Comparative Analysis of Local Positioning Methods in Wi-Fi/Indoor Networks

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Abstract: The rapid development of various LBS-oriented applications and services requires the development of new and improvement of known local positioning methods in order to increase the accuracy of determining the user's coordinates. First of all, it connects to methods for determining the location of users in rooms, subject to a high concentration of users and the presence of various difficulties in the propagation of radio signals. To determine the local location of a user in a Wi-Fi/Indoor network, the Fingerprinting method is considered. The comparison of the results of user positioning in the Wi-Fi/Indoor network based on the Fingerprinting method using various algorithms for determining user coordinates, such as the probabilistic Bayesian method and complex approximation using complex planar quadratic splines, was carried out. It has been established that the use of the Fingerprinting local positioning method using quadratic complex flat splines can improve the accuracy of determining the user's location coordinates, thereby ensuring the provision of LBS services and applications to users in the premises.

1 INTRODUCTION

The development of LBS (Location-based Services) services and applications is in demand today due to the active introduction of IoT (Internet of Things) technologies and devices, as well as further improvement of UE (User Equipment) mobile communication subscriber devices for determining the user's location, geolocation, local search and targeted advertising. LBS services are quite demanding in terms of positioning accuracy and appropriate choice of radio access technology, especially for IPS (Indoor Positioning System) indoor positioning. The most commonly used radio access technologies for local positioning are Wi-Fi (IEEE 802.11n/ac/ad), Bluetooth or BLE (Bluetooth low energy) (IEEE 802.15.1). Other technologies are also used, such as RFID (Radio Frequency IDentification) and NFER (Near-Field Electromagnetic Ranging), optical and inertial technologies, built-in smartphone sensors (gyroscope, compass, accelerometer, barometer, etc.) and LED lamps, magnetic sensors are used and many others [1-3]. Wi-Fi technology (IEEE 802.11n/ac/ad) has an unconditional priority for local positioning due to its widespread use on almost all user devices and indoor coverage, which allows using the existing infrastructure of already widely deployed radio access networks.

An important and urgent task today is the choice of a local positioning method that would allow achieving high positioning accuracy, and, given the need for implementation on smartphones, would satisfy the conditions of restrictions on power, memory, security, speed and the amount of necessary computing resources.

It is known [1-5] that the Fingerprinting method provides the highest positioning accuracy, which can use various algorithms to determine the location coordinates, such as: k-nearest neighbors KNN (K-Nearest Neighbor) and k-nearest neighbors methods using WKNN weight coefficients (Weighted K-Nearest Neighbor) [5],[7-8], probabilistic Markov and Bayesian methods [4-6], least squares [3-4] and neural network methods [9-10].

Using each of these methods to determine the user's coordinates in a Wi-Fi/Indoor network allows achieving the required positioning accuracy results with varying degrees of error, computational complexity, and time costs.

Therefore, the authors consider it appropriate to consider the problem of positioning in a Wi-Fi/Indoor network for the Fingerprinting method based on the probabilistic Bayesian method and compare the results obtained with the positioning results using a complex spline approximation.

The purpose of this work is to compare the accuracy results of the local positioning of a user in a Wi-Fi/Indoor network using the Fingerprinting method based on a probabilistic Bayesian approach and complex spline approximation.

2 THE FINGERPRINTING METHOD IN LOCAL POSITIONING PROBLEMS

The Fingerprinting method is used for local positioning in a Wi-Fi/Indoor network and is known as the method with the highest positioning accuracy. The functioning of the Fingerprinting method is performed in two stages (Figure 1), one of which is implemented off-line and involves the formation of a Fingerprinting DataBase of the results of measuring the values of the RSSI signal strength level (Received Signal Strength Indicator) for the room in question (Measuring the original of the RSSI signal at the RPs) at predetermined reference points RP (Reference Point), which are distributed evenly throughout the room (Arrange Reference Point).

The Fingerprinting DataBase stores measurement data of RSSI power values and the MAC address of access points, AP_i, $i=\overline{1,3}$, known as “radio fingerprints” [11-12]. At the second stage on-line while positioning the user, measurements of the current RSSI values are performed (On-line measuring the RSSI of the estimation position).

The received data is matched against RSSI values stored in the DataBase. To determine the user's coordinates, we use the Bayesian approach and complex approximation based on flat quadratic spline functions [13-14].

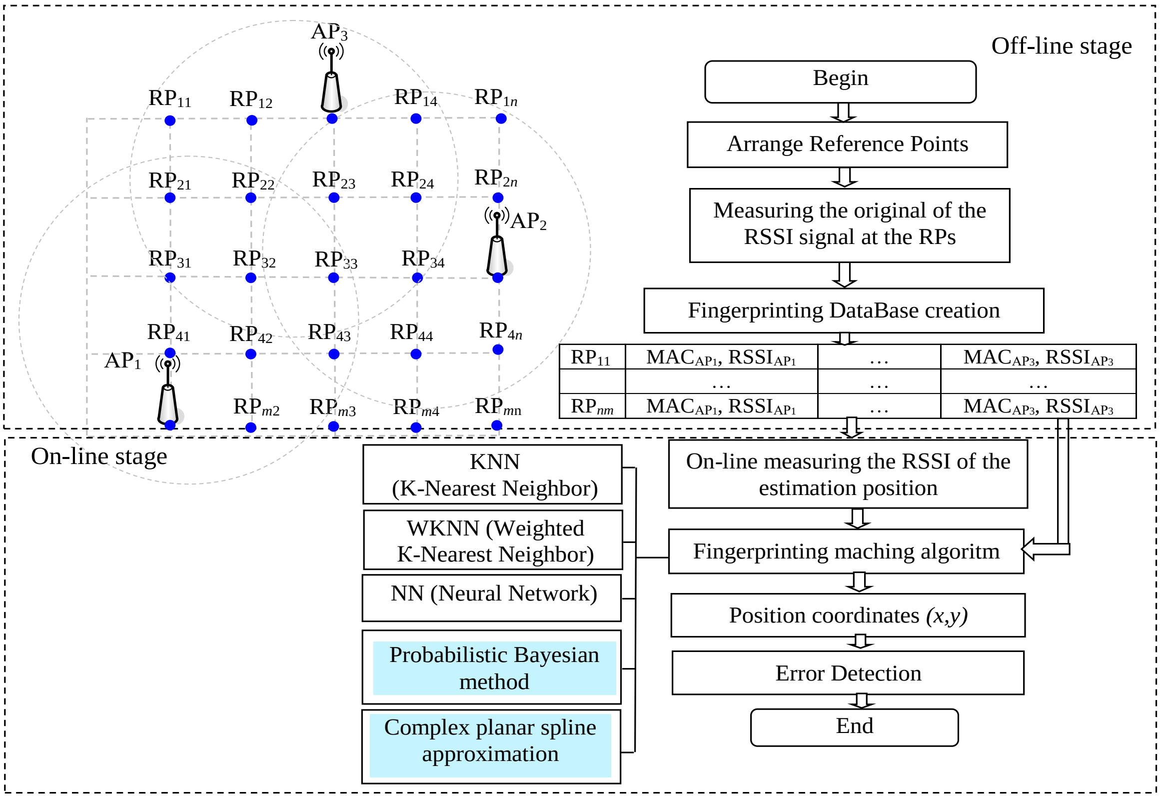

Figure 1: Algorithm for local positioning Fingerprinting of a user in a Wi-Fi/Indoor network.

2.1 Finding the User's Location using Complex Spline Approximation

To find the user's location in the Wi-Fi/Indoor network, consider a spline approximation. As an approximating function, we will use a complex plane quadratic spline [11-12]. Consider a Wi-Fi/Indoor network (Figure 1), which consists of a set of access points AP$_i$, where i is the number of access points AP$_i$, $i=\overline{1,3}$. Denoting the coverage area of the Wi-Fi/Indoor network as $\overline{G}$, for which $\overline{G} \subset Q$ (Figure 2), where $Q=[a,a+H]\times[b,b+H]$, with the side $H > 0$ and step $h_N = \frac{H}{N}$, N – natural number, $x_k = a + kh_N$, $y_j = b + jh_N$, $k, j = 0, 1,..., N$. Besides, $\overline{G} = G \bigcup \partial G$, where ∂G – domain boundary G. Let's divide the Wi-Fi/Indoor network coverage area into segments, then $Q = \bigcup\limits_{k,j=0}^{N-1} Q_{k,j}$, where

$$Q_{k,j} = \left\{ z = x + iy : x \in [x_k, x_{k+1}] \;, y \in [y_j, x_{j+1}] \right\}.$$

We denote such a partition by Δ_N. We define the domain G_N as the union of all segments $Q_{k,j}$ for which $Q_{k,j} \cap G \neq \varnothing$.

Using the finite element method, we consider that at each point of the considered Wi-Fi/Indoor network, the user device UE (User Equipment) will be within the range of at least three reference points RP. To find the user's location, we use the Fingerprinting database, which stores statistical data on measurements of RSSI values at access points AP$_i$, $i=\overline{1,3}$, which we denote by $f(z_i)$, $i=\overline{1,3}$.

To find the coordinates of the user's location, consider one of the elements of the gap, which is included in the G_N domain with vertices P_1, P_2, P_3 and P_4 for which the following conditions are met (Figure 2):

$$\text{Re } P_1 = \text{Re } P_4, \text{Re } P_2 = \text{Re } P_3, \text{Im } P_1 = \text{Im } P_2, \text{Im } P_3 = \text{Im } P_4. \quad (1)$$

Based on the grid domain G_N, we construct a quadratic planar complex spline $S_\Delta(z)$ that interpolates the function $f(z)$ (or its continuation) at the vertices of the rectangles $Q_{k,j}$ included in the domain G_N, setting

$$S_\Delta(z) = a + bz + c\bar{z} + d(z^2 - \bar{z}^2), \quad (2)$$

if $z \in Q_{k,j} \subset G_N$, where coefficients a, b, c, d are determined from interpolation conditions at points $z_{k,j} = x_k + iy_j$:

$$S_\Delta(z_{k,j}) = f(z_{k,j}), \quad S_\Delta(z_{k+1,j}) = f(z_{k+1,j}),$$
$$S_\Delta(z_{k,j+1}) = f(z_{k,j+1}), \; S_\Delta(z_{k+1,j+1}) = f(z_{k+1,j+1}).$$

Function $S_\Delta(z)$ – continuous in G_N [13].

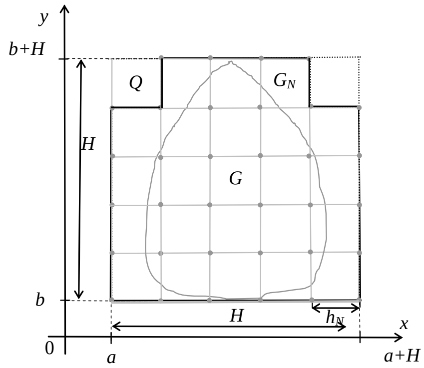

Figure 2. Domain G_N.

Lemma. Let the function $\varphi(z)$ be continuous in the cell domain $\overline{G_N}$, $S_\Delta(z)$ is a quadratic planar spline of the form (2),

$$|f(z) - S_\Delta(z)| \prec h\omega(f, h), \quad (3)$$

where $\omega(f, h)$ – is the modulus of continuity of the function f in G_N, symbol $\prec$ means for $a > 0$ and $b > 0$, $a \prec b$, if $a \leq b$, where c – const.

2.2 Finding the User's Location Using Bayesian Method

Consider Bayesian method for determining the user's location in a Wi-Fi/Indoor network. To do this, we use the Fingerprinting DataBase database, which stores statistical data on measurements of RSSI values by access points AP$_i$, $i=\overline{1,3}$. Then

$$X = \left\langle (x_i, y_i), P_{r_i}[\lambda_i / (x_i, y_i)] \right\rangle, i = \overline{1,3},$$

where (x_i, y_i) – coordinates of the i-th point of the user's location from the Fingerprinting DataBase, $P_{r_i}[\lambda_i / (x_i, y_i)]$ – conditional probability of obtaining measurements of the RSSI signal of the transmitter of the user device with a distribution λ_i at a point with coordinates (x_i, y_i), N – number of access points AP$_i$, $i=\overline{1,3}$.

Using Bayes formula [14], we determine the posterior probabilities of the events:

$$P(H_i / A) = \frac{P(H_i)P(A/H_i)}{\sum_{k=1}^{n} P(H_k)P(A/H_k)}, \quad (3)$$

where $H_1,\ldots,H_n$ – a complete group of incompatible events for which the following conditions are met $H_i \bigcup H_j = \Omega$, Ω – space of elementary events, $H_i \bigcap H_j = \varnothing$, $i \neq j$, H_1 – an event that determines that the user's location is in the *i*-th element of the split, $P(H_i)$ – a priori probability of finding the user in the *i*-th element of the partition, $P(A/H_i)$ – conditional probability of the user being in the *i*-th element of the partition, $_i$, $P(H_i / A)$ – a posteriori probability of the user being in the *i*-th element of the partition after the experiment.

Then the coordinates of the user's location will be determined according to the expressions:

$$\bar{x} = \frac{1}{k}\sum_{i=1}^{k} \max_{x_i} \; P(H_i / A), \; \bar{y} = \frac{1}{k}\sum_{i=1}^{k} \max_{y_i} \; P(H_i / A) \quad (4).$$

2.3 Experiment

To conduct an experiment of positioning UE user devices in a Wi-Fi/Indoor network based on the Fingerprinting method, a fragment of a Wi-Fi/Indoor network in a room is considered, which consists of three access points AP$_i$, $i = \overline{1,3}$ with coordinates AP$_1$ (0,0), AP$_2$ (8,4), AP$_3$ (4,8). TP Link Tech access point equipment of IEEE 802.11n/ac standard uses dual frequency band 2.4/5 GHz (20/80 MHz), 2452-2472 MHz, 5170-5250 MHz.

During the first stage of the experiment, a Fingerprinting database was formed based on the measurement results of RSSI values obtained using the Open Source Wi-Fi Analyzer application for the considered room at evenly distributed points RP. The placement of RP points (RP$_{11}$…RP$_{mn}$) is shown in Figure 1, and the RP coordinates and RSSI measurements for the access points AP$_i$, $i = \overline{1,3}$, which are used in the experiment, are shown in Table 1.

In the experiment, a number of restrictions were adopted that do not take into account the peculiarities of signal propagation inside the premises (reflection from walls and ceilings, diffraction, multipath and interference conditions, etc.).

At the second stage of the experiment for five UEs, measurements of the current RSSI values from three access points are performed AP$_i$, $i = \overline{1,3}$.

Table 1: Results of measurement of RSSI values.

RP coordinates		RSSI value, dBm		
		AP$_1$	AP$_2$	AP$_3$
RP$_{12}$	(2,8)	-71	-69	-52
RP$_{13}$	(4,8)	-68	-62	-42
RP$_{22}$	(2,6)	-67	-64	-51
RP$_{23}$	(4,6)	-70	-59	-42
RP$_{24}$	(6,6)	-74	-50	-45
RP$_{31}$	(0,4)	-45	-70	-64
RP$_{32}$	(2,4)	-43	-69	-68
RP$_{34}$	(6,4)	-74	-42	-74
RP$_{42}$	(2,2)	-48	-58	-60
RP$_{43}$	(4,2)	-56	-61	-60
RP$_{45}$	(8,2)	-70	-49	-72
RP$_{54}$	(6,0)	-59	-76	-56
RP$_{55}$	(8,0)	-72	-62	-74

The data of the current measurements of RSSI values of devices for UE users (RSSI$_{AP1}$, RSSI$_{AP2}$, RSSI$_{AP3}$) is shown in Table 2, for example, for the user UE-1 with coordinates (5;5), the RSSI values (-77, -63, -59) dBm are obtained.

Table 2: UE RSSI Values Measurement Results.

UE coordinates		RSSI value, dBm		
		AP$_1$	AP$_2$	AP$_3$
UE-1	(5;5)	-77	-63	-59
UE-2	(2,5;2,2)	-54	-71	-69
UE-3	(7,3;1,2)	-73	-61	-78
UE-4	(3.48;7.62)	-79	-76	-47
UE-5	(1.6;5.2)	-72	-72	-67

2.4 Accuracy of User Location Based on Complex Spline Approximation and Bayesian Method

To determine the accuracy of determining the user's location in the Wi-Fi/Indoor network using a complex spline approximation based on a flat quadratic spline, we use Lemma 1 (Section 2.1) expression (3). The results are summarized in Table 3.

To determine the positioning accuracy of a user device in a Wi-Fi/Indoor network using the Bayesian method, we use the value of the mean absolute error MAE (Mean Absolute Error) [6]:

$$MAE = \left(\frac{(x_{est} - x_{real})}{x_{real}} + \frac{(x_{est} - x_{real})}{x_{real}} \right) \cdot 100\%, \quad (5)$$

where x_{est}, y_{est} – user location coordinates determined during the experiment, x_{real}, y_{real} – real coordinates of the user's location.

The obtained results of positioning accuracy using the probabilistic Bayesian method are shown in Table 3.

Table 3: Comparison of local positioning results using complex spline approximation and Bayesian method.

User, coordinates	Complex spline approximation	Mean absolute error MAE, %
UE-1 (5;5)	(5.15;5.1)	5,1
UE-2 (2,5;2,2)	(2.7;2.31)	9,6
UE-3 (7;1)	(7.2;1.12)	10.0
UE-4 (3;7)	(3.1;7.2)	6,3
UE-5 (1;5)	(1.1;5.18)	8,6
User, coordinates	Bayesian method	Mean absolute error MAE, %
UE-1 (5;5)	(5.32;5.72)	20,8
UE-2 (2,5;2,2)	(2.75;2.25)	12,3
UE-3 (7;1)	(7.3;1.2)	24,1
UE-4 (3;7)	(3.48;7.62)	24,8
UE-5 (1;5)	(1.15;5.2)	19,1

3 CONCLUSIONS

The obtained results allow us to conclude that the greater accuracy of determining the user's coordinates in the Wi-Fi/Indoor network using the Fingerprinting method is achieved using complex spline approximation using flat quadratic splines. Moreover, it could be argued that regardless of the location of the user, the error is 10%. When determining the coordinates of the user's location, the use of the probabilistic Bayesian method gives a positioning error of up to 25%. Therefore, it is advisable to use the Fingerprinting method based on complex approximation using flat quadratic complex splines to find the user's location.

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