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Optimizing the placement of BLE transmitters for Indoor Positioning Systems

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Abstract. The article presents the results of experimental research related to the optimization of the placement of BLE transmitters (beacons) inside rooms in order to locate the user. The experiments were carried out to check how far BLE transmitters can be moved away from each other so that the average localization error was at a level acceptable to the user. The value of the localization error was assumed based on the literature (less than 1 m). As a result of the conducted experiments, a mathematical formula was defined to calculate the required number of BLE transmitters for the exact location inside the rooms. The experiments used BLE transmitters, rooms inside the building of Siedlce University of Natural Sciences and Humanities and a mobile application with a database. In the study of the optimization of the placement of beacons, the fingerprint technique was used.

Keywords. Indoor Positioning Systems, Optimization, Bluetooth transmitter, BLE, Fingerprint.

1. Introduction

Due to the rapid development of technologies and their wide availability, the navigation systems can be used by any interested user. Navigation systems, tracking or determining the location of the user or vehicle, are based on GPS (Global Positioning System). These solutions work very well in open spaces. The problem becomes when we want to use these navigation systems inside buildings. The GPS signal is stopped by the building structure (walls, roof, which are made of steel and concrete). In order to replace the GPS signal, other solutions can be used [12], for example based on non-radio technologies (magnetic fields, pedestrian dead-reckoning, intelligent lighting), wireless technologies (Wi-Fi, triangulation, Bluetooth Low Energy transmitters) or others, e.g. hybrid solutions. Wireless technologies such as BLE (Bluetooth Low Energy) and Wi-Fi are used for IPS (Indoor Positioning System) [13]. BLE-based communication is very well supported by mobile devices and is intended for short-range wireless transmissions. The low power consumption and low cost of the BLE transmitter seems more promising than other wireless technologies [15]. Thus, these transmitters can be used to determine the user's positions. Currently, the techniques used for IPS are mainly fingerprinting and triangulation and their improved versions [14]. In this paper, a technique based on BLE transmitters and fingerprint were selected for user localization. We will focus on this solution.

1.1. Related works

In [3], the authors tried to reduce the number of reference points using the fingerprint technique, where, using four beacons placed in the corridor at a distance of 2.5 m by 4.5 m, it was possible to achieve, in most cases, an average measurement error of 1 m with 64 reference points in this area. The authors use BLE transmitters as a wireless technology to implement the proposed IPS approach. As they used fewer reference points, the method they propose is less cumbersome and less time-consuming than the traditional fingerprint method. Moreover, the obtained location estimation is better than the WCL (Weighted Centroid Localization) technique used independently. This method consists of two main stages of operation. The first step, using fingerprint techniques, uses sparsely populated reference points (RPs) and WCLs separately, respectively. Using the location estimated in the first step, the WCL is run again for the final location estimate. The proposed locating technique reduces the number of RP required by over 40% compared to the normal fingerprint locating method with a similar localization estimation error.

The research presented in [5] focuses on reducing the localization error when using the fingerprint technique. The article proposes a fingerprint-based internal localization method, called FPFE (Fingerprint Feature Extraction), to locate a target device (TD) whose location is unknown. Beacon nodes (BN) and Bluetooth Low Energy (BLE) are arranged in location areas to periodically transmit signals. The resulting signal strength index (RSSI) values of the beacons sent by different BNs are measured at different reference points (RP) and stored in a database. For positioning, the TD obtains the RSSI values of beacon packets of different BN. FPFE then uses auto encoders (AE) or principal component analysis (PCA) to extract the most important information. It then measures the similarity of these PR and TD information using Minkowski distance. Then the k RP related to the shortest distances k Minkowski are selected to estimate the position of TD. The results of the experiments performed show that the FPFE achieves an average error of 0.68 m, which is better than other related fingerprint-based internal location methods.

The research described in [6] shows the reduction of the localization error using the fingerprint technique with the ENTM (Eight-Neighborhood Template Matching) algorithm. The authors of the research used an 8m x 8m room, in which four transmitters were placed. The authors presented the indoor fingerprint technique based on the eight neighborhood template. Based on the analysis of the signal strength of neighboring reference points in the database, the methods of matching and generating the eight neighborhood templates were investigated. In the conducted study, the internal environment was divided into four quadrants for each BLE transmitter. Then, different templates were generated for different points, and the unknown point was located based on the Euclidean distance. The results of the experiment show that the localization error is 1.0 m, which is about 0.2 m less than the K-Nearest Neighbor (KNN) and Weighted K-Nearest Neighbor (WKNN) algorithms.

In the research presented in [16], the trilateration technique was used for localization. The article presents an analysis of the accuracy of the location of objects in a mobile device based on the BLE transmitters technology. Research begins by analyzing the signal strength along the corridor to create a path loss model for the BLE transmitter. Two scenarios were considered when creating the model: with a line of sight and without a line of sight. In both cases, two tests were performed: the chi-square test and the Shapiro-Wilke test. The obtained data was filtered using various types of filters, incl. median, moving average, and then they were compared. In the next step, the authors assessed the internal trilateration algorithm on a model created for an example hall. An RSSI map was created and a log propagation model was designed. The obtained average error was 1.09 m for 1-9 m and 1.75 m for 1-20 m, and after trilateration the positions with an average error of 2.45 m were reached.

The results of the research [8] resulted in increased accuracy of localization with the use of triangulation. The article presents a newly developed model of the path loss taking into account signal smoothing using the Kalman filter. The developed model was tested using four wireless technologies (WLAN, Bluetooth, Zigbee and Synapse SNAP), 20 experiments were performed in a laboratory environment and 1,500 datasets were analyzed to verify the accuracy of the distance estimation. The results show an average 50% improvement in the accuracy of the distance estimation. Thanks to the use of the filter, the authors managed to achieve an average localization error of 0.66 m in a research environment of 3 m by 5 m with the use of three BLE transmitters located in the corners of the room.

The results of the work [9] show the improvement of the efficiency of the fingerprint technique using KF (Kalman Filter) and UK (Universal Kriging). Depending on whether the base station is in the same room as the user equipment, two indoor scenarios are considered. In a test room named A, the proposed KF and UK algorithms achieve a 53% improvement in localization accuracy. In the test room named B, the efficiency improved by 43% thanks to the proposed algorithm, a localization error of 1.44m was achieved, which was achieved in 80% of the tested samples.

1.2. Bluetooth Low Energy

The first BLE (Bluetooth Low Energy) transmitters appeared in 2010 and used the Bluetooth 4.0 version. In the new standard, the transmission speed has been reduced from 40 Mb / s (in version 3.1) to 1 Mb / s, but thus the energy consumption has been minimized, and the range has been increased to 100m [10]. Thanks to this technology, it was possible to create, inter alia, beacons that were used in this work. Beacons allow, for example, to track objects, navigate in buildings or monitor parking spaces [7]. In this study, Blue Charm beacons model BC08-MultiBeacon were used. According to the manufacturer, the device uses Bluetooth 5.0 in its store and the transmission range reaches up to 90m..

1.3. Location fingerprinting

Location fingerprinting is a technique in which a location is identified by a record of radio signals. The fingerprinting technique it is not at all concerned with the distance, but rather tries to obtain a unique combinations of RSSIs that distinguishes a location from all other locations. The fingerprinting technique is based on a radio map, which is a collection of fingerprints [4]. A fingerprint is a set of radio signals measured at a particular location, in which each signal is associated with the device from which it was emitted. This technique comprises an offline phase, in which the radio map is created, and an online phase, where the actual position estimation takes place.

The online phase consists in mapping the surface covered with the signal from the BLE transmitters. A mesh of points is created over the entire surface. Each point has a fixed location.

In this work, points were determined at intersections of the grid at 1m distances. At each point of the grid, the appropriate number of signals from the BLE transmitters is registered. This data is saved with the position and ID of the transmitter in the database. The data at each point should be downloaded in different directions, because the human body causes interference to the signal [2]. In order to eliminate the potential impact of the presence of other people on the accuracy of the receiver's position (an obstacle suppresses the signal), BLE transmitters are placed at a height above the average height of people. In the tests, the height of placing BLE transmitters was assumed to be 2 m.

The positioning takes place in the online phase. There are records in the database that contain x and y position and signal strength of BLE transmitters and their identifiers. Positioning is done in such a way that a smartphone with a dedicated application receives signals from BLE transmitters and compares these received signals with those stored in the database. Finally, the set with the signal strengths closest to that received is selected, and position (x and y) [4] is returned from this record.

1.4. Signal smoothing

The signal received from the BLE transmitters does not have a constant value in time, although the receiver and the transmitter do not move. Therefore, a filter is required to smooth the received signal strength. The ARMA (Auto Regressive Moving Average Filter) filter was used in this work. The ARMA filter is implemented in the AltBeacon library used in the mobile application. It changes the strength of the received signal up to 10% compared to the raw signal [3].

The new value of the signal is calculated by the equation (see Equation 1), where *n(t)* - the new smoothed signal power, *c* - the smoothness parameter. The default value of the parameter *c=0.1* was assumed in the paper.

$$n(t) = n(t-1) - c * (n(t-1) - n(t)) \tag{1}$$

In the online phase, it should be determined which of the signal data stored in the database will be the closest to the currently received. In this work, the Euclidean measure was used (see Equation 2). Where *Dj* - distance between the signal from the base (RSSIoffline) and the received signal (RSSIonline), *i* - number of BLE transmitters from *1* to *n*.

$$D_j = \sqrt{\sum_{i=1}^{n} (RSSI_{i_{online}} - RSSI_{i_{offline}})^2} \tag{2}$$

2. Mobile application for recording the signal of BLE transmitters

The research application was developed in Android Studio and programmed in Kotlin for Android version 6.0. The AltBeacon library [4] was used to interact with BLE transmitters. It is used by companies such as KFC, McDonald's and Coca-Cola and has already been used in over 16,000 mobile applications. Google's Firestore databases were used for data storage. The application operation process is as follows (see Figure 1). In the first phase (offline), a grid of reference points and their positions (x, y) are established. Further, at each point, the RSSI signal (50 frames) from the four BLE transmitters in the range is recorded. For a single measuring point, only the four transmitters with the strongest signal are selected. This data is saved to the database. In the online phase, at any location (different from the reference points), 10 frames are registered from the four strongest BLE transmitters. This signal is smoothed with an ARMA filter. Then the data from the online phase is compared with that stored in the database (equation 2). Finally, the best-matched (closest) x and y coordinates of the point from the database are returned.

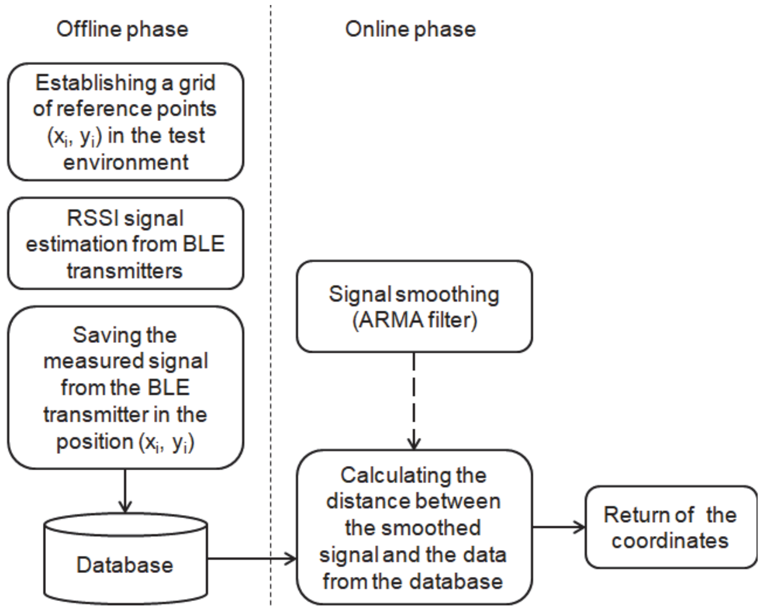

Figure 1. Implementation of the localization process based on the fingerprint method (own elaboration)

3. Experimental research

3.1. Evaluation of the usability of the ARMA filter

The aim of the study is to evaluate the effectiveness of the ARMA filter.

Tools. One Blue Charm BLE transmitter (BC08-MultiBeacon) was used for the experiment. The Tx Power value was changed every step. The frequency of sending signals from BLE transmitters was set to 650ms, the receiver was a Samsung Galaxy S5 (SM-G900F) and its own mobile application.

Research environment. The experiments were conducted in an university corridor. A BLE transmitter was placed on the wall at a height of 2 meters from the floor.

A method. Measurement points are placed on the line every 1m from the BLE transmitter. At each point, 200 signal samples were taken and saved to the database along with the current distance from the BLE transmitter. The test was carried out four times for different powers, with each power running up to the signal sending limit given by the manufacturer. For -4dBm 26m, -8dBm 21m, -12dBm 15m and -16dBm 10m.

Results. Only selected results of the experiment are presented in the paper.

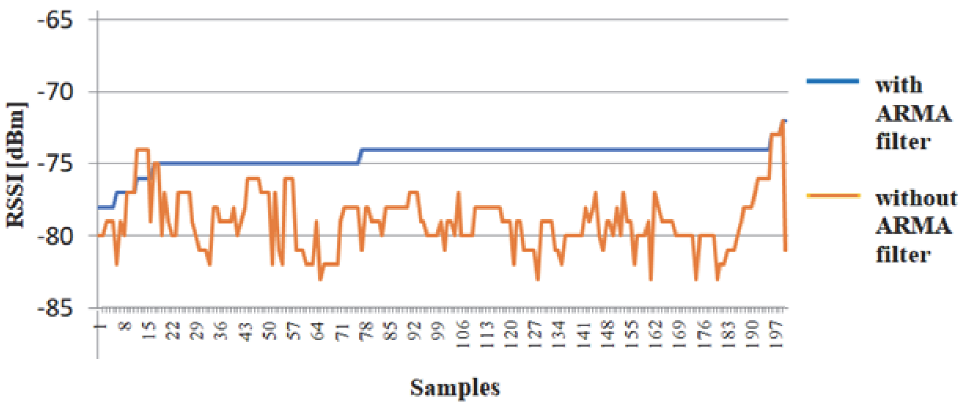

Figure 2. Assessment of the operation of the ARMA filter at a distance of 8m and a set power of -12tx (own elaboration in Excel)

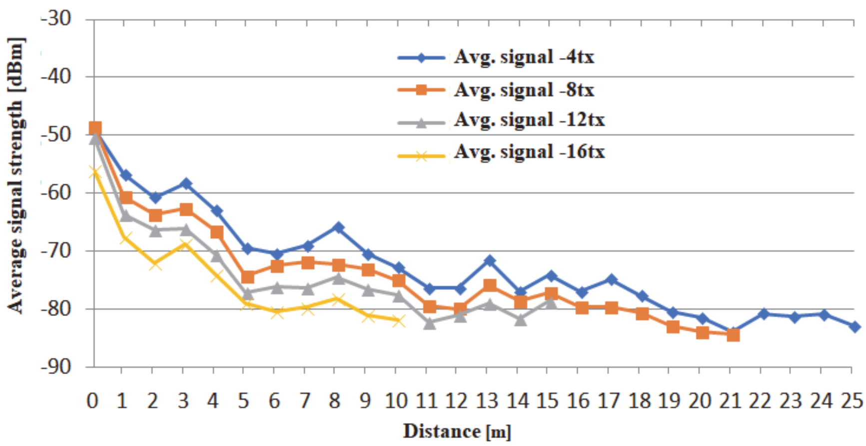

Figure 3. Average signal from BLE transmitters with different power settings (own elaboration in Excel)

Conclusions. The data analysis shows (see Figure 2) that the ARMA filter plays a role and significantly stabilizes the received signal. The results of the signal strength versus distance (see Figure 3) with the average signal values can be seen, it shows that the signal strength at measurement points distant by 1m is different. This will determine the location of the user with an error with this value.

3.2. Evaluation of the impact of the distance between BLE transmitters on the location error

The aim of the study was to investigate the maximum distance we can place BLE transmitters so that the average location error does not exceed 1 m.

Tools. For the purposes of the study, four BLE transmitters Blue Charm (BC08-MultiBeacon) with Tx Power set to -4dBm and the frequency of sending signals every 650ms were used, the receiver was a Samsung Galaxy S5 (SM-G900F) and its own mobile application. The number of recorded samples in the online phase has been changed to 100.

Research environment. The study was conducted in the university corridor. BLE transmitters were placed on the walls at a height of 2m. The dimensions of the corridor are 3 m wide and over 20 m long. Figure 4 shows this place.

A method. Seven experiments were performed. After each of them, two BLE transmitters changed positions 1 m further. The initial phase consisted in mapping the examined area with a grid of measurement points, each point was distant from the other by 1 m. 50 signals were collected at each point. The data was saved to the database along with the real position (offline phase). In the second phase (online), signal measurements were made at predetermined points (randomly selected). These points did not change and were constant for all seven experiments and their locations were memorized for the purpose of determining a localization error.

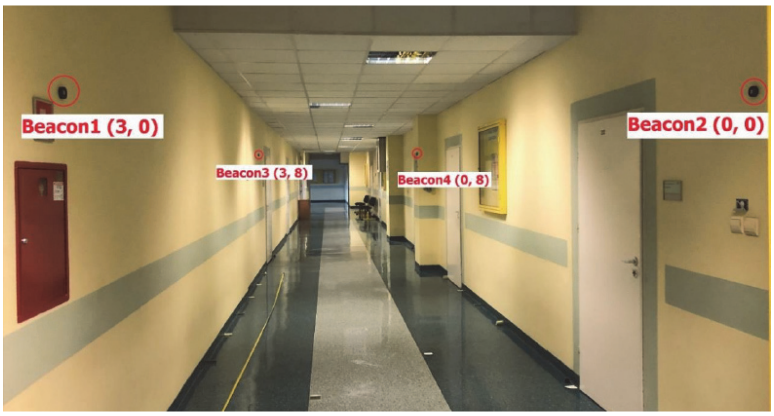

Figure 4. University corridor and initial placement of BLE transmitters (the photo was taken with a smartphone iPhone X, own elaboration)

Results. Figure 5 shows the average localization error for the measurement points (their x and y positions are fixed for 7 experiments) as a function of the distance between the BLE transmitters.

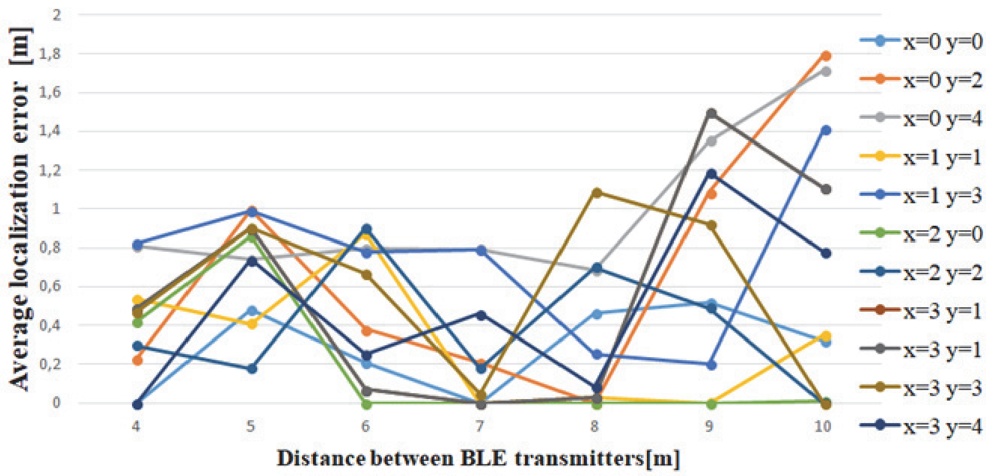

Figure 5. Average localization error at selected points (own elaboration in Excel)

Conclusions. On the basis of the obtained data (see Figure 5), it turned out that when the beacons were spaced 8m apart (point x = 3, y = 3), the mean localization error was above 1m. At distances below 8m, the error does not exceed 1m at each point. According to the obtained measurements, it can be determined that the maximum distance to which the transmitters can be set up while maintaining the average localization error below the level of 1m is 7m. It is also worth noting that when the BLE transmitters are placed more than 8 m apart, the error significantly increases, which means that the research was discontinued.

3.3. Verification of the obtained results in a new research environment

The aim of the test is to check whether the average localization error below 1 m will be maintained in a different test environment.

Tools. Four BLE transmitters by Blue Charm (BC08-MultiBeacon) with Tx Power set to -4dBm and the frequency of sending signals every 650ms were used. The measuring device was a Samsung Galaxy S5 (SM-G900F) smartphone with its own mobile application. 100 samples per test point were recorded in the online phase.

Research environment. The experiment was carried out in the lecture room number 130 of the university (see Figure 6). Two BLE transmitters were placed in the corners of the lecture hall, the width of which was 5.8 m. The other two BLE transmitters are 7m away from the previous ones. Each transmitter was located 2 meters above the floor.

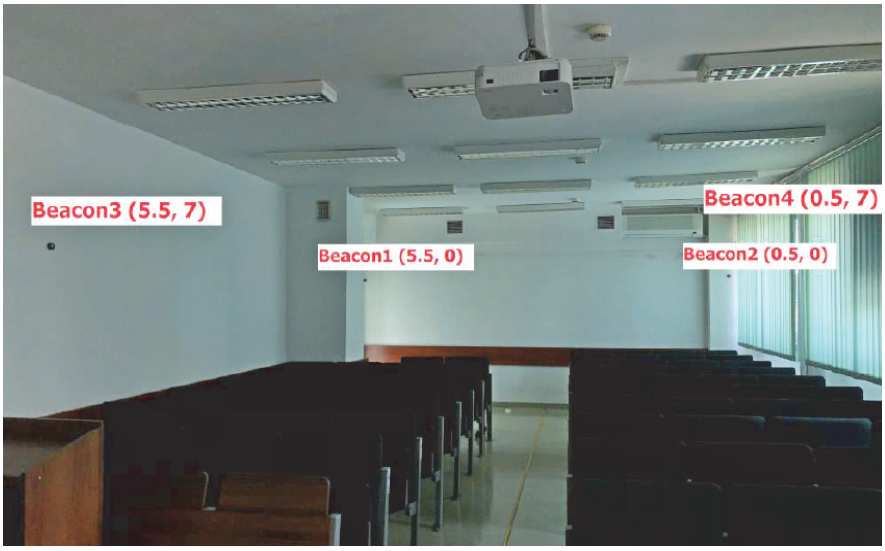

Figure 6. Lecture room number 130 at the university as environment to verify the obtained results (the photo was taken with a smartphone iPhone X, own elaboration)

A method. The initial phase of the measurement consisted in mapping the studied area, i.e. collecting 50 signals from BLE transmitters in a grid of measurement points spaced 1 m apart. Then the signals were saved to the database along with the real position (offline phase). Further, in the second phase, the locations for ten measurement points were randomly selected. 100 signals from BLE transmitters were recorded for each measurement point. The data was saved to the database along with the position for later checking the accuracy of the location.

Results. Figure 7 shows the mean localization error at selected points.

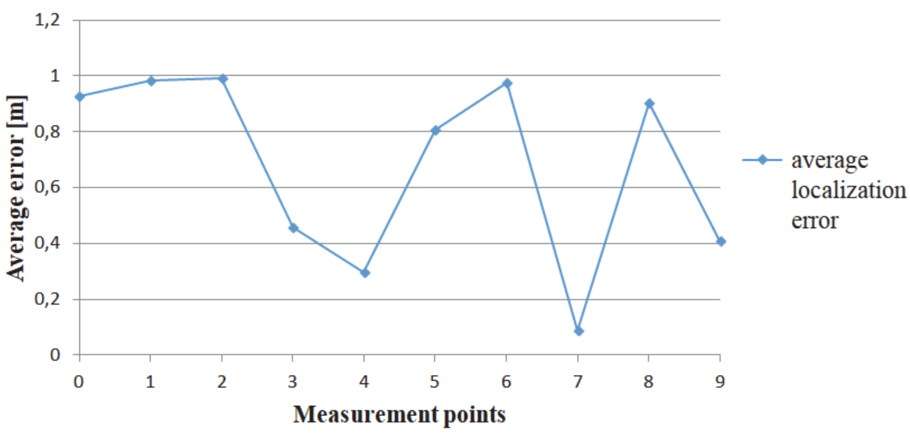

Figure 7. Average localization error at selected points (own elaboration in Excel)

Conclusions. On the basis of the obtained results (see Figure 7 allows us to clearly state that the spacing of BLE transmitters every 7m (grid) along the sides of the room is optimal for keeping the average localization error below 1m. The result of the study also allows to estimate the required number of BLE transmitters in similar rooms.

As a result of the analysis of the collected data [1] from this study, it was noticed that three transmitters at a distance of 7m from the receiver are enough to obtain an average localization error below 1m.

4. Optimizing the placement of BLE transmitters

In order to calculate the minimum number of BLE transmitters, it is first necessary to take measurements of the room. Then divide the width by 7, add 1 and round up to a whole number, repeat the same for the length. The obtained results should be multiplied with each other. The result will be the number of BLE transmitters needed to maintain the optimal mean localization error below 1m. Equation 3 shows how to calculate the optimal number of BLE transmitters. Where: x is the number of beacons needed for a given room, l is the length of the room, w is width, and $\lceil\ \rceil$ is the function that rounds up. This function is based on rounding a real number up to a natural number greater by one than the property of this number.

$$x = \left\lceil \frac{l}{7} + 1 \right\rceil \cdot \left\lceil \frac{w}{7} + 1 \right\rceil \tag{3}$$

For example, for a corridor with a length of 30 m and a width of 5 m, the calculations are presented in equation 4. The calculations show that in order to keep the localization error below 1 m, 12 BLE transmitters should be used.

$$x = \left\lceil \frac{l}{7} + 1 \right\rceil \cdot \left\lceil \frac{w}{7} + 1 \right\rceil = \left\lceil \frac{30}{7} + 1 \right\rceil \cdot \left\lceil \frac{5}{7} + 1 \right\rceil = \lceil 5{,}286 \rceil \cdot \lceil 1{,}714 \rceil = 6 \cdot 2 = 12 \tag{4}$$

In the case of larger rooms, the beacons should be placed on inner elements e.g. structural columns in the large halls, furniture in the large offices, rack in the warehouse or on the ceiling. It will be impossible to place BLE transmitters, e.g. in a sports hall (large distances between walls and ceiling). No such experiments were performed in this work.

5. Summary

Current research pays little attention to the optimal placement of BLE transmitters. Work on IPS focuses mainly on minimizing the localization error by using various positioning techniques. In the experiments, the authors showed that the optimal location of the BLE transmitters is a 7 m grid. Such an arrangement of the transmitters ensures that the average location error is below 1 m. This distance results from the research carried out in different rooms (corridor, lecture hall). The fingerprint technique and the ARMA filter were implemented to carry out the research. These research results will be used in designing the deployment of BLE transmitters of the NaviSecuce system [11], which is being worked on under the "UPH in

Siedlce – Uniwersytet MAXI" project. The NaviSecure system is to provide independent navigation and ensure the safety of disabled people inside the university building.

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