprinting and Time of Flight (TOF).

Trilateration: For trilateration at least three senders (beacons) are necessary. The beacons have a specific range which is represented as a circle with radius of the distance or as a sphere in 3D space. The current location is where the three circles overlap. Hence, the location is determined by measurement of distances, which can be calculated by RSSI and some fitting algorithm as we described in the section before.

Triangulation: Triangulation is similar to trilateration. The difference is that triangulation involves the measurement of angles instead of distances. This method cannot be used with iBeacons, because the API doesn't provide any angle value.

Fingerprinting: The basic idea of fingerprinting is to create a map of measurement vectors at specific locations in a first phase. These vectors and locations will be stored. In the positioning phase the device returns a measurement vector. This vector is matched against the collected data by the help of some algorithm like k-nearest neighbor. The best matching vector is then proposed as location. Fingerprinting has the advantage that it reaches high precision. On the other side it is necessary to create a large map of measurements which is not feasible for large buildings like airports.

Time of Flight: Time of Flight calculates the distance between sender and receiver by the time the signal takes to travel. Electromagnetic waves travel at known constant speed. The main drawback of this technique is that each receiver and sender needs a high-precision synchronized clock, which can't be easily realized with cheap hardware.

In our work we used trilateration as positioning technique. This is based on RSSI calculated distances. This decision is due to the fact that the trilateration algorithm is simple in implementation and requires low infrastructure setup effort, but also promises relatively high accuracy. The main problem with this approach is that it is prone to measurement errors. Wrongly calculated distances have high impact on localization precision. There is a lot of ongoing research how to improve the distance calculation based on RSSI. For example Gaussian-weighted correction model were proposed in [Ge15].

7 System Design and Implementation

After the theoretical basis which covered iBeacon technology, distance calculation and positioning techniques we present our system design and implementation. Our indoor localization solution approach can be categorized in five areas:

1. **Modelling:** Build a map e.g. usage of JOSM for OSM Data
2. **Rendering:** Generate an image based on the map and rendering rules
3. **Data Storage:** Storage for map data, Points of Interest, etc.
4. **Sensors:** Bluetooth Signals, usage of Beacons and iOS CoreLocation Services
5. **Positioning:** usage of Algorithms e.g. Triangulation, Fingerprinting

Before these five areas will be discussed in more detail, an overall technical architecture diagram will be illustrated. This diagram shows all necessary components and also how the defined areas belong together to build the indoor localization application.

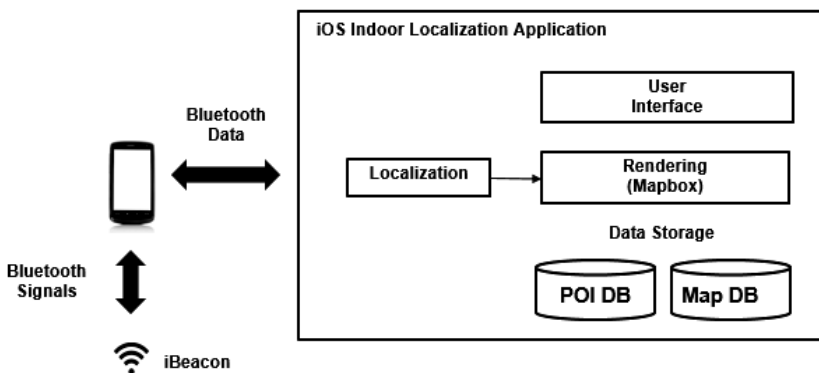


Figure 5: Technical Architectur

7.1 Modelling

For map building we are using JOSM (Java OpenStreetMap Editor) [JO15], an editor for OpenStreetMap Data. It is possible to download extracts from the database i.e. map data and to extend and load back this data. That means that a specific building can be extracted from the database and thereupon can be enhanced with an indoor map e.g. office rooms. Figure 6 illustrates the process of creating an indoor map.



Figure 6: Process of creating an indoor map

Usually, building maps exist as a file for example a JPG image. This JPG image has to be converted in a new data structure to make it useful for localization approaches. Information like POIs, Rooms etc. must be extracted in order to include them into our indoor localization application. Therefore we are using nodes, relations and ways in JOSM to represent the rooms, corridors and Points of Interest. Additionally the JOSM editor provides tagging functionality. Tags can be used to describe the type of the nodes and ways, for instance the various levels of the building, room reference, amenities, corridors, stairs and a lot more. These tags are structured as a key/value pairs e.g. amenity=café. Our iBeacons are defined as nodes with following tags: beacon=yes, major=1, minor=1 depending on the major and minor values. Each node and so each beacon has specific coordinates assigned. The following Figure shows the created map. On the left there is the map of the building, represented with the aid of nodes and ways. On the right there are some properties like for example the tags, relations and layers.

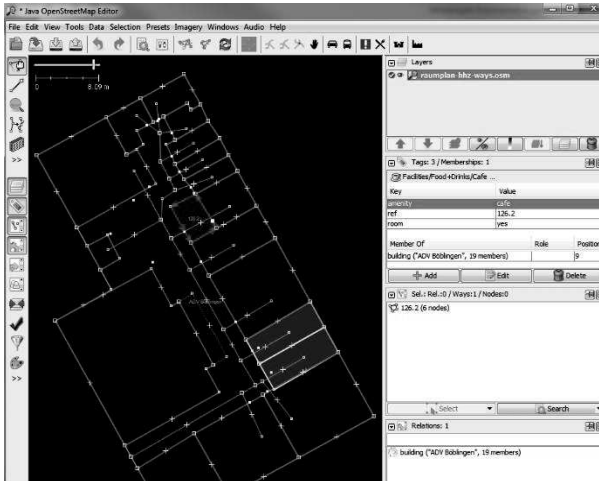


Figure 7: JOSM Map

7.2 Rendering

Rendering is the process of taking raw geospatial data and building a visual map based on that. Various rendering software applications and libraries are present. Most of them support different file formats as map data input e.g. XML, OSM, GeoJSON, PostGIS, SQLite. In our rendering process the previously built map is the basis. Rendering provides the flexibility to display maps in different styles. The map can be styled in many ways for example highlighting specific areas like amenities.

7.3 Data Storage

Our map is stored in XML format and as a sqlite database locally on the device. The XML is used to extract POI data. The sqlite database contains rastered tiles built by the rendering framework. A tile is a map extract in quadratic form. This type of storage reduces memory consumption by only loading the tiles from the database which are necessary for display. Other map data doesn't have to be loaded into memory.

7.4 Sensors

For the final App we used the Beacons on maximum power level to increase the transmission range. The Beacons, which are modeled in the map are arranged at a distance of around 15 m between each other. The Apple CoreLocation API method `didRangeBeacons` will return a sorted array of Beacon objects each second [Ap15]. From these objects we read major and minor to retrieve the location of the beacon from our map data. The next step then is the calculation of the position out of the measured RSSI values of the Beacons.

7.5 Positioning

Our positioning algorithm always uses the three strongest sending iBeacons. In the first step we calculate the distance to the Beacon based on our RSSI curve fitting method, described in section 5. After that we determine the position using the trilateration algorithm. Our results are promising. In clear line-of-sight environment we achieve $\sim 1\text{m}$ precision. On the other side, if obstacles like walls or persons block the transmission our system cannot calculate the distance accurately and fails to achieve high precision. Our tests inside the building achieved only $\sim 5\text{m}$ precision, which is not enough for indoor localization.

8 Conclusions and Future Work

With our described solution we examined the feasibility of iBeacon technology for indoor localization. This technology can be used with modern smartphones which support Bluetooth 4.0. Our approach is based on a before-hand created map of the building and the

positions of our iBeacon senders. In the second step we calculated the distance between device and sender using RSSI linear curve fitting. Finally with the help of trilateration algorithm our solution estimated the position of the user.

The results are promising. In clear line-of-sight we achieve $\sim 1\text{m}$ precision, but if obstacles block the transmission, precision of our solution drops heavily to only $\sim 5\text{m}$. These results are not feasible for indoor localization and have to be improved through further applications. Therefore we propose hybrid approaches like [He14] stated. Furthermore an obstacle factor for distance calculation could improve precision. Other Positioning algorithms like Fingerprinting promise better precision, but require more fore-hand effort. A more fine-grained distribution of iBeacons would also have a major impact on the precision. On the other side large scale iBeacon distribution induces Infrastructure management.

The current state of our solution is applicable for large buildings like airports where high precision ($\sim 1\text{m}$) is not necessary. On the contrary most indoor localization use cases require high precision to create added-value for users. Location-based Services in buildings offer a great advantage for customers to search places or products. The iBeacon technology developed by Apple Inc. enables retailers to send specific notifications to smartphones, if the user is near to specific Beacons. There are not only use cases for location-based advertising like notification sending, but it is also possible to guide or track customers within shops. Such use cases require high precision, which our current solution cannot provide, but one can imagine the variety of possible applications.

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