Indoor Localization Methods Based on Wi-Fi Lateration and Signal Strength Data Collection

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Abstract—**The paper describes two Wi-Fi lateration methods based on signal propagation model and signal strength data collection for indoor localization using Android-based mobile device. The considered methods use log-normal path loss model for signal propagation and received signal strength measurement collection for distance estimation and lateration approach for localization. The indoor signal propagation problem is resolved by received signal strength measuring and special ring radio map building those improve localization accuracy. Indoor localization technique opens possibilities for development various intelligent systems that provide the user location-based information inside buildings.**

I. Introduction

Development of indoor localization solutions based on effective localization algorithms is a very promising, difficult and complex problem. This problem requires creating of maps based on floor plans of indoor areas, choosing the effective localization techniques and algorithms, deploying the appropriate facilities inside buildings. Modern solutions like a Navizon [1] or WiFiSLAM [2] can offer much more than just indoor localization with acceptable accuracy (about 2-3 m). The methods using Wi-Fi are more preferred because Wi-Fi networks are prevalent in most public buildings and their use doesn't require additional infrastructure and allows to determine a location of each user of mobile device [3].

There are a lot of algorithms based on wireless signal information e.g. [4], [5], [6], [7] and [8]. The main challenges of using such algorithms and based on those techniques are the provision of acceptable accuracy and deployment cost. Due to these reasons the significant interest in many research communities to use Wi-Fi-based indoor localization techniques is gained. The Wi-Fi localization algorithms could be classified on signal propagation techniques and various fingerprinting techniques based on signal data collection.

The indoor localization techniques based on signal propagation use such methods like lateration and angulation. Lateration estimates an absolute or relative position of an object by measurement of distances from multiple reference points, using geometry. For usage of this method are needed at least three fixed reference points to determine the indoor position. The main idea is the calculation of distances between access points (AP) and mobile device to provide the area of localization. These distances can be provided by such signal measurement information like a received signal strength (RSS), the time of arrival of radio signals from transmitters (TOA), the time difference of arrival of several radio signals (TDOA), the time-of-flight of the signal traveling from the transmitter to receiver (RTOF), the received signal phase (POA) [9]. Similar approaches are based on angulation method and using measurement of arriving signal angle (AOA). These methods have some drawbacks. In indoor environments, it is difficult to use line-of-sight channel between the transmitter and the receiver. Moreover the signal would be suffer from moving people and reflecting surfaces. Due to the multipath signal propagation, the time and angle of arrival and receive signal strength would be affected, and the localization accuracy could be decreased. Thus the creation of effective signal propagation model for indoors is very difficult task, and using such methods requires signal path loss calculation, RSS measuring or multiple measurements.

Fingerprinting is a popular technique not using radio signal propagation geometry, but based on signal data collection and providing high accuracy. This approach requires building a database of RSS and indoor coordinates (fingerprint database or radio map). Fingerprinting consists of two phases: 'training' and 'positioning'. During the training phase the fingerprint database is constructed. The RSS database consists of real coordinates of reference points and related to these signal strength values of accessible transmitters (Wi-Fi access points). The position estimation can be realized as a measure of accessible radio signals and searching matches in the database of the nearest point to the receiver using an appropriate search/matching algorithm [10, 11]. However, there are a lot of problems like a vast number of RSS measurements at training phase and unstable Wi-Fi signal that provides changes in the primary radio map.

In this paper two indoor localization methods based on Wi-Fi signal strength lateration technique and RSS data collection are considered.

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The rest of the paper is structured as follows. Section II presents an overview of wireless indoor localization techniques. Section III introduces two indoor localization methods. Main results are summarized in Section IV.

II. Related work

There are a number of indoor localization techniques and solutions based on several wireless technologies like a Wi-Fi and RFID. One of existing solutions for indoor localization is Navizon Indoor Triangulation System [1] which uses proprietary Wi-Fi nodes to estimate locations of several Wi-Fi devices within indoors. This solution uses war-driving approach to obtain WSN information and special API which can provide the estimated location to the user. Navizon solution requires its own Wi-Fi node infrastructure and the localization accuracy is defined by node placement and depends on its density. The company doesn't open an implementation of its triangulation algorithm, but differs from methods proposed in this paper in using its own infrastructure, triangulation approach and special node placement approach for acceptable accuracy satisfaction.

The next significant instance of indoor localization systems using its own infrastructure is the European project Smartmuseum [12]. In scope of this project a recommendation system for visitors of museums has been implemented. This system supports indoor and outdoor excursions with positioning. The system can provide information on the various kinds of cultural objects and an present to the user some information about places of interest based on user's location defined using GPS if the user location is open area. If the user location is inside the building RFID technology is used for positioning. Each RFID tag stores the URL of the web page with information about the subject of the cultural heritage. Custom applications are developed for Windows Mobile 5 and 6 versions, Symbian versions 9.3 and 9.4.

Place Lab [13] project's aim is to determine user location indoor and outdoor. Technically, the system is based on several radio beacons, which may be Wireless LAN access points, fixed Bluetooth stations, and GSM towers. They all employ protocols which assign beacons a unique or semi-unique ID. Using this ID Place Lab system can localize user indoor position. Accuracy of the presented approach is 13-30 meters.

The Horus [14] is a WLAN Location Determination system, characterized by high accuracy: through the using of a radio map and a probabilistic location determination technique and low computational requirements: through the use of clustering techniques.

RADAR [15] is a radio-frequency based system for locating and tracking users inside buildings developed by Microsoft Research. This system is one of first indoor localization systems that use a radio map. For user mobile device localization the signal strength of each of the APs are measured. It then searches using the radio map database the signal strength values that best matches the signal strengths it has measured. The system estimates the location coordinates associated with the best-matching signal strength to locate the user position. This solution uses specific technique called nearest neighbor(s) in signal space (NNSS) algorithm to locate the user device position. The NNSS algorithm computes the Euclidean distance between each signal strength value in the radio map and the measured signal strength. Accuracy of the RADAR is 2-3 meters.

WiFiSLAM [2] is the most discussed indoor localization startup acquired by Apple Inc. in 2013. This solution uses GraphSLAM algorithm that improves Gaussian process latent variable model approach to determine a map of signal strength without modeling the propagation from transmitting nodes explicitly. This robust approach provides the accuracy about 2 m.

In [16], an indoor localization application improving the sensing capabilities of the current state of the mobile devices is presented. The application is implemented for the using on smart phones and it includes offline and online phases of fingerprinting. Accuracy of presented approach is up to 1.5 meters. The approach [16] is differs from presented in this paper methods in using signal data collection to determine an average value of signal strength to location estimation instead of building some kind of radio map.

In [17] the localization algorithms which allow computing a location estimate from unreliable RSS measurements are considered. This work presents the way improvement the quality of localization algorithms despite the high degree of uncertainty of the RSS measurements. In addition a stochastic framework for RSS-based localization that includes the uncertainty in RSS measurements by replacing distance estimates with probability distributions is presented.

In this paper method of Wi-Fi lateration based on signal propagation model and Wi-Fi lateration based on RSS ring radio map are considered. The first method uses log-normal path-loss model combined with premeasured RSS data. This method is considered for validation goals. The second method proposes a ring radio map constructing for location estimation instead of classical radio map with one-line placed nodes. This method uses signal data collection and radio map like [2], [14], [15] and [16] but the kind of radio map is different and doesn't use probabilistic [2],[14] or deterministic [15] location determination technique.

III. INDOOR LOCALIZATION METHODS

A. Wi-Fi lateration technique for indoor localization

The localization in wireless networks is a process of position determination in the whole area or just in a defined part. The result of the localization process is the estimated position or area, which are obtained by employing a certain localization technique. The lateration method is based on knowledge of reference point positions and the distances to them.

The Wi-Fi lateration method uses parameters of known Wi-Fi networks like a frequency of Wi-Fi signal, its signal strength, the network MAC-addresses and real coordinates of Wi-Fi access points in the location. The signal strength received by mobile device can be used for distance estimation between the AP and the mobile device. By using this method one considers three or more APs allocated in the building. The RSS in these points decrease exponentially depending on distance between transmitter and receiver and random noise factor. Thus this dependency can be considered as function of distance. The distance estimated by RSS is presented as a circle around an access point. The intersection of three APs radiuses provides a point or an area of receiver. This model can be shown as such equation system [18]:

$$d_1^2 = (x-x_1)^2 + (y-y_1)^2$$

$$d_2^2 = (x-x_2)^2 + (y-y_2)^2$$

$$\ldots$$

$$d_n^2 = (x-x_n)^2 + (y-y_n)^2$$

where x_1, x_2, x_n, y_1, y_2, y_n are the coordinates of access points, d_1, d_2, d_n are the estimated distances.

The solution of this equation gives points of circles intersection providing an area of indoor localization (Fig. 1).

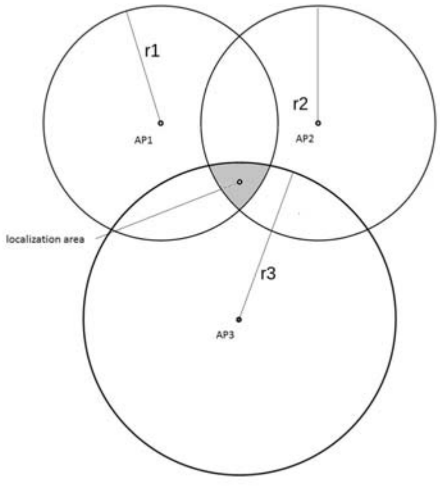

Fig. 1. Indoor localization area provided by trilateration approach

The Wi-Fi lateration approach generally consists of two steps: the first step, converting RSS to estimated distance by some estimation technique (it may be signal propagation model for indoor WLAN signals); the second step, computing location by using estimated distances. Also, it is necessary to determine an approximate radius with same values of RSS for each AP. This problem requires the signal prediction model building. Path loss of radio signal is the largest and most variable quantity of gains and losses from the transmitter to the receiver. It depends on frequency, antenna orientation, penetration losses through walls and floors, the effect of multipath propagation, the interference from other signals, among many other factors [20]. Depends on this drawbacks lateration approaches could provide acceptable accuracy within one room.

B. Wi-Fi lateration based on log-normal path loss model

Due to the environment varies significantly from place to place, the simplest way to find the relationship of RSS and the distance from transmitter to receiver is collecting RSS data at points with the known coordinates within location. This is a learning procedure in addition to the lateration approach. The RSS data are collected to determine the signal propagation model. The learning procedure usage can improve lateration process by adoption to real environment particularities. In spite of this learning procedure is simple, it depends on signal propagation line direction and environment particularities like walls, furniture and others. This procedure should be performed for many directions.

There is a log-normal path loss model for estimation of distance between receiver and transmitter [19]:

$$RSS = P_t - PL(d_0) - 10 \propto log_{10}\frac{d}{d_0} + X_{\sigma_{RSS}} \quad (1)$$

where *RSS* is the received signal strength dBm, *d* is the true distance from the sender to the receiver, α is the path-loss exponent, P_t is the transmit power of the sender in dBm, $PL(d_0)$ is the power loss in dBm at a reference distance d_0. The quantity $X\sigma_{RSS}$ in dBm is a random variable representing the noise in the measured RSS and is often assumed to be a zero-mean Gaussian random variable with variance RSS.

The noise $X\sigma_{RSS}$ in measured RSS can come from both time varying and time-invariant sources. The errors cannot be averaged out by taking multiple measurements, as the path loss model cannot be specifically designed for each wireless channel in each deployed network. Several researchers have observed that the random effects of shadowing are appropriately modeled by assuming the $X\sigma_{RSS}$ is Gaussian.

In our RSS-based localization technique the RSS from the Wi-Fi APs on the floor in the building should be measured and collected. This measured value RSS can be mapped to an estimated distance $\hat{d}$:

$$d = k\, 10^{\frac{P_t - RSS + X_{\sigma_{RSS}}}{10 \cdot \propto}} \quad (2)$$

where k is a constant incorporating both $PL(d_0)$ and $\log10(d_0)$.

Given the empirical values of k and α, the resulting model in (2) can be used to compute a distance estimate $\hat{d}$ from a measured RSS as

$$\hat{d} = k\, 10^{\frac{P_t - RSS}{10 \cdot \propto}} \quad (3)$$

Also, calculation k and α parameters can be given by curve fitting. The obtained by such approximation distance estimates could be used as a distances from receiver (user mobile device) to transmitter (Wi-Fi access points) by calculation localization area while lateration process.

During the implementation average real RSS measurements for one access point produced by Android application are compared with measurements calculated by equation 3. The measurements made for distances from 1 to 15 meters in 15 points within the indoor area in which Wi-Fi access point is allocated. The signal strength is measured 10 times for each of these 6 points. The area of the room is 25 square meters. The comparison is produced for the network with signal frequency 2412 MHz and is shown in Table I.

On the Fig.2 the real and estimated by equation 3 distances are shown.

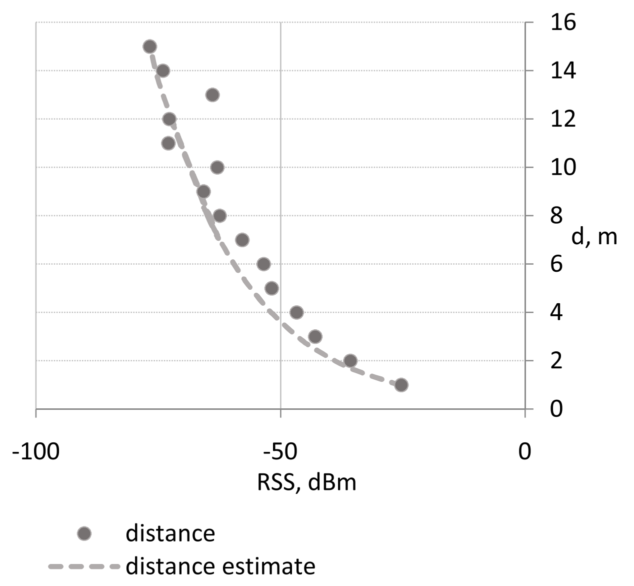

Fig. 2. Estimated and real distances between access point and mobile device

Presented in the Table 1 comparison results show that the signal propagation model is viable for using even within the large indoor area with one wall on the signal line. As shown in the table the significant errors are produced after 9 meters of distance where a wall is allocated. The localization accuracy of this approach is about 3-6 meters. Also, using this approach requires some improvements.

TABLE I. THE COMPARISON REAL AND ESTIMATED DISTANCES

Distance, m	Distance estimate, m
1	0,97
2	1,69
3	2,47
4	3,03
5	3,98
6	4,33
7	5,48
8	7,00
9	8,34
10	7,19
11	12,25
12	12,12
13	7,58
14	12,99
15	15,00

C. Wi-Fi lateration based on ring radio map

Second simple way to estimate distance between transmitter and receiver within indoor area is constructing a radio map of received signal strength level rings. This approach based on RSS data collection provided by a number of RSS measurements within assigned radiuses. For distance estimation could be used minimum and maximum RSS levels corresponding to each assigned radius. Thus, the distance estimation could be defined as an interval corresponding to the measured RSS level interval.

In this work average signal strength levels were measured by distance of three access points allocated in the three rooms within the floor. This data are collected to distance estimation for lateration method described above. These measurements are made for each access point in 15 radiuses at the 1 meter interval and at 30 degrees interval along the circle by assigned radius. The measurements are made using developed Android application. This application found three different access points by MAC addresses and measured the RSS levels of each access point. The RSS level changes at time therefore it is necessary to use its maximum value. The AP RSS levels are displayed on the Fig.3.

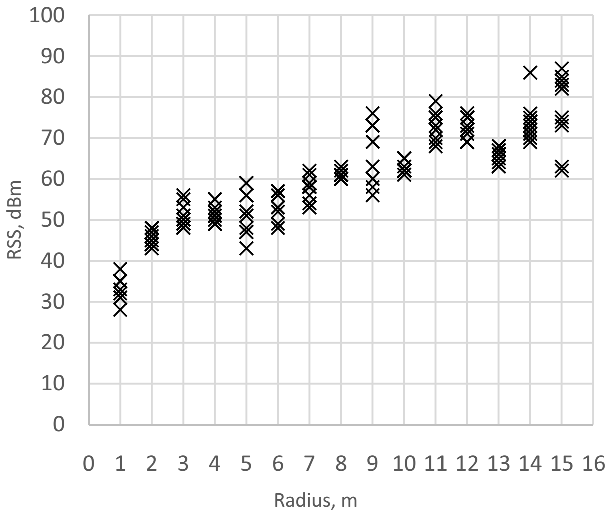

Fig. 3. RSS level measurements for the access point for one direction

The measurements may be selected for distance estimation by intervals of RSS level those corresponds to the ring areas around an access point (Fig. 4).

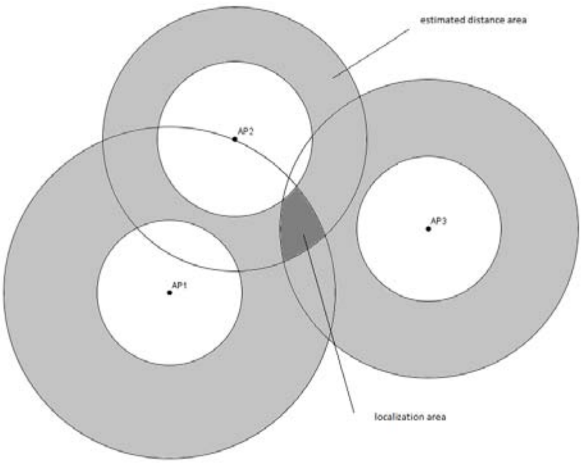

Fig. 4. Indoor localization by estimated distance segments intersection

These areas have internal and external radiuses produced by distance interval estimation. The ring areas can have intersections if the minimum RSS level of an external area is lower than the maximum RSS level of an internal area.

If the current RSS measurement is within such intersection then the internal area should be selected. If the maximum of an external ring is lower than maximum of an internal ring, then the external maximum should be exclude from localization process. Thus it is possible to determine the distance by the RSS as an interval between two values. For localization the Android-based application is used that calculates an intersection of ring areas corresponding to estimated RSS level. This application uses java.awt library for building geometrical primitives and founding these intersections.

The method provides 2-5 meter accuracy depends on environment particularities like a wall, furniture and access point disposition. The localization process is shown on the Fig.5.

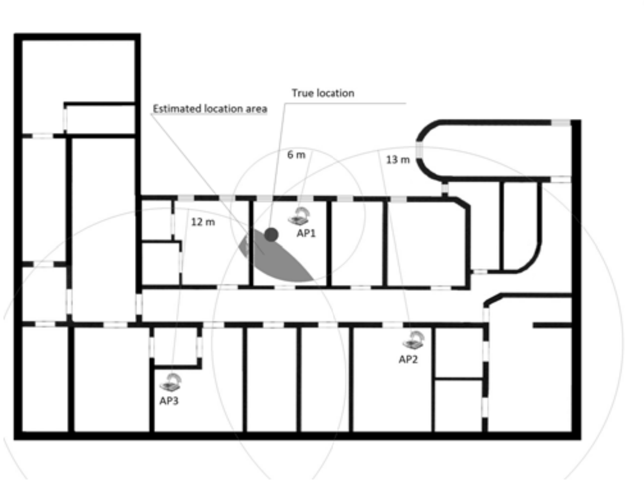

Fig. 5. W-Fi lateraion localization based on RSS data collection

IV. Conclusion

The presented Wi-Fi lateration methods are used for indoor positioning and provide acceptable accurate localization within one room if the number of access points is lower and their allocation density is low. For its improving can be used more accurate signal propagation models or expanded measures of signal strength including most number of reference point.

Moreover, the further work can be continued on the Wi-Fi fingerprinting approach based on probabilistic approaches because the indoor localization algorithm described above may be considered as a special case of fingerprinting. The realization of fingerprinting approach requires also advanced measurement of RSS and building the radio map and can provide high accurate indoor localization.

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