Optimization of Algorithms in Relation to iBeacon

Jan Budina, Martin Zmítko, Pavel Kříž
University of Hradec Kralove, Czech Republic.
jan.budina@uhk.cz

***Abstract*—The boom of portable electronics and high-speed wireless networks has brought changes throughout society, including development in positioning systems. Indoor localization is more and more important. With modern technology, we are able to track people in shopping complexes and offer them discounts for surrounding goods. The following text deals with the design and description of methods to determine user's position based on fingerprint technology. The text focuses on the description of algorithms in relation to the iBeacon. Three main algorithms were described in the text. The following text describes the implementation of Knn algorithm. The main goal of this paper is to clearly describe the basic positioning algorithms for the readers, introduce implementation of the Knn algorithm and its usage in real environment.**

***Index Terms*—iBeacon; Optimization; Bluetooth; Fingerprint; Algorithm; Position System.**

I. INTRODUCTION

The world around us is constantly evolving; the way of life has changed in recent decades. Along with the development of technology, the actual requirements for what it should provide are increasing. A man`s life is becoming increasingly surrounded by things that make life easier for him, whether they are automatic doors, smart temperature regulators in the home or mobile applications with certain benefits to their users.

The following article deals with the indoor localization using iBeacons, especially in relation to the algorithms used in this issue. In open space, this problem is solved by GPS technology. If we come into buildings or confined areas, we face several problems, which we have to deal with. One of the technological innovations that can be used in this way is called iBeacons. iBeacons was developed by Apple in 2013. iBeacon can be defined as an electronic beacon that transmits data via the protocol Bluetooth 4.0 LE (low energy). Data may be some information for discounted goods at a department store or, for example, data indicating the position of the device. iBeacon consists of a small transmitter, charged by a 1,5 V watch battery, which can supply the device for several years (according to the required power). [1][2][3]

This device is also capable of processing signal. However, for practical use, the iBeacon itself is not sufficient enough. It needs the support of Bluetooth 4.0 within the system. Since the author is Apple itself, support in iOS since version 7 is exemplary. Android platform has supported this technology without restriction since version 5.0, and for Windows Phone system, there is no integration even in version 8.1. The iBeacon brings advantages in its use of the Bluetooth protocol, which is used by the majority of smart phones. It is therefore possible, iBeacon, placed in a specific shelf, can be used to send customers information about currently ongoing discounts on products. [5][6]

II. PROBLEM DEFINITION

What is iBeacon and how to use it can be best learnt, especially in [1][3][4] This article focuses on describing the issue of iBeacons in relation to utilized algorithms. The issue of suitability of using a specific algorithm for the given type of problem is very extensive. This issue is mainly related to complexity [9][10]. The following text focuses on the description of algorithms in relation to the iBeacons, emphasizing on the three algorithms.

A. The Asymptotic Complexity

This is a method of the classification of algorithms. It specifies the operating demands of algorithms by determining the way the behavior of the algorithm will vary depending on the scaling of the input data. These algorithms can be sorted by criteria into classes (N, NP). In this case, the criteria are time and memory complexity. In the issue of iBeacons in relation to algorithms, several aspects can be identified. These aspects can be basically divided into two groups according to the method of determining the user's location via iBeacons. [7]

1. Calculation based on the location of sig. transmitters
   The triangulation method is used to determine the position.
2. Comparing the measured values of received signal / signals with stored reference fingerprints in the database.
   Can be subdivided into: [19]
   - K – of the nearest neighbors
   - The method of the smallest M-angle (Smallest M-vertex polygon)

Due to the diversity of different algorithms and especially regarding their accuracy and resistance to random effects, different solutions to how the transmitters should be deployed can be found in literature. [7][8][19]

III. RELATED WORK

A. Algorithms in relation to the location of transmitters

The method of triangulation is used to determine position. This method is based on the basis of the geometrical properties of the triangle, which are then used to determine the position. Triangulation method is further divided according to whether it uses information about the signal range (range based) or the direction (direction based). The "range based" uses Received Signal Strength (RSS), Time of Arrival (ToA) or Time Difference of Arrival (TDoA) information. When using the information from the RSS, we are working with attenuation of the signal from a reference point. On the contrary, when we work with ToA, we use the information about the delay between the signal promotions from the reference point. The principle working with TDoA uses the correlation analysis and calculation of delays ti – tj – these are time differences from the individual signal recipients. On the contrary, triangulation algorithms, which are using direction based information work with Angle of Arrival (AoA) and Angle of Departure (AoD). This principle involves working with the range of the RF signal, where the key point is the determination of differences between phases or differences between the amplitude of the signal. Triangulation using the AoA is based on the reception of several signals from transmitters (iBeacons). The following relations apply:

$$\frac{sin(\alpha)}{BC} = \frac{sin(\beta)}{CA} = \frac{sin(\gamma)}{AB} \quad (1)$$

$$\frac{sin(\theta)}{BC} = \frac{sin(\beta)}{CE} = \frac{sin(\pi - \theta - \beta)}{EB} \quad (2)$$

where α, β, γ are the angles at the top of the triangle in question [12][13][14].

Asymptotic complexity: O (n log s), where s <= n

B. *Algorithms in relation to the fingerprint method k-Nearest Neighbors*

It is a nonparametric method of classification which uses so-called supervised learning. The classification is a process where we include recognized elements into corresponding classes based on the properties for a particular class. Each class can be characterized by a particular cluster of iBeacons that corresponds to a certain position. This is actually a modified method of finding the nearest neighbor. We extend the method of constant K, which expresses the number of nearest detected transmitters. In the k-Nearest Neighbors we can see dislocation of iBeacons for the case where each class is represented by three transmitters. But this is not the only possible division of the given space. It would also be possible to divide the space into polygons, where the iBeacon signals from different classes will overlap. By doing so, we could also specify small polygons for the most accurate positioning of the particular device. It is appropriate to choose the constant K between 2-4 depending on the surroundings and the number of iBeacons. In our case, it is ideal to choose constant K equaling 3, because we will try to find the three closest neighbors. [11][19] We will use the same method for finding the nearest neighbor as for the previous method, except that now we will seek two smallest distances. For better illustration, there is a table with traceable transmitters and their distances stated in Table 1 below.

Table 1
The distance between devices and transmitters

Device Name	Distance
iBeacon 03	4 m
iBeacon 05	4 m
iBeacon 06	3 m
iBeacon 10	4 m
iBeacon 11	1 m
iBeacon 12	1 m

The nearest neighbors are iBeacons 11 and 12. They both belong to the same class, in which we can also include devices. In case we had here each transmitter from another class, by using the method of triangulation, we could determine the approximate location of the device. The positions of transmitters are known, and therefore it is not a problem to use the method of triangulation. [14][15][16][17][18]

Asymptotic complexity: O (n)

The variable "n" here refers to the number of transmitters.

The smallest M-vertex polygon method

This method uses the RSS signal values to determine the position based on each signal source, applying the following equation:

$$Lp = \frac{1}{N}\left(\sum_{i=1}^{N} \frac{1}{Wi} \, |xi - xi'|^{p}\right)^{1/p} \quad (3)$$

L_p in this case is the distance between the measured vector of RSS signal [x1, x2, ..., xn] and a record in the database of fingerprint imprints[x1 ', x2', ..., xn '].

Wi is used here to take account of the signal in the calculation of the algorithm. This means that by using the given value of wi, we may for example consider, that the signal passes through the wall.

p is selected depending on whether we calculate so called L1 distance or L2 distance. L1 is the Manhattan distance (p=1). L2 is the Euclidean distance (p = 2).

This method is similar to the method of k-Nearest Neighbors. In this case, however, one disregards the position of the transmitters, but takes into account the measured RSS signals

The algorithm basically depends on the following procedure:

- Select M of the closest database records (with minimum signal distance Lp).
- Determine the position, depending on the diameter of the positions of these M points (transmitters) in M – polygon. [20][21]

Asymptotic complexity: O (n + m)

IV. Solution Design

The actual solution was designed in the form of an experiment. The experiment was carried out within SPEV research of the faculty in the campus premises. This article is therefore the output of the overall project which deals with the prospects and utilization of iBeacons. The first step of this project was to verify the characteristics of iBeacons made by Estimote by undertaking a number of simulations, testing and by drawing a conclusion for the optimum placement of the transmitters in the campus. You can learn more on this subject here [3]. In the second step, it was necessary to theoretically design and establish a system utilizing iBeacons. It is an architecture consisting of several layers. The layer 3 represents a database structure. It is the database that stores individual fingerprints and other available information from the device that has scanned the imprints. The actual algorithms for determining the position work with this database. The actual transfer between the fingerprint scanning application and the database is implemented using the jSON format. By using the database, we can store a lot of information. Such information allows us to better filter eventual data on outcomes and evaluation. Next layer (2) further provides access to other systems, such as to study systems for obtaining information about students, for availability of additional educational materials or connection to the school portal. Layer 2 represents the interface on the edge of layers 1 and 3. Different modules or other applications using the fingerprint database can be connected to the database through the mentioned interface. The uppermost layer (layer 1) can be represented as an application layer (e.g. a mobile application). It is a cluster of several independent modules. These modules will promote education and e-learning, their detailed design is planned for the next phases of the project. One can read more about the individual modules and detail description of the proposed system in [4]. Implementation of some algorithms from chapter 3 is also a part of layer 1.

A. Knn algorithm implementation

The k-Nearest Neighbors algorithm uses the K visibility to the nearest iBeacon transmitters around the device along with a combination of fingerprints in the database. The device is always trying to get the most fingerprints for the most accurate position, along with the smallest distance to a given fingerprint. The selection of the appropriate coefficient K is very important for this algorithm. Coefficients 3 to 4 are usually calculated with in the publications [13][17]. However, this coefficient is only suitable when the fingerprint database is formed by an even distribution into the grid.

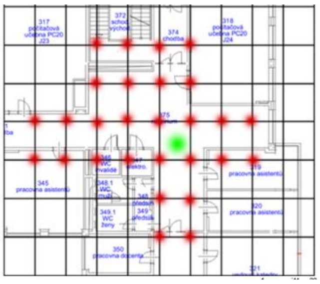

Figure 1: Diagram of theoretical fingerprints

In Figure 1, the diagram of theoretical fingerprints, red color represents fingerprints stored in the database and the green one shows the device that tries to determine its location. This is a theoretical an ideal dislocation of fingerprints in the database, which cannot always be accomplished. An ideal coefficient for this particular example is 3. In our case, there was no ideal fingerprint dislocation. The real fingerprints and their positioning can be seen in Figure 2: Diagram of scanned fingerprints.

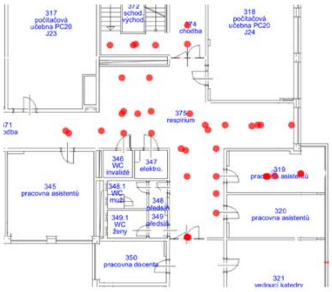

Figure 2: Diagram of the scanned fingerprints

The fingerprint database is not formed by an ideal grid that would provide the best possible conditions. Often there is duplication of fingerprints when two different fingerprints occur near each other. In real conditions it is not possible to create a perfect fingerprint network, because every Bluetooth device has a different setting of internal hardware. Furthermore, the devices may be turned differently and thus from the same position we can measure very different values with various devices. Such values will affect the overall accuracy of the system, due to which one cannot realistically achieve the highest accuracy.

B. Results of comparing algorithm coefficients

The above mentioned algorithm converts all values into the box plot graph that visually expresses the efficiency of using the coefficients on specific data. In Figure 3: Bluetooth visible fingerprints, one can see different measurement accuracy for different coefficients.

On the X axis, there is the coefficient K and on the Y axis one can find the measured distance between the device and the fingerprint, relative to its current position. In this boxplot graph, the red rectangle represents 50% of the observed values, namely quartiles Q1 and Q3. The smaller the height, or in other words the variance of the rectangle, the more accurate results we obtain. The upper quarter encloses 99% of the observed values and the remaining extremes, depicted by spots and triangles are ignored.

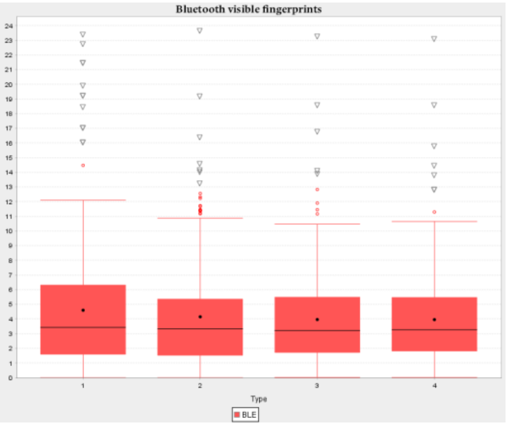

Figure 3: Bluetooth visible fingerprints

Table 2
Example of measured values

	avg.	med.	min	max	Q1	Q3	Q1-Q3
K=1	4,6	3,43	0	12.1	1,6	6,32	4,72
K=2	4,16	3,33	0	10,87	1,54	5,36	3,82
K=3	3,96	3,21	0	10,47	1,73	5,49	3,76
K=4	3,96	3,27	0	10,56	1,82	5,46	3,64

Both Table 2: Example of measured values and Figure 3: Bluetooth visible fingerprints show that using the method of only one nearest neighbor is quite inaccurate. Variance of 50% of the values is quite large and the maximum is consistently high. In other cases, the results are much improved and by applying a coefficient k = 3 we obtain the most accurate values with minimal variance between quartiles Q1 and Q3. However, the variance of the individual values is relatively high for all the coefficients. This variance is not caused by using the position searching method, but by Bluetooth technology and the actual devices. This causes mutual interference and instability of the signal. However, quality is also influenced by the actual measuring device that creates a fingerprint database. The signal strength is dependent on both the used hardware and on the rotation angle of the device. This creates numerous inaccuracies which are negatively reflected in the created database.

C. Current status and future prospects

These technologies are extensively used in education. All communications are based on the transmission of information, such as sharing learning materials or access to laboratory equipment. This slowly brings us to a technology called e-learning, which provides access to electronic learning materials. The aim is to provide educational materials to students in the simplest form so that they do not depend on a lengthy search for information on e-learning portals. One of the solutions that allows us to get the required materials to the students faster and more accurately is to determine the position of the student and then based on the schedule of the particular classroom provide him/her with relevant materials. This eliminates the daily search for materials on e-learning portals and it is also ensured that only the student who is physically present in the classroom can get access to the materials. We decided to implement this idea at our faculty, where we deployed a total of 50 iBeacon transmitters onto several floors, both in the corridors and into the classrooms. At the beginning, it was necessary to solve the problem of optimal deployment of the individual transmitters so that they cover the widest area possible [3]. This ensured the infrastructure of transmitters and their fingerprints. This was then followed by the creation of the database of fingerprints for different positions of the device towards the transmitters and the subsequent determination of the most accurate position using Knn algorithm, which is described in this article. Based on determining the most accurate position, the information can be further used for navigation application, for example Open Day at the faculty or for games similar to Geocaching inside the building.

V. CONCLUSIONS

The objective of this article was to apprize readers with the topic of iBeacons in relation to algorithms which appear in this issue. In the introductory part, the readers are clearly and comprehensibly introduced to a set of the most widely used algorithms related to positioning based on the signal sources. Each of the algorithms was described to such an extent that its principle is clear. This work is thus connected with some other articles related to this issue [3][4]. The fundamental part is the chapter 5, which is in the form of an experiment dealing with the applicability of the selected algorithm. The aim of this paper was to examine various algorithms and their behavior in specific conditions (the campus) and then the appropriate determination of coefficients of given algorithms for further research needs. Thanks to the partial research that covers this article, we came to the conclusion that it was impossible to create an ideal environment in which one could to fill the fingerprint database with the most accurate data for all the cases. We always have to work with inaccurate data and derogations, which can be minimized by using the Knn algorithm. It always uses several neighboring fingerprints, which gradually refine the position of the device. Ideal setting for the Knn algorithm in our particular case is the constant K = 3. In this setting, there is a minimum variance of values which leads to the highest accuracy. Even at the highest accuracy the derogation can reach up to 3 to 4 meters, which for indoor localization is a very high value. On the other hand, for the purpose of locating the student, to determine whether or not she/he is in the classroom, this value is sufficient enough, since the iBeacon signal has difficulties to reach through the walls outside of the classroom [3].

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University of Hradec Kralove, Faculty of Informatics and Management, Department of Informatics and Quantitative Methods, Hradec Kralove, the Czech Republic.

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