A Novel RSS-Ratio Indoor Positioning scheme in WLAN environments

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Abstract
In this paper, a novel indoor positioning scheme exploiting the ratio of received signal strengths (RSS) from multiple access points is proposed in wireless local area networks (WLAN) environments. In the proposed scheme, the RSSs from multiple APs are measured at the WLAN device of the user and the ratio of measured distance value is used to estimate the position of the user. The performance of the proposed scheme is evaluated through experiments in ordinary indoor office environments during office hours. According to the results, the performance of the proposed scheme is super to that of conventional lateration method. The positioning error of proposed scheme is reduced about 82% with that of conventional lateration scheme.

Keywords: Indoor, Positioning, WLAN, RSS

Introduction
Recent years, the demand on positioning technology has grown in various fields such as Fintech, online to offline (O2O) service, mobile commercial service, location based services, and internet of things (IoT). Position estimating, also called localization, has been addressed as the most fundamental and important context in ubiquitous environments. As the size of buildings and underground spaces are increased and even connected, the complexity of indoor space is remarkable increased and thus indoor positioning technologies have been noticed as core technology. However, the well-known positioning technology named global positioning system (GPS) does not work in indoors and not suitable for indoor positioning system because of the loss of satellite signals in indoors and underground spaces. To overcome the limit of GPS, various technologies have been introduced for indoor position estimation of the user, but it still suffers from environmental, costly and practical implementation problems [1, 2]. The wireless local area networks (WLAN) is one of the most preferred methods for indoor positioning scheme, because many WLAN devices are already installed in indoors and underground spaces to provide internet services. Therefore, it is possible to minimize the additional costs for infrastructure installation. From this point of view, indoor positioning scheme based on WLAN has considered as cost effective method.

The conventional positioning methods exploiting WLAN are based on the proximity [3, 4], the fingerprint [5] and the lateration [1], also known as triangulation. A proximity technique determines the position of the user, when the user is near an access point (AP), of which location is known. A fingerprint method estimates the position of the user by comparing the real-time received signal strengths (RSS) and the pre-measured database. The RSS is also used in the lateration scheme. In lateration, firstly distance between WLAN device of the user and the APs is measured, and then the position of the user is estimated by solving the least squared method with the estimated distances. However, these conventional methods have some technical problems of low accuracy, practical implementation, or computational complexity.

In this paper, a novel indoor positioning scheme exploiting the ratio of RSSs from multiple APs is proposed in WLAN environments. In the proposed scheme, the RSSs from multiple APs are measured at the WLAN device of the user and the ratio of measured distance value is used to estimate the position of the user. The process of estimating position is similar with lateration method, but the proposed scheme is more simple and easy to implement for estimating the position of the user. The performance of the proposed scheme is evaluated through experiments in ordinary indoor office environments during office hours.

The rest of the paper is organized as follows. In section 2, the system description of positioning schemes based on WLAN is provided, and the problems of conventional schemes also are discussed. In section 3, a novel indoor positioning scheme exploiting the ratio of RSSs from multiple APs is proposed. In section 4, the proposed scheme is evaluated and reviewed. In section 5, concluding remarks and future works are discussed.

Theoretical Background

Proximity Method
Generally, proximity methods have three approaches to estimate position: Sensing physical contact such as RFID/USN and NFC tagging technologies, observing wireless cellular access points, and monitoring automatic ID systems [3, 4]. The positioning technique based on WLAN can be defined as zone based technique and it is well known that its accuracy is not high as other positioning techniques because it is based on the zone detection instead of ranging estimation.

Fingerprint Method
Various wireless signals can be existed in indoor environments. These signals can represent the characteristic of specific location, which can be differentiated as specific zone. Fingerprint method uses this characteristic of Wi-Fi, Bluetooth, 3G or other wireless signals at specific area [6], [7]. This technique can be categorized by two phases: offline or database phase and positioning phase. The first phase measures the signal strength from the surrounding beacons and collects signal data to build a fingerprint database at the known point. This step is referred as offline, site survey, database or training phase. In the second phase, referred as
online, runtime or positioning phase, the user obtains the vector of signal strengths at the specific point in real time. The position of the user is estimated by comparing the measured signal with the fingerprint in the database. To decide the position, nearest neighbor method is used between the trained database and the real-time measured signals. There are several algorithms to compute the correlation: Euclidean distance, Manhattan distance, Mahalanobis distance [8]. However, time-varying characteristics of wireless signal is a factor, which degrades the performance of fingerprint method. Moreover, the error of position estimation can be caused by sensors of different models and brands, which have different specification[9].

**Lateration Method**

Lateration method, which is generally known as triangulation method, uses the RSS values from APs. This method computes the intersection of coordination with at least three distance values from transmitter to receiver. Wireless signal power is attenuated according to the distance in line of sight environment. Free space path loss model is used for the relationship of between transmitter and receiver [10, 11]. Friis free space equation can be expressed according to free space path loss model. Its mathematical expression can be rearranged as log-distance path loss model referred to as log-normal distribution, and the formula can be described as follows [12]:

\[
\text{RSS(dBm)} = P_{\text{ref}} - 10 \cdot k \cdot \log\left(\frac{D}{D_0}\right)
\]  

(1)

where \(P_{\text{ref}}\) means the RSS value at reference distance 1 meter, \(D\) is the distance value mentioned in equation (2) and \(k\) is loss coefficient. Equation (1) can be rearranged for distance estimation as follows:

\[
D = D_0 \cdot 10^{\frac{P_{\text{ref}} - \text{RSS}}{10 \cdot k}}
\]  

(2)

Coordinates of location are obtained via lateration matrix with the computed distance value between AP and receiver. The matrix of lateration can be expressed as follows:

\[
\hat{H} \hat{x} = b
\]  

(3)

For the estimated position, matrix formula, (3), can be transformed as follows:

\[
\hat{x} = (H^T H)^{-1} H^T b
\]  

(4)

Where

\[
H = \begin{bmatrix}
    x_2 - x_1 & y_2 - y_1 \\
    x_3 - x_1 & y_3 - y_1 \\
    \vdots & \vdots \\
    x_{n-1} - x_1 & y_{n-1} - y_1
\end{bmatrix}
\]  

(5)

and \(x\) is the estimated coordination of position, \(n\) is total number of APs, the index of number means the sorted value of strongest RSS value in descending order, and \(d\) is the distance value mentioned in equation (2).

**Proposed Scheme**

**System Description**

The system architecture is shown in Fig. 1. There are two approaches for position estimation with lateration method. In the one approach, APs transmit its wireless signal to the user. The WLAN device of the user collects RSSs from APs and sends the information of RSSs to the database for position estimation. In this approach, the device of user collects the RSSs without informing its information to APs and communicates with the database for position estimation. In the other approach, on the contrary to previous approach, APs receive the signal from the device of the user. The APs send the information of RSS from the device of the user to the database. In this approach, the APs collects the information of the user and communicates with the database for position estimation. To calculate distance to each AP, parameters should be predefined as shown in equations (1) and (2). The distance to each AP is computed by using the RSS information at the server and the position of the user is estimated with the distance information.

![Figure 1: System schematic](image-url)
precise estimation of position, while the fingerprint scheme needs much time to collect training data for building database. Moreover, the database should be updated frequently because the measured RSS at known point tends to be affected easily by the changes of surround environment. In ideal situation, it can estimate the position of the user if three circles with the estimated distance intersects at the same point. In real situation, however, it is hard to estimate the position accurately because many coordinates of estimated position are created or none of intersection point is occurred. This problem makes the ambiguity and thus causes huge estimation error. Besides, sensors of different models and brands have different specification and sensor measurements even at the same position [9].

Although the lateration scheme has some problems, the distance estimation of lateration scheme is used in the proposed scheme because its algorithm has low complexity for calculation and it is suitable for real-time positioning. Instead of the least squared method of the lateration scheme, we propose the RSS ratio technique to estimate the position of the user. The proposed scheme always provides only one coordinate as shown in Fig. 2, and it can alleviate the above mentioned problems.

Fig. 3 shows the flowchart of the proposed scheme. The RSSs from the device of the user are gathered at the APs around the user for a time T in order to mitigate the impact of the changing characteristic of wireless signal, and the low pass filter is used. The averaged RSSs are sorted by descending order and the predefined number of APs are selected as the APs for the position estimation, because the reliability of strongest AP is high than that of the lower AP. At least three APs are to be selected for position estimation. Note that there are two selection methods for positioning: fixed and dynamic selection. In this paper, however, simple fixed selection method is considered for simplicity and dynamic method will be discussed in the future works.

To solve the problem of intersection, the calculated distance from each AP is converted into the ratio for considering the weights of all the APs. The weight of each AP is decided with the converted distance as follows:

$$W_{AP_i} = \frac{\sum_{i=1}^{n} dis_i}{dis_i}$$

Where $W_{AP_i}$ is weight value of $i$-th AP among the selected APs, $n$ is the number of selected APs for position estimation, $dis_i$ is the converted distance of $i$-th AP in accordance with equation (2). Normalization is described as follows:

$$NorW_{AP_i} = W_{AP_i} / \sum_{i=1}^{n} W_{AP_i}$$

Finally, the estimation of the position of the user is expressed as follows:

$$\hat{P} = \sum_{i=1}^{n} AP\_Pos \cdot NorW_{AP_i}$$

Where $AP\_Pos$ is the installed location of WLAN AP.

**Experiment Results**

**Environments**

In the experiments, the user uses a necklace type WLAN device with 802.11 b/g Wi-Fi standard. The communication channel of WLAN is set to be automatically selected. All the APs are installed on the wall of about 2.5m height from the floor. The RSS of the device of the user is collected at 5 APs for 30 seconds. 20 reference points are considered and each AP gathers about 65average samples from each reference point. Reference RSS of each AP was measured from 1m distance and applied for computation as shown in table 1. The experiment was performed in ordinary office hour and environment. The space of experiment is about 167m², 12.89m by 12.98m as shown Fig. 4.
Experimental Results

Although all the APs were the same model of a company, as shown in Table 1, the measured reference RSSs are different. Given with the reference RSS, the positioning performance of the proposed scheme is compared with that of conventional lateration scheme in terms of different number of APs. Fig. 5 shows the comparison of position estimation error between the proposed scheme (dashed lines) and the conventional scheme (solid lines) at 20 points. As shown in the figure, the proposed scheme outperforms the conventional scheme. The positioning error of the 3, 4, and 5 APs is decreased from 19.03m to 3.37m, from 14.42m to 2.71m and 13.93m to 2.43m, respectively. It indicates that the performance of the proposed scheme is enhanced about 82.3%, 81.2% and 82.6% respectively. On the while, it is shown that performance is also improved in accordance with the increased number of APs for position estimation. The summary of results is given in Table 2.

Fig. 6 shows the average error at the 20 points with different sampling rates. It shows that the accuracy of positioning can be enhanced by increasing the sampling rate, and the performance is converged from 24 sampling rate. To find optimal parameter \( k \) of equation (2), simulations are performed as shown in Fig. 7, and it shows that the optimal value is about 1.4 to 1.6.

Table 1: Reference RSS value of each AP at 1m distance

<table>
<thead>
<tr>
<th>AP</th>
<th>RSS at 1m (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP0</td>
<td>-40.94</td>
</tr>
<tr>
<td>AP1</td>
<td>-49.85</td>
</tr>
<tr>
<td>AP2</td>
<td>-42.85</td>
</tr>
<tr>
<td>AP3</td>
<td>-39.05</td>
</tr>
</tbody>
</table>

Table 2: Average Position Error with the number of APs

<table>
<thead>
<tr>
<th>Number of APs</th>
<th>Conventional (m)</th>
<th>Proposed (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 APs</td>
<td>19.03</td>
<td>3.37</td>
</tr>
<tr>
<td>4 APs</td>
<td>14.42</td>
<td>2.71</td>
</tr>
<tr>
<td>5 APs</td>
<td>13.93</td>
<td>2.43</td>
</tr>
</tbody>
</table>

Figure 4: Experiment environment (left) and installed APs (right)
Conclusions and Future Works
In this paper, a novel indoor positioning scheme exploiting the ratio of RSS from multiple APs is proposed in WLAN environments. The performance of the proposed scheme is evaluated through experiments in ordinary indoor office environments during office hours. According to the results, the performance of the proposed scheme is superior to that of conventional lateration method. The positioning error of proposed scheme is reduced about 82% with that of conventional scheme. In contrast to the high complexity of conventional method through the complex matrix operation, moreover, the proposed scheme has a low complexity through simple operations. Performance of proposed scheme is evaluated with various situations, such as different number of APs, sampling rates, and parameter values. To enhance the performance, various conditions of environments have to be considered in actual space, where is surrounded by many walls, steels, and glasses. Study of characteristics of RSS with different models of various companies also is needed. As future works, we will study about performance analysis according to the position of APs and decision method for optimal AP position. Dynamic AP selection method also needs to be researched.

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