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Mobile Positioning Solution Suitable for Intelligent Transportation System based on IEEE802.11a

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Abstract. Most of outdoor localization systems is based on range based measurements. Thus, the mobile terminal needs calculate its distance from the reference station. It can be represented by a base station or an access point. Performance of this approach is highly affected by signal fluctuations due to multipath propagation, especially in dense urban areas. In this paper, we propose and evaluate the feasibility of implementation positioning system in outdoor environment. Proposed localization system is based on finger-printing approach and utilizes signals from the IEEE 802.11a network. IEEE 802.11a is not traditional platform for mobile positioning, but it is widely implemented in recent years and would be utilized for this purpose. We analyze the influence of different factors on the positioning accuracy and provide some recommendation to implementation of the system based on the IEEE 802.11a.

Keywords. Intelligent Transportation system, mobile localization, fingerprinting,WiFi

Introduction

Position of mobile device is very important information in mobile services. In-crease of location based services (LBSs) can be observed over last decade and it is not difficult to find rich offer of smartphones with GNSS (Global Navigation Satellite System) support or other platforms used to the position estimation in the market. Growing LBS market has great potential, stimulates development, improvement of technologies speeds up progress.

When a service provider is going to provide LBSs, he needs to make a decision about the most appropriate positioning system for the business. Decision like that, should be based on LBSs requirements, e.g. the positioning accuracy, need of mobile device modification and etc. Implementation and operating costs also play very important role [1] - [4].

Positioning systems have already been implemented in many sectors of our life e.g. intelligent transport systems, commercial sector, industrial military and etc. [5, 6]. They can be used in navigation systems, tracking systems or searching systems.

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Many positioning systems exist and each has its own advantages and disadvantages. GNSSs offer great cover-age area with good accuracy in the outdoor environment. Unfortunately, these systems are not applicable in dense urban areas due to low positioning accuracy. It is mainly caused by multipath propagation and obstacles in line of sight. On the other hand, positioning systems based on the radio communication networks seem to be more suitable for this kind of environment [7] - [10].

Generally, positioning methods used in outdoor are based on observation of various signal parameters. Common positioning methods are based on Cell Identification (Cell ID), Time of Arrival (ToA), Received Signal Strength (RSS), or Angle of Arrival (AoA) measurements [1], [3], [7], [9], [11] - [14]. Most of positioning methods is sensitive to multipath propagation. Consequently, these methods are not suitable for dense urban environments.

Time based methods are the most accurate, but too expensive to implement in current networks. On the other hand, basic methods (Cell ID and RSS) do not require high implementation costs, but their accuracy is poor. Therefore it is necessary to use method, which is able to achieve good accuracy and it is not expensive.

Many research teams have paid an attention on the issue of mobile positioning using the received signal strength information [15] - [18]. This interest could be based on the fact that signal strength information can be simply measured in mobile device and does not require additional implementation costs compared to other methods. The RSS information can be processed in various ways, the Trilateration way or another way based on fingerprinting method. The Fingerprinting method seems to be more suitable for Non-Line-of-Sight (NLoS) environment compared to Trilateration way. Furthermore, MS must not be modified. Therefore, we decided to use Fingerprinting method in this work.

Our fingerprinting solution is based on RSS. Generally, the RSS collection can be performed by either measuring in a real environment or predicting as described in [16]. In first case, it is very time consuming, but precise and real RSS information are collected. On the other hand, predicting of RSS is more comfortable, but the data is highly dependent on a quality of map model of a given environment and propagation model used in simulation. There is a compromise between the demanding effort and accuracy in [16].

Many fingerprinting based positioning systems are implemented in IEEE802.11 networks. These are mainly used in indoor environment, but can also be successfully installed in urban areas. In this paper, we are interested in a novel positioning concept based on IEEE802.11a. This standard is not often implemented as standards, which use 2.4 GHz frequency band. Anyway it can be implemented in outdoor.

This paper examines the accuracy of positioning system based on the fingerprinting method used in IEEE802.11a network. Here we focus on an impact of different environments on positioning accuracy. The positioning accuracy is evaluated by mean, median and 95% error.

The paper is structured as follows. Section 1 summaries related works where mobile positioning is based on fingerprinting method. Section 2 deals with the architecture of proposed system. Test scenario is depicted in the Section 3. Section 4 deals with achieved results. The Section 5 concludes the paper and presents some ideas for the future work.

1. Related Works

1.1. Fingerprinting

Fingerprinting algorithms can be implemented in various ways from mathematical point of view and can be divided into two main frameworks - deterministic and probabilistic. In our work we deal with fingerprinting positioning based on the deterministic algorithm - Nearest Neighbor method (NN), which can achieve sufficient accuracy compared to more complicated method, in case that density of radio map is high enough [19].

Accuracy of the used method in radio networks is mainly determined by two factors. Firstly, signal properties vary much at relatively small area. For instance, in few meters range, signal from an AP (Access Point) can get attenuated, get lost or be replaced with a stronger one. Secondly, these signals are relatively constant in time. This allows data gathering and their use in future to estimate position of mobile device.

Main disadvantage of fingerprinting positioning is sensitivity for environment changes such as object movement in the building (e.g. people, furniture), which altogether affect signal properties. For this reason it is necessary to update the radio map, but basically, walls and furniture affect the signal most of all and therefore update is not required so often.

Fingerprinting method consists of two phases. At first, radio map for an area where planned localization service is desired (see Figure 1) must be created and stored in the database. Radio map can be viewed as database of spots with known position (coordinates) coupled with various radio signal properties, e.g. RSS, AoA, or propagation time. The phase in which radio map is created is called off-line phase or calibration phase.

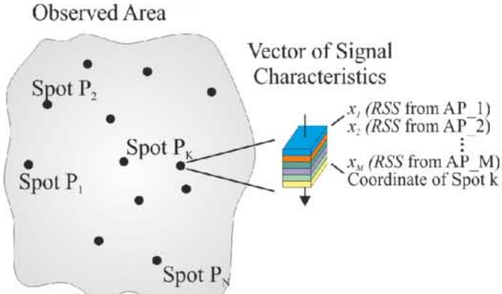

Figure 1. Radio map for fingerprinting using RSS.

After the radio map is created and stored in the data-base, the second phase can take place. This phase is called on-line phase or positioning phase. During this phase MS measures signal properties at unknown spot. In the next step, the radio map is searched to find the best match from existing spots. The match is actually the nearest point from database and its coordinates are considered as MS position (for NN method). Next sections deal with fingerprinting in more details.

Localization Algorithm

The most common method to find the best match from the radio map database and actually perform localization is the Euclidean algorithm. Let's assume a fingerprint in radio map, which is characterized by vector **P**:

$$\mathbf{P} = [x_j] = [x_1, \ldots, x_M], \tag{1}$$

where x_j characterizes the spot, i.e. values of the signal properties, in our case RSS. M represents number of APs in the range during the radio map creation. In general, let's consider the radio map contains fingerprints collected at N reference points.

$$\mathbf{P}_i = [x_{ij}] = [x_{i1}, \ldots, x_{iM}], \; i = 1, \ldots, N. \tag{2}$$

Unique identifiers of APs (commonly MAC address and SSID) are stored in radio map as well as reference point coordinates. These are coupled with x_i, but are not shown here for the simplicity of the model. The whole radio map contains all fingerprints $\mathbf{P_i}$ and creates the set **S** written as

$$\mathbf{S} = \{\mathbf{P_i} : i = 1 \ldots N\}. \tag{3}$$

During the localization of MS, the signal properties are measured at unknown spot and new fingerprint **Q** is obtained

$$\mathbf{Q} = [y_j], \; j = 1, \ldots, M. \tag{4}$$

The Euclidean distance d_k between vectors $\mathbf{P_k}$ and **Q** is defined as

$$d_k = |\mathbf{P}_k - \mathbf{Q}| = \sqrt{\sum_{j=1}^{M} (x_{kj} - y_j)^2}. \tag{5}$$

When Euclidean distance formula is applied on the en-tire radio map, the vector of distances **D** is obtained. The vector **D**, contains all distances between vectors $\mathbf{P_i}$ stored in the radio map and vector **Q**, and can be calculated as

$$\mathbf{D} = [d_i] = [|\mathbf{P}_i - \mathbf{Q}|] = \left[\sqrt{\sum_{j=1}^{M} (x_{ij} - y_j)^2} \right], \; i = 1, \ldots, N. \tag{6}$$

The element of vector **D** with minimum value defines the nearest reference point to **Q**. Its position is recorded within radio map and its coordinates are considered as the position estimate.

2. Positioning System

The developed positioning system based on Wi-Fi was designed at the University of Zilina and it is called WifiLOC. Basic principles of WifiLOC are described in the following part.

2.1. WifiLOC Positioning System

WifiLOC was primarily developed to be used in the in-door environment, but it can also be modified for operation in the outdoor environment. WifiLOC utilizes RSS information from surrounding Wi-Fi access points to estimate position of mobile device. The system is based on the above mentioned fingerprinting positioning algorithm and RSS information.

WifiLOC was developed based on mobile-assisted positioning concept. It means that all necessary measurements are performed by the localized mobile station. Measured data are sent to the Localization Server (LCS), which is connected in the network. The position of mobile device is estimated (calculated) on a server side. The architecture of the system is depicted in Figure 2.

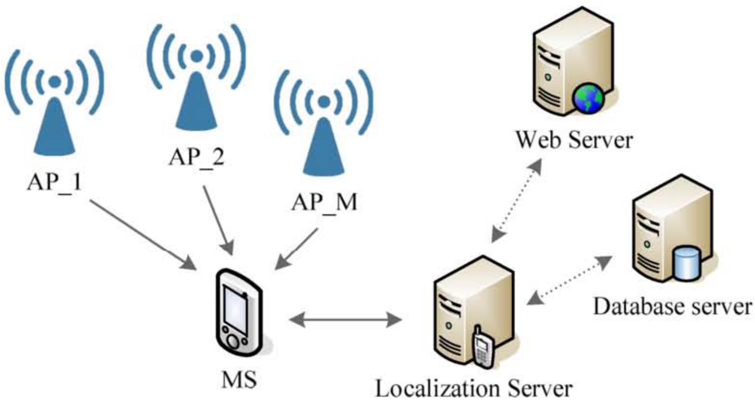

Figure 2. The architecture of the WifiLOC system.

The communication within the system is based on the client-server architecture. The architecture of the system can be divided into the three independent parts:

- localization server,
- network of reference stations (access points),
- mobile device - user, client.

3. Experimental Scenario

The main goal of the experiments is to evaluate the performance of positioning system based Wi-Fi, working in 5 GHz ISM (Industrial, Scientific and Medical) frequency band. Experimental scenario was realized at the campus of the University of Zilina.

The investigated area is shown in the Figure. 3. Size of the area where positioning system was deployed is 450x100 meters. Measurements during both phases were performed in highlighted lines, with points spaced 3 m apart. The experiment was implemented in the network based on IEEE802.11a standard. Six APs (Nanostation M5 Loco - Ubiquiti Networks™) were distributed around the area on the roofs of the surrounding building. All used APs were in the range over the whole observed area and Line of Sight (LoS) signal propagation was dominant. Measurements were per-formed using mobile terminal: Lenovo ThinkPad T431s with external GPS module for accurate position determination. Mobile terminal is not equipped with omnidirectional WiFi antenna, therefore it is important to take into account its orientation.

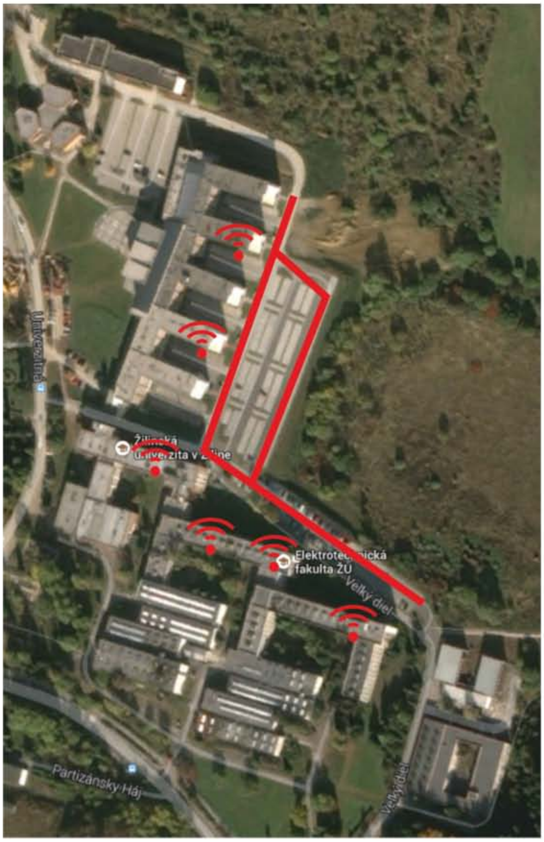

Figure 3. Experimental area – University of Zilina campus.

100 position estimates per scenario on the observed area were performed to evaluate the performance of WifiLOC based on IEEE802.11a for each scenario. During the off-line phase, fingerprints were created at the reference points, sent to the localization server and stored in the radio map database. Mobile terminal moved with slower pedestrian walking speed (thus about 3 km/h) during the on-line and off-line phase.

The signal power in the frequency band is influenced significantly by moving reflectors (pedestrians, cars) in the observed area. The problem of the signal power fluctuations was partially eliminated by estimation of local average power from the measured data. It is calculated as

$$\overline{RSS} = \frac{1}{N_s}\sum_{i=1}^{N_S} RSS_i \ , \tag{7}$$

whereN_s is the number of samples (in this case $N_s = 10$). The average value is used for further processing.

For the analysis of the achieved positioning error, the distance between real – precise position (obtained by GPS module) and the estimated position was calculated. This distance was obtained by Vincenty formula. The formula is commonly used in the geodesy to calculate the distance between two geo-points in WGS 84 system. Obtained results were statistically processed and are analyzed in the next section.

The measurements were performed in the three different scenarios. The scenarios differ in some conditions during the on-line phase of the fingerprinting method:

- Scenario 1 - off-line and on-line phase were per-formed in the same way and under the same conditions, i.e. localized terminal orientation and the number of movable object in the area was very similar.
- Scenario 2 - off-line phase data were used from Scenario 1. Much more moving objects were situated in the observed area during on-line phase compared to Scenario 1. The moving objects were pedestrians and several cars. In this scenario we investigated an impact of movable objects quantity on the positioning accuracy.
- Scenario 3 - off-line phase data were again used from Scenario 1. In this scenario antenna orientation of the localized terminal was changed during on-line phase. In this scenario we investigated an impact of localized terminal orientation on the positioning accuracy.

Parameters of the scenarios were purposely defined because of significantly different conditions in both phases of the positioning process. Movable objects (reflectors) have an unpredictable impact. For example, reflectors could have been at a point during phase of map creation but not in the phase of localization. This phenomenon has significant impact on the positioning accuracy. The static reflectors should not have significant impact, e.g. building, parking cars. Terminal antenna orientation plays important role on the signal gain of receiving signal. The laptops are not traditionally equipped with omnidirectional antennas. Generally, users do not take into account orientation of their mobile device during the localization. Therefore it is interesting to know the influence on positioning accuracy. These results would give us realistic view on the system performance. The achieved results are analyzed in the following section.

4. Experimental Results

This part analyzes experimental results obtained by WifiLOC positioning system based on IEEE802.11a. The performance of the system is evaluated by basic statistical characteristics and cumulative distribution function. The obtained positioning results for all scenarios are shown in Table 1 and Figure 4.

Table 1. Positioning error vs. Scenario

Positioning error		Scenario 1	Scenario 2	Scenario 3	Overall
Median error	[m]	9.14	12.15	11.00	10.76
Mean error	[m]	11.69	19.37	19.89	16.98
95% error	[m]	28.52	42.74	87.98	53.08

Scenario 1 would be denoted as ideal case, since conditions were almost same during the both phases of the experiment. Amount of movable reflectors was similar and antenna orientation was same in all measurements. Obtained results in this scenario are the most accurate. Median error value is 9.14 m. Value of 95% error is 28.52 m.

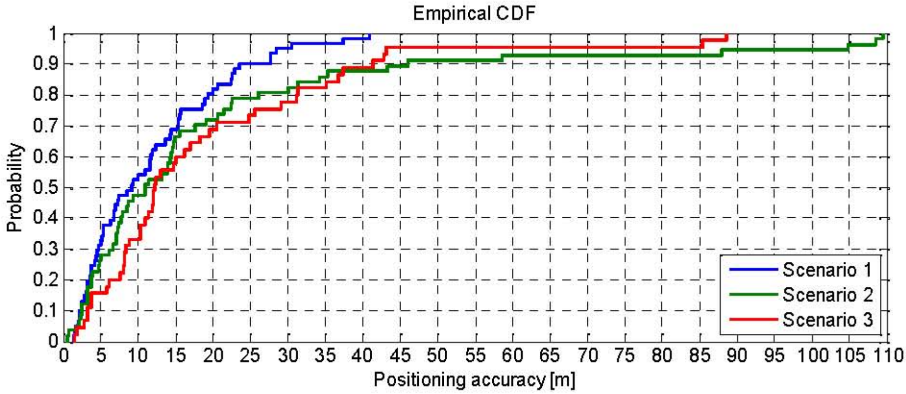

Figure 4. The architecture of the WifiLOC system.

The results obtained during the next scenarios are less accurate in case of median value. The most significant difference can be seen in extreme values of positioning error, i.e. 95% error (see Figure 4). 95% positioning error for Scenario 2 is approximately 1.5 and Scenario 3 is three times higher compared with Scenario 1. It is caused by considerable fluctuation of received signal strength. The fluctuation is indirectly shaped by different antenna orientation and moving objects in the observed area. The higher number of moving objects means little more extremely inaccurate position estimates compare with different antenna orientation.

According to achieved results, it can be concluded that IEEE802.11a is suitable for mobile positioning. The values of positioning error are similar compare with IEEE802.11b/g based on 2.4 GHz frequency band. It is caused that mobile terminal was almost always in LoS with monitored APs and signal in 5 GHz frequency band are not so interfered in the experimental area compared with 2.4 GHz frequency band.

5. Conclusion and Future Works

We verified a positioning solution WifiLOC based on fingerprinting method and network based on IEEE802.11a standard. This network is not often used for mobile positioning. Therefore we try to bring new possible utilization of the network. The solution uses received signal strength information for position estimation. In the used ISM frequency band (5 GHz), signal is very sensitive to obstacles and reflectors. On the other hand, the interference is smaller compare with 2.4GHz ISM band.

The experiments were implemented in three different scenarios. Impact of moving objects in the area and orientation of the mobile terminal antenna on positioning accuracy was investigated. According to the obtained results it can be said that these two factors negatively affects the positioning accuracy.

Future works can be focused on implementation of Rank Based Fingerprinting algorithm [20] to the WifiLOC and further testing of the developed positioning system.

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