12th IEEE International Conference
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AICT 2018
INTERNATIONAL CONFERENCE

APPLICATION
OF INFORMATION
AND COMMUNICATION
TECHNOLOGIES - AICT2018

17-19 October 2018, Almaty, Kazakhstan

CONFERENCE PROCEEDINGS

17-19 October 2018, Almaty, Kazakhstan

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SESSION 6. COMMUNICATION, NETWORK AND HARDWARE

SESSION 7. ICT IN BUSINESS ADMINISTRATION, GOVERNANCE, FINANCE AND ECONOMY

RSSI Based Bluetooth Low Energy Indoor Positioning

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***Abstract*—People usually spend time inside buildings like offices, shops, hospitals, airports, train station and other indoor spaces. Nowadays, the task of positioning and navigation in this kind of environment is becoming more relevant and useful. Commonly used GPS (Global Positioning System), which is typically used in obtaining location information, has no use in closed spaces. Thereby, we need new technology of real-time location system. In this research work we investigated usage of Bluetooth Low Energy RSSI to estimate location. We experimented with the following mathematical filtering functions to smooth rssi and improve accuracy: median, mode, single direction outlier removal, shifting and feedback filtering. For position calculation, we used trilateration algorithm. Our research based on assumptions and experiments of works of other researches. The goal was to achieve accuracy of 1-2 meters.**

***Index Terms*—Internet of Things, trilateration, localization, RSSI, Bluetooth Low Energy**

I. Introduction

Buildings nowadays became bigger, more complex and full of different things, from various kind of spice in grocery store to branches of gates in airports. The necessity of guide through indoor space, which is not simple map, but is a system with updating in real-time client position feature, has grown up. Main items of Real-Time Location Services (RTLS) are [1]:

- basic station equipment providing reference points with fixed coordinates, according to its coordinates and received signal strength it is possible to identify the position of active label;
- active label radio electronic device that attaches to the monitoring object and interact with basic station;
- server software provides management of measurement process, distance and coordinates calculation, processing and accumulation of data.

Bluetooth Low Energy compatible devices, typically called Beacons, were chosen as a basic stations, because of their sufficiently small size, low battery consumption, lower cost. Beacon is based on Bluetooth low energy proximity sensing by transmitting a universally unique identifier picked up by a compatible app or operating system. [2] RSSI value used in calculation of approximate distance between beacon and client device. Since beacon transmit radio waves, RSSI value oscillate influenced by absorption, interference and diffraction effects. In this case, it should be implemented special filter to make RSSI amplitude lower. Authors in work [3] mentioned that beacons abilities such as durability, mobility and high reaction time have led to Bluetooth BLE technology replacing Wi-Fi for positioning purposes.
Trilateration algorithm was chosen for coordinates calculation due to its simplicity in understanding and implementation. It depends on the amount of beacons, which must be three.
This research mostly based on work [3].

II. Related works

Main questions about RTLS using beacons concerns the reliability of beacons RSSI in distance calculation and compatibility of geometric algorithms. The result of work [4] shows that the RSSI technology gives an unacceptable high error and thus is not reliable for the indoor sensor localization. The reasons are such signals characteristics: signal attenuation, signal interference and multipath propagation [3]. Attenuation occurs when signal pass through objects, as a result strength of signal become weaker. RSSI and distance have inverse proportional dependence. Interference caused by interferences between other wireless signals. Multipath is a signals receiving through their multiple collisions.
However, beacon still has advantages and special calibration must be done with RSSI values. Authors of works [5], [6] have mentioned the median values of RSSI, which is the middle of sorted array of numbers. We also considered the mode value, or modal value, which is the most repeated RSSI among the set of received values. Work [7] presents algorithm of single direction outlier removal. Authors used mean and standard deviation values, calculated from last ten RSSI of a sequence of received signals, to create a threshold RSSI value. Finally, only RSSI that passed threshold used in further calculations. Feedback filtering, proposed in work [10], use value of previous round to calculate value of current round. Every time we get RSSI it's a round. Work [11] proposed usage of feedback filtering in novel approach named shifting. Every 20 RSSI value smoothed via addition percantaged values of current RSSI and previous average value. The result is a new average value of 20 smoothed RSSI.

The next question about RTLS is an algorithm for positioning calculation. Work [3] proposed the trilateration algorithm, which needs coordinates of basic stations and distance to them from active labels. Using RSSI we can calculate approximate distance from Beacons to smartphone and we will also know position of Beacons. In work [7], author used triangulation algorithm, which is very similar to previous one, except the usage of triangles centroid. The last figured out algorithm, fingerprint, was examined in work [8]. It uses probability distributions to generate fingerprint map of indoor space. We have chosen the algorithm from work [3], trilateration, because it is easier to implement and it can simply work in 2D coordinates. Comparing with trilateration, triangulation needs to know more information about receiving angle and need more research on Beacons antenna behavior.

III. Methods

During the research, we designed a client-side application for Android operating system and server-side application. Client-side application communicates with bluetooth devices, calculates RSSI and forwards data to server-side application. Server-side application receives data from mobile application, store meta-data into database and perform further calculations to get coordinates and to improve accuracy.
Next sections describe formulas and algorithms that we implemented on server-side application.

A. RSSI and distance relation formula

From work [3] we got the formula for RSSI based distance calculation.

$$RSSI = -(10n\log_{10} d - Tx) \qquad (1)$$

, where $RSSI$ is an obtained RSSI value, Tx is a transmission strength in a distance of one meter, n is an attenuation constant, d is distance between transmitter and receiver. From formula (1), we can calculate distance with obtained RSSI, but we also need to know n and Tx. Tx is a defined value, which Beacon transmit in its meta-data and set by manufacturer. In our experiments we have defined Tx value independently. Attenuation could be calculated experimentally on defined set of distances. However, some researches [7], [9] use common coefficients, despite the possibility of increasing inaccuracy. In positioning calculation we used filtered value of RSSI. Filtering we will describe further.

B. RSSI filtering

Server part accepts RSSI list and proceed with main calculations. As we mentioned before RSSI needs filtering due to its instability. During this research work, we have implemented three RSSI filtering methods: mode, median and single direction outlier removal (SDOR).

- Mode method counts occurrences of each RSSI value and finds RSSI with maximum occurrences.
- Median method sorts all RSSI values at first, then it chooses RSSI in the middle of the list.
- SDOR presented in work [7] uses ten recent RSSI values to calculate threshold. Their mean $(rssi_{mean})$ and standard deviation $(rssi_{std})$ of these ten RSSI are calculated. Any RSSI that is below $(rssi_{mean} - 2 * rssi_{std})$ is removed from the stored RSSI. Then the average value of the remaining RSSI, $rssi_p$, is the pre-processed RSSI and used in next calculations.
- Feedback filtering based on idea that RSSI of round n-1 affect RSSI of round n, see formula (2). The average value of all calculated RSSI is corresponding to smoothed RSSI value. See example in Fig. 1
- Shifting filtering based on the same idea as a feedback filtering except the definition of a round. In shifting filtering, round is a period of 3 seconds. During round system gets number of RSSI, and if it is first round it calculates the average value of all received RSSI, else it use formula (2), where $RSSI_n$ is received RSSI and $RSSI_{n-1}$ is smoothed average value of previous round. The average value of all calculated RSSI is corresponding to smoothed RSSI value of round n. See example in Fig. 2

$$RSSI = \alpha * RSSI_n + (1 - \alpha) * RSSI_{n-1} \qquad (2)$$

, where α is a coefficient and equal to 0.75.

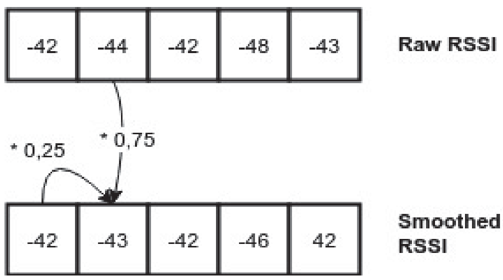

Fig. 1. Feedback filtering example

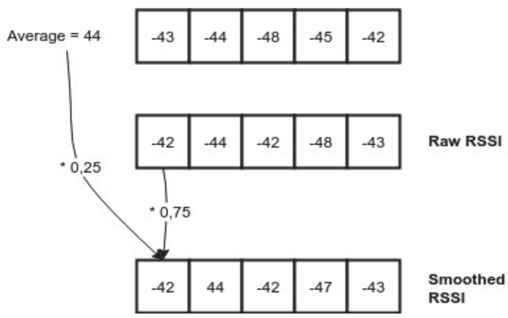

Fig. 2. Shifting filtering example

C. Trilateration and coordinates calculation

The beacons are located in a room as shown in Fig. 3. Smartphone with client-side appplication moves around the room. The application passes RSSI list to server at every second. Beacons located in a form of hexagon, taken from work [3]. We examine eight triangles by trilateration algorithm. In Fig. 3, Beacons represented as circles with numbers.

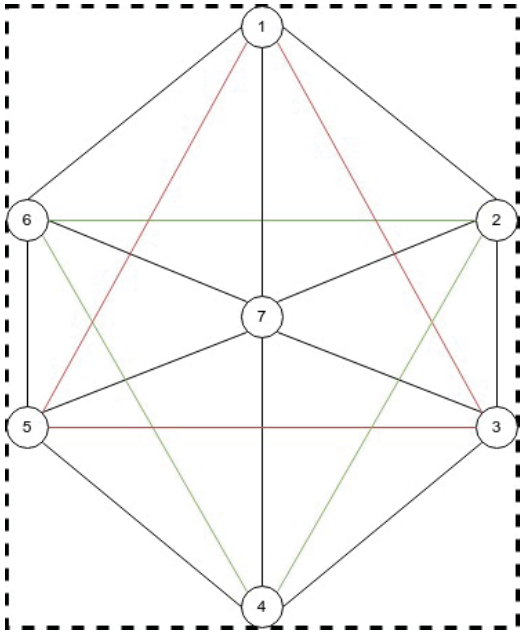

Fig. 3. Room plan with Beacons location

To calculate distance we use formula (1) and estimated attenuation values. Now we can use trilateration algorithm. Trilateration is a technique that calculate the intersection point of three circles. Our Beacons represented as circles with distance to them as a radius. The coordinates of smartphone could be calculated via the construction of three equations for each circle:

$$\begin{aligned}(x-x_1)^2+(y-y_1)^2&={r_1}^2\\(x-x_2)^2+(y-y_2)^2&={r_2}^2\\(x-x_3)^2+(y-y_3)^2&={r_3}^2\end{aligned} \quad (3)$$

In theory, if distance to each Beacon is correctly defined, we can get accurate coordinates of the smartphone. Since we have eight triangles, created by Beacons, we have to get one point coordinates from eight possible points. For this purpose, authors of work [3] implemented Center of Gravity(COG) algorithm. During experiments we have noticed, that not accurate distance cause insufficient work of COG., because we got significant amount of points that were outside of the map. Finally, we decided to use method of centroid calculation, which is a simple calculation of average for x and y.

IV. Tests and Results

During experiments we used 7 Beacons. Characteristics of used devices presented in Table I.

TABLE I
DEVICES CHARACTERISTICS

Devices	Technical characteristics
Beacons	CSR H13323v1 1010 IC with size EEP-ROM SPI programming connector PCB antenna User pushbuttons RGB LED User slide switch Power switch AA holders on reverse
Smartphone	Sony Xperia XA1 Bluetooth 4.2

A. RSSI and distance relation formula

Table II shows the results of attenuation, calculated in different distances for filters SDOR, feedback and shifting. We calculated attenuation on each meter from two to seven. Tests showed that RSSI value is not constant increasing.

TABLE II
SIGNAL ATTENUATION CONSTANTS MEASURED EXPERIMENTALLY

Distance	SDOR		Feedback		Shifting	
	attenu-ation	*RSSI*	*attenu-ation*	*RSSI*	*attenu-ation*	*RSSI*
2	1,3287	-56	2,6575	-48	3,3219	-56
3	1,0479	-57	2,9342	-54	2,3054	-57
4	2,4914	-67	3,6541	-62	3,1558	-65
5	1,7168	-64	3,4336	-64	2,8613	-66
6	1,6706	-65	3,2127	-65	2,4416	-65
7	1,1832	-62	3,0765	-66	2,1299	-64

During experiments, we have noticed that single direction outlier removal, feedback and shifting algorithms work better, because it has less amplitude than other examined techniques. Figure 4 shows the comparison between real received RSSI values and filtered values. Every 3 seconds smartphone passes data to server-side, where calculation held. SDOR, feedback and shifting algorithm showed better results than median and mode, and they were selected for main positioning experiments.

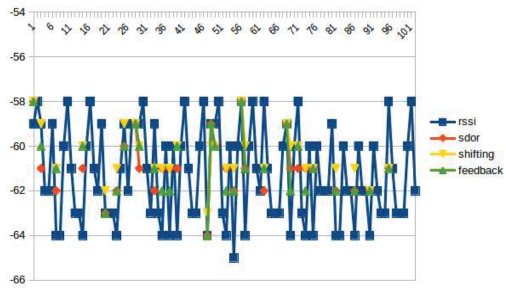

Fig. 4. Graph of RSSI and its filtered values

B. Trilateration and coordinates calculation

For experiments, we used empty room without obstacles and furniture. Size of the room is 5.40:8 m, we scaled this room into schematic image of size 270:400 pixels. Further, all sizes imply pixels.

Calculations were made for two points with coordinates (135,100) and (135, 300). COG and Centroid method were tested in final point determination. COG has shown very bad results, calculated point was mostly outside the map. In final calculations, we used Centroid method. Feedback filtering showed the most stable results for each estimated points. Results are shown in Fig. 5. Yellow and green dots are corresponding to actual point1 and point2 and blue with red are estimated points for point1 and point2. Smartphone was lying at one point during 10 minutes.

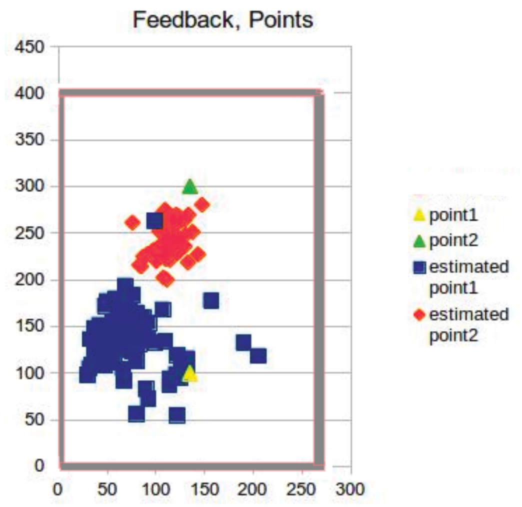

Fig. 5. Results of positioning with feedback filtering

We used distance between Mean of calculated points and actual position point as accurate index. Table III represents accurate indexes for all three implemented filtering.

TABLE III
ACCURATE DISTANCE

Algorithms	Point1	Point2
SDOR	71.8221	96.0439
Feedback	71.2957	64.5774
Shifting	35.0309	84.5167

Comparison of RSSI filtering algorithm, in Fig. 4, shows feedback and shifting as the best filter among presented. However, we will look further for more accurate RSSI filtering, because it is the main issue in our research work. It is seen that the spread of RSSI is very wide. Figure 4 shows RSSI jumps by 7 points, under the conditions that the smartphone and devices are in place. Results on RSSI value prove estimation of [4] that RSSI could be not reliable for localization purpose. Figures 5 shows spread of estimated coordinates after filtering. We can conclude that we achieve accuracy up to 1-1.5 meters.

CONCLUSION

In this research work, we have examined RSSI based Bluetooth low energy indoor positioning. Implemented five filtering algorithms: median, mode, single direction outlier removal (SDOR), feedback and shifting. Coordinates calculation held by trilateration and centroid algorithms. We can conclude that RSSI based Bluetooth low energy indoor positioning depends on several conditions, which make whole work complex from mathematical point of view. Firstly, smartphone as active label make RTLS dependent on its signal receiving capability. Substituting of defined smartphone to another one leads to accuracy fault, because of the attenuation coefficients change. Secondly, it is needed to make deep research on Beacon. During experiments, it was noticed that after 7-8 meters, RSSI values start to increase and then again going down. Thirdly, attenuation was calculated at each meter from two to seven, as a result we could not expect accuracy more than one meter. However, system showed the ability to define certain contour for active label. Implementation of more accurate filters could probably improve localization system. On the other hand, more calculations with basic stations results in RTLS inflexibility for adding new Beacons. In future work, we would like to apply machine learning for coordinates calculations. Basic idea is to create model with principle of relativity between RSSI values to each basic station such that for each set of RSSI relativity there will be certain point in plane.

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