Method of iBeacon Optimal Distribution for Indoor Localization

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Abstract. Currently one of the most widely used systems for GPS locating is very suitable for outdoor environment, but in buildings is practically not applicable. For indoor locating, the device based on Bluetooth can be used. It can measure and determine the approximate location. This article deals with the issue of building a network of transmitters on the basis of which the position can be determined and presents a new method for the assessment of a layout of individual transmitters in the building.

Keywords: iBeacon · Localization · Mobile context · Bluetooth 4.0 low energy

1 Introduction

Fast wireless data networks, smart mobile phones as versatile and multifunctional devices, along with the decreasing price of these components are now increasingly talking about Internet of things. The Internet of things, i.e. interconnection of commonly used devices should greatly facilitate our lives and create smart environments. Smart environments can then automatically respond to user's initiatives and help him/her solve everyday problems.

One of the characteristics of smart environments is that equipment working in it is able to interact and "intelligently" respond to the user's initiatives or automatically based on the current context to predict the user's desires. A simple example of interaction in such an environment can be e.g. automatic dampening of the lighting in the room after a user begins to watch a film from the DVD player. The smart environment enables to provide a wide range of services based on the current context (state) without asking them.

The following basic contexts are usually distinguished: [1]

- Location
- Identity
- Time
- Activity currently carried out, state

The following text will focus on the issue of localization inside buildings in order to provide contextually relevant services.

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2 The Issue of Localization in Buildings

One of the most common ways of the localization is Global Positioning System (GPS) technology, which has basically become a standard for localization in the open field [2]. Nevertheless, the localization using GPS module device does not have in some cases sufficient accuracy and it is difficult to use it inside buildings [1, 2]. For localization inside buildings, it is therefore advisable to choose a different technology.

Bluetooth Smart 4.0 technology, which has very low energy demands on its device in comparison with previous types [3], has become an interesting medium for localization inside buildings. So as to be able to perform the localization using this technology some infrastructure should be created, similar to that which is used at GPS, where the localization infrastructure is formed by satellites. Apple's standard called iBeacon, which was established in 2013 [4], was chosen to create such a localization infrastructure.

iBeacon is a device - an electronic beacon, enabling to transmit certain data on Bluetooth 4.0 LE (low energy) protocol. These data may be information on the current ongoing discounts in the shop on a certain type of goods, data with the position etc. The device consists of a small transmitter powered with a 1.5 V-hour battery that can supply the device according to required performance for several years. The battery life varies from manufacturer to manufacturer [5, 6].

For the localization a device which can process Bluetooth 4.0 LE signal is needed. Theoretically, only Bluetooth 4.0 support is required, but practically the support in the actual operating system device is necessary. As the author is Apple, support in iOS version 7 and above is exemplary. The most widely used Google Android system supports this technology without restriction from version 5.0 and the third most frequently represented Windows Phone integration is not even in Version 8.1. iBeacon transmitters can be used for both possibilities of targeted ads and the possibilities for localization providing proper positioning of each transmitter.

Each iBeacon has its own unique identifier. With the ability to measure the signal strength from the iBeacon or more iBeacons, the position of the device which receives the signal/signals can be determined. This positioning system requires a functioning digital map of the area in which the localization will be carried out and also the well known position of individual transmitters. Nevertheless, determining the position based on the signal strength from of each iBeacon may be hiding certain issues in the form of difficulty in determining the correct position of each iBeacon in covering space.

3 Related Work

The accessible literature describes many ways of localization based on the method of collecting and processing fingerprints of signals. Two basic groups can be identified [7]:

- A calculation based on the location of the transmitters of signals.
  - Triangulation method is used to determine the positioning.

- Comparing the measured values of received signal/signals with stored reference fingerprints in the database. It can be further divided into [9]:
  - The nearest neighbor
  - K-nearest neighbors
  - Probabilistic method
  - Method of Neural Networks
  - Support vector machine
  - Smallest *M*-vertex polygon

Due to the diversity of different algorithms and particularly with regard to their accuracy and resistance to accidental impacts, various solutions, how transmitters should be distributed/placed, can be found in the literature [8, 13, 14].

Some solutions are based on observations of radio signal spread used when measuring the signal strength at different locations [10]. Therefore, in principle, it is an identification of locations of transmitters based on power, noise level and signal quality. To ensure reliable results, the measurement must be repeated several times.

Another approach is to use discrete mathematical methods. It is a distribution of the covered area with a cell grid. Particular transmitters are then placed in the middle of the cells. It is very important to select an appropriate accuracy of the grid [13–18].

Some models use both of these approaches. To optimize the deployment, a signal loss (path loss) or the signal strength (power) can be used. Model based on signal loss can be built on different properties which are known to spread the signal. It may be, for example, the average loss of signal on the path, the maximum loss or convex combination [19].

The model can be used both for calculating the coverage of the area of the transmitter, but also for determining the maximum distance between two transmitters. Convex combination of average and maximum loss is given by [19]:

$$F_1(a_1, \ldots, a_N) = \frac{1}{M}\sum_{i=1}^{M} \min_j g(a_j, r_i) \tag{1}$$

$$F_2(a_1, \ldots, a_N) = \max_i \min_j g(a_j, r_i) \tag{2}$$

where F_1 is a function of the average signal loss and F_2 is a function for maximum signal loss. Other variables are explained in Table 1. The functions of convex combination is then the following:

$$F_3 = \psi F_1 + (1 - \psi) F_2 \tag{3}$$

for which the following applies:

$$\min_j g(a_j, r_i) \leq g_{\max} \ \forall i = 1, \cdots, M \tag{4}$$

Relationship of convex combination of F_1 and F_2 is then:

Table 1. Description of the various variables in the formulas.

Variable	Significance
a_j	Transmitter
r_i	Receiver
$d(a_j, r_i)$	Distance between the transmitter (a_j) and the receiver (r_i)
$g(a_j, r_i)$	Loss path from the transmitter (a_j) to the receiver (r_i)
g_{max}	Maximum tolerated loss path
P_t	Transmit power
P_r	Received power
R_{th}	Received threshold
μ	Limiting parameter for selecting the maximum allowable loss
$\psi \in [0,1]$	Convex combination of coefficient to define the sum of a maximum function

$$F_3(a_1, \ldots, a_N) = \psi\left(\frac{1}{M}\sum_{i=1}^{M} \min_j g(a_j, r_i)\right) + (1-\psi)\left(\max_i \min_j g(a_j, r_i)\right) \quad (5)$$

The referred relationship describes that the signal loss is assessed against the maximum allowable g_{max} loss. This limitation ensures that the quality of the received signal will always be above a certain threshold. Determining thresholds can be done by the following relationship.

$$g_{\max} = P_t - R_{th} \quad (6)$$

To determine the number (N) of required transmitters, the following algorithm is used. The initial setting $N = 1$:

```
1. Attempt to solve the problem (1) - (2)
2. Is there any solution?
     a. Then N is a number of transmitters needed
     b. Else N = N + 1
3. Repeat step 1
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Just right the number of transmitters can be a significant parameter for the future draft of the optimum deployment of iBeacons [21], because for localization purposes, at least three transmitters should be seen at each site [19, 20]. Particular tools for deployment of transmitters for localization purposes in the interior are presented below.

3.1 Ekahau - Optimum AP Deployment for Wifi Signal Emission

Ekahau company focuses on providing a system for determining the position via received Wi-Fi signal called Site Survey. This system seems to be appropriate for a number of similarities between Wi-Fi and Bluetooth technologies. Based on the map of covered area and after defining the required parameters the Site Survey system is able to propose appropriate deployment of Wi-Fi Access Points. Defined parameters are as follows: [21].

- Minimum signal strength of the most powerful AP (Wi-Fi Access Point)
- The minimum signal to noise ratio (SNR)
- Minimum data transfer rate
- Minimum number of APs in range
- Channel Overlap (the maximum number of audible APs on the same channel)
- Minimum Ping Round Trip Time
- Packet loss (% of packet losses calculated from the last 10 packets). The system uses visualization of the estimated signal emission in the map to determine the optimal deployment of AP in the area. With this tool, it is possible to observe a number of parameters such as the number of clients per AP, access to each AP, capacity visualization, the overall coverage, data rate or the expected locations with noise. An interesting visualization is a number of audible AP at the site.

3.2 Creation of HeatMap

To search the appropriate position of transmitters, it is possible to use relatively accurate but a computationally demanding method called HeatMap formation that is formed as follows. Firstly, a 2D model building outlining the individual rooms is created while it is not necessary to record any parameters on the barriers affecting the spread of the radio signals. Then we record measured values of signals at various points of the building in the HeatMap. The values are recorded in the prepared model.

Obviously, it is not possible to perform measurements at each point of the building, but the more measurement is taken, the more accurate model is obtained. Based on these measurements, the coverage for each point in the building is calculated then. The basic algorithms work under the assumption of a linear signal loss. If we make measurements before the obstacle/barrier, the algorithm records these very different values of the received signal and is also able to process the HeatMap.

The advantage of this method is high accuracy, which is affected only by the amount of measurements performed. The main disadvantage is the difficulty of conducting a number of measurements while search for the optimal deployment was necessary at every change of deployment of transmitters to create a new HeatMap.

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4 Optimum Location of iBeacon

Indoor localization can be performed in a four-wall windowless room where it would work reliably, however real and unstructured. The environment in the form of various types of walls and other obstacles can result in complications that make it difficult to find an appropriate placement of iBeacon to get the most accurate outcome. To cover the largest possible amount of practical situations, model situations, in which measurements are created, will be developed. The measurement results will serve as a basis for further research in the use of iBeacon.

In each model situation the following data will be recorded:

- room layout (plan),
- masonry materials (concrete, glazing, etc.),
- density of built-up area (computer lab, auditorium, etc.),
- arrangement of objects in the room,
- potential sources of interference.

In the specific case, for example, it is a rectangular room where the tables and computers are placed.

Model situations will serve as a data source for subsequent assessment and resulting determination of the optimal placement for a particular situation. Several test scenarios that differ both in deployment of iBeacon equipment and in their settings will be ready for each model situation. The aim is to monitor how the signal power and other parameters of the source transmitter are changing. The main assumption, which must be met to determine the appropriate deployment of iBeacons, is visibility of three or more devices with sufficient signal power from most of the possible positions in the model situation.

4.1 Transmitted Data by iBeacons

Localization of the mobile device can be performed on the basis of broadcast data by an iBeacon transmitter. The data transmitted by iBeacon are described in detail in the following text.

Bluetooth operates in the ISM 2.4 GHz frequency band (similar to WiFi). According to [11] the communication itself consists of two parts of promotion (advertising) and connections (connecting). The promotion is one of the ways to make devices well-known. Subsequently iBeacon sends so called Transmit Packet at interval of 20 ms to 10 s. The actual packet has a length of 47 bytes. Its structure is shown in Fig. 1.

The data is further divided into:

- iBeacon prefix (9 B)
- Proximity UUID (16 B)
- Major (2 B)
- Minor (2 B)
- TX power (1 B).

TX power value that indicates the strength of the transmitted signals is the most important for localization. On the basis of the intensity of the transmitted signal (TX power) and the received signal intensity (RSSI), approximate location can be determined [22].

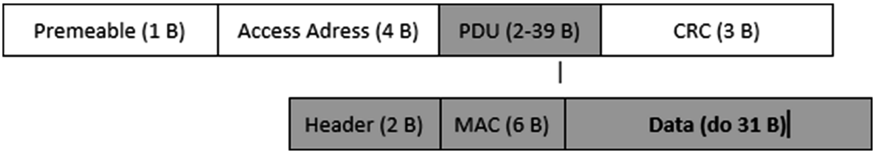

Fig. 1. Packet structure transmitted by iBeacon.

5 The Method of Optimum Allocation of iBeacon Position

The task of the proposed method is to cover as much space by the least number of iBeacon (transmitters). To obtain the optimum solution, at first the model will be created, which will then be tested in a real environment.

The proposed model is based on the division of the area, which is intended to be covered with a signal, to square shaped cells of a predetermined size. The size of cells in the model corresponds to the accuracy that is required for positioning of proposed solutions. It is recommended to choose a network of cells so that the interface of each cell coincides with obstacles in the space, e.g. the wall of a building or other obstacles, significantly suppressing electromagnetic radiation.

If the obstacle is located within a cell, similarly as it is shown in Fig. 2, the cell must be split at the point through which an obstacle passes.

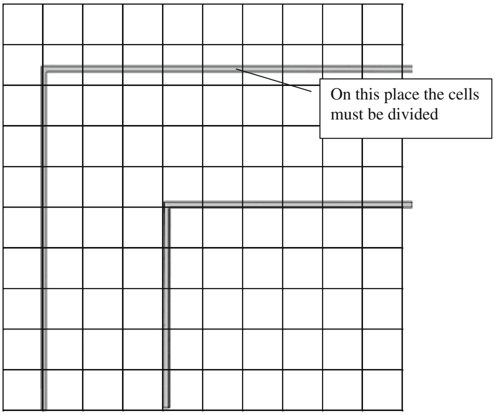

Fig. 2. Covering space (Curved corridor), divided into cells.

In the second stage, the model is equipped with transmitters whose location is chosen with respect to adequate free space around individual transmitters. Based on the predicted signal damping with increasing distance from the transmitter and on the basis of the radiation characteristics of the transmitter, the individual cells are rated on a scale expressing the estimated signal strength in the middle of the cell. The largest value is determined as the evaluation of the cell which is in reach of more than one transmitter.

If the cell is divided by an obstacle into several parts, every part of the cell is evaluated separately.

In Fig. 3 there is an example of evaluation of a model situation. The values are rounded to whole numbers by the following relationships. Evaluation of the cells in Fig. 3 is defined as the RSSI level of estimated intensity of received signals in the cell, according to the formula expressing the signal fading with increasing distance [12]:

$$C_{RSSI} = -(10 \cdot n)\log_{10}(d) + A, \tag{7}$$

where n is a signal propagation constant, d is a distance from the transmitter and A is a set value of the transmitted signal power (Tx Power). Based on experimental testing, the value $n = 3,5$ was determined. The value of Tx Power was set to $A = -74$. Signal attenuation caused by the barrier must be determined experimentally regarding the character of the obstacles. The calculation may be further refined with respect to the transmitter radiation characteristics.

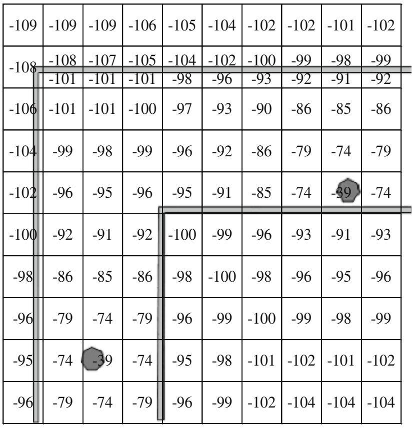

Fig. 3. Transmitters (gray polygons) positioned in covering area and the cell assessment according to the estimated signal strength in the cell.

In such a model we are trying to place the transmitter so as to achieve the greatest value of the variable S, defined as:

$$S = \sum_{i=1}^{m}\sum_{j=1}^{n}\begin{cases} c_{i,j} \in C \\ \overline{x_{i,j}} \in \overline{X} \end{cases}, \tag{8}$$

where c is evaluation of the undivided cell, C is a set of retained cells, $\bar{x}$ is a weighted average of the evaluation of all parts of the undivided cells, $\overline{X}$ is a set of all cells divided and m and n is a number of cells in the model in horizontal and vertical direction. Calculation of the weighted average $\bar{x}$ is given by:

$$\overline{x} = \frac{\sum_{i=1}^{n} x_i \cdot \frac{s_i}{s_c}}{s_c}, \quad (9)$$

where n is a number of parts of the cell, s_c is an area of the whole cell, s_i is an area of the i-th part of the cell, and x_i is evaluation of the i-th part of the cell. By finding the maximum of S value, the optimum area coverage by transmitters will be obtained. K coefficient is then calculated from the total sum. The coefficient expresses the level of coverage area, as defined in the following relation:

$$K = \frac{S}{m \cdot n}, \quad (10)$$

where n is a number of cells in the horizontal direction and m is a number of cells in the vertical direction.

6 Validation of the Model

The model of transmitters deployment has been tested on a set of model situations (Fig. 4) using test scenarios. All measurements were carried out by 6 Nexus telephone with Android 1.5. Estimote (from the manufacturer) and the Locate Beacon applications were used for measurements. When calculating the values in the model, obstacles were taken into account. The expected value in the cell model and the actual measured value at a particular location were always compared for each model situation.

The measured and calculated values of a signal for the situation in Fig. 4a re depicted in Table 2 (values in the table are in the shape of *measured value/calculated data*).

From the result of measurement, it is evident that the signal does not reach from the first person to the third iBeacon over the corner of the room. Another interesting fact is that the signal attenuation between the first person and the first iBeacon is higher than −100 dB, but between the first person and the second iBeacon is −98 dB, while the difference in distance is at least five times greater. On the other hand, for the fourth person and the third iBeacon, the attenuation corresponds to the theoretical assumptions. In the second case (Fig. 4b) there has been a selection of the situations. The chosen situation corresponds to the model detecting the presence of a person in the room and has brought a lot of knowledge about the signal propagation through the walls of the building. The aim was to determine whether a person is inside the room or not. Theoretically iBeacon should be able to cover the entire room without any trouble, and at the same time not to pass through the wall. Even through around 30 cm thick walls, the signal attenuation spreads out into the hall. Measured and calculated values are recorded in Table 3.

The results have shown that differences in signal attenuation are minimum and little reveal whether the user is inside or outside the room. Fault limit was −100 dB but attenuation of −98 dB is very close to this limit.

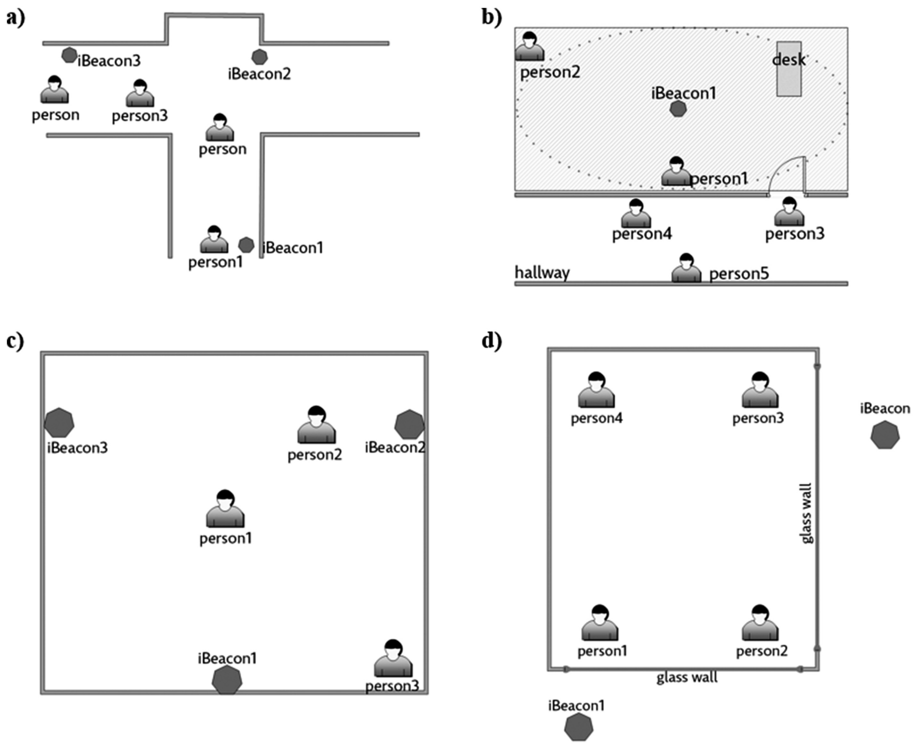

Fig. 4. **(a), (b), (c), (d).** Model situations in which the measurement was performed.

Table 2. Measured and calculated values for the model situation in Fig. 4a

	iBeacon1	iBeacon2	iBeacon3
Person1	−103 dB/−85 dB	−98 dB/−98 dB	—/−106 dB
Person2	−90 dB/−91 dB	−80 dB/−85 dB	−97 dB/−95 dB
Person3	−95 dB/−98 dB	−83 dB/−91 dB	−95 dB/−91 dB
Person4	−103 dB/−104 dB	−77 dB/−95 dB	−81 dB/−82 dB

Table 3. Measured and calculated values for the model situation in Fig. 4b.

	iBeacon1
Person1	−98 dB/−90 dB
Person2	−98 dB/−100 dB
Person3	−92 dB/−93 dB
Person4	−101 dB/−105 dB
Person5	−100 dB/−104 dB

In Fig. 4c there has been a selection of a room where two walls were formed by glass. The glass is metallised, which significantly influences the signal propagation.

Table 4. Measured values for model situation in Fig. 4c

	iBeacon1	iBeacon2
Person1	−100 dB/−99 dB	—/−103 dB
Person2	−92 dB/−93 dB	—/−100 dB
Person3	−100 dB/−104 dB	—/−99 dB
Person4	−96 dB/−101 dB	—/−100 dB

This situation was chosen because these materials are often used for glazing for buildings. Results are presented in the following table: (Table 4)

In the situation of Fig. 4c it was also interesting to observe how the signal is periodically lost from iBeacon2, although it was placed as iBeacon1 1.5 meters from the glass walls (the correct function of iBeacon2 has been several times verified).

The last measurement (Fig. 4d) was carried out at an ideal situation - a rectangular room without any obstacles that would affect signal propagation. The first person should theoretically have the same signal from all iBeacons, however, the actual measurements proved significant differences as shown in Table 5. Paradoxically the best result was at the third person, placed in the corner, where intensity of signals from particular transmitters were measured as expected.

Table 5. Measured values for model situation in Fig. 4d

	iBeacon1	iBeacon2	iBeacon3
Person1	−90 dB/−95 dB	−96 dB/−96 dB	−83 dB/−83 dB
Person2	−80 dB/−91 dB	−94 dB/−91 dB	−82 dB/−91 dB
Person3	−80 dB/−88 dB	−92 dB/−95 dB	−90 dB/−101 dB

The average deviations from the actual and measured are as follows:

- Situation in Fig. 4a – 4, 9 dB
- Situation in Fig. 4b – 3, 8 dB
- Situation in Fig. 4c – 2, 7 dB
- Situation in Fig. 4d – 5 dB

In calculating the average deviations, the condition, when the measurement could not detect a signal from the transmitter, were not included in the calculation. The measurement also proved an expected fact that if there are a larger number of obstacles, which significantly affect the propagation of electromagnetic signals, the model unlike the reality loses accuracy caused by signal reflections.

The proposed model could very well take into account attenuation caused by obstacles. However, due to a very difficult estimate how the signal reflects from obstacles (there are no data on the exact composition of the material of obstacles and their properties) the errors caused by signal reflections cannot be taken into account in the model.

7 Conclusion

The article has introduced localization issues in the interior using Bluetooth technology, particularly the issue of deployment of transmitters of Bluetooth signal on the basis of which reception the localization is implemented.

For designing optimal distribution of transmitters in the interior, the existing solutions have been investigated and a new method which is able to assess the proposed deployment of transmitters for the specific situation has been proposed. The method was further tested in a real environment, where the fact that the influence of various reflections and signal distortion caused by walls and equipment in the building may also occur in measuring significant deviations from the theoretical values has been proved.

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